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Post Harvest Processing Methods and Physiological Alterations in the Coffee Fruit

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METHODS OF COFFEE PROCESSING

It is well known that the way the coffee fruits are processed has pronounced effects on the final quality of the beverage. Basically there are two methods to process coffee fruits, the dry and the wet methods (Clarke, 1985; Vincent, 1985).

In the dry method the coffee fruits brought from the field are laid out in drying patios to be exposed to the sun until they reach 10-12% humidity. Drying machines are also used to dry the coffee fruits. In both cases some classification may be undertaken before drying. The dried product, also know as Natural Coffee, may be dehusked or not before storage.

The wet processing method produces coffee of better quality than the dry method (Clarke, 1985; Vincent, 1985). This coffee is known as Washed Coffee. The fruits from the field are pulped and allowed to ferment for the elimination of the mucilage. In the pulping stage the exocarp is removed exposing the mesocarp (mucilage), which adheres to the endocarp. The fermentation process may be carried out by keeping the pulped fruits in water or not. Depending on the local climate (temperature) the fermentation period has to be controlled to avoid over-fermentation, which may decrease the quality of the beans and consequently the beverage quality. Fermentation for 16 h has been used for places where Robusta is cultivated (warmer regions), increasing to 48h for higher altitude locations (Vincent, 1985) or even to 80 h (Clarke, 1985). After fermentation, the remaining mucilage adhering to the endocarp is removed manually or mechanically, or also by leaving the coffee in running water for 6 to 16h. Then the beans are dried to 10-12% humidity, which occurs in a shorter time than for the dry process, usually in a week under favorable climate conditions. Washed coffees have less body, higher acidity and they are more aromatic than the Natural coffees.

There were indications that Natural and Washed coffees present differences in some typical compounds, which are important for the development of the beverage quality (Menezes and Clifford, 1987; Menezes, 1994; Balyaya and Clifford, 1995). Therefore, assuming that this is a not a result of microbe action, one may argue that such alterations are the consequence of seed metabolism.

THE EFFECT OF THE PROCESSING METHOD ON THE COFFEE QUALITY

Despite the important relationship between the processing method and coffee quality, so far very little has been done to understand this fact under a physiological point view, apart from analysing some of the constituents in the dry and wet processed coffees. In most of these studies caffeine and chlorogenic acids were analysed. Some reports showed that coffee quality was apparently related to the ratio between isomers of chlorogenic acid and that this ratio was affected by the maturation stage of the beans (Ohiokpehai et al., 1982, Clifford and Kazi, 1987). Using this information, Menezes (1994) studied the ratio between caffeoylquinic acids (CQA) and dicaffeoylquinic acids (DCQA) in Arabica coffee harvested at different maturation stages and processed by the wet or the dry method. She observed that the ratio CQA/DCQA was always higher in the wet processed coffee, except for the stages where the fruit was still green (immature fruit), when the ratio was similar or slightly lower than for other developmental stages. Menezes (1994) concluded that it is important to avoid green fruits because they decrease the coffee quality. Balyaya and Clifford (1995) studied the contents of chlorogenic acids and caffeine in wet and dry processed coffees and did not observe any difference regarding the alkaloid but did find a lower phenolic value in the wet processed coffee. In both reports no physiological explanation was offered for the observed variations.

DOES A RELATIONSHIP BETWEEN GERMINATION AND QUALITY EXIST?

Endosperm represents more than 95% of the coffee seed weight with the embryo positioned on the basal side, next to the peduncle in the fruit. Because germination of *C. arabica* ceases below 6% of humidity, seeds were defined as intermediary between the recalcitrant and orthodox classes (Ellis et al., 1990). In fact, the loss of the germination viability seemed to be related to the interruption of the germination process, which was believed to be already occurring in the mature fruit (Ellis et al., 1991). In other words, low water availability led to the embryo death. This observation has support in the fact that several days before the complete maturation of the fruit the embryo already has the ability to germinate (Estanislau, 2002).

However, what prevents the coffee seed from germinating inside the fruit? It has been suggested that inhibitors in the pulp would be responsible (Bytof et al., 2000; Selmar et al., 2001). It was also suggested that a relationship might exist between germination and coffee quality of the wet processed coffees. By removing the pulp in the wet process the embryo is released germination and despite the short period of time comprised between pulping and mucilage washing it might be enough for important physiological changes to take place. Bytof et al. (2000) and Selmar et al. (2001) showed that amino acids changed significantly in their composition and content in coffee fruits processed by the wet method. This was not only observed in coffee harvested and processed as in a coffee farm but also under laboratory controlled conditions. For both coffee types an initial reduction in the amino acid content was observed, followed by an increase, decrease and stabilization of the content. However, such complex variation was observed in a shorter period of time in the wet processed coffee and the amino acid level was higher at stabilization. Although the aim was not the same and the way the coffee fruits were processed differed from the Bytof and Selmar reports, the data of a previous report also showed large variations in amino acids (Arnold and Ludwig, 1996). However, the processing methods did not significantly influence the amino acid composition.

Such variations might be important because of the role of amino acids (and also proteins and peptides) in the formation of volatile compounds during coffee bean roasting. During roasting, these nitrogen compounds react with carbohydrates (mainly sucrose and the product of its breakdown) in the Maillard reaction - and compounds involved in the aroma, such as pirazines are formed (Bytof et al., 2000). Alanine would be the main amino acid in such a reaction. On the other hand methionine and cysteine are involved n the formation of sulfured volatile compounds.

Selmar and his group (in this congress) also obtained evidence that germination is in progress in wet processed seeds by following the expression of isocitrate lyase (ICL), an unique enzyme of the glyoxylate cycle, where fatty acids are converted into carbohydrates during respiration. Characteristically this enzyme is increased during germination of oil-rich seeds such as castor bean and sunflower. The expression of ICL is described as one of the early events in germination. We have done a preliminary search in the Coffee EST database of the Brazilian Coffee Genome Project and found 8 ICL ESTs but most (7) from a library made from germinating seeds.

If the hypothesis that germination is already occurring in the seeds of mature fruits is correct, are the alterations in the seeds processed by the wet method the same as dried seeds left to germinate in water? The time seems to be crucial. Freshly harvested fruits have seeds with approximately 50% of water content. In addition, the time between pulping and the beginning of the drying may vary from 20 to 80h, according with the local temperature. When fermentation is carried out in water and the fermented mucilage is removed with water, the conditions for germination seem to be even more favourable.

BIOCHEMICAL ALTERATIONS DURING COFFEE SEED GERMINATION

Several studies have shown that coffee seeds with 10-12% humidity suffer profound alterations in the early days of germination. Cytochemical studies revealed that after 4 days of germination the cell wall of the endosperm of coffee seeds undergo marked alterations, releasing sugars for the embryo growth (Dupriez, 1962).

Galactomannans are the main cell wall sugars of the coffee seed. Takaki and Dietrich (1980) detected mannanase activity after 5 days of germination. Endo-_-mananase activity was also detected by other authors after 7 days of germination and transcripts of the enzyme were detected only after 15 days (Marraccini et al., 2001). Such differences might be due to the high amount of RNA extracted from the endosperm compared with the embryo, interfering in the extraction of specific mRNA for the Northern experiments. It has been shown that polyssomes are formed just after imbibition and that mRNA synthesis takes place (Bewley and Black, 1994).

Giorgini and Comoli (1996) observed mannanase activity only after the radicle has protruded from the seed and the activity increased with GA3 application. Marraccini et al. (2001) did not observed the same results when GA3 was applied 24h after seed imbibition. This difference might be explained by the time the hormone was offered to the seeds. Giorgini and Comoli (1996) applied GA3 since the beginning of imbibition and Marraccini et al. (2001), 24h later.

Data from Takaki & Dietrich (1980) support results from both Giorgini and Comoli (1996) and Marraccini et al. (2001) and in addition to the detection of mannanase activity 5 days after imbibition (the seeds were imbibed for 48 h in water or in water + GA3) they also detected a large amount of free mannose and less glucose. Mannose was detected after 15 days in the control seeds. In the seeds treated with GA3 there was a reduction in the cell wall polysacharides containing mannose. The mannanase activity was higher in these seeds too. Since exogenous GA3 inhibits (0.5 – 1.0 mM - too high???) coffee seed germination (Takaki and Dietrich, 1979), but it does not have an inhibitory effect on the embryo growth (Válio, 1976), Takaki & Dietrich (1980) discussed the possibility that mannose is a potent inhibitor of coffee seed germination. Detached coffee embryos had their growth inhibited 50% by 0.1 mM mannose, but not by the same concentration of glucose, fructose and galactose (Takaki and Dietrich, 1979).

Mannose is known as a strong inhibitor of cellular processes and it is usually found in very low amounts in coffee seeds. Redgwell et al. (2003) determined that free mannose varied from 0.25 to 0.09 mg/g from the 11^{th} to the 37^{th} week after flowering in the coffee seed. However, Takaki & Dietrich (1979) observed that 0.1 mM mannose would inhibit embryo germination. Using this value to calculate the concentration in the seed a corresponding amount in the coffee seed would be 0.018 mg/g. Therefore, it would appear that the level found by Redgwell et al. (2003) is enough to inhibit coffee embryo germination. However, Silva (2002) could not confirm the results obtained by Takaki & Dietrich (1979) with detached embryos. After 10 days the length of embryos incubated with mannose was similar to the control with water.

The endocarp is a physical barrier for coffee seed germination (Válio, 1976) and apparently the diffusion of water and oxygen does not have regulatory importance in the process. However, Velazco & Gutierrez (1974) observed that fragments of the endocarp inhibited germination. The presence of inhibitors in the coffee seed was also studied by other authors, and there are indications that no only gibberellins but also ABA might be involved in the process (Maestri and Vieira, 1961; Gopal and Ramaiah, 1971; Válio, 1976; Silva, 2002).

The information contained in the reports cited above fit well to the model proposed for lettuce germination, a seed which has endosperm (Bewley and Black, 1994). In this model, the radicle and hypocotyl have important role regarding the control of the hormone production as well as being a sink for products generated by hydrolysis of the reserves during germination (Figure 1, adapted from (Bewley and Black, 1994). Cytokinins and gibberellins produced in the embryo antagonize the action and/or biosynthesis of ABA, as well as inducing enzymes for the degradation of the seed reserves (endo-β-mannanases, β-mannosidases and galactosidases). Galactomannans located in the endosperm are then hydrolysed by endo- β-mannanase activity, and oligomannans are originated, which in turn are converted to mannans (by β-mannosidases) and galactose (by β-galactosidases). In this model, mannosidases are already present in the seed before germination but galactosidades and mannanase are induced by a signal from the radicle over a very short period after imbibition (2-3h). Even though in this model the role of hormones is still not well understood, the importance of their participation is very strong since the effect of the axis on the activity of enzymes may be replaced by the application of gibberelin and citokinins. Similarly, ABA application decreases activity of endo-β-mannanases.

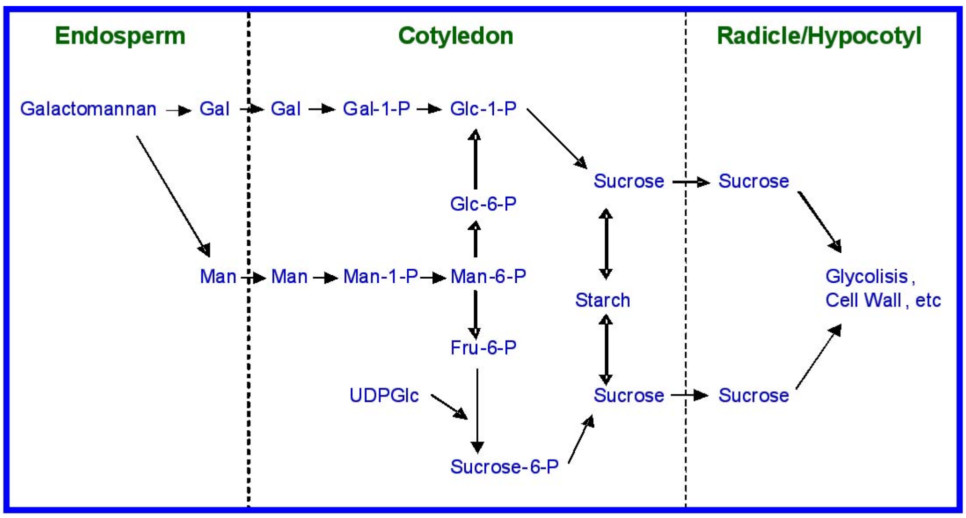

Figure 1. Degradation of galactomannans during germination ofseeds containing endosperm.

However, according to this model the products from the reserve degradation may retro-inhibit the activity of the enzymes if they are not removed from the system (Bewley and Black, 1994). Therefore, radicle and hypocotyl are important as sinks, incorporating mannose in their metabolism (Figure 2).

A preliminary search in the Coffee EST database of the Brazilian Coffee Genome Project using the key words endo-β-mannanase or β-mannosidase recovered 36 ESTs for the former (2 from a library from germinating seeds) and 115 from the latter (66 from the same library).

Germination is considered complete when the radicle is protruded from the seed. In several seeds protrusion is a consequence of embryo imbibition occurring through the expansion of the cell volume (Bewley and Black, 1994). This seems to be the case for coffee. Studying the autotoxicity of caffeine in the coffee seed Waller et al. (1986) showed that the first cell divisions in the radicle started after protrusion as a mechanism to avoid the effects of the alkaloid in the endosperm.

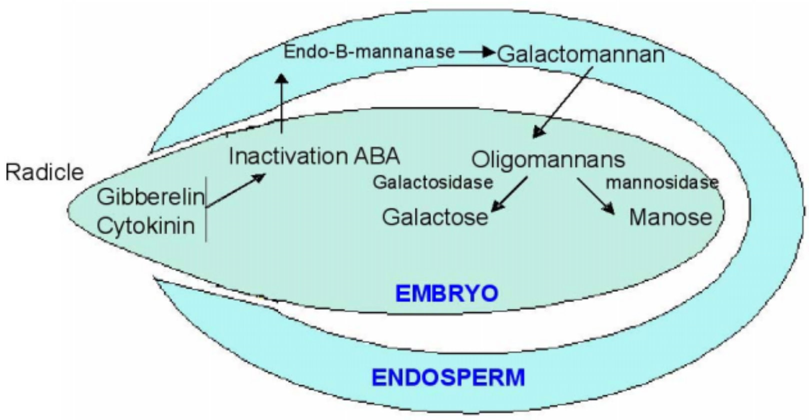

Figure 2. Mobilization control of reservesduring germination of seeds containing endosperm.

Indeed, recent studies with flow cytometry showed that before protrusion only cell expansion occurs in the embryo and that ABA inhibits the increase of pressure potential in the cells (Silva, 2002). Cell divisions are rare and only observed in the apex of the radicle, which might be related to the softening of the adjacent endosperm, due to an increase of cellulase and endo-β-mannanase activities, allowing the radicle to protrude. Curiously, ABA inhibits the expression of endo-β-mannanase, but not cellulase, suggesting that this hormone controls both phases of germination, that is, the increase in volume of the embryo and the softening of the endosperm near the radicle apex (Silva, 2002). Confirming the similarity with the lettuce model, gibberellins are needed for the elongation of the cells during the increase in volume of the embryo and also for the softening of the endosperm (Silva, 2002). The inhibition of the germination observed by exogenous GA3 application (Válio, 1976; Takaki and Dietrich, 1980) might be due to the release of a factor present in the endosperm and that directly affects embryo growth (Silva, 2002). This factor might well be mannose since gibberellins stimulate endo-β-mannanase activity.

In the coffee seed the embryo is positioned on one side of the seed (next to the peduncle insertion in the fruit) and it lies in the more external layers of the endosperm. In Robusta it is even more superficially positioned. Therefore, it is possible that during the wet process not only the embryo may acquire water and expand but also that free mannose is washed out from these external layers allowing the embryo to start germination. Bytof et al. (2000) and Selmar et al. (2001) suggested that inhibitors in the pulp would prevent germination however after pulping a considerable amount of mucilage (which is in close contact with the endocarp in the intact fruit) still remain adhered to the seed. In addition, Estanislau (2002) observed that the embryo was able to germinate after 120 days after flowering while the seeds only germinated only after 225 days.

The germination of the coffee seed depends on the temperature and usually takes from 10 to 15 days (Rena and Maestri, 1984). However, activity of endo-β-mannanase was observed by Takaki & Dietrich (1980) and Marraccini et al. (2001) at 5 and 7 days after imbibition, respectively. It is possible that part of this activity comes from the recovery of embryo cells during water uptake, when organeles such as mitochondria may recover their functional capacity (Bewley and Black, 1994). Takaki & Dietrich (1980) and Marraccini et al. (2001) did not detect mannanase activity before imbibition. However, Silva (2002) observed activity of this enzyme with 2 days of imbibition in extracts prepared from the endosperm near the site of radicle protrusion. The activity doubled on the third day and tissue printing of the seeds showed that by the fifth day the activity was still restricted to that site in the seed but by the seventh day it was detected in other parts of the endosperm.

To our knowledge only one report contains data on the sugar profile during germination of coffee seeds. Takaki & Dietrich (1980) detected glucose and mannose after 15 days of germination. Therefore, because of the lack of data little can be inferred from what happens in seeds processed by the wet and dry method regarding sugar composition. Available modern techniques could be used to study the cell wall and soluble carbohydrates in the embryo side during germination as well as in coffees obtained by the wet and dry methods. These data might elucidate if germination takes place in wet processed seeds using germinating seeds for comparison. Preliminary results obtained by Silva (E.A.A. Silva, personal communication) showed that following the activity of endo-β-mannanase at the protrusion site of the radicle there was release of mannose. Therefore, the detection of mannose only several days after imbibition as observed by several authors might be due to the dilution of the mannose in the whole seed endosperm taken for analysis.

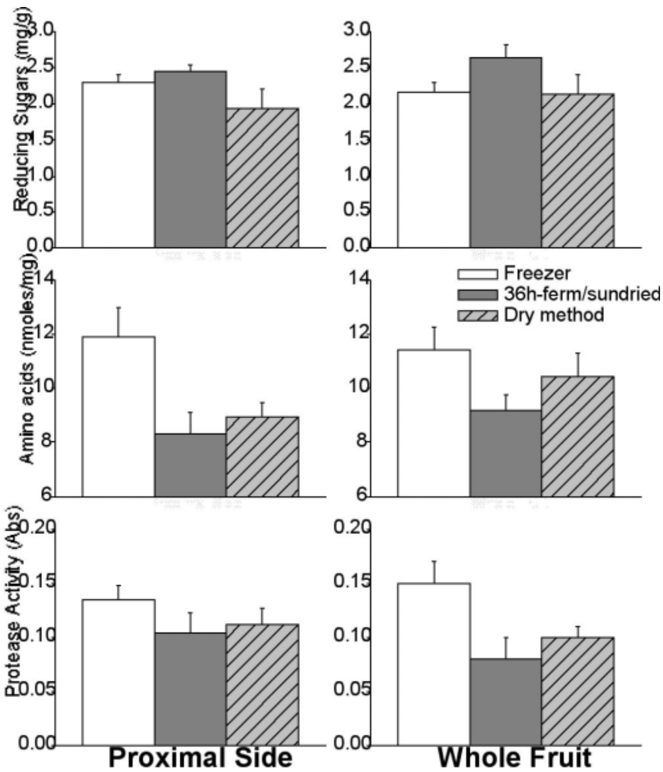

Figure 3. Reducing sugars, amino acids and protease activity in seedsfrom fruitsprocessed in different ways.

We have done preliminary experiments processing coffee fruits in three different ways (1- drymethod with sun drying; 2- wet method with 36h fermentation and sun drying; 3- pulping, elimination of mucilage by friction and freeze drying) and measured reducing sugars, amino acids and protease activity in the whole fruit and in the half containing the embryo (proximal side). We did not observe significant differences between the wet and dry processed coffees but the freeze-dried seeds were higher for proteases and amino acids (Figure 3). This result is an indication that the processing method itself already induces changes in the seeds. Contrary to previous results (Ludwig et al., 2000) we observed that protease activity is very high in coffee seeds (Mazzafera et al., 2004, http://www.iac.sp.gov.br, First International Symposium on Coffee Quality of IAC). Therefore, since protease activity is present in dried seeds, additionally to amino acids, it might be possible that oligopeptides are originated during the very early imbibition stage and also participate in the aroma/quality formation. However, their role in the quality of beverage is still unknown (Montavon et al., 2003).

IS THE QUALITY LOST DURING THE DRYING STEP?

Selmar and his group (this congress) have obtained evidence that a stress situation takes place during the drying step since the water potential drops dramatically. They observed that β-aminobutyric acid (GABA), a non-protein amino acid which is largely and rapidly produced in response to biotic and abiotic stresses (Bouché and Fromm, 2004), is always higher in dry processed than in wet processed coffees.

The amino acid extracts used to obtain the data in Figure 3 were used for qualitative analysis in HPLC and confirmed the Selmar results (Figure 4). This preliminary analysis also showed interesting variations regarding the freeze-dried treatment.

GABA is synthesized in plants by glutamate decarboxylase (GAD) and this enzyme acitivty is rapidly increased by stressing situations that affect the level of the cytosolic calcium. So far 5 *GAD* genes were identified in *Arabdopsis thaliana* and at least for *GAD1* and *GAD2* it is known that their expressions are tissue specific. The isoform GAD1 is expressed in the roots and GAD2 in all plant tissues. A preliminary search in the Coffee EST database of the Brazilian Coffee Genome Project showed 39 sequences recognized as GAD and the highest frequency (10 ESTs) was from two fruit libraries (green immature and red mature fruits). The fruits collected to make these libraries were in that stage where the endosperm was already hardened (loss of water?).

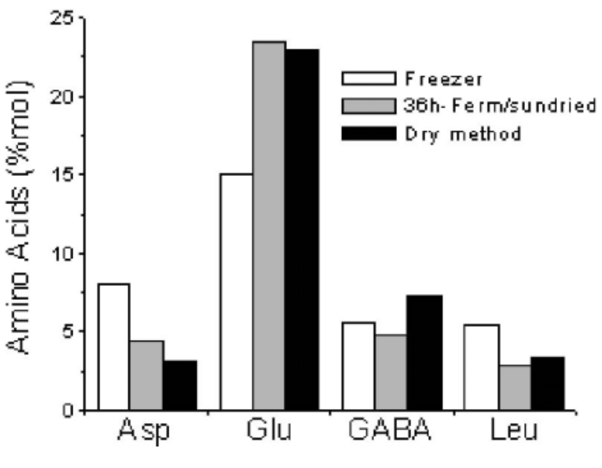

Figure 4. Amino acid compositionin the proximal side of seeds from fruits processed in different ways.

Therefore, parallel to the idea that the quality is improved by the wet processing method, one may argue that the drying step, both in the wet and dry methods, might induce changes in the coffee seed. The wet method being less drastic for the seed to reach 10-12% of humidity (one week) than for the dry method (3 weeks) might provoke smaller changes in seed metabolism. Our previous results cited above with freeze-dried seeds may be an indication of that.

To our knowledge this point of view has not as yet been explored. Experiments where fresh collected fruits were rapidly pulped, the mucilage removed by friction and the resulting seeds freeze-dried before roasting, might answer this question.

CONCLUDING REMARKS

After oil, coffee is the most important commodity in the world. Not so long ago several of the producing countries began to place coffees of better quality in the market. In part this was possible because of the adoption of techniques such as fruit classification (separation of the cherries) and the wet processing method. Compared with the knowledge accumulated for other physiological processes in the coffee plant we may conclude that almost nothing is known of the physiology of the coffee fruit. We have paid too much attention determining the contents of compounds that may be involved in the quality of the beverage (itself a very difficult task) without concern of what is going on in the fruits. Perhaps by studying specific situations, which have profound effects on the beverage, we may find clues to understand how quality is formed still in the fruits or at least know how it may be attained. The wet method seems to be a good example.

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Participatory Methods in Coffee Extension: an Indian Experience

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SUMMARY

Participatory methods are introduced in order to facilitate the process of involving all the stake holders in development process. These methods are introduced in coffee extension with a pilot project called Farmers' Participatory Methods (FPM). Main objective of the project was to empower small coffee growers and re-orient the extension strategy for better interaction between extension staff and growers through participatory way. It started with providing training to the extensionists in participatory methods and organizing workshops for the growers. The present study made an attempt to understand the impact of this programme on growers and the extensionists. It also looked into the institutional arrangements for the implementation of the programme. The results indicate that the programme could achieve the objective of developing better interaction between extensionists and growers. However it failed to achieve in developing a sense of participation in the growers. Lack of involvement of all the stakeholders in project planning was identified as one of the important reasons for the low levels of achievement of this programme.

INTRODUCTION

Growing awareness about the limitations of conventional development approaches in meeting the needs of people led to the exploration of alternative methodologies to provide equal opportunities to all the stakeholders in the process of development. This resulted in the development of 'Participatory Approaches'. The basic philosophy of these approaches is that all the stakeholders should participate in all the processes like problem identification, identification of strengths, alternative solutions, planning, monitoring and evaluation.

The concept first introduced by Robert Chambers was evolved mainly around appraisal of local resources in the form of Participatory Rural Appraisal (PRA). But soon it found many applications in the form of Participatory Learning and Action (PLA), Participatory Learning Methods (PALM), and Participatory Plant Breeding (PPB) etc. The common ideology running through all these approaches is participation.

Participatory methods are extended to extension services by several research institutions and voluntary organizations. This changed the conventional one way approach of extension staff going to the farmer and giving the advice. The changed approach is based on the ethos of 'farmer first' giving opportunity to the farmer to share his rich practical experience with the extension staff and the researchers in order to develop location specific solutions. This led to the development of 'Participatory Technology Development' appropriate to a given set of conditions. Participatory methodologies are used extensively in Integrated Pest Management (IPM) by agricultural institutions in many developing countries with different levels of success. Through participatory IPM training, vegetable growers in Indonesia could follow more sustainable practices (Norwell &Humming, 1999). Similarly another study in the case of paddy has shown that through participation IPM farmers could discover solutions which did not depend on insecticides, but maximized the effectiveness of natural cycles and predators (Ooi- Pac, 1998). Farmer Participatory Research was initiated in Colombia in order to develop a low volume application system for field use in coffee and this resulted in the identification of operational constraints and user perceptions. (Aston et al., 1998). Similarly farmer participatory IPM research and extension in Kenya has empowered farmers to be able to make informed decisions on crop management and generated considerable enthusiasm among the participating farmers (Nyambo et al., 1997).

The farmer's Research Project in South Western Ethiopia clearly showed how by merely giving an opportunity to farmers from different regions to come together stimulates their skills and leads to technology development (Mengesa et al., 1997). Several benefits of participatory IPM for food security, farmer well being and rural development are reviewed by Wheel and Wulp (1999). Challenges for farmer participation in coffee research and extension were reviewed by Williamson (1999).

FARMERS' PARTICIPATORY MANAGEMENT (FPM) IN INDIA

A pilot project of Farmers' Participatory Management (FPM) was launched by coffee Board in India from April 2000 for a period of one year. The objectives of this project were.

1. To provide small coffee growers an opportunity in decision making for sustainable management of their holdings
2. To re-orient the extension strategy for better interaction between extension staff and growers
3. To facilitate sustained coffee production, increase crop productivity and production of quality coffee.

Two training programs /workshop were conducted to train the extension staff in participatory methods. A total number of 130 extension personnel and the research specialists participated in the workshop. These trainers in turn facilitated the bi-monthly participatory training workshops conducted in each zone. Apart from this, zonal workshops of research-extensionists prior to every bi-monthly workshop were conducted in order to provide information to extensionists from subject matter specialists. A Senior Liaison officer/Junior Liaison officer facilitied the workshop.

OBJECTIVES OF THE STUDY

The important objective of this study is to understand the impact of participatory methods in coffee extension on coffee cultivation. The study uses pre and post scenario in understanding the impact. The study made an attempt to address the following issues

1. What is the impact of FPM on knowledge levels of the participating growers in
    a. Identification of pests and diseases
    b. Nutrition Management
    c. Bush Management
    d. Adoption of recommended measures
2. What are the relative merits of conventional extension system and the participatory system?
3. What are the perceptions of the growers regarding FPM?

The study is based on field survey. Primary data were collected from the growers with a pre-tested questionnaire. In depth interviews with the sample growers were undertaken in order to collect qualitative data. The study was undertaken in two traditional coffee growing regions of India namely Chikmaglur and Madikere districts of Karnataka. The sample consists of 36 growers from each region.

SOCIO ECONOMIC PROFILE OF THE FPM PARTICIPANTS

An analysis of age composition of the participants shows that majority of the participants are in the age group of 26 to 40 years in the case of Chikmaglur. But in the case of Madikere majority are in the age group of above forty years. There are participants of above sixty years of age in Madikere (Table 1).

Table 1. Age Group.

	Chikmaglur	Madikeri
Below 25	1 (3.77)	1 (0.70)
26-40	19 (52.77)	11 (30.98)
41-60	15 (41.66)	19 (54.22)
Above-60	1 (3.77)	5 (14.08)
Total	36	36

Source: Sample survey.

Table 2. Education.

Education	Chikmaglur	Madikeri
Illiterate	1 (3.77)	1 (3.77)
Primary	11 (30.55)	3 (8.45)
SSLC	9 (25.00)	8 (24.65)
PUC	6 (16.66)	5 (15.49)
Degree/diploma	7 (19.44)	13 (38.03)
Professional		2 (5.55)
PG	2 (5.55)	2 (5.55)
Total	36	36

Source: Sample survey

Similarly education background of the participants shows that all are literates except one from each region. However the there are more degree holders in Madikere than in Chikmaglur.

Most of the participants in both regions are owner cultivators who are the decision makers regarding production and marketing.

FPM IMPACT ON CROP MANAGEMENT

Coffee crop responds to better management. Management of proper bush, control of pest and proper nutrition management are identified as important management aspects which influence the quantity and quality of coffee crop. These aspects were given importance in the FPM of extension. These methods started with the understanding of existing knowledge in these above three aspects and share the experience among the growers with appropriate clarifications from the coffee Board extension and research staff.

SOURCES OF KNOWLEDGE ABOUT CROP MANAGEMENT

The survey indicated that most of the farmers (more than 98%) are aware of these practices and many of them have been in coffee cultivation for many years. According to them they have learnt the methods of bush management, identification of pests and disease and nutrition methods through a combination of various sources like the knowledge gained by from forefathers, observing what the friends and neighbors are doing and consulting the Coffee Board extension staff. From the Table 3 it can be observed that Coffee Board extension staff is an important source of information in the case of identification of pests and natural controls both in Chikmagalur and Madikeri region. FPM has also been identified as an important source along with other sources. Greater percent of respondents acknowledged FPM as a source in Madikeri than in Chikmagalure region.

Table 3. Sources of Knowledge (Percentage of Growers to total sample growers).

Source	Bush Management	Nutrition Management	Pest Identification	Natural Control of Pests
Chikmagalur				
Forefathers	27.78	38.89	41.67	47.22
Friends and Neighbours	11.11	44.44	69.44	13.89
Coffee Board Extension Staff	86.11	27.78	27.78	77.78
FPM	63.89	86.11	69.44	44.44
Only FPM				5.56
Madikere				
Forefathers	50.00	61.27	69.44	43.66
Friends and Neighbours	16.67	26.06	27.78	7.04
Coffee Board Extension Staff	77.78	83.80	94.44	76.76
FPM	52.78	56.34	69.44	64.79
Only FPM	5.56	2.82		8.45

Source: Sample survey. Note: Percentages do not add up to hundred due to multiple answers.

Though many growers said they are aware of natural control of pests and acknowledged that CB extension is the source of this knowledge, what they consider as natural control of pests is only uprooting, burning of infected plants and timely spraying of chemicals (Table 4). Only few growers are aware that optimum shade management is one of the controls.

Table 4. Methods of Natural Control of Pests
(Percentage of growers to total sample growers)

	Chikmagalur	Madikere
Uprooting and burning	70.00	80.00
Optimum shade management	24.00	35.00
Timely spraying and vigilance	65.00	70.00

Source: Sample survey. Note: Percentages do not add to hundred due to multiple answers.

DIFFERENTIAL IMPORTANCE OF VARIOUS COMPONENTS OF FPM

FPM has been introduced in order to empower grower for better understanding of crop management. Among the different aspects that were introduced, quality management aspects appear to have greater impact on the growers (Table 5). Greater percentage of growers acknowledged that quality aspects have been more useful. Though nutrition management was also given importance by the growers in Madikeri region, it was not given importance in Chikmagalur. Growers in both regions acknowledged that management of pests and diseases as useful issue.

Table 5. Relative importance of various components of FPM (Percentage of growers to total sample growers).

Component	Chikmagalur	Madikere
Bush Management	42.00	40.00
Pest and Disease Management	24.23	40.00
Quality Aspects	50.00	65.00
Nutrition Management	25.00	52.00
Scientific Methods	32.0	….

Source: Sample survey. Note: Percentages do not add up to hundred due to multiple answers.

PERCEPTIONS OF GROWERS ABOUT FPM

Farmers' participatory Methods are considered as exchange of views and learning from others by majority of the growers. Many farmers (42% of sample growers in Chikmagalur and 40% in Madikere) viewed this as a process of learning technology and timely operations. For another 38 percent of sample growers from chikmagalur it is leaning from other growers. It is also considered as an interaction of growers with Coffee Board extension staff. Some growers viewed it as group discussion. This clearly shows that though the programme could have some positive impact, it could not achieve in developing the spirit of participation among the growers (Table 6).

Table 6. What the growers understand by FPM (Percentage of growers to total sample growers).

Opinion	Chikmagalur	Madikere
Interaction with Coffee Board officers and Extension staff	11.56	29.17
Learning from other growers	38.46	9.72
Group discussion	7.69	8.33
Leaning about technology and timely operations	42.31	52.78

Source: Sample survey.

SUSTAINABILITY OF FPM

Sustainability of this programme and active participation of the growers depends on how much do they consider this programme useful. Majority of the growers consider that it is useful because it improved their technical knowledge. According to them this helped in reducing the wastage and helped in better utilization of resources because through this, they have learnt the scientific way of crop management. Through they were growing Coffee for many years and were practicing all these management practice, they were doing it unscientifically and were blindly following either their forefathers or friends and neighbors. Some of the growers have expressed that they were blindly applying fertilizers without knowing how much to apply. Majority of the growers are considering this as a means of access to better knowledge (Table 7).

Table 7. Opinions about usefulness of FPM.

Opinion	Chikmagalur	Madikere
Helped in improving scientific Knowledge	42.16	51.20
Helped in exchange of ideas	27.03	10.25
Helped in reducing waste	20.81	25.35
Helped in greater interaction	10.00	13.20

Source: Sample survey.

The growers want this programme to continue because it helped them in better understanding and also it improved interaction between growers and extension staff (Table 8).

Table 8. Opinions about the need for continuation of FPM (Percentage of growers to total sample growers).

Opinion	Chikmagalur	Madikere
For better three way interaction	11.90	20.32
To learn about new technology	19.05	31.30
Better way of transfer technology	16.67	20.53
To gain practical knowledge	23.81	27. 83
No reply	28.57	…

Source: Sample survey.

FPM- INSTITUTIONAL ISSUES

Coffee Research and Extension are two important wings of Coffee Board. While research wing works under the guidance and control of research director, extension wing in traditional areas has two joint directors to cater to the extension needs of Karnataka, Kerala and Tamil Nadu. These two are supported by five Deputy Directors, fourteen Senior Liaison Officer, twenty eight Junior Liaison officers and a number of Assistant Extension Officers, Extension Inspectors etc. The conventional system of extension services include field visits, follow up visits, group gatherings, demonstrations, awareness campaigns, mass contact programme, radio talk, distribution of literature and organizing field days. FPM has been introduced to improve the interaction process between the researchers-extensionists and the growers. Introductory workshops were organized for extensionists to sensitize them to the participatory methods.

These methods are also aimed at improving the communicative abilities and understanding of the role of ecological balance in controlling the pests and diseases. Unlike in the conventional methods of extension where the extensionists are used to only giving inputs, they also receive inputs from the experienced growers to pass on the information to the scientists for validation and guide the research priorities.

The study made an attempt to understand the views of the extensionists involved in FPM in Chikmaglur and Madikeri regions. (All together 45 extensionists are involved in the implementation of this programme in all these traditional areas).

For Majority of the extensionists it is a new methodology. Though earlier extension also involves interaction with the growers, this method gave the extensionists an opportunity to address a group of farmers in one area. Taking a group of growers into the field, observation of pests, collection of samples, bringing them back and translate them into a meaningful sequence, observe the pattern, soliciting clarification and identifying regional/local difference etc. gave extensionist an opportunity to be more innovative in sending the message to the growers.

The extensionists have acknowledged that while the objectives of extension remained same, the approach has changed.

The relative merits and demerits of both approaches as explained by the extensionists are summarized below.

Table 9.

Old approach	New Approach
1. Individual approach	1. Group approach.
2. Methodology is estate visit, demonstration, literature supply	2. Identification of the problems in a group. Training in all aspects of coffee to selected group
3. Difficult to Monitor	3. Easy to monitor
4. No individual leadership building	4. Develops confidence and leadership in extensions staff
5. No possibility of learning from growers	5. Educative process to extensionists
6. More expensive and less efficient	6. Less expensive and more efficient
7. Sectoral approach	7. Holistic approach

FPM is cost effective. Initially, the costs are high because of investment in human capital. From the tour programme of the extensionists it was observed that on an average each Junior Liaison officer was taking up a minimum of five and a maximum of 15 days of tour to cover 25 to 50 estates which works out to be Rs. 24 to 36 per estate in conventional extension methods. But it costed Rs. 62 under FPM (under the current FPM it coasted Rs. 10 Lakhs to conduct 200 workshops for extensionists- farmers Group Workshop and another 0.50 Lakhs for regional review workshops). Since major share of the expenditure was on capacity building in FPM methods, the marginal cost of the programme is likely to be less in future.

SUMMARY, CONCLUSIONS AND SUGGESTIONS

FPM was introduced by Coffee Board Extension wing with twin objectives of empowering small growers in better crop management and improving interaction between the extension staff and growers. Present study made an attempt to understand the impact of this programme on growers and extensionists. The study mainly brought out the following points.

1. This programme introduced for the first time revolutionized the approach of coffee extension from teaching/prescribing to learning and interaction.
2. It helped in capacity building of extensionists and growers.
3. Though the growers are aware of the practices introduced, it helped them in sharpening their skills and understand the science behind the crop management. This helped in reducing the wastage of resources.
4. It gave an opportunity for growers to share their experiences/problems with fellow growers and extensionists and seek solutions immediately.

However, there are problems in the implementation of this programme. It looks like it is a well conceived but ill implemented idea. The problems are as follows.

1. Though it is conceived as participatory method, there is no participation of all stake holders in project planning. The project was prepared without the participation of growers, extensionists and researchers. Due to this, this approach also became a top down approach in which the implementation of the project took place with planning from top.
2. Due to lack of participation in the planning, the scheduling of the programme is not commensurate with the expectations/convenience of growers and extensionists.
3. Some extensionists are of the opinion that the growers come to FPM meetings out of compulsion.
4. The opinions of the growers indicate that they looked at the programme only as an interaction with other growers and extensionists. The essence of participation in the true sense is not understood by them.
5. Only a few growers are addressed in the pilot project. Only when this critical mass of people take the philosophy to many growers it will be successful. Otherwise, it will be a waste of resources.
6. There are no appropriate short term institutional changes in the extension set-up with the introduction of FPM, though it is a pilot project. The extensionists are burdened with additional duties of organizing workshops, preparing reports along with their usual extension duties. This has an impact on the quality of work in original and extra duties. Even growers consider the bi-monthly meetings a burden.

SUGGESTIONS

FPM is an excellent mechanism in reaching the growers. It made an impact on the entire extension wing and on certain sections of growers who directly participated. The following suggestions are made to make it effective and truly participatory.

1. The planning process should involve all the stake holders. Involvement of representatives of growers, extensionists and researchers will be able to help in appropriate planning.
2. Appropriate institutional changes are needed in the extension wing. Identify those extensionists who understood FPM in its true sense and are articulate, train them and allocate their services to FPM. The non-FPM duties should be reduced to this group, so that they can concentrate on FPM effectively.
3. Timing of meetings, modalities and formats for reporting etc. are to be prepared with the participation of extensionists.
4. Regional extension offices should be given greater autonomy in planning and implementation.
5. Participatory Extension Methods can be effective only under Participatory Research domain. It is necessary to promote the concept of Participatory Research as a first step and Participatory Extension complements Participatory Research.

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Breeding and Selection of Coffee Cultivars for Hawaii with High Cupping Quality using Mokka Hybrids

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SUMMARY

A coffee breeding and selection program to develop unique coffee cultivars for Hawaii was initiated in 1997. Crosses were initiated in 1999 and 2000 and resulted in 1500 progeny. Sixty nine hybrid families were produced using Mokka and other varieties currently grown in Hawaii. Twelve Hybrid families were selected by tree morphology and fruit/ bean characteristics for advanced trials in commercial fields. Preliminary data showed that hybrids with Mokka had good cupping quality compared to Catuai. The 1st field evaluation in a commercial field was initiated this year. The first yield and bean quality data from these trials will be available in fall 2005.

INTRODUCTION

A coffee breeding and selection program to develop unique coffee cultivars for Hawaii was initiated in 1997. Hawaii is the only state in the US growing coffee. In Hawaii, 100% arabica varieties are grown targeting the high value specialty coffee market. No major disease and pest problems exist except for root knot nematodes (*Meliodegyne konaensis*) at Kona (Esenback et al., 1994). A single variety Typica (introduced from Guatemala) has been grown since the1800s at Kona, while Catuai has been the major variety for growers with mechanical harvesting at the other regions of the state.

We are especially interested in the introduction of Mokka flavour into high yielding and larger bean size cultivars. Mokka is an arabica coffee variety (*C. arabica*) originating in Ethiopia. Historically, Mokka coffee was exported from Mokka port in Yemen. The original Mokka is considered as a mutant of Typica (Calvaho et al., 1965). Mokka was introduced to the University of Hawaii coffee germplasm collection in the mid 1950s from Brazil. It is currently commercially cultivated on the island of Maui in Hawaii. The accession is now considered to be Mokka hybrid. Cupping quality of Mokka hybrid was evaluated to be excellent by coffee cuppers in US (personal communication, Kaanapali Coffee Company), but bean size is very small, about 30-40% of Red Catuai. In 1999, we made crosses focused on increasing Mokka seed size while maintaining its excellent cupping quality. AFLP analysis showed that Mokka hybrids in Hawaii are closely clustered with Kona Typica (genetic similarity = 0.944) (Steiger et al., 2002).

During the last 5 years, potentially elite individual trees were selected from 5 Hawaii coffee growing regions in Hawaii. A common field was established at the Hawaii Agriculture Research Center (HARC) Kunia Substation on the island of Oahu using seed and cuttings (clones) from these selections. These trees were evaluated for tree and cherry morphologies (Nagai et al., 2001). Over 200 crosses were made during the 1999 and 2000 flowering seasons between the selected genotypes including Mokka hybrids. About 1500 progeny resulting from the crosses were planted in the summer of 2000. A population from a Mokka cross was also used for construction of a genetic map for arabica coffee (Pearl et al., 2004).

We report evaluation of fruit and bean characteristics and selection of hybrid families for advancing to field trials at commercial fields.

EVALUATION OF 1999 PROGENY

During 2001 and 2002, 1999 progeny (H99-series) was evaluated for tree morphology and fruit/bean characteristics at HARC Kunia Experimental Station. Tree height was measured and general tree shape and number of vertical branches and branching were evaluated. Distribution of fruit and bean characteristics is shown in Figure 1. 100 cherry and green bean weight data indicated that increased fruit and bean size hybrid families were obtained in the progeny. Recovery of green bean from fruits showed the large variation, while no correlation was observed with fruit and bean weight.

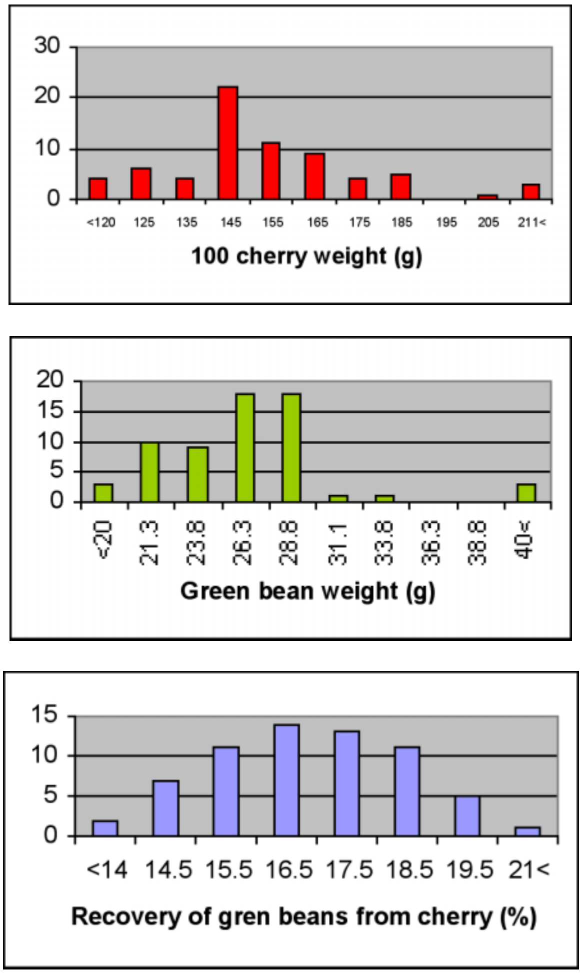

Figure 1. Distribution of fruit and bean characteristics among H99- progeny. (a) 100 fruit weight (gram), (b) Green bean weight (gram) and (c) Recovery of green bean from fruit (%).

SELECTION OF 12 HYBRID FAMILIES FOR FURTHER EVALUATION

Twelve hybrid families were selected based on tree morphology, yield and fruit and bean characteristics evaluated in 2001 and 2002. Table 1 is the list of 12 hybrid families and their parentages. The parents of 7 out of 12 selected hybrids are Mokka or Mokka hybrids. Table 2 shows fruit and green bean characteristics of selected families. Both 100 fruits and green beans weight of H99-54, H99-56, and H99-22A, mokka hybrids, are higher than those of both Typica and Catuai. H99-36, Mokka parent, MA1-12, x Margogipe, had the highest fruit and bean size among 12 selected hybrids (44.1% increase compared to MA1-12 self progeny).

Table 1. List of 12 selected hybrid families and their parentage.

Hybrid #	Parentage	Pedigree
H99-54	OA13-5 self	Blue Mtn x Mokka Hyb self
H99-56	MA8-3x MA1-12	Red catuai x Mokka Hyb
H99-60	MA10-5 self	Mokka Hyb self
H99-74	#6661x Catuai	Catuai
H99-131	BMT1x 6661	Typica x 6661
H99-150	MA6-2x SL28	Red Catuai SL28
H99-153	MA7-1 x SL28	Red Catuai SL28
H99-160	MO24-8 x mocha2	Red Catual x mokka
H99-169	OA13-1 BMT-1	BMT Mokka x Typica
H99-22A	MA1-12 self	Mokka Hyb self
H99-36	MA1-12 x Margogipe	Mokka Hyb x Margogipe
H99-43	MA10-5 x Y. Bourbon	Red Catuai x Bourbon
KA17	Yellow Catuai	
KO34	Typica	

Table 2. Fruits and bean characteristics of 12 selected hybrid families.

HybridNo	N	100Fruit wt(g)	greenbean wt (g)	greenbean/fruits(%)
H99-54	11	187± 5	33.5 ± 0.9	18.0 ± 0.4
H99-56	5	178 ± 7	25.4 ± 0.8	14.3 ± 0.3
H99-60	3	152 ± 6	27.2 ± 0.9	17.9 ± 0.3
H99-74	15	150 ± 2	26.7 ± 0.4	17.8 ± 0.2
H99-131	3	148 ± 6	28.7 ± 0.5	19.4 ± 0.9
H99-150	3	162 ± 18	25.3 ± 1.7	15.7 ± 0.6
H99-153	3	205 ± 33	31.6 ± 4.7	15.5 ± 0.7
H99-160	15	140 ± 2	20.9 ± 0.4	14.9 ± 0.1
H99-169	3	143 ± 8	29.4 ± 4.4	20.6 ± 2.0
H99-22A	5	179 ± 9	29.2 ± 1.4	16.3 ± 0.2
H99-36	5	258 ± 17	42.9 ± 4.3	16.5 ± 1.2
H99-43	3	148 ± 2	24.5 ± 0.7	16.5 ± 0.3

CUPPING SCORES OF SELECTED HYBRID FAMILIES HARVESTED AT KUNIA

Cupping evaluation of 12 selected hybrid families was conducted by the Kauai Coffee Company cupping team. Bulked fruits from the hybrid families were harvested from Kunia field in fall 2003. Fruits were processed according to HARC protocol, and dried at 25°C for 2 weeks until moisture content reached to 12%. Samples were sent to Kauai Coffee Company as green beans with parchment. Cupping was conducted by 4 trained cuppers using duplicates for acid, body and aftertaste and was scored as 1-10. *C. canephora* and Yellow Catuai, grown in the same field, were used as controls.

Table 3. Cupping of 12 selected hybrids from Kunia field 2003.

Hybrid #	Pedigree	Cupping Score
H99-54	(Typica x Mokka Hyb) self	7.3 ± 0.2
H99-56	Red catuai x Mokka Hyb	7.5 ± 0.2
H99-60	Mokka Hyb self	7.6 ± 0.3
H99-74	6661x Catuai	6.9 ± 0.9
H99-131	Typica x 6661	6.4 ± 0.6
H99-150	Red Catuai x SL28	7.1 ± 0.9
H99-153	Red Catuai x SL28	7.4 ± 0.5
H99-160	Red Catual x Mokka	7.5 ± 0.2
H99-169	(Typicax Mokka) x Typica	7.5 ± 0.1
H99-22A	Mokka Hyb self	6.7 ± 1.2
H99-36	Mokka Hyb x Margogipe	6.7 ± 1.2
H99-43	Red Catuai x Bourbon	6.8 ± 1.3

FIELD TRIAL OF SELECTED HYBRID FAMILIES AT A COMMERCIAL FIELD

A field trial of 12 selected hybrid families was initiated at the Kauai Coffee Company this year. The objective of the trial is to field evaluate selected hybrid families at a commercial field comparing with currently grown cultivars under the company's standard cultivation practices. The current operation is by mechanical harvesting with 90% Catuai variety. The trial is with RCB experimental design. Two locations (4 replications) and 14 entries (12 hybrid families and 2 control varieties, Yellow Catuai (KA17) and Kona Typica (KO34) were used for the trial. The seedlings were planted in April 2004. Tree morphological data will be taken at 6, 12, and 18 months from planting. We expect the first fruit data in fall 2005. Both superior hybrid families and individual trees will be selected. The selected hybrids are planned to be cloned by vegetative cuttings and micropropagation via somatic embryos for further large-scale evaluation or commercial planting.

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Establishment, Agronomic and Qualitative Evaluation of Collections of *Coffea arabica* and *Coffea canephora* Cultivated Varieties

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SUMMARY

In the mid nineties it has been decided to bring most of the cultivated varieties under comparative growing and post harvest conditions in order to be able to evaluate these varieties on fully comparable bean samples. Many cultivated varieties from different sources have been transferred to the Nestlé Research Center Tours (NRC-T) where they have been DNA fingerprinted before the selection of subsets well representative of the available genetic diversity. A selection of 30 *C. arabica* and 55 *C. canephora* accessions were *in vitro* propagated through micro-cuttings and then transplanted for multilocated and replicated field trials. The agronomic criteria have been regularly recorded during the development of the trees and the first significant crops have been comparatively processed and evaluated for biochemical, processing and sensory characteristics. The diversity observed for these traits were statistically analyzed with a special emphasis on the variety effect and its genetic origin. A very large diversity has been observed for all *C. canephora* recorded characteristics and a lower one, but still significant, for some of the Arabica characteristics. That leads to a variety ranking and to a better use of the existing diversity through the recommendation of varieties well adapted for both the growers and the processors according to the final consumer product.

RÉSUMÉ

Dans le milieu des années 90, il a été entrepris de collecter les principales variétés de café cultivées, et de les planter dans des sites où elles pourraient être évaluées et récoltées dans des conditions totalement .comparables. Les variétés reçues de differentes origines ont été transférées au Centre de Recherche Nestlé Tours où elles furent identifiées par marqueurs moléculaires. 30 accessions de *C. arabica* et 55 de *C. canephora* représentant la diversité génétique disponible ont été sélectionnées puis multipliées par micro-bouturage pour plantation en essais comparatifs multilocaux et répétés.

Les données agronomiques ont été notées et les premières récoltes significatives ont été étudiées pour leurs caractéristiques biochimiques, d'aptitude à la transformation industrielle et sensorielle. Les données obtenues ont été analysées statistiquement avec un intérêt tout particulier pour l'effet variété et son origine génétique. Une très grande diversité a été observée pour toutes les caractéristiques étudiées sur *C. canephora*, elle est plus restreinte bien que toujours significative pour *C. arabica*. Cette étude permet la classification des variétés et donc une meilleure utilisation de la diversité existante par la recommandation de

variétés optimales pour l'agriculteur et pour le transformateur en fonction du produit de consommation finale.

INTRODUCTION

Most of the comparative evaluation of qualitative traits of coffee beans has been based on samples defined according to their geographic origin. Usually these samples are constituted of a mixture of beans produced from different varieties, cultivated and processed differently (Guyot et al., 1996). These origin samples are therefore not fully characterized and reproducible. Moreover the variety effect cannot be dissociated from environmental and post harvest effects. In 1994, Nestlé took the decision to set up a Coffee Core Collection of most of the *Coffea arabica* and *Coffea canephora* varieties currently grown in the world and few ones of specific interest. Many cultivated varieties made available from different sources have been transferred to the Nestlé Research Center Tours were they have been DNA fingerprinted. The most relevant and diversified ones were selected to set up the field collections in order to study agronomic and quality performances in fully comparable conditions and samples.

The main objectives of the project are:

- To set up a database recording agronomic performances, processing and sensory characteristics of the beans. This database (Catalogue) could be used by agronomist, purchasing and processing people for guidance towards certain sources,
- To recommend to coffee growers the best planting material for the benefit of both growers and processors in areas where Nestlé uses direct procurement and/or support local supply,
- To establish correlation between biochemical and quality characteristics of the beans and with genetic groups,
- To make constantly available comparative samples for any further analysis which might be requested in the future.

MATERIALS AND METHODS

The collection of seeds and plant material (cuttings) started in 1995 led to the reception by NRC-Tours of 338 Arabica accessions (including pure Arabicas and varieties derived from Timor Hybrid) and 218 clones of Coffea *canephora.*

All these accessions were fingerprinted using 12 microsatellites markers for *C. arabica* and 24 RFLP probes for *C. canephora* (Crouzillat et al., 2004). A majority of duplicates could therefore be eliminated. A first selection of 30 varieties of Arabica (including 15 dwarf types and 15 tall types) and 55 clones for *Coffea canephora* was made. It quite well covers the available genetic diversity.

Due to phytosanitary reasons and also to get a fully homogeneous and identical material plantlets from each accession have been produced *in vitro* through micro cutting They were transplanted in several locations for comparative trials. The sites and their main characteristics are listed in Table 1. The experimental design is a Fisher blocks, all with 3 replications except in China with only 2 and in Thailand with 4 replications. A local variety or clone is included in each trial as a reference and experimental control. The dwarf and tall types of Arabica were planted separately. Each single plot is equivalent to 15 trees of the same variety or clone.

Table 1. Locations of the different collections.

	Arabica		Coffea canephora			
	Ecuador	China	Ecuador	Philippines	Thailand	Mexico
Planting year	1999	2000	2000 & 2001	1999	1999 & 2001	1998 & 2001
First production	2001	2003	2002	2002	2001	2001
Varieties	30	23	55	20	23	20
Situation (Province)	Pichincha	Yunnan	Los Rios	Davao	Chumphon	Chiapas

The agricultural data were regularly recorded during the development of the trees. The vigour is estimated by the plant height, the trunk diameter and the canopy size (Leroy, 1993). The green coffee samples were dry processed for *Coffea canephora* and wet processed for Arabica. Physical parameters were recorded during the green coffee processing. Green coffee samples from the collections were extensively characterised for chemical composition including the detailed characterisation of carbohydrates, proteins, chlorogenic acids, organic acids and minerals. These samples were blindly characterised for their sensory profile by well-trained panels. The main attributes were rated from 0 to 5 according to their intensity and compared to a reference sample (rate 3 for the main attributes).

RESULTS AND DISCUSSION

The genetic diversity of the collections

Using the 12 microsatellites a total of 72 alleles were detected on the 338 fingerprinted accessions of *C. arabica*. Only 44 of them showed polymorphism and were used to map these accessions with Principal Component Analyses (PCA) (Figure 1).

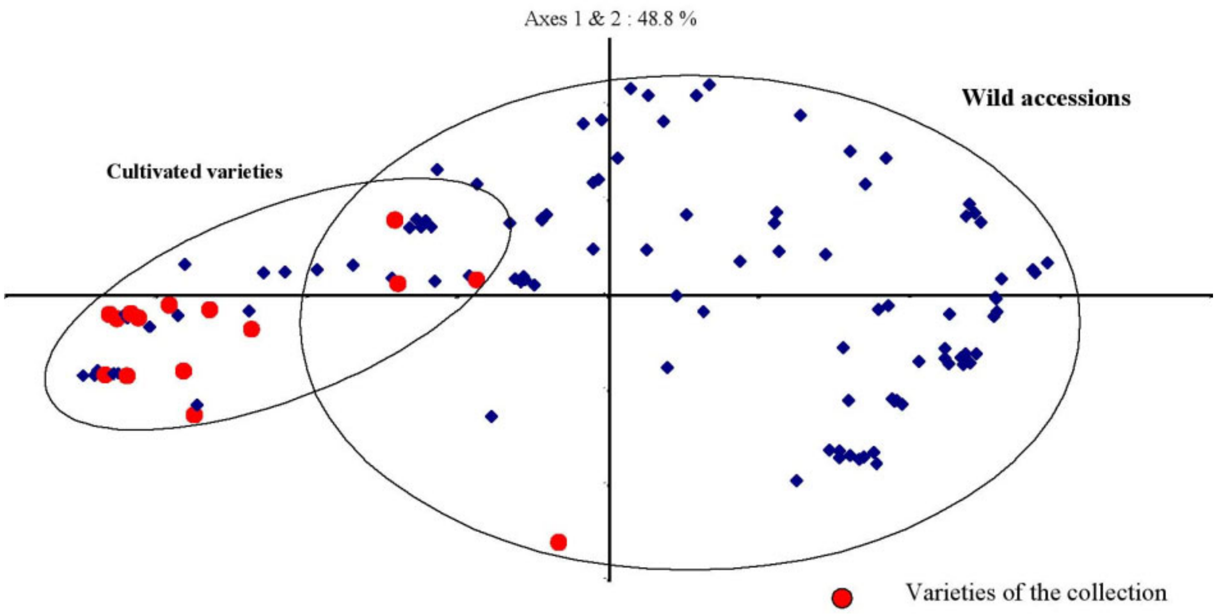


Figure 1. PCA showing the genetic diversity among *C. arabica* accessions.

Based on these DNA markers the study of the genetic diversity of the Arabicas leads to the following conclusions:

- The majority of the commercial varieties have a very narrow genetic base. Two clusters of these Arabicas are made of seven varieties. As already mentioned in literature (Anthony et al., 2002) a small part of the *C. arabica* natural diversity is "used" in the commercial varieties,
- The collection planted in field (commercial varieties) is not covering the whole natural diversity of the species,
- The usage of some microsatellites allows to differentiate the pure Arabica varieties from the varieties obtained through hybridisation with Timor hybrid (i.e. Catimor, Sarchimor).

Using 24 RFLP probes a total of 90 alleles were detected on the 218 analysed accessions of *C. canephora*. Those alleles showing polymorphism (90) were used to map the accessions with PCA (Figure 2).

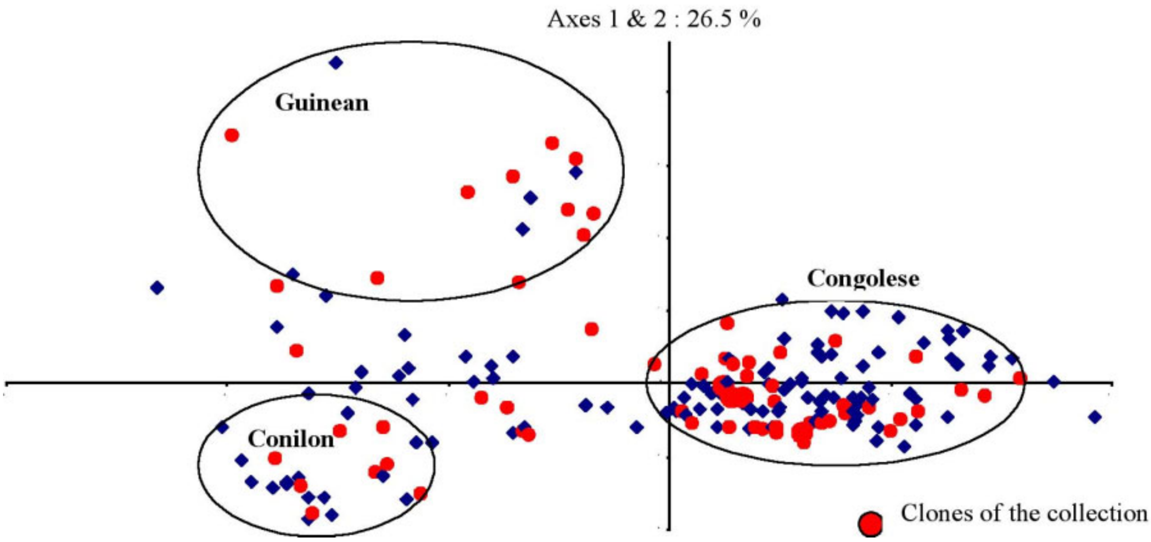


Figure 2. PCA showing the genetic diversity among *C. canephora* accessions.

The genetic diversity study with RFLP markers of the *C. canephora* accessions leads to the following conclusions:

- The genetic diversity in *Coffea canephora* is very large including three main groups in the cultivated varieties (Congolese, hybrids with Guinean type, Conilon) (Montagnon et al., 1998).
- Most of the cultivated varieties belong to Congolese group.
- The selected collection is well covering the natural diversity of the species.

The phenotypic diversity

The chemical characteristics of the samples produced in the collections were compared to the variability observed in a wide range of commercial samples analysed by Nestlé.
For Arabica, different situations were observed:

- A similar distribution between the collections and the commercial Arabica for protein, chlorogenic acid and caffeine. The caffeine distribution in China is nevertheless narrower compared to the commercial Arabica,
- A narrower distribution for lipid, total carbohydrates, ash and organic acid.

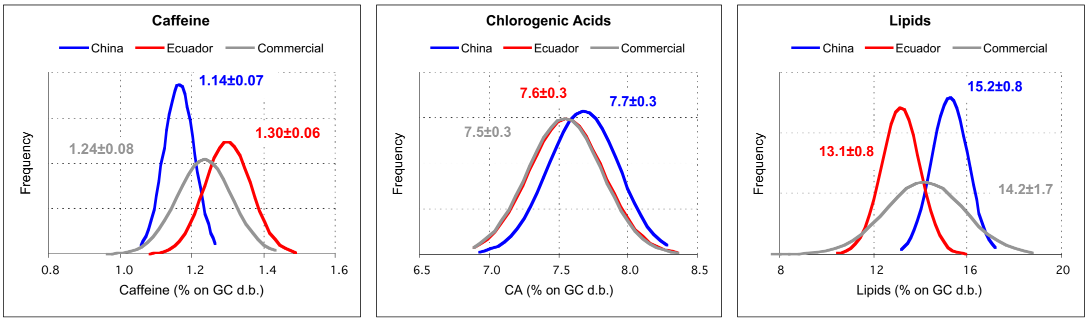
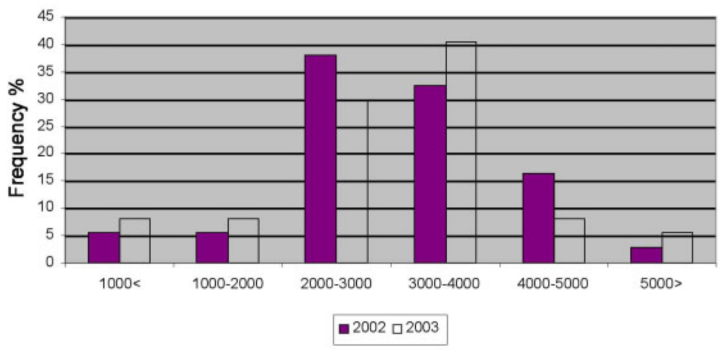


Figure 3. Chemical diversity evaluated by NIR spectroscopy for the Arabica collections compared to commercial samples.

The same comparison was done for *C. canephora* and led to the following situations:

- A similar distribution for lipids, proteins, caffeine, and organic acids
- A different distribution for total carbohydrates, chlorogenic acids and trigonelline.

The observed phenotypic diversity is also well illustrated with the range of bean yield from the collections of *C. canephora* planted in Ecuador (Figure 4).



Ecuador	Gcyield Kg/ha 2002	Gcyield Kg/ha 2003
Min	85	47
Max	5274	5993
Average	2970,6	2959,8
StDv	1125,0	1186,1
Max-min	5189	5946

Figure 4. Distribution of yield of *C. canephora* collection (kg of green coffee/ha).

The *C. arabica* have a similar distribution, ranging from 500 kg to more than 5 tonnes of green coffee/ha. The range of values observed for agricultural parameters is large for both species. It confirms that the collections planted in field are well diversified as it was already shown by DNA fingerprinting.

The part of diversity due to varieties and their genetic background can be estimated by the correlations obtained from year to year on some parameters:

Table 2. Correlation coefficients between 2 consecutive years (2002 & 2003) (agricultural parameters).

Parameters	*Coffea canephora*	Arabica	
		Tall types	Dwarf types
Number of varieties	37	15	15
Field yield	0.58***	0.54*	0.62*
Output	0.55***	0.56*	0.49*
Peaberries %	0.94***	0.84***	0.61**
Weight of 100 beans	0.97***	0.84***	0.75***

** significant to; *** highly significant.*

The correlations are strong for some characteristics like the peaberries % and the weight of 100 beans indicating that these two parameters are stable and probably strongly genetically determined. The weight of 100 beans is known to be heritable on Robusta (Charrier & Berthaud, 1988). The field yield and the output have lower correlations indicating that even if the genetic background is significant the impact of the environment and the year is also quite strong.

The statistical effects (variety, replication, sites, year)

Table 3. Statistical effects identified in the collections.

	Coffea canephora	Arabica
Genetic & phenotypic diversity in the collections	Large	Narrow
Statistical variety effect	Strong	Strong
Site effect	Strong	Strong
Year effect	Low	Low
Replications effect	Low to no effect	Low to no effect

The major statistically significant effects were the variety and the site effects. The replication effect was very low and even sometimes not significant. For example, there was no statistical difference between replications for the biochemical composition of *C. arabica* green coffee. The diversity of values observed for the biochemical composition in one site is mainly due to the varieties. Some more investigations with next crops are still necessary to identify the variety characteristics that are more influenced by the environmental conditions (site and year) or by the genetic background.

High performing varieties

The contrasted conditions prevailing in the different sites of the experimental design have a strong influence on the variety performances. Nevertheless, it is possible to select some varieties performing well in every site. This is illustrated in Table 4 for *C. canephora*. The same observation can be done for dwarf *C. arabica* for the selection of three high yielding varieties in Ecuador and China. The *C. arabica* tall types are not adapted to the Chinese conditions where they are strongly affected by rust (*Hemileia vastatrix*) and coffee stem borers. These high performing varieties are good candidates for projects of assistance to farmers.

Table 4. Top yielding *Coffea canephora* clones in different locations (kg of green coffee/ha, average of 2 significant harvests).

Clones	Ecuador (38)*	Mexico (11)	Philippines (20)	Thailand (13)
Average in the site	2991	1803	1448	583
Clone 1	4142		2450	807
Clone 2	4093	2522	3095	815
Clone 3	3273	1962	1950	516
Clone 4	3916		1630	1021
Clone 5	2920	2039	1820	618

* *Number of clones compared in each site.*

Genetic background and phenotypic traits of *Coffea canephora* clones

The biochemical composition and sensory value were characterised for the Congolese and Guinean groups of *C. canephora* identified by DNA fingerprinting (Table 5).

Table 5. Biochemical and sensory characterization of the main groups in *C. canephora.*

	Congolese group	Guinean group
Sucrose *	High (5.0 – 7.0)	Medium (4.9 – 6.3)
Proteins*	Low (9.3 – 14.0)	High (12.2 – 16.3)
Chlorogenic acids*	Low (9.6 – 11.0)	High (11.6 – 12.9)
Caffeine*	Low (1.7 – 2.3)	High (2.7 – 3.6)
Trigonelline*	High (0.5 – 0.8)	Low (0.4 – 0.6)
Quinic acid*	Low (0.27 – 0.44)	High (0.32 – 0.63)
Sensory evaluation	Strong aroma	Bitterness , fermented taste

* *% DM of green coffee.*

A contrasted biochemical composition was observed between the two groups. As already reported by Montagnon et al. (1998) for caffeine and cup quality. An illustration of the genetic influence on the cup quality can be obtained through the comparison of the genetic distance with the sensory value estimated by the balance between the positive and the negative attributes (Figure 5). The highest values are observed in the branch of the Congolese group, whereas they are low in the Guinean group. This relation is an additional indication that the genetic background has a strong influence on the sensory value of green coffee.

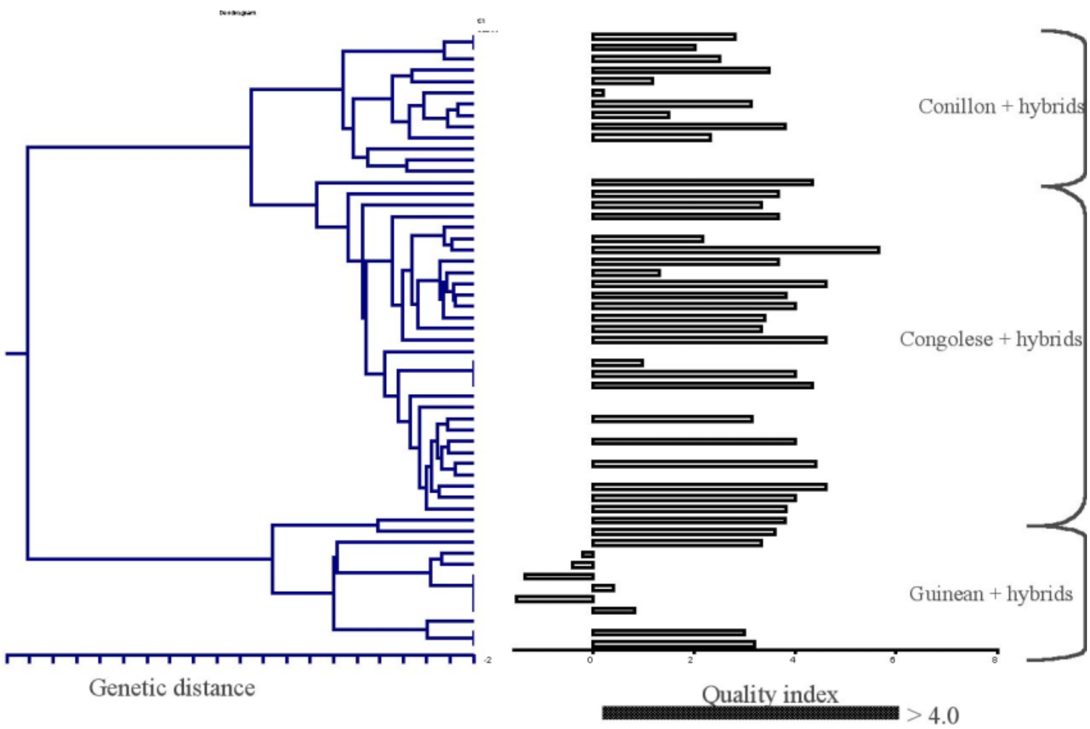


Figure 5. Relation of genetic distance with cup quality of *C. canephora.*

CONCLUSIONS

The coffee varieties collected worldwide and planted in different field conditions are well diversified. The collections are covering a large part of the diversity encountered in commercial coffees. The DNA analyses allowed to classify the coffee varieties in different genetic groups: cultivated varieties versus wild accessions for *Coffea arabica;* and Congolese, Guinean and Conillon groups for *Coffea canephora*.

The varieties are statistically different for many characteristics and stable from year to year for some of them. For *Coffea canephora* a strong relation was observed between the genetic group and the sensory value. For *Coffea arabica* and *Coffea canephora*, it was possible to identify varieties with good agricultural performances in contrasted environmental conditions.

The genetic and phenotypic diversity of these collections is being used to investigate on the understanding of the quality of coffee beans. Coffee samples of well-identified varieties produced in comparable and reproducible conditions will greatly facilitate this investigation. The field collections will be regularly updated with newly collected interesting genotypes.

The collection of *Coffea canephora* is used as a source of genetic material for large-scale propagation project. The best clonal varieties are propagated through somatic embryogenesis and delivered to farmers collaborating with Nestlé markets in direct procurement of green coffee such as Thailand and Mexico.

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Mapping of Coffee Quality in Nicaragua According to Regions, Ecological Conditions and Farm Management

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SUMMARY

Over the production cycles of 2001 and 2002, surveys of around 1000 farms were undertaken in the main coffee producing regions of Nicaragua to relate coffee biochemical composition and beverage characteristics to geographical origin, ecological conditions and farm management practices. At the peak of harvest, a sample of mature coffee berries was collected from each coffee farm and samples were wet-processed uniformly. Bean size and the percentage of defects were assessed. For the 2001 production cycle, coffee tasting was performed at the laboratories of UNICAFE in Nicaragua and CIRAD in France to compare evaluation results. Green bean samples were also analyzed for their biochemical composition by Near Infra-Red Spectroscopy (NIRS).

This study highlights differences between coffee regions for bean biochemical composition evaluated by NIRS. This technique allows for the discrimination of coffees according to their regional provenance and could be used to certify the geographical origin of coffee in Nicaragua. These results also show that caffeine content is not affected by altitude. On the other hand, bean size increases while the percentage of defects decreases with increasing altitude. Trigonelline and chlorogenic acids content increase with decreasing altitude. Bean sucrose concentration and beverage acidity increase with increasing altitude. Coffee beverage from the lowland Pacific regions was bitter than that originating from higher altitudes. Consequently, coffee of the high altitude zones of Northern Nicaragua is characterized by higher acidity, low bitterness and is preferred by the tasting panels. Although less acid, some coffees originating from low areas of the Pacific regions present good cup quality.

Effects of plantation productivity and shade could be not detected in this study, mostly due to the fact that productivity was low and shade was very uniform in all regions. Organically grown coffee results in higher quality than intensively and low-inputs managements.

Due to the particular flavor and quality of the coffee beverage, some distinct areas in the Northern regions of higher altitude as well as a few areas in the Pacific regions appear to be promising to initiate work on agricultural norms and geographical delimitation to develop labels of appellation of certified origin.

Finally, some recommendations were provided to the Nicaraguan coffee sector in order to improve its coffee marketing strategies such as maintaining coffee separate according to

production origin, better documenting the distinct beverage attributes of each production zone and channeling coffees to the most appropriate markets.

INTRODUCTION

Arabica coffee (*Coffea arabica* L.) is a cash crop of major economic importance in Central American countries that have a long-lasting reputation of producing coffee of high quality. In this region and particularly in Nicaragua (Kühl Arauz, 2004), coffee systems are very diverse, ranging from coffee grown traditionally under shade in complex agroforestry systems to intensive coffee cultivation in full sun. In Nicaragua, ecological conditions also differ greatly. Sub-optimal conditions for coffee cultivation, characterized by low-altitudes and high temperatures, predominate in the Pacific regions while optimal conditions with higher altitudes and annual rainfall are predominant in the Northern part of the country.

Due to the persistent low market prices caused by world overproduction, there is a strong interest from the coffee sector of Nicaragua to produce, promote and market coffee of high quality in order to alleviate financial difficulties encountered by producers. Numerous factors affect coffee quality (Clifford and Wilson, 1985) ranging from ecological conditions (Cannell, 1985) to maturity of coffee berry at harvest and processing, agricultural management (Beer et al., 1998) and genetic properties of cultivars (Bertrand et al., 1999, 2003).

The present study was aimed at relating coffee biochemical composition and beverage characteristics to geographical origin, local ecological conditions and farm management practices. Therefore, surveys of around 1000 farms were undertaken in the main coffee regions of Nicaragua during two consecutives production cycles (2001 and 2002) with coffee samples collected at the peak of harvest, bean biochemical composition analyzed by near infrared spectroscopy and cup quality assessed by panels of coffee experts.

MATERIAL AND METHODS

Farm surveys

In 196 coffee farms in 2001 and 727 in 2002, agricultural practices such as the presence and intensity of shade, fertilization regimes and coffee plantation productivity were recorded. Ecological conditions such as altitude, slope steepness, soil depth and color, mean temperature, annual rainfall and length of the dry season were also documented by the extension agents of UNICAFE with the help of a network of non-governmental organizations and coffee cooperatives in the different regions of Nicaragua.

Bean characteristics and biochemical composition

In each farm, around 5 kg of ripe berries were taken during the peak of harvest. Coffee samples were processed by the wet method (wet de-pulping, anaerobic fermentation for 24 hours, sun-drying and de-husking) to obtain ready to be roasted coffee beans. Processing was undertaken by UNICAFE in its regional centers following strictly the same procedures to avoid any negative effect of processing management on coffee quality. For the two production cycles of 2001 and 2002, coffee bean size was assessed with a series of sieves after sun drying beans to a water content of 12%. Percentage of green beans with small sizes (< 15/64) was calculated. For the production cycle of 2001, a 50 g sample of green beans was analyzed for caffeine, trigonelline, chlorogenic acids, fat and sucrose content by near infrared reflectance spectroscopy (NIRS) based on calibration curves established for each compound (Guyot et al., 1993). These analyses were performed on a NIRS model 6500 (NIRS System Inc., Silver spring, Md) based on reflectance of ground green coffee (grinding < 0.5 mm). The NIRS system was driven by NIRS2 (4.0) software (Intrasoft Intl., Port Matilda, PA) (Davrieux et al., 2003).

Beverage quality

For the 2001 production cycle, coffee tasting was performed at the laboratory of UNICAFE in Nicaragua and the one of CIRAD in France to compare evaluation results. For the 2002 production cycle, coffee tasting was solely performed in Nicaragua. Cup quality tests were assessed on an infusion prepared with 12 g of roasted and ground coffee. A panel of 2 persons in Nicaragua and 7 persons at CIRAD tasted three cups of 120 ml of infusion for each sample. The main beverage attributes (acidity, bitterness, astringency and body) were estimated using scales ranging from 0 to 5, where 0 = nil, 1 = very light, 2 = light, 3 = regular, 4 = s trong and 5 = very strong. An additional preference score was used ranging from 0 = not good for drinking, 1 = bad, 2 = regular, 3 = good, and 4 = very good. The tests were repeated three times and values are means of three sessions.

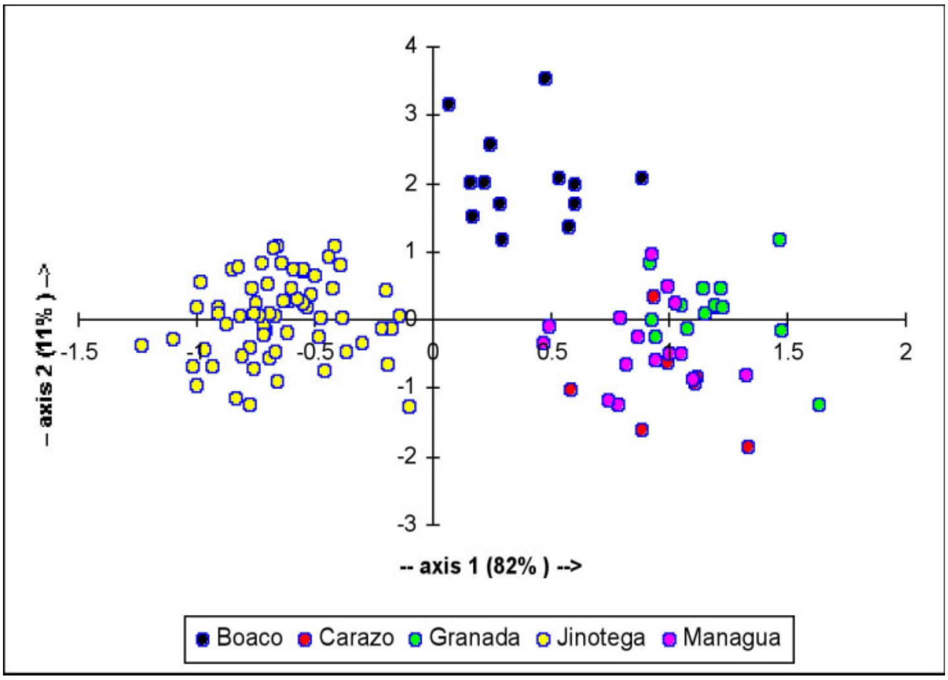

Figure 1. Graphic presentation of coffee samples on two discriminant axes (axes 1 and 2) allowing a good differentiation of the Boaco region (Central part of country) and the Jinotega region (Northern highland part of country) from the Pacific lowland regions (Granada, Managua and Carazo).

RESULTS AND DISCUSSION

NIRS analyses and discrimination of geographical origin

For the production cycle of 2001-02, 196 samples were analyzed by NIRS from 7 regions. With spectral data, a Principal Component Analysis (PCA) was undertaken to define twelve principal components best representing the variability of the set of samples. With these principal components, a Discriminante Factorial Analysis (DFA) was performed on five groups corresponding to the five regions with a minimum of 7 samples. This DFA technique allows to differentiate statistically and graphically groups according to their regional origin (Figure 1). The first discrimant axis permits to differentiate coffee samples from the region of

Jinotega situated in the Northern highlands of Nicaragua (Figure 2) and the second axis the ones from the region of Boaco situated in the center of the country with lower altitudes (Table 1). The three remaining groups (Carazo, Granada and Managua) originating from the Pacific lowlands of Nicaragua and geographically (Figure 2) as well as graphically close together (Figure 1) could also be differentiated by a second set of discrimant axes (figure not shown). Interestingly, for Madriz, Matagalpa and Nueva Segovia, high-altitude regions of Northern Nicaragua, where there were not enough samples to include in the DFA, all the samples were classified with the region of Jinotega, closed geographically (Figure 2) and ecologically (Table 1). The same could be observed for the four samples of the Pacific region of Masaya as these samples were classified with the Carazo, Granada and Managua regions. Therefore, the present results show that this technique could be used to certify the geographical origin of coffee in Nicaragua if the current database is dully completed with coffees originating from all regions.

Figure 2. Map of Nicaragua with Pacific coffee producing regions (Carazo, Managua, Masaya and Grenada), Central region (Boaca) and Northern regions (Matagalpa, Jinotega, Esteli, Madriz and Nueva Segovia).

Biochemical composition and beverage quality

Comparison of the tasting results indicates that the Nicaraguan and French laboratories were in agreement when assessing coffee quality, although some differences appeared when characterizing beverage body (data not shown).

This study demonstrates that they are some distinct differences between coffee regions in terms of bean biochemical composition evaluated by NIRS and that these differences are strongly related to ecological conditions, particularly altitude (Table 1). These results show that contents of trigonelline and chlorogenic acids increase with decreasing altitude (Table 2). Caffeine content is not affected by altitude (Table 3). On the other hand, bean sucrose concentration and beverage acidity increase with increasing altitude. Coffee beverage from the lowland Pacific regions was bitter than that originating from higher altitudes (Table 3). Consequently, coffee of the high altitude zones of Northern Nicaragua is characterized by higher acidity, low bitterness and is preferred by the tasting panels (Table 3). Such beneficial effects of high altitude have been documented in other coffee producing countries of Central America (Guyot et al., 1996; Decazy et al., 2003). Although less acid, some coffees originating from low areas of the Southern Pacific region present good cup quality (Table 3). Bean size increases with increasing altitude while the percentage of defects decreases (Table 1). Lower rainfall regimes and longer dry periods have certainly contribute to the lower bean size and higher percentage of defects in the Pacific regions as soil water availability and plant water status have a strong influence on berry development (Carr, 2001; Vaast et al., 2002). This is an important aspect to consider as bean physical aspects are often the only criteria on which bean quality is assessed at the farm gate. Differences in rainfall pattern could also be the reason for the higher quality of coffee originating from the region of Boaco compared to the region of Managua that have the equivalent mean altitude (Table 1).

Table 1. Mean altitude (meters above sea level), annual rainfall, length of the dry season (months with less than 100 mm), yield (kg of green coffee per ha), percentage of defects and percentage of beans of small sizes (< 15/64) in the 7 coffee regions surveyed during the production cycle of 2001-02.

Production 2001/2002							
Region (number of samples)	Mean Altitude (m)	Annual Rainfall (mm)	Dry period (Month)	Shade Level (%)	Mean yield (kg ha^{-1})	Defects (%)	Small bean size (%)
Jinotega (64)	1140	1787 ab	4	35±24	1680 a	1.75 ab	5.84 a
Matagalpa (3)	1017	1947 a	4	11±15*	980 bc	0.24 a	8.30 ab
Boaco (13)	756	1520 b	5	41±14	1185 b	3.60 b	6.01 a
Managua (15)	767	1242 c	5.5	41±13	965 bc	5.89. c	10.61 ab
Granada (14)	649	1417 b	6	42±9	1020 bc	7.65 d	18.82 bc
Carazo (7)	536	1550 b	6	46±17	900 bc	2.25 ab	15.29 bc
Masaya (4)	401	1179 c	6	41±19	800 bc	3.12. b	24.59 c

*Mean values within a column with the same letter(s) do not differ significantly according to the Student-Newman-Keuls test (P < 0.05). * Shade level not properly characterized.*

Table 2. Biochemical composition of coffee originating from the 7 coffee regions surveyed during the production cycle of 2001-02.

Production 2001-02						
Region (number of samples)	Mean Altitude (m)	Trigonelline (%)	Chlorogenic acids (%)	Saccharose (%)	Fat (%)	Caffeine (%)
Jinotega (64)	1140	0.85 a#	8.74 a	6.74 a	11.77 a	1.35 a
Matagalpa (3)	1017	0.90 ab	8.90 ab	6.73 a	11.27 a	1.32 a
Boaco (13)	756	0.87 a	8.78 a	6.48 ab	11.41 a	1.33 a
Managua (15)	767	0.95 bc	9.03 b	6.21 abc	12.00 a	1.37 a
Granada (14)	649	0.94 bc	9.00 b	5.96 bc	12.29 a	1.32 a
Carazo (7)	536	0.98 c	9.05 b	6.00 bc	12.45 a	1.29 a
Masaya (4)	401	0.98 c	9.08 b	5.80 c	12.17 a	1.22 a

Mean values within a column with the same letter(s) do not differ significantly according to the Student-Newman-Keuls test (P < 0.05).

Table 3. Beverage characteristics of coffee originating from the 7 coffee regions surveyed during the production cycle of 2001-02.

Production 2001-02						
Region (number of samples)	Body*	Acidity	Bitterness	Astringency	Aroma	Preference**
Jinotega (64)	2.39 a[#]	2.84 a	2.30 a	2.14 b	2.78 ab	3.10 a
Matagalpa (3)	2.40 a	2.60 ab	2.20 a	1.93 a	2.87 a	3.33 a
Boaco (13)	2.40 a	2.78 a	2.26 a	1.92 a	2.83 a	3.25 a
Managua (15)	2.61 a	2.21 ab	2.43 b	2.12 b	2.11 b	2.60 ab
Granada (14)	2.59 a	2.16 b	2.31 a	2.21 b	2.51 ab	2.22 b
Carazo (7)	2.54 a	2.54 ab	2.49 b	1.97 a	2.77 ab	2.45 ab
Masaya (4)	2.20 a	2.60 ab	2.55 b	1.80 a	2.55 ab	2.50 ab

*[#] Mean values within a column with the same letter(s) do not differ significantly according to the Student-Newman-Keuls test (P < 0.05). * The scores for body, acidity, bitterness, astringency and aroma are based on a scale of 0-5. ** Overall preference is based on a scale of 0-4.*

Coffee tasting, performed solely by the laboratory of UNICAFE for the second production cycle of 2002-03, confirms the results on cup quality obtained during the previous production cycle of 2001-02. Ranking of regions according to overall cup preference are very similar from one year to the next (Table 4).

Table 4. Comparison of overall cup quality of coffee according to regional origin during two consecutive production cycles.

Production 2001-02		**Production 2002-03**	
Region (number of samples)	Preference*	Region (number of samples)	Preference
		N. Segovia (181)	3.42 a
Matagalpa (3)	3.33 a[#]	Matagalpa (36)	3.39 a
		Esteli (31)	3.29 ab
Jinotega (64)	3.10 a	Jinotega (159)	3.26 ab
		Madriz (77)	3.21 ab
Boaco (13)	3.25 a	Boaco (14)	3.14 ab
Managua (15)	2.60 ab	Managua (76)	2.99 ab
Masaya (4)	2.50 ab	Carazo (42)	2.98 ab
Carazo (7)	2.45 ab	Masaya (42)	2.85 b
Granada (14)	2.22 b	Granada (32)	2.22 c

*[#] Mean values within a column with the same letter(s) do not differ significantly according to the Student-Newman-Keuls test (P < 0.05). * Overall preference is based on a scale of 0-4.*

No statistical analysis could be undertaken on the influence of coffee cultivar on cup quality in the present study due to the fact that the dwarf cultivar "Caturra" is predominant (more than 75%) in all the regions. The other cultivars (red and yellow Catuai, 3 Catimores and 2 traditionals: bourbon and Tipica) are under-represented and furthermore not homogeneously distributed in the regions.

Table 5. Beverage characteristics of coffee according to agricultural management during the production cycle of 2002-03.

Management (number of samples)	Aroma*	Acidity	Body	Preference**	Yield (kg ha^{-1})	Shade (%)
Organic (99)	4.17 a[#]	3.28 a	3.41 a	3.41 a	773 b	44 a
Conventional (84)	3.85 a	3.04 b	3.12 b	3.12 b	1160 a	32 a
Low inputs (589)	3.65 b	2.92 b	3.14 b	3.14 b	746 b	38 a

[#] *Mean values within a column with the same letter(s) do not differ significantly according to the Student-Newman-Keuls test (P < 0.05). * The scores for aroma, acidity and body are based on a scale of 0-5. ** Overall preference is based on a scale of 0-4.*

Table 6. Comparison of coffee beverage characteristics of some outstanding districts with respect to mean attributes of their region during the production cycle of 2002-03.

Production 2002/2003 **Region** / District	Acidity*	Aroma	Body	Preference**
Nueva Segovia	3.27	3.97	3.43	3.42
Macuelizo	3.67	4.37	3.63	3.67
Matagalpa	3.14	4.33	3.42	3.39
San Ramon	3.33	4.67	3.78	3.67
Esteli	3.29	3.84	3.29	3.29
Condega	3.47	4.20	3.40	3.60
Jinotega	3.28	4.03	3.33	3.26
Jinotega	3.83	4.35	3.78	3.55
Granada	2.28	2.59	2.34	2.22
Dioromo	2.83	3.67	2.83	3.16

** The scores for aroma, acidity and body are based on a scale of 0-5. ** Overall preference is based on a scale of 0-4.*

It has been documented that high coffee fruit load has a strong effect on coffee bean size and cup quality due to competition for carbohydrates and nutrients among developing berries [3,13]. In the present study, effects of plantation productivity could not be detected mostly due to the fact that overall productivity is low (less than 1000 kg of green beans per hectare) and quite comparable within and between regions (Table 1). Although shade has been shown to improve coffee quality (Guyot et al., 1996; Decazy et al., 2003; Vaast et al., 2004; Muschler, 2001), the predominance of a rather uniform shade in all the farms and regions did not permit to evidence its positive effects in this study (Table 1). Certified organically grown coffee results in higher quality than conventionally and low-inputs managed plantations (Table 5). This is certainly the result of a better overall agricultural management, particularly soil fertility, by organic farmers that regularly incorporate compost and organic amendments and hence maintain adequate soil organic matter content in their plantation and a more balanced nutrient availability for coffee plants. Due to the persistent coffee crisis, many coffee farmers are becoming organic producers "by default" as they can no longer afford to invest in agrochemical inputs. This will not necessarily translate into higher coffee quality as many farmers are not compensating this lack of inputs by more careful agricultural monitoring of their plantation.

Due to the particular flavor and quality of the coffee beverage (Table 6), some distinct areas in the Northern regions of higher altitudes as well as a few areas in the Pacific regions appear to be promising candidates to initiate work on agricultural norms and geographical delimitation of coffee zones to develop labels of appellation of certified origin. For example, coffee originating from the district of Dioromo is a mild coffee with medium acidity and higher aroma than the other parts of the Pacific lowland region of Granada. Likewise, coffee originating from district of San Ramon is a highly acid coffee with higher aroma and body than the other parts of the Northern highland region of Matagalpa.

CONCLUSION

NIRS allows for the discrimination of coffees according to their regional provenance and could become a very valuable tool to certify the geographical origin of coffee in Nicaragua if the reference data base is duly completed for all coffee producing regions of the country. Distinct differences between coffee regions in terms of bean size, bean biochemical composition and cup quality, are strongly related to ecological conditions, particularly altitude. In order to improve its coffee marketing strategies and hence revenues to producers, it is recommended that the Nicaraguan coffee sector separates coffees according to their origin of production, documents better the distinct beverage attributes of each production zone and channels these coffees to the most appropriate markets in accordance to the taste of consuming countries. Furthermore, it appears worth initiating work on labels of appellation of certified origin to add a premium to coffee from areas where particular flavors and high cup quality were highly noticeable. Finally, further investigations are underway in contrasting regions to investigate in details the role of shade level and plantation productivity on coffee biochemical composition and cup quality.

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Sustainable Coffee Production Systems

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THE SETTING

As the most valuable agricultural commodity, coffee is significant in the livelihoods of a large part of the tropical world in developing countries. An estimated 25 million families in 52 exporting countries depend on coffee. It is the second largest traded commodity in the world market after petroleum. Sustainable coffee production calls for:

- reduction in production costs,
- increase in productivity per unit area,
- improved quality, and
- enhanced farmer's income.

Baker (2001) explored some of the critical issues facing the international coffee industry at the start of the 21st century. He analyzed the latest thinking on a range of topics such as the coffee smallholder; mechanization of the harvesting of coffee; sustainable coffee; the specialty coffee market; organic coffee; coffee pests and diseases; coffee and biodiversity; genetically modified coffee: health effects from coffee consumption; and Ochratoxin A in coffee.

The Indian coffee industry has a heritage that dates back to the 19th century providing direct employment to about half a million unskilled rural workers and indirectly to an equal number. Apart from being cultivated in the ecologically sensitive zones of the western and Eastern ghats, coffee contributes significantly to sustain the unique bio-diversity of the region and is also responsible for the socio-economic development in some of the most remote and underdeveloped areas.

DEFINITION OF SUSTAINABILITY

From an agro-ecological perspective, the sustainability may be defined as a measure of productivity:

- Per unit-time.
- Per unit amount of soil erosion.
- Per unit decline in soil organic matter or pH.
- Per unit efflux of carbon di-oxide from soil.
- Per unit increase in nitrate nitrogen concentration in ground water.
- Per unit of economic costs & value added, etc.,

Sustainability is not synonymous with stability. Sustainability remained conceptual for a large part until Singh et al. (1990) developed two indices to identify the practices, which give maximum sustainable yield or maximum sustainable income. The sustainability should be an evolution criterion on the process of *identifying, screening and adopting techno-biological* *solutions to the farmers' problems*. Greater attention must be paid to learn from their indigenous knowledge.

According to FAO, sustainable farming should involve the successful management of natural resources to satisfy changing human needs while maintaining or enhancing the quality of environment and conserving natural resources (FAO Report, 1989). However, the concept of sustainability in any production system is "*a synthesis of ideas originating from various sources, spontaneously modified or redefined, in order to reflect the current agriculture-related environmental problems and economic pressures on farming community*".

Sustainable coffee production system (SCPS) is a broad concept based on the totality of the coffee life cycle. Sustainable farming practices include maintenance of *shade systems, low energy input agriculture, near organic culture practices and conservation of biological diversity* represented by keystone fauna and flora. It should promote sustainable livelihoods of the peasantry (Damodaran, 2002).

COFFEE ECOSYSTEM

When grown in traditional systems, coffee is part of integrated agro-forestry system. A typical coffee plantation ecosystem in India comprises of a three tier system, with the coffee plant occupying the lowest tier, and two tiers of 'temporary and permanent shade trees' crowning above them. Shade trees in coffee ecosystems of India have the additional advantage of forming 'standards' for entraining pepper vines. The inter-crops of spices and fruits confer India's coffee ecosystems with a poly-culture status. These ecosystems in their traditional mode harbour rare avian fauna, besides providing corridors for movement of large mammals. A typical coffee plantation ecosystem in the Western Ghats has natural areas comprising of cultivated wetlands growing paddy, swamps and marshes, streams and ponds (Damodaran, 2001a, b). This agro-forestry system supports the long-term sustainability of coffee yields and conserves water, soil, and biodiversity.

In the last few decades, intensification of traditional shade coffee systems into 'sun coffee' plantations had significant environmental implications. While sun coffee yielded high in the short-term, given the use of external inputs and a higher plant density, there are concerns about the long-term sustainability of the production gains. Conversion from 'shade coffee' to 'sun coffee' led to clear felling of tropical forest trees, higher soil erosion, and higher run-off of applied inputs (Damodaran, 2001a, b).

NATURAL RESOURCES MANAGEMENT

Soil

Coffee production varies mainly with differences in soil properties such as physical, chemical and biological attributes (structure, clay content, compaction, biological activity, drainage conditions and available soil water). Irrigation and nutrient requirements are also in relation to soil properties. Proper soil management without impairing soil health is the prerequisite for achieving higher coffee productivity and sustainability.

According to Raghuramulu et al. (1996) the coffee soils in India belong to red and lateritic groups generally with texture ranging from sandy loam to clay loam and are deep and well drained. These precious soils are subject to severe erosion when the forest canopy is selectively cleared for establishing new plantations, and also in exposed patches of established plantations. Measures like terracing, contour planting, planting of shade trees etc., were suggested to prevent the loss of topsoil. The soil moisture was also found to be limiting during the period November-May in south-west monsoon regions. Cultural operations such as cover digging, scuffling, mulching, staggered trenches/pits were found to be useful in conservation of soil moisture in coffee estates.

Soil physical properties

In the Farmer-Participatory Research Programme (FPR) on Sustainable Coffee Production Systems of the Coffee Board in S. India, baseline data were collected on the soil physical properties of the selected plantations (First Ann. Rept., 2003, FPR on SCPS, Coffee Board). Sand fraction was found to be high in all the samples analyzed, which ranged from 58 to 78 per cent in Chikmagalur district, Karnataka. The soils are classified under the textural class sandy clay loams (SCL) and sandy loams (SL). High percentage of sand would lead to leaching losses of nutrients particularly nitrogen and sulphur. Soil water holding capacity, nutrient holding capacity and soil aggregation are very poor in these types of sandy soils. Therefore there is a need to improve these characteristics of the soils by enhancing the organic matter status of the soils through cover crops, by addition of organic manures/composts/green manures and by microbial inoculants, besides enhancing soil aggregation. Earlier, in a long-term field experiment at three sites in Parana, Brazil, aggregation of coffee soils was found to increase by mulching, application of compost and cutting weeds above the ground level (Pavan et al., 1995a).

Soil chemical properties

In most of the estates the available nitrogen status was found to be low and the available phosphorus and potassium status was found to be medium. Among the secondary nutrients, the available magnesium status was found to be very poor in all estates. It ranged from 130 to 300 ppm with a mean of 218 and 248 ppm in surface soils of robusta and arabica estates, respectively. Imbalance of calcium, magnesium and potassium ratios in soils would cause yield reductions. Calcium and sulphur levels of the soils are optimum for coffee cultivation. Among the micronutrients studied only the soil zinc status was found to be low in most of the estates. The copper, iron and manganese status was found to be optimum.

The soil available copper status was found to be substantially higher in arabica estates. Application of copper fungicides routinely for arabica estates to control leaf rust could be the possible reason for the accumulation of copper in the soils. Though there is no copper toxicity in the plant, soil beneficial microorganisms might be affected. Similarly, the soil calcium, phosphorus, potassium and magnesium status was slightly better in arabica estates when compared with robusta estates.

Soil biological properties

The soils have sufficient population of bacteria (48 to 120 X 10^5 cfu) and low fungi and actinomycetes population (2 to 9 X10^4 and 8 to 16 X 10^4 cfu) respectively. Apart from the coffee rhizosphere, microbial analysis were also made on coffee phyllosphere (leaf), caulosphere (trunk), coffee berries, pepper rhizosphere and shade tree rhizosphere in all estates surveyed to understand better the microbial distribution in coffee ecosystem and study the effects of INM and IPM treatments on the whole system.

Water

Rainfall pattern

Coffee areas with their dense evergreen forests and misty mountains are the heartland of coffee in India. Kodagu records the highest rainfall in the state of Karnataka among the coffee growing areas. The normal annual rainfall is 2717 mm. It was gradually reduced in the last few years; 2000-2655.5 mm; 2001-2279.2 mm; 2002-2078.4 mm and 2003-1810.9 mm. In the other coffee growing belts too there has been a drastic reduction in rainfall.

Coffee is predominantly cultivated as an un-irrigated crop worldwide. Under Indian conditions, summer showers during February-March are essential for normal flowering and fruit set. Insufficient and/or delayed blossom showers coupled with lack of backing showers would result in partial to complete failure of crop. Apart from this, adequate soil moisture is also required during dry winter months to support the development, maturity and ripening of current season crop and the vegetative growth required for next crop. Any serious water stress when the trees are carrying a heavy crop would affect the vegetative growth, which would form the next year's bearing wood. Between the two major species of coffee, arabica is more drought-tolerant and hence does not require irrigation under normal conditions. On the other hand, robusta coffee is more sensitive to moisture stress and responds well to timely irrigation.

Rainwater harvesting

Of late, drought in coffee areas has become more common affecting the production. It is quite essential, therefore, to harness the rainwater at the estate level, and store in ponds so that water can be used for supplemental irrigation in the case of robusta, nursery, spraying, post harvest processing, livestock, irrigation of valuable commercial crops like vanilla and other domestic purposes.

Irrigation water management

In India, initial experiments were concentrated mostly on arabica coffee, which did not yield any positive response. Later, the experiments on robusta coffee have yielded most significant results, which formed the basis for present day recommendations on robusta irrigation. The most decisive results obtained were by irrigating only for blossom alone which improved yields by 35-51%; irrigation for blossom & backing by 48-57% and winter irrigation combined with blossom and backing by 85-95% over un-irrigated plots (Awatramani and Satyanarayana, 1973). Sprinkler irrigation has been in vogue in India in order to give fillip to the blossom rains as well as backing showers and thus has resulted in 50-90% increase in yields of robusta coffee (Rao, 1983).

Drought tolerance in coffee

Some of the Ethiopian arabicas like Tafarikela and African diploid species such as *C. liberica, C. excelsa, C eugenioides* were found to be drought tolerant because of the deep root system as compared to robusta. Indian selections such as S.288, S.333, S.795 are better adapted to the drought conditions. S.9 and S.11 are also reported to be drought tolerant (Sreenivasan, 1985). The differential responses of coffee cultivars to osmo-regulation were shown by the accumulation of free proline, nitrogen, potassium, calcium, phosphorus and carbohydrates under water deficit (Venkataramanan et al., 1986).

Two commercially important Arabica scions Cauvery and S.795 were grafted onto six different rootstocks. The grafts with Abeokutae and Excelsa rootstocks were found to be more efficient in osmo-regulation when compared to those on other rootstocks.

Atmosphere

Increasing concentrations of greenhouse gases such as CO_2, CH_4, N_2O, etc. and their role in photochemical interactions and the consequential climate change have been recognized as serious threats in the last three decades. In view of the intensification of agriculture and industry to meet the demands of the growing population, the contribution of greenhouse gases to global changes is expected to increase. There is, therefore, an urgent need to develop possible mitigation options, which are feasible, economically viable and environmentally friendly. It was projected in the UN Earth Summit 1997 that about 15-20% reduction from 1990's level in the total greenhouse gas emission by 2000 A.D. would be required to minimize the impact of these gases on climate and agriculture.

Coffee environment

The production of coffee is highly correlated to weather conditions, since the coffee tree is sensitive to low temperature and moisture. Therefore, annual production of coffee is unpredictable until the end of the harvest season.

Climate change

The past decade has witnessed phenomenal changes in global climate: drought in the southern hemisphere and floods in the northern hemisphere. A record rise in temperature or a sudden cold wave, heavy cloud bursts, bushfires, earthquakes, or severe drought; have resulted in significant changes both at the micro- and macro-habitat. Coffee farmers in India were in for a rude and unexpected shock when they felt the impact of El Nino and La Nina. All coffee farmers took it for granted that any change in the global environment will be slow and will take ages to happen. They were so casual and confident that nature would never let them down. The inevitable man-made changes are affecting the entire planet. One may call climate change by different names, but today no matter what we call it, global warming has emerged as a clear and potential danger threatening mother earth and all its inhabitants (Titus and Pereira, 2003). .

Worldwide the forest cover is dwindling at an alarming rate. Reports from the World Resources Institute indicate that more than 80% of the planet's natural forests have already been affected or destroyed. The developing economies are catching up with the west in terms of carbon dioxide emissions into the atmosphere. Research pouring in from different parts of the globe states that carbon dioxide is responsible for about 60% of net radioactive increase between 1950 and 2000 A.D. (Titus and Pereira, 2003).

Biodiversity

Biodiversity encompasses ecosystems, species, and landscapes as well as intra-specific (genetic) levels of diversity. This would suggest that species diversity would enhance ecosystem stability. Such stability would enhance the sustainability of any crop production system.

Coffee plantations world-wide, especially, shade-grown Indian coffee plantations were the first to be affected by the change in ecosystem. Looking back, coffee plantations in India are basically rich biodiversity parks located in the ecologically sensitive western ghat reserve forests. One can find an incredible array of rare herbs and shrubs in the most remote places. Coffee has mutually coexisted with the native flora and fauna and in fact satellite images have thrown light that wherever coffee plantations exist, the biodiversity of the region has also been enriched. This peaceful coexistence has continued for centuries in a complimentary set up, wherein the energy levels of the biotic community are proportionately balanced. Loss of one species will have a tremendous bearing on the other. This heritage site is a lodge for the survival of thousands of species of trees, shrubs, herbs, wildlife and so on. Most species of plant and insect life have disappeared before they were discovered. Even though the Western ghat reserve forests were shrinking at an alarming rate, institutions worldwide realized the importance of this vital link for the future existence of man and nature, and hence protected it as one among the 18 hotspots of the world (Titus and Pereira, 2003).

Biodiversity and IPM

The possible complex system of biodiversity of coffee plants, their pests, pathogens and natural enemies, and their interactions is illustrated in Figure 1.

Bird diversity

Mr. K. R. Sethna, Planter & Bird Watcher, Yellikodige Estate, Aldur, Chikmagalur dist., Karnataka, India (personal communication) reported the species of birds found in organic coffee ecosystems in Aldur block, Chickmagalur district, Karnataka, India. The list included 81 species, of which 21 were insectivorous predators keeping pests under check.

Crop diversity in coffee ecosystems

Intercropping with ginger and elephant yam in young Robusta is not only a source of higher return from unit area per unit time, but also provides food and employment opportunity for plantation workers and small growers (Nair, 1976). During the pre-bearing period of coffee, the interspace could be profitably utilized for cultivation of ginger (2nd year of planting coffee) and turmeric (3rd year), besides raising of banana (1st year) as initial shade which also provides an early income. Establishment of permanent shade tree species like; silver oak and *balanji* in the first year of planting coffee itself could be used as live standards for training pepper when they attain sizeable growth during fifth year (Korikanthimath et al., 1995).

As coffee is a labour-intensive crop, especially in the initial pre-bearing years, and as the cost of cultivation is escalating, raising a cover crop with a leguminous plant like *Mimosa invisa* may work out advantageous. It has been estimated that the mulch available may come up to about 3-5 m.t./acre on dry basis. It offers a greater scope to a wide range of estates at least for a few initial years to save expenditure on weeding (Balasubramanian, 1970). *M. invisa* also prevents soil erosion by binding the soil and checking run off water to considerable extent. Coffee plants grown in experimental plot indicated more number of green flush and branches than control due to the higher N status (Mohankumar, 1996). Cowpea and horsegram are also good in smothering weeds in young coffee plantations. They add biomass to soil (cowpea 4.1 MT/ha and horsegram 3.4 MT/ha). Weed smothering efficiency of horsegram (82% and 52%) and cowpea (68%) was higher than other cover crops. Blackgram, horsegram and cowpea also improved soil fertility (Keshavaiah et al., 1998).

Muralidhara and Raghuramulu (1997) discussed the types of mulches, advantages and disadvantages of mulching, methods of application, nutrient composition of different mulches, and effects of mulching on growth and yield of coffee and on soil conditions in plantations. It is concluded that plant-based mulches generally increase the growth and yield of coffee plants, conserve soil moisture, improve soil nutrient status, reduce runoff and soil losses, and control weeds.

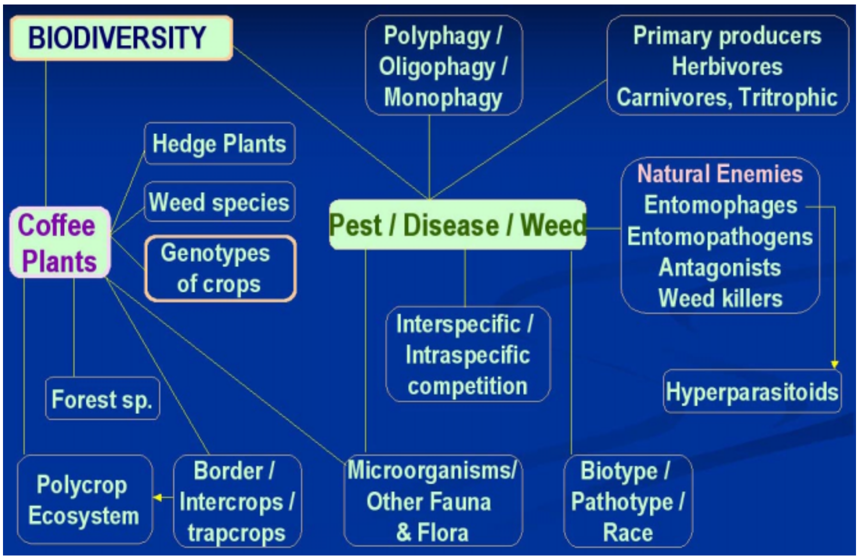

Figure 1. Biodiversity of the host plants, pests/Pathogens/weeds, their natural enemies and their interaction.

Diversity of microorganisms in the soil

The soil acts as a reservoir for millions of microorganisms, of which more than 85% are beneficial for plant life. Thus, the soil is a resilient ecosystem. Good soil consists of 93% mineral and 7% bio-organic substances. The bio-organic parts are 85% humus, 10% roots, and 5% edaphon. Humus is a product of the synthetic and decomposing activities of the microflora; it exists in the dynamic state. It is under continual attack, yet it is constantly reformed by the subterranean inhabitants. Similarly, edaphon is a world of life and consists of microbes, fungi, bacteria, earthworms, micro-fauna, and macro-fauna as follows:

- 40% fungi/algae
- 40% bacteria / actinomycetes
- 12% earthworms
- 5% macro-fauna
- 3% micro / meso-fauna

Thus, soil microorganisms provide precious life to soil systems catering to plant growth. These microorganisms work incognito to maintain the ecological balance by active participation in carbon, nitrogen, sulphur and phosphorous cycles in nature. Soil microorganisms play a pivotal role both in the evolution of agriculturally useful soil conditions and in stimulating plant growth (Titus and Pereira, 2003).

Chemicalization of Agriculture

In the process of increasing the productivity, more and more of synthetic chemicals like fertilizers, pesticides, herbicides, soil amendments, etc. were used, which began to affect not only the soil health and agricultural production but the whole environment. The consumption of chemical fertilizers has been increased four-fold in the last quarter century. The use of nitrogenous fertilizers has shown very significant increase (Figure 2, 3), which has led to many pest and disease problems besides pollution of ground water. Fertilizer nitrogen is highly mobile and is lost considerably due to evaporation, seepage and run off. Nitrogenous fertilizers are used excessively in hill crops in the country. Hence, production and use of various organic manures should be improved not only for enhancing the crop productivity and reducing cultivation costs but also to protect environment and avoid pest and disease outbreaks.

Indiscriminate use of chemical pesticides has particularly affected man and his environment and contributed significantly to reduced productivity of crops.

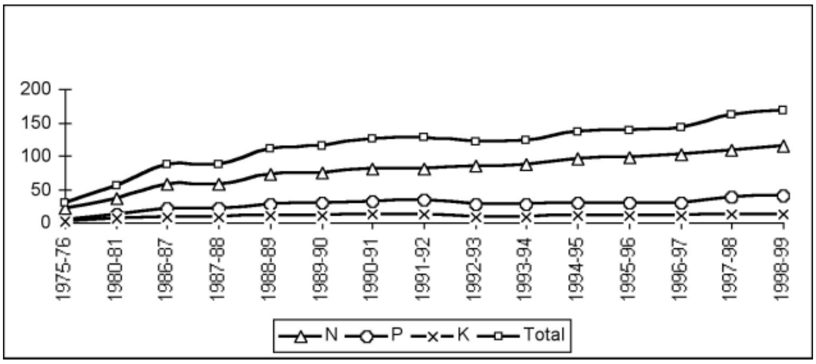

Figure 2. Consumption of fertilizers (nutrients) in lakh tonnes (agricultural statistics at a Glance, govt. of India, 1999).

Chemical fertilizers, pesticides, seeds and irrigation water are the four major inputs needed in agriculture. Over use of the former two will be polluting the environment. During the last two decades fertilizer consumption showed 195% compounding growth rate during the decennium 1980-1990 and another 99% during 1990-2000. Similarly, pesticide consumption increased by 71% and 58% respectively during the corresponding period (Table 1).

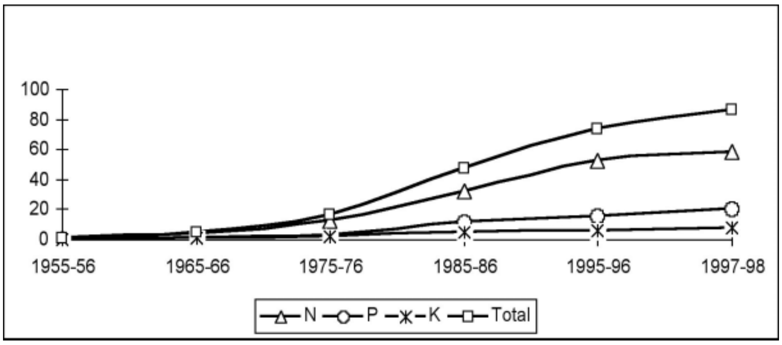

Figure 3. Consumption of plant nutrients (kg:ha) (Fertilizer statistics, 1997-98, Govt. of India, New delhi).

Table 1. Cost estimates for agricultural input requirements in India (US $ billion).

Input	1980	1990	2000
Fertilizers	4.9	13.0 (195)	25.9 (99)
Seeds	5.0	6.2 (24)	7.2 (16)
Pesticides	0.7	1.2 (71)	1.9 (58)
Irrigation	4.9	6.2 (27)	7.3 (18)

Figures in parentheses are decennial per cent change.

Among the traditional coffee growing states in India, Tamil Nadu state consumed maximum quantity of chemical pesticides during 1994-95 for all crops (Table 2). Karnataka state had consumed less than half the quantity. However, in the last few years the consumption in all the states has come down drastically.

Table 2. Major consumers of pesticides in India.

States	Quantity (MT of Tech. Grade)	States	Quantity (MT of Tech. Grade)
Andhra Pradesh	13,000	West Bengal	5,800
Uttar Pradesh	11,000	Haryana	5,200
Tamil Nadu	9,500	Gujarat	5,100
Maharashtra	6,900	Karnataka	4,400
Punjab	6,400	Rajasthan	2,900

Source: G Singh (1996). Country Report, Pesticide Application Technique, FAO.

INTEGRATED NUTRIENT MANAGEMENT

Nutrient status of coffee soils in South India

The level of soil nutrients varied from zone to zone and from location to location within each zone. The highest level of available nutrients and lowest acidity were seen in Kodagu zone in Karnataka while poorest soils and the maximum acidity were met with in Kalpetta zone in Kerala.

Heavy use of nitrogen started up showing in increased nitrate concentration in underground waters. Due to these alarming signals, Integrated Nutrient Management (INM) has become a sustainability concept. It involves meeting a part of the nutrient need of crops by organic manures, crop residue, green manures, dual purpose legumes and bio-fertilizers. The importance of INM was recognized following the long-term fertilizer experiments in many crops throughout India. Application of N alone reduced the crop yield after a decade or so. Application of P along with N extended it to some more years but in NPK plot some yield was obtained even after two decades. However, plots receiving a part or all nutrients through FYM not only maintained but also recorded a gradual increase in crop yield over years. Combined application of FYM and inorganic fertilizer was the best.

The deficiency of different micro and secondary nutrients, especially of Zn and S, became yield-limiting factors within a few years, depending upon soil nutrient status. Addition of deficient nutrient or high dose of FYM (10-15 MT/ha) corrects this situation. Secondly, where N alone is used, its adverse effect on yield and soil quality became disastrous in acid soils. Thirdly, it is the deficiencies of Zn and S and other micro or secondary nutrients (Fe, Mn, B, Cu and Ca), which are emerging as yield-limiting and sustainability-disturbing factors and necessitate correction of their deficiency through appropriate nutrient input and management. Continuous monitoring of changes in the nutrient status of soils is, therefore, quite essential as it is observed that 49% soils in the country are deficient in Zn, 25% in Fe, 55% in Mn and 3% in Cu. The situation is changing under intensive cropping and unbalanced and improper use of fertilizers.

Biofertilizers

In recent years, use of bio-fertilizers holds much promise to improve the yield of crops. Biofertilizers sustain soil fertility resulting in increased crop yield without causing any environmental, water, or soil hazards. Of the many micro-organisms which are identified as bio-fertilizers, *Azotobacter*, *Azospirillum*, Phosphorus Solubilizing Bacteria (PSB) and Vesicular Arbuscular Mycorrhizae (VAM) have a significant role in crop nutrition. *Azospirillum* stimulates plant growth. Inoculation with *Azospirillum* increases the number, length and weight of roots besides bud development, number of leaves and leaf weight in many crops.

Organic manures

Farm yard manure, composts and various kinds of other organic manures are becoming increasingly in short supply and costly leading to their less application thereby affecting the soil health and crop productivity and quality adversely. The situation has created a renewed interest in the biological transformation of farm wastes including all organic wastes into valuable manures. The compost manure prepared out of farm wastes can be profitably used in the fields for the cost-effective production of crops. This nutrient-rich compost (Choudhury et al., 1993) is a better supplement for farm yard manure, the cost of which is escalating day by day due to shortage of cattle dung. Besides, it is poor in nutrient quality. Much information is available on the use of various organic manures and their positive effect on various crops (Palaniappan and Natarajan, 1993).
With a view to minimise the use of chemical fertilizers, farmers should be able to produce different kinds of organic manures and apply as part of INM system. As our cattle wealth is fast declining, adequate quantity of farmyard manure could not be produced in recent years in the country. Hence, a new thrust is necessary to the production and use of other kinds of organic manures as well.

Recycling farm wastes as compost

Most coffee farms are known for the availability of tonnes of organic raw material needed for preparation of compost. Poultry litter, sheep droppings, piggery waste, cattle dung, any of the above mentioned products (singly or in combination) are added to fresh leaf litter, weeds, succulent stems, coir pith, press mud, or coffee husk in layers. At times, an inoculum of beneficial free-living nitrogen-fixing and phosphorus solubilizing bacteria along with strains of *Trichoderma* and *Mycorrhizae* are inoculated to the mixture of organic residues so as to hasten the process of decomposition. The entire process of composting is either done by the pit or the heap method (Titus and Pereira, 2003).

Soil amended with organic materials (neem cake, coir compost, farmyard manure, and *Gliricidia* leaves) showed better antagonist growth and survival than soil alone. The carrier materials (neem cake, coir pith, farmyard manure, and decomposed coffee pulp), which served as nutrient additives to the crop, enhanced inoculum production (Saju et al., 2002).

The ability of the earthworm *Eisenia fetida* to transform coffee pulp into a valuable compost was evaluated by Orozco et al. (1996) in Columbia. The C and N contents were not affected by the depth of the bed, whereas time affected both. An increase in the fractionation ratio, determined by calculating the C in the fraction smaller than 100 μm as a percentage of C in the samples as a whole, and low values of humic-like substances were recorded during vermin-composting. After ingestion of the pulp by the earthworms, an increase in available P, Ca, and Mg but a decrease in K was detected.

Green manure crops

With a view to minimize the use of chemical fertilizers farmers should be able to produce different organic manures and apply. Green manures are the bulky organic manures that can be produced under any situation. A large number of leguminous crops are used for green manuring in South India. Daincha (*Sesbania aculeata*), sunnhemp (*Crotalaria juncea*), wild indigo (*Tephrosia purpurea*), indigo (*Indigofera tinctoria*) and *Pillipesara* (*Phaseolus trilobus*) are the most popular crops with farmers. *Sesbania speciosa* is an introduction from South Africa and is slowly getting popular. A number of other crops like cowpea, lablab, redgram, *Crotalaria striata*, etc. are also grown as green manure crops in some places (Sankaran and Mudaliar, 1997). Leguminous green manure species are able to fix atmospheric nitrogen and do not necessarily depend on the nitrogen in the soil. The phosphorus present in green manure is in the organic combination and becomes available for use by the succeeding crop.

INTEGRATED PEST MANAGEMENT (IPM)

Causes for Pest Depredations

The following are the important causes for severe pest damages:

- Monocultures and rapid increase in the area under coffee crop,
- Lack of natural enemy load of the pests on the tree,
- Changing climatic conditions, and
- Excessive application of chemical fertilizers

The white stem borer has been stated to be still a threat if uncontrolled. Monocropping results in persistence of this insect, which in turn is aggravated by negligent control measures, destruction of the environment, introduction of susceptible host material and unproductive cultural practices. Further, cultivation of coffee under greatly reduced shade has been disastrous as it resulted in outbreak of the pest in 1960s and 1970s. Better performance of coffee in moderate to good land and under forest cover is reported in the same periods (Balasubramanian, 1987).

Biological control

The value of biological control is now well recognized particularly in the context of environmental protection as well as stable pest management strategy (Table 3).

The need for biological control of major pests of coffee in India has been highlighted by Prakasan (1987) and Venkatesha et al. (1995). Veeresh et al. (1992) observed field parasitization of white stem borer by *Allorhogas pallidiceps* up to 19.81% during September–December flight period in Kodagu district. Cerambycid grubs proved better hosts compared to other species of larvae used for culturing the parasitoid. An egg parasitoid, some effective predators and a bacterium, *Serratia* sp. were observed (Shylesh et al., 1992). *Iphiaulax* sp., a new braconid parasitoid, and *Apenesia* sp. were recorded from coffee white stem borer by Venkatesha et al. (1997). Seetharama et al. (2002) reported that *Apenesia* sp. is a potential natural enemy for the biological control of coffee WSB in India.

Table 3. Advantages and disadvantages of biological control and chemical control methods.

Category	Biological Control	Chemical Control
Environmental pollution, danger to man, wildlife, etc.	None	Considerable
Upsets in natural balance, ecological disruption	None	Common
Permanency of control and economics	Permanent and therefore economical. Initial cost is the least.	Temporary. Repeated applications required and so not economical
Development of resistance	Extremely rare, if ever.	Common
Impact on pests become effective, but continues to be effective	Takes time to but may rebound	Speedy result
Range of action	Specific or narrow	Broad

Host Plant Resistance

Most adults of the stem borer emerged from the stems of *Coffea arabica* (72%), followed by *C. canephora* (52%), *C. liberica* (28%) and *C. excelsa* (20%) (Venkatesha et al., 1995). Srinivasan and Ramachandran (1997) reported that S.2931 showed higher yield, quality and resistance to leaf rust (*Hemileia vastatrix*) and white stem borer (*Xylotrechus quadripes*). About 85-90% of plants were completely resistant to rust. Schoeman (1995) showed the possibility of grafting scions of arabica coffee onto borer-resistant robusta coffee rootstocks.

Pesticides of Plant Origin

One of the viable alternatives to chemical pesticides is the development and use of better botanical pesticides, which are environmentally safe, effective against pests, easy and economic. As plants and insects have co-evolved over millions of years, they have accumulated specific secondary plant chemicals to counteract the insect damage. These bioactive chemicals include insecticides, antifeedants, insect growth regulators, juvenile hormones, ecdysones, repellents, attractants, arrestants, etc. Hence, plants are thought to be an important alternative source for chemical pesticides. Over the years more than 6000 species of plants have been screened and nearly 2400 plants belonging to 235 families (Grainge and Ahmed, 1988) were found to possess significant biological activity against pests and diseases (Table 4).

Over centuries, the natives of Far Eastern tropics had used derivatives of plants like *Derris elliptica* (Wall.) Benth., *Lonchocarpus utilis* A. C. Smith and *Tephrosia* spp. for the insect control and later during 1929 the structure of active of ingredient of 'rotenone' was discovered. Subsequently, ryanodine from powdered root, stem and leaves of *Ryania speciosa* Vahl., quassin from the bark of *Quassia amara*, jerveratrum from dried seeds of sabadilla, *Schoenocanlon officinale* A. Graz (Crosby, 1971) were also used as pest control agents. There are several discoveries, which are considered to be the landmarks in the development of plant origin pesticides. These discoveries enabled the scientists to progress and develop ecologically safer pesticides.

Table 4. Types of pest control action reported in plant species.

S. No.	Pest Control Action	No. of Species of Plants
1.	Insecticidal	1053
2.	Antifeedant	230
3.	Repellent	225
4.	Growth inhibitor	32
5.	Attractant	27
6.	Rodenticidal	29
7.	Acaricidal	2
8.	Nematicidal	58
9.	Fungicidal	100
10.	Bactericidal	4

Experiments were conducted in Kerala, India by Chandrika et al. (2001) to determine the insecticidal potential of the local weed plant, *Clerodendron infortunatum*, against the rhinoceros beetle. At high concentrations (10% w/w), the plant caused mortality of the full-grown beetles within 10 days. There are many other species of plants with botanical pesticidal value such as species of *Azadirachta, Pongamia, Melia, Madhuca, Vitex, Ipomea, Jatropha,* etc., which should also be exploited against coffee pests. The biopesticide feed-stock tree species found on the hills and foothills are listed in Table 5.

Table 5. Trees with insecticidal activity.

Tree species	Plant part / product	Active principle	Activity
Albizia lebbeck	Seed, leaf, pod, bark and root	Caffeic acid, alkaloids and quercetin	Insecticidal
Anacardium occidantale	Shell oil	Phenolic compounds	Insecticidal
Annona squamosa	Stem leaf and semi – ripe fruit	Annonine	Insecticidal
Azadirachta indica	Seed and seed oil	Azadirachtin, nimbidin, salanin, meliantrol and other bitter principles (tetra nor terpenoids)	Antifeedant, oviposition deterrent, IGRs and insecticidal
Butea monosperma	Flower extract	Chalcones and aurones	Termiticidal
Hardwickia binata	Heartwood	Mopanol and epicatechin	Antifeedant
Madhuca latifolia	Seed and seed oil	Saponins	Repellents and insecticidal
Melia azedarach	Fruit and seed	Meliacin	Antifeedent and insecticidal
Pongamia pinnata	Seed and seed oil	Karanjin	Repellent and insecticidal

IPM

White stem bore

The factors responsible for the increased incidence of white stem borer in India were highlighted by Sreedharan and Kumar (2001). They include changes in cultivation practices, rainfall distribution during the winter flight period of the beetle, discrepancies in the adoption of control measures by the growers and cultivation of Cauvery coffee (a good stem borer host). The importance of various control options, such as shade maintenance, tracing and destruction of infested plants, bark scrubbing and pesticide application (particularly lindane) was stated in the effective management of the borer.

Berry borer

An integrated approach with the judicious combination of cultural/phytosanitary measures, biocontrol and need based application of pesticides was found to be the best strategy to combat berry borer effectively. Adoption of phytosanitary measures scrupulously played the key role in suppressing the pest build up. Though biological control measures are promising there is a need to standardize the production and application technology of biocontrol agents. The need-based use of selective pesticides will continue to be a part of berry borer management strategy until such a time when an universally adoptable, cost effective and sustainable biocontrol programme is evolved (Sreedharan and Balakrishnan, 1999).

Mass trapping of CBB adults was done by Dufour et al. (1999) in El Salvador with host plant allelochemicals. Residual CBB population present in the dry coffee berries on the ground was the major source of the first migrations. The old dry fruits still present on the branches seemed to act as a temporal refuge. Reduction in damage was 34.8% using the basic trap mixture of 1:1 ethanol: methanol, and it reached 50.7% using the alcoholic mixture in association with two terpenes.

In a 3-year study in Wynad, Kerala, India, Vijayan et al. (1999) found that shade favoured the incidence of CBB. Cultural operations (shade regulation, correct pruning, thorough and timely harvesting, and removal of left over and off-season fruits) resulted in significantly lower infestation of coffee by CBB than was observed at a site where such measures were not adopted (Vijayalakshmi et al. 1997).

According to Cure *et al.* (1998) control measures should be taken between the end of one growing season, after harvesting, and beginning of fruit maturation in the next growing season, targeting adults before oviposition begins. Reddy and Rao (1999) reported that severe infestations of CBB were observed in 1998 for the first time on Arabica and Robusta coffee cultivated under coconuts in Mandya District, Karnataka, India (200 km from traditional coffee-growing areas). To prevent the spread into new areas, they suggested the following:

i. Dry coffee to correct standard weights,
ii. Complete harvesting as soon as possible,
iii. Ensure collection of left-over crop to complete harvesting,
iv. Use picking mats to reduce gleanings and collect the maximum amount of gleanings,
v. Use boiling water treatment on infested fruits before processing,
vi. Continuously monitor pest occurrence,
vii. Spot spray affected plants with endosulfan once during April-May and repeat during July and August,
viii. Spray with *Beauveria bassiana* during May when 90% humidity prevails,
ix. Destroy infested coffee if observed as a stray case,
x. Use new gunny bags, and
xi. Avoid irrigating coconuts during December and January.

An integrated CBB management programme was outlined by Sreedharan et al. (1994) incorporating cultural, phytosanitary, mechanical, chemical and biological methods.

Coffee rust disease management

Rainfall during March/April, number of rainy days, minimum temperature and rust inoculum present during the same period showed positive correlations with rust build up during the subsequent months. Drought period preceding blossom showers and maximum temperature during March-April showed negative correlation with rust build up. Multiple regression analysis indicated the function with three variables namely drought period preceding blossom showers, rainfall or maximum temperature during March-April and variation in level of rust from April to may was highly efficient (r^2 99%) (Nataraj et al., 1993).

Biological control of leaf rust

An efficient and practical method for the massive production of strains of *Verticillium* sp. with high potential as hyperparasites of *Hemileia vastatrix* was developed by Canjura et al. (2002) in El Salvador. The media for the production contained molasses, yeast, and distilled water, with different quantities of molasses (120, 80, 40, and 8 g/litre), with or without the addition of rust urediospores into the media. For three *Verticillium* strains, final spore concentrations of 2.3 x 106 and 5.5 x 109 conidia/ml were obtained. The best combination of ingredients was 8 g of molasses/litre in the absence of rust urediospores; higher concentrations did not improve production. Three applications of five mixtures of strains in coffee plants affected by rust were administered.

Verticilium hemileae, the hyperparasite of coffee leaf rust pathogen, *Hemilea vastatrix* was commonly observed on the uredospores of rust affected coffee leaves especially during the humid weather conditions. To utilize this parasite for rust disease control suitable media were identified for large scale multiplication. After 12 days, the colony forming units (cfu/g of the substrate) were highest in maize substrate, followed by rice bran (Bhat, Personal Communication; First Ann. Rept., 2003, FPR on SCPS, Coffee Board).

Coffee root exudates and root diseases

The fast growing coffee roots are known to produce the following substances in the root exudates, some of which are antagonistic to root pathogens such as *Aspergillus* spp., *Fusarium* spp. and *Rhizoctonia solani*: alkaloids, auxins, phosphorus, vitamins, amino acids, potassium, nucleotides, enzymes, calcium, flavanoids, flavins, sodium, sugars, nitrates, iron, bromide / chloride ions. It is now generally accepted that the main factors for the stimulation of microorganisms in the rhizosphere are the excretion of organic substances by roots. This means that the release of metabolites by roots is an important factor determining the quantitative and qualitative composition of rhizosphere microflora. The root exudates can selectively inhibit or stimulate the growth of soil borne fungal pathogens. A particular type of root exudate can influence a certain group of microflora and also might influence the pathogen (Gopal, 1972).

Coffee nematodes

A total of 108 soil samples were collected from the root-zone of different crops including banana, arecanut, coconut, coffee, cardamom and shade trees to determine the biodiversity of *Glomus fasciculatum* in different districts of southern Karnataka, India (Babu et al., 2003). Among 108 soil samples, 5 isolates were selected based on spore morphology and spore load and were evaluated against *Radopholus similis* infecting banana under greenhouse conditions. Among the isolates tested, Udupi Areca isolate was effective in improving plant growth and reducing nematode population both in the soil and roots. The root colonization and number of chlamydospores formed by this isolate were maximum followed by Davanagere Banana isolate.

Farmer participatory research in S. India

A project titled ”Farmer Participatory Research for Sustainable Coffee Production through Integrated Crop and Farming Systems Management” has been implemented by the Coffee Board of India in five districts in four states in South India from July 2003. Malady-remedy analysis has been carried out as one of the components, especially the soil physical, chemical and biological properties, and biodiversity, with a view to develop suitable approaches to maximize coffee productivity, optimize cultivation costs, reduce environmental pollution, and ensure sustainability in the production systems. The upgraded INM and IPM modules being tested in the FPR are given in Figure 4 and 5.

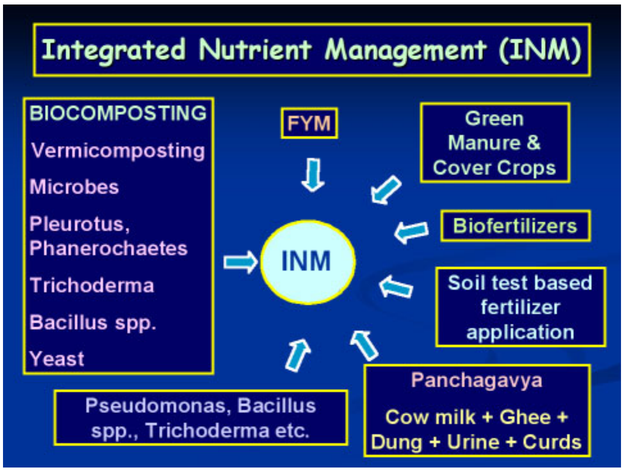

Figure 4.

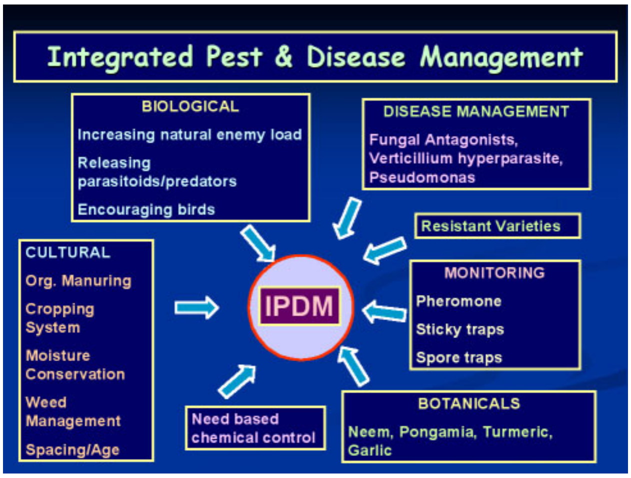

Figure 5.

Biotechnology

Since the first successful report of plant regeneration through somatic embryogenesis from orthotropic shoots in coffee by Staritsky in 1970 there has been a steady flow of information on coffee biotechnology. There are a number of reports on successful plant regeneration from leaf, stem, embryo and integument tissues in different species. Successful micro-propagation through shoot tip and node cultures is achieved. In some countries thousands of micropropagated plants are successfully established in the field (Sreenath and Naidu, 1997). Recently, the DNA fingerprinting techniques like RFLPs, RAPDs, PCR and sequence analysis have been applied for coffee genome analysis. Among them, AFLP technique has several advantages and becoming more powerful tool for genetic analysis. These DNA marker techniques having great potential in the marker assisted genetic improvement and bio-diversity evaluation of coffee plant. Engineering disease and pest resistance is considered more important in the Indian context (Sreenath, 1998). Promotion of accumulation of dehydrins confers drought tolerance. It is possible to produce drought tolerant coffee plants by introducing known dehydrin genes from wheat (Em gene), cotton (LEA gene), and the resurrection plant (*Ctarostigma plantagineum*) (Santa Ram, 1998).

To make coffee plant resistant to the CBB *via* genetic engineering, the prospect of using the genes through genetic engineering that inhibit alpha-amylase activity by low levels of the amylase inhibitor from common bean, *Phaseolus vulgaris* and much less so by the amylase inhibitor from *Amaranthus* has been shown (Valencia et al., 2000). The cry1Ac gene of Bacillus thuringiensis has been successfully used for transformation of *Coffea canephora* and *C. arabica* to confer resistance to the coffee leaf miner (*Perileucoptera coffeella* and other Leucoptera spp.) (Leroy et al., 1999). More than 100 transformed plants from independent transformation events have been obtained for each coffee genotype. The insecticide protein was detected in most of transgenic trees. Some plants have demonstrated substantial resistance to leaf miner in bioassays with the insects. Induction of resistance by *Pseudomonas* spp. in coffee plantlets against the coffee rust was shown by Porras et al. (1999) in Columbia.

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A Review of Coffee-Banana Based Cropping Systems in Tanzania: the Economics

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SUMMARY

The coffee-banana based cropping system is the most widespread farming practice characteristic in the Kilimanjaro region Mbeya, Kagera and Arusha areas of Tanzania. The benefits to adopting this system versus a pure coffee system, is that it offers higher returns to the smallholder. On average, farm sizes featuring coffee-banana interplanting are about 3 acres, with banana being the main subsistence crop and coffee a subsidiary cash crop. In the past few years, lower coffee prices have caused many farmers to neglect their coffee in favor of banana, significantly reducing the revenue potential of their farms. High production costs, especially in controlling coffee berry disease and coffee leaf rust have further eroded coffee's profitability to farmers.

The first step that Tanzania Coffee Research Institute (TaCRI) at Lyamungu has taken to address these specific issues is to develop improved coffee hybrids that are resistant to coffee berry disease and coffee leaf rust.

TaCRI carried out field trials and surveys in intercropping of coffee with banana to find out the best configuration of coffee-banana interplanting that would provide the greatest economic return to smallholders. The studies revealed that the crop arrangement of one banana stool to six coffee trees was optimal and a dramatic improvement on the traditional system where farmers tend to plant very close, at a ratio of one banana stool to one coffee tree. In economic terms, the results were very clear indeed. Total revenues generated by adopting the optimal coffee-banana cropping system were 50% higher than a pure coffee system, and 42% higher than the traditional system of 1 banana to 1 coffee.

The study clearly concludes that by adopting this optimal system, both productivity and profitability improves. The paper discusses the yield and economic returns of different coffee + banana intercropping systems.

INTRODUCTION

Coffee contributes to around 20% of the total export earnings with over 400,000 smallholders depend on this crop for income in Tanzania (TCB, 2001). The area under coffee has increased from 195,000 to 261,000 hectares over the past 15 years (SAP 2002; TCB, 2001). The average coffee production in Tanzania is between 40,000-50,000 metric tones per year (SAP, 2002). Smallholders produce 95% of the total production while the remaining comes from estates.

The coffee-banana based cropping system is the most widespread farming practice characteristic in the Kilimanjaro region Mbeya, Kagera and Arusha areas of Tanzania. The benefits to adopting this system versus a pure coffee system, is that it offers higher returns to the smallholder. Most of farm sizes of the coffee-banana interplanting are about three acres, with banana being the main subsistence crop and coffee as a subsidiary cash crop. Nevertheless, banana is the predominant food crop in Arusha, Kilimanjaro and Kagera regions contributing to 50%, 80% and 100% of the basic food needs respectively (Anonymous, 2000).

In the past few years, low coffee prices in world market have caused many farmers to neglect their coffee in favor of banana, significantly reducing the revenue potential of their farms. High production costs, especially in controlling coffee berry disease and coffee leaf rust have further eroded coffee's profitability to farmers.

Heavy shading particularly from banana and permanent in coffee based cropping system reduce flowering potential of coffee trees. This encourages fungal diseases particularly leaf rust and coffee berry diseases, thus in turn decrease in total productivity from component crops. The different patterns/arrangements of intercropping systems of coffee+ banana were evaluated from 1995-2003 with the aim of identifying the economic pattern of planting coffee and banana for smallholders. The paper discusses the yield and economic returns of different coffee + banana intercropping systems.

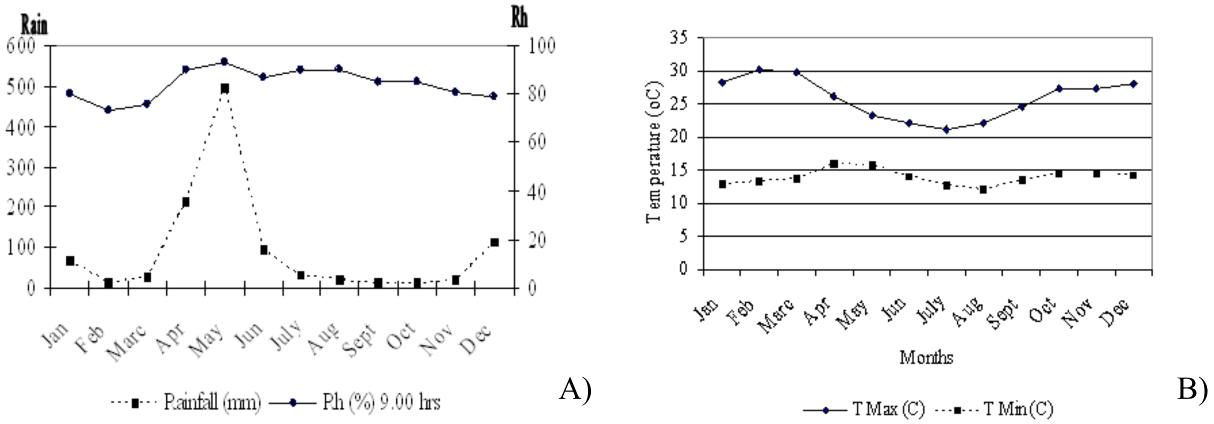

Figure 1. A) Average Rainfall, Relative Humidity at Lyamungu Coffee Research Institute (TaCRI). B) Average temperatures at Lyamungu Coffee Research Institute (TaCRI Source: Met Station Lyamungu 1948-2003).

MATERIALS AND METHODS

The studies were conducted from 1993 to 2003 at the Lyamungu Coffee Research Institute (TaCRI) (3° 14' S, 37˚ 15' E, 1268 m.asl), on the slopes of Mt Kilimanjaro. The climate is humid with a long-term mean annual rainfall of 1575.7 mm, about half of which falls in April- May and is bimodal in distribution with April and November as the wettest months (Figure 1A). The mean long-term daily maximum and minimum temperatures of the area are 24.9 and 14.1°C respectively (Figure 1B). The soil at the experimental site was classified as a Mollic Andosol (FAO, 1994), originating from the volcanic activity of Mt. Kilimanjaro. The study included coffee varieties KP 423, and improved coffee hybrids (SC 6, SC3, and F1/L4), which were intercropped with banana (local varieties). The data collection included yield of parchment coffee, green banana, number of pseudo stems, production costs (labour and material inputs) and total revenue/income from the cropping systems. The average prices of parchment coffee and banana used in the study were estimated from the market that prevailed. The cost: benefit ratio (CBR) was determined by dividing the net income or benefit by production costs. The abbreviations for cropping systems as presented in Table 1 are as follows: CS_1 stands for pure coffee stand, CS_2 for pure banana, CS_3 for a row of coffee alternated by a row of banana, CS_4 for two rows of coffee alternated by two rows of banana, CS_5 for three rows of coffee alternated by three rows of banana. The conventional/traditional (CS_6) without a pattern of banana but coffee planted in rows, and for improved cropping system (CS_7) three alternated by a row of banana. Table 1 shows various row arrangements (planting ratios) and the planting time used in the study. Appendices 1 & 2 show the variables and value of Tanzanian Shilling and U$D) used during the study.

Table 1. Cropping systems of coffee + banana intercropping and plant density and planting time

Cropping system (CS)	Type of crop (Coffee or Banana)	Spacing (m)	No. of trees ha^1	Row planting arrangement of crops (C:B)	Planting time
CS_1	C= coffee	3 x1	C = 3333	Pure coffee	1993
CS_2	B = banana	3 x 3	B = 1111	Pure banana	1993
CS_3	C+ B	As in CS_1 and CS_2	C = 3333 B = 1111	1:1	1993
CS_4	C+B	As in CS_1 and CS_2	C = 1667 B = 556	2:2	1993
CS_5	C+B	As in CS_1 and CS_2	C = 1667 B = 556	3:3	1993
CS_6	C+B	C = 1330	B = over 1330	Banana without pattern	1980
CS_7	C+B	C = 2.5 x 1.25 B = 10 x 2.5	C = 2400 B = 400	3:1	1999

RESULTS AND DISCUSSION

Yields and planting arrangements

The total and mean yields of parchment coffee, banana, and banana stems during the 6 years (1995-2000) of various cropping systems are presented in Table 2. The yield obtained from the pure coffee stand (CS_1) was 3 to 4 times of the intercropped coffee in (CS_3, CS_4 and CS_5) as in Table 2. This yield reduction is influenced when coffee is being intercropped with other crops the yield due to high moisture, nutrients and light competition caused by component crops than in pure stand. However, the yield in CS_5 was slightly higher than CS_4 and CS_3 (Table2). This is attributed to the crop arrangements (of three coffee rows alternated by three rows of banana (CS_5) had less plant competition to coffee trees in CS_5 than the coffee trees in CS_3 and CS_4. Reports by (Kimemia, 2002; Njoroge, 2002; Liyanage et at., 1984); Trenbath, 1974) have shown that the crop arrangements in intercropping have a major effect on growing environment both above and below ground levels for the maximization of productivity of the component crops. It was observed that the mean yield of green banana was highest in CS_3 followed by pure banana stand (CS_2) and lowest in CS_5. The planting arrangement of one row of coffee alternated by a row of banana (CS_3) seemed to favor banana than coffee in terms of yield. This could be due to the modification of microclimate, the high shade and moisture a regime in this system (CS_3) both from high plant density of coffee and banana.

Figure 2. Improved cropping system in at the Research Station.

Figure 3. Traditional cropping system in farmer's field.

The results in Table 3 present the two cropping systems of coffee + banana intercropping of conventional/ traditional (CS_6) and improved (CS_7) from surveys and experiments carried out by TaCRI. The mean yield improved banana + coffee of parchment coffee is 4800 kg ha^{-1} from CS_7 and that of conventional systems is 166 kg ha^1. This huge difference in yield is due to the plant arrangements of coffee and banana in the systems. By planting three rows of coffee between a row of banana where coffee and banana are spaced at 2.5 x 1.25 m and 10 x 2.5 m respectively. In this row arrangement, coffee yield increased particularly due to the increase in number of coffee trees (2400 ha^1) in improved cropping system (CS_7) compared to the traditional/ conventional system (CS_6) with the density of coffee trees (1330 ha^1). The low density planting density of banana of 400 stools ha^1 in improved cropping system (CS_7) enhanced larger bunches from the widely spaced plants (Mitchell, 1963). Figure 2 is the improved cropping system with systematic row arrangements of banana and coffee Figure 3 is the farmer's practice as in described above in material and methods section.

Table 2. Total and mean yields of Coffee parchment, Green banana Pseudo stems of banana (1995-2000).

Cropping system	Row arrangement of crops	Coffee (kg ha1)		Banana (kg ha1		No. Stems ha1)	
	Coffee - C and Banana - B)	Total	Mean	Total yield)	Mean	Total	Mean
CS_1	Pure = C	6197	1033				
CS_2	Pure = B			68,528	11421	4,324	721
CS_3	C+B= 1:1	1480	247	108,843	18144	5,757	960
CS_4	C+B = 2:2	1581	263	62,719	10453	3,686	614
CS_5	C+B = 3:3	2046	341	61,363	10227	3,761	626

Source: Agronomy Annual report 2000

Table 3. Comparison of yields in improved and conventional /traditional cropping systems of banana + coffee intercropping in 2003.

Cropping system	Row arrangement of crops C:B	Plant density ha^{-1}	Mean yield		
			Coffee (kg ha1)	Banana (kg ha1)	No. Stems ha1)
CS_6	1:1	1330	166	60000	3000
CS_7	3:1	2400	4800[1]	48000	1200

Source: Agronomy Survey 2000 and 2003.

Table 4. Cost variables of various cropping systems of coffee and banana (1995-2000 and 2003).

Type of cropping system	Row arrangement of crops	Total income/revenue (Tsh. Ha1)	Variable costs (Tsh. Ha1)	Net benefit) (Tsh. Ha1)
CS_1	Coffee	6414930	4416583	1998347
CS_2	Banana	5342058	1529585	3812473
CS_3	C+B= 1:1	9930996	4683748	5247248
CS_4	C+B = 2:2	6500460	2794522	3705938
CS_5	C+B = 3:3	6892236	2846285	4045957
CS_6	C+B = 1:1	5033125	549400	4483725
CS_7	C+B = 3:1	8580000	801700	7778300

Source: Agronomy Annual Report 2000

Total revenues and Cost benefit ratio CBR of different cropping systems

Total incomes, variable costs and net benefit of various cropping systems has shown highest returns in terms of net benefit and (CBR) in improved cropping system (CS_7) which was 1:10 and most of it came from parchment coffee contributing to approximately 55 percent and 40 percent from green banana as shown Figure 4. The banana proved to play a big role in the traditional/ convectional cropping system where it contributed to about 80 percent of total income while coffee contribution was only one percent of total revenue Figure 4. The contribution coffee to the revenue in CS_5, CS_4, CS_3 decreased and were 30, 25 and 15 percent respectively. This was also reflected in CBR of 1:8 in system of CS_6 (Figure 5). This is in accordance with Njoroge (2002) who reported also. Intercropping in coffee is likely to depress coffee yields. However, this is compensated by the total net income, which is generally higher than for sole coffee. The intercrop system also may ensure food and income security especially during the years when coffee prices are low.

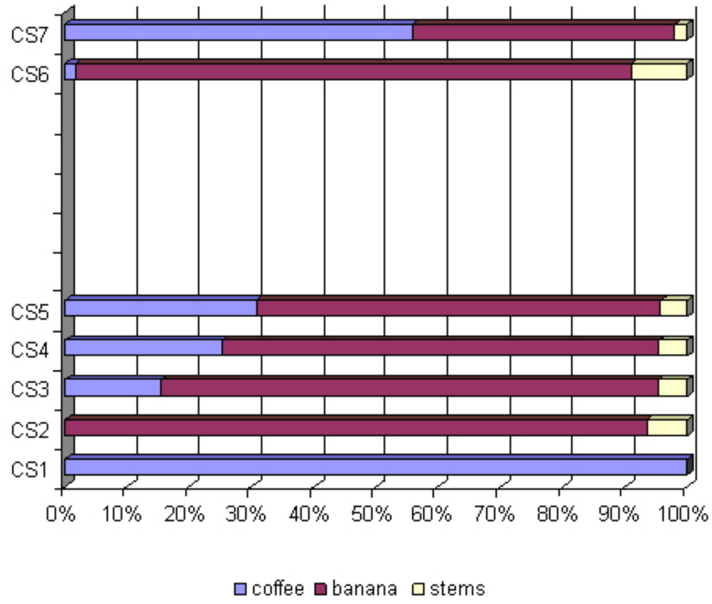

Figure 4. Percent total incomes/ revenue in different cropping system.

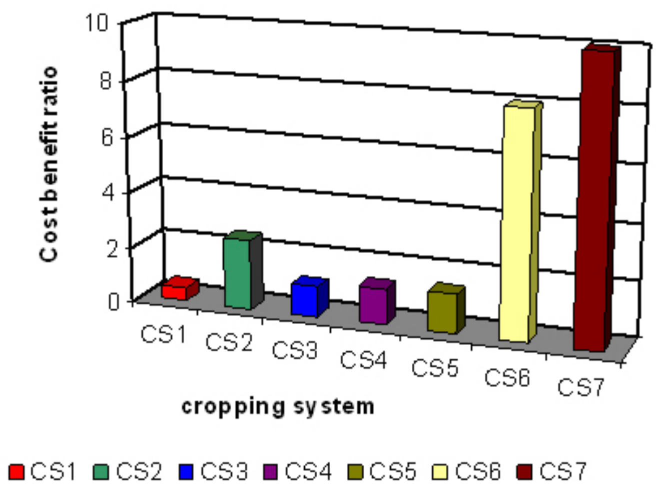

Figure 5. Cost Benefit ratios in the different cropping systems.

CONCLUSIONS AND RECOMMENDATIONS

In this study, the intercropping of banana with coffee was more profitable than growing pure stand coffee. The high monetary value realized in improved cropping system (CS_7) was mainly due to the high produce of the coffee. Banana was more profitable for the farmer in traditional / conventional cropping system (CS_6) but was the most detrimental system to the coffee yields probably due to high shade and nutrient competition. With current low coffee prices, the farmer may consider it unprofitable to grow coffee alone and hence the nation loose foreign exchange.

Therefore, a better option would be that of CS_7. To maximize scarce land resource, it is recommended that smallholder farmers in suitable areas to adopt this intercropping system using the following plant configuration:- to planting one row of bananas after every three rows of coffee with the following spacing rules: allow 2.5 m between each row of coffee and allow 1.25m between each plant within the row. Each row of bananas will be 10m apart, and 2.5m and allow between each banana plant within the row.

The spacing above would give plant population hectare of 2400 coffee trees and 400 banana stools. The increase in the total revenue in the improved coffee + banana cropping system is improve by more than 50% compared to the pure stand of coffee trees. The economic returns of the improved coffee + banana system are 42% over the traditional cropping systems.

ACKNOWLEDGEMENT

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Appendix 1. Costs and variables used in Traditional system (CS_6) and improved system (CS_7).

Coffee + banana traditional system (CS_6)	Value (T Sh.)
Planting	32400
Weeding	27000
Fertilizer application	54000
Application of pesticide	
Inputs (fertilizer) -manure	220000
Post harvest	13500
Harvesting	67500
Others	135000
Subtotal	549400
Yield coffee	83125
Intercrop (banana)	4500000
Pseudo stems	450000
Total revenue	**5033125**

Coffee + banana Improved system (CS_7)	**Value (T Sh.)**
Planting	32400
Weeding	40500
Fertilizer application	13500
Pesticide application	37800
Inputs (fertilizer)	360000
Post harvest	140,000
Harvest	110000
Others	67500
Subtotal	**801700**
Banana	Value (T Sh.)
Coffee	4800000
Intercrop (banana)	3600000
Pseudo stem	180000
Total revenue	**8580000**

Appendix 2. Mean value of U$D in Tanzania Shillings 1995-2004.

Year						
1995	1996	1997	1998	1999	2000	2004
558	596	653	653	799	700	1030

Source: Bank of Tanzania Quarterly Economic Bulletin (own calculations)

Year of Production and Canopy Region Influence Bean Characteristics and Beverage Quality of Arabica Coffee

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SUMMARY

Berry characteristics at harvest and organoleptic properties of the coffee beverage were evaluated in 1997 and 1998 on 18-year old coffee arabica trees. The trees were at two different production years in a 5-year rotational coppicing cycle; one group of trees in its third year (Y3) of production and a second group in its fifth year (Y5) of production, the last year before rejuvenating by coppicing. Light availability, dry matter partitioning and biochemical content were measured in three distinct canopy regions on Y3 and Y5 trees in 1998. In the two years, the bean dry weight was higher on Y3 trees than on Y5 trees but was not affected by the canopy region. Significant differences between trees in their third or fifth production were observed in 1997 for beverage quality. Trees in Y3 had a more balanced fruit to leaf ratio than that of trees in Y5. In 1998, significant differences for beverage quality were observed between canopy regions of the Y5 trees. Coffee beans from branches in the upper canopy region had higher fat content than those harvested in the middle and lower regions. Coffee beverage quality prepared with beans collected in the upper region was better than that originating from the middle and lower regions. The upper region was characterized by a more acid beverage and was preferred by the judging panel. The upper canopy region had a better-balanced dry matter distribution between leaves, berries and twig (25-31% of berries, 20-28% of leaves and 36-40% of wood, respectively). On branches in the middle canopy region, bean dry weight was significantly greater than that of the other two organs combined (leaves and twig). In the lower canopy, twig dry matter was much greater than that of berries and leaves combined. Low bean weight of Y5 trees can be attributed to low carbohydrate reserves of these trees. We make the hypothesis that depletion of reserves in Y5 trees, more accentuated in middle and lower canopy regions, exacerbated competition for carbon allocation within tree with detrimental effects on bean filling and coffee beverage quality. On top of harvesting only ripe berries, agricultural practices such as pruning that provides a balanced fruit to leaf ratio could help produce coffee of higher quality.

INTRODUCTION

The best quality Arabica coffees can be sold with a premium of 50% more than the basic market price. Consequently, there is an increasing interest by coffee growers to produce higher quality coffee and improve economical viability of their farms. Coffee quality is evaluated through size of beans, their lack of physical defects and the quality of the beverage. Factors affecting quality are edapho-climatic conditions (Clifford and Wilson, 1985), coffee berry harvest and bean processing (fermentation, washing, drying, storage, roasting and beverage preparation) as well as genetic properties (Montagnon et al., 1988) and agricultural practices (Cannell, 1974; Guyot et al., 1988; Guyot et al., 1996). However, the effects of tree physiological conditions on coffee quality are thought to be important, but have been rarely investigated.

Variability within coffee tree for bean production and quality is also worth investigating due to coffee architecture, alternate bearing pattern, contrasting fruiting zones and pruning regime. Coffee tree architecture has been described as pertaining to the Roux's model (Hallé et al., 1978). On the tree trunk, two primary plagiotropic branches are formed at each orthotropic node. Each node on these plagiotropic branches has two leaves and is capable of flowering and fruiting. The fruiting period of a plagiotropic branch can spread over thirty months. Such primary branches may then die in the event of a heavy crop or give rise to secondary branches, which can also bear fruit (Snoeck and Reffye, 1980). Due to the dynamic nature of the developing canopy as well as pruning regime, a coffee tree may have young primary plagiotropic branches in their first year of production in its upper canopy, primary branches in their second to fourth year of production in its middle canopy and older branches bearing few berries but many young secondary fruiting branches in its lower canopy. These three populations of branches have contrasting production patterns and experience highly different light conditions. Moreover, coffee experiences a strong alternating production pattern. After a series of high productions, the tree is exhausted. In intensive coffee cultivation, the coppicing practice takes place every five years. In numerous fruit tree species, it has been demonstrated that fruit quality is affected by numerous factors such as tree carbohydrate reserves and, light variability within the canopy (Souty et al., 1999; Warrington et al., 1996; Barritt et al., 1991). The purpose of this study was to examine the relationships between year of production within a coppicing cycle and the berry position within the coffee tree canopy and bean size and coffee beverage quality.

MATERIALS AND METHODS

Plant material

The study was carried out in 1997 and 1998 on Arabica (*Coffea arabica* L.) trees of the 'Catuai' cultivar planted at the Coffee Research Centre (CICAFE), Heredia, Costa Rica, at 1180 m elevation, with an annual average temperature of 21°C, on an Andosol soil and with 2200 mm of annual rainfall. The plot of 3500 trees was planted in 1980 without shade. Plant spacing was 2 m between rows and 1 m within rows. Plants were intensively managed receiving 1000 $kg.ha^{-1}$ of 18N-3P-10K-8Mg-0.5B fertilizer annually split equally into two applications in May and August, 250 $kg.ha^{-1}$ of N (as urea) in November and two foliar applications per year of copper hydroxide (1.5 $kg.ha^{-1}$) to prevent leaf and fruit diseases such as coffee leaf rust (*Hemileia vastatrix*) and leaf and fruit brown eye spot (Cercospora *coffeicola*). 'Catuai' is a dwarf cultivar with a maximum height of 2.5 meters after 4 to 5 yields. The 18-year-old trees were managed on a five-year rotational coppicing cycle, where one every five rows was stumped at about 40-50 cm above ground level.

In 1997, twenty-four trees, oriented North-South, were randomly selected within the plot to study the effects of production year on bean characteristics and coffee beverage quality. Twelve trees were in their fifth year after coppicing (Y5) and the other twelve in their third year after coppicing (Y3).

In 1998, the study was repeated and complemented by measuring light availability and carbon allocation within producing branches in different tree canopy regions. A new group of twenty-four trees were randomly selected within the same plot at the same stages in their coppicing cycle; again, twelve trees in their fifth year of production after coppicing (Y5) and twelve ones in their third year of production after coppicing (Y3). To study the different regions of the canopy, each tree was divided into three tiers (upper, middle and lower regions). The first canopy region extended from orthotropic node 6 from the top to node 9 and comprised leafy primary plagiotropic branches with few nodes bearing fruit. The second region went from node 12 to node 15 and comprised primary plagiotropic branches with a large majority of heavy fruiting nodes but with few leaves. The lower canopy region extended from node 20 to node 38 and comprised plagiotropic branches that had already produced the previous years and bore secondary and tertiary branches that had few fruiting nodes.

Light measurements

In order to estimate the % light transmission within the canopy, prevailing during the 1998-1999 production cycle, instantaneous measurements of photosynthetic photon flux density were taken in February 1999 at the end of the harvest, under clear sky conditions (1800 to 1900 μmol m^{-2} s^{1}), at 1 m above the canopy using a Li-Cor line quantum sensor (Lincoln, NE) placed horizontally. For each tree canopy region, duplicate spot measurements were recorded at three distances on the plagiotropic branches; 2 at the base of the branch inside the canopy close to the tree trunk, 2 in the middle of the branch and 2 at its periphery. Values presented are means of 72 spot readings. All readings were taken between 10:00 a.m. and 02:00 p.m. (i.e. solar noon ± 2 h). Light availability was expressed as a percentage of full sunlight values.

Dry matter partitioning

In November 1998, one branch was cut from each canopy region of each tree. Specific leaf weight (dry matter/leaf area) was determined for all the existing leaves. Leaf area was measured with a LI-COR area meter. Dry matter was recorded for leaves, berries and twigs. Concentration of N, P, K, Ca, Mg and C was analysed on leaves, berries and twigs. Total nitrogen was determined by the Kjeldahl method (Jones and Case, 1990) and other elements, Ca, Mg and K, by atomic absorption spectrophotometry (AAnalysis 100, Perkin Elmer) after wet digestion with a mixture (5:1) of nitric and perchloric acids. Phosphorus was determined by spectrophotometry at 660 n.m (LAMBDA1, Perkin Elmer), following a colorimetric method with molybdene blue. Carbon content was determined after mineralization. Data are expressed as percentage of dry matter.

In 1997 and 1998, ripe berries were collected during the harvest peak, which extended over a period of four weeks. Yields (kilograms of fresh berries per tree) and dry weight of 200 beans were recorded. In 1998, a 50 g sample of dry coffee beans taken from each experimental unit was analyzed for caffeine, trigonelline, fat and sucrose content following methods already published by Guyot et al. (1988). The analyses were performed by near infrared spectrometry by reflectance of green coffee after grinding to <0.5 mm. A NIR spectrometer system (model 6500, NIRSystem, Inc. 1201 Tech Road Silver spring, Md 20904, USA) driven by NIRS2 (4.0) software (Intrasoft Intl., LLC, RD109, Sellers Lane, Port Matilda) was used for biochemical determination.

Beverage quality assessment

Samples were prepared from fully ripe berries. Two-kg coffee samples were prepared by the wet processing method (depulping, fermentation and drying). Samples of 1000 g of coffee beans were collected after screening through a size 17/36 of a inch sieve and eliminating most defective beans. After 6-7 minutes of roasting, cup quality tests were carried out on an infusion prepared with 12 g of ground coffee. A panel of eight professional judges tasted three cups of 120 ml of infusion for each sample. The main beverage attributes (aroma, body, acidity) were estimated using a scale ranging from 0 to 5 where 0 = nil, 1 = very light, 2 = light, 3 = regular, 4 = strong and 5 = very strong. A preference score was used ranging from 0-5 where, 0 = not good for drinking, 1 = very bad, 2 = bad, 3 = regular, 4 = good and 5=very good. The tests were repeated three times. Values presented are means of the three tasting sessions.

Data analysis

Statistica© software (Statsoft, Inc. 1993) was used to perform all statistical analyses. The mean values of relevant factors were compared by the Duncan test at $P \leq 0.05$). The correlation coefficients among variables were computed and only the significant interrelationships ($P \leq 0.05$) with their implications for coffee bean characteristics and beverage quality are presented and discussed.

RESULTS

Effect of production year on production, dry weight of 200 beans and beverage quality

The Y3 tress produced more than the Y5 trees. This effect was greater in 1997 than 1998, respectively 19% and 11%. During the 1997 harvest, the dry weight of 200 beans was significantly affected by the production year (Table 1). Y5 trees had lighter beans than Y3 trees. This trend was also observed in 1998. For the 1997 harvest, the acidity of the beverage and the overall preference score differed significantly with production year (Table 1). In 1998, no significant difference was observed between production years Y3 and Y5 for organoleptic properties and cup quality.

Table 1. Effects of production year on dry weight of 200 beans and beverage characteristics, during the 1997 and 1998 harvests.

Year of observation	Yield number comparison	Yield in fresh berry (kg/tree)	Dry Wt of 200 beans(g)	Acidity	Overall score
1997	Y3 trees	3.1 a	33.4 a^{y}	3.0^{x} a	3.26^{y} a
1997	Y5 trees	2.6 b	27.5 b	2.6 b	2.30 b
F probability		0.03	0.002	0.04	0.02
1998	Y3 trees	3.0 a	29.6a	3.02a	3.18a
1998	Y5 trees	2.7 b	27.8b	2.84a	2.95a
F probability		0.06	0.008	ns^{z}	ns

^{x} *The scores for acidity and overall quality were based on a scale of 0-5, where 0=nill and 5=very strong. Each value is based on 3 scorings by 8 judges.* ^{y} *Means within a column separated for Duncan test, P=0.05.* ^{z}*ns = no significant.*

Dry matter partitioning and light availability as affected by year of production

Large differences were observed in 1998 between Y3 and Y5 trees for yield and biomass distribution (Table 2). The trees in Y3 had branches with a total dry matter that was 50% greater than that of branches of trees in Y5. The leaf dry matter of trees in Y3 was much greater than that of trees in Y5 whereas berry and twig dry matter were not significantly different between years of production. The light transmission varied markedly depending on production year. There was a highly significant difference ($P < 0.001$) between trees in Y3 or Y5 (36.6% and 26.3% for Y3 and Y5, respectively). The most important difference was for the total leaf area which was far larger for trees in Y3 than in Y5 (Table 2). The fruit to leaf ratio (calculated as 'fruit dry matter/leaf dry matter') was 1.51 for trees in Y3 versus 2.57 for Y5. Coffee berries produced by trees in Y3 had significantly higher carbon content than those of trees in Y5.

Table 2. Effects of production year on dry matter partitioning, total leaf area and berry carbon content of coffee producing branches.

Year of observation	Yield number comparison	Total dry matter (g)	Leaf dry matter (g)	Berry dry matter (g)	Twig dry matter (g)	Total leaf area (cm^2)	Fruit carbon content (%)
1998	Y3 trees	215.18 a^y	58.05 a	87.7 a	69.4 a	6526 a	47.2 a
1998	Y5 trees	143.43 b	27.17 b	61.9 a	54.3 a	3375 b	46.8 b
F probability		0.03	0.04	ns^z	ns	0.015	0.029

^{y} *Means within a column separated for Duncan test, P=0.05.* ^{z}*ns = no significant.*

Effect of canopy region on dry Weight of 200 beans and beverage quality

The acidity and the overall cup quality scores (Table 3) differed significantly depending on the canopy region for trees in Y5. The beverage prepared with beans from the upper region received a significantly better score than that of the middle or lower region. On the other hand, no significant different for beverage quality was observed between regions of trees in Y3. No significant different for bean dry weight was observed between canopy regions for trees in Y3 or Y5 (data not shown).

Table 3. Effects of canopy region on beverage quality on Y5 trees in 1998.

	Acidity		Overall standard	
Age of the plant	**Y3**	**Y5**	**Y3**	**Y5**
Upper region	2.9^x a	3.3 a^y	2.8 a	3.3 a
Middle region	2.9 a	2.7 b	3.0 a	2.8 b
Lower region	2.6 a	2.4 b	3.0 a	2.7 b
Probabilidad	ns	0.008	ns^z	0.003

^{x} *The scores for acidity and overall quality were based on a scale of 0-5, where 0=nill and 5=very strong. Each value is based on 3 scorings by 8 judges.* ^{y} *Means within a column separated for Duncan test, P=0.05.* ^{z}*ns = no significant.*

Dry matter partitioning and light availability as affected by canopy region

The differences in branch biomass between canopy regions were contrasted (Table 4). The upper region of the canopy was characterized by branches with low biomass (2 to 3 times lower than the biomass in the two other regions), but with balanced distribution between leaves, berries and twig (25-31% for berries, 20-28% for leaves and 36-40% for twig, respectively for Y3 and Y5). The fruit to leaf ratio for the upper region was lower than 1. No significant difference between Y3 and Y5 was observed for dry matter partitioning in the upper region.

The total dry matter of branches in the middle region of the canopy differed little from that of the lower canopy, although dry matter partitioning between the three organs types (berries, leaves and twig) was quite different. For the middle region, leaf dry matter was very low (26-36% of total weight for Y3 and Y5, respectively), whilst that of the berries was very high (67%). The fruit to leaf ratio was therefore highly unbalanced in favor of berries (4.4 and 5.7 for Y3 and Y5, respectively). In the lower region, the twig and leaf dry weights were high. Twig dry matter predominated in that region (39-47% of total dry weight for Y3 and Y5, respectively). The fruit to leaf ratio in this lower region was similar to that of the upper region

(< 1). Leaf area of the branches in the upper and middle regions of the canopy were not significantly different and were much lower than that of the branches in the lower region.

Table 4. Effects of canopy region on dry matter partitioning and leaf area of coffee producing branches on trees in Y3 and Y5.

	Total dry matter (g)		Leaf dry matter (g)		Fruit dry matter (g)		Twig dry matter (g)		Leaf area (cm^2)	
Age of the plant	Y3	Y5	Y3	Y5	Y3	Y5	Y3	Y5	Y3	Y5
Upper region	99 b^y	72 b	27.6 b	15.0 a	25.2 b	23.9 b	36.2 b	29.4 a	3725 b	1985 b
Middle region	250 ab	162 ab	37.7 b	18.9 a	168.8 a	109.4 a	54.0 b	38.0 a	2896 b	1485 b
Lower region	296 a	201 a	108.9 a	53.3 a	69.1 b	52.4 a	118.1 a	95.7 a	12958 a	7175 a
Probabilidad	0.04	0.05	0.03	ns^z	0.01	0.03	0.02	0.00	0.02	0.04

^{y} *Means within a column separated for Duncan test, P=0.05.* ^{z}*ns = no significant.*

Light availability decreased substantially with depth within the canopy of trees in Y5 (Table 5). This pattern was less pronounced for trees inY3. Significant differences were detected among canopy regions for the specific leaf weight for trees in Y5. This parameter was the lowest in the lower canopy region whereas no significant difference was found between the upper and middle regions. The relationship between light transmitted and specific leaf weight, was significant (r = 0.78), which means that higher exposure to sunlight increased specific leaf weight. For the upper region, light availability was not significantly different between trees in Y3 and Y5.

Effect of canopy region on coffee bean chemical composition

The production year did not affect coffee bean mineral concentrations (Table 5). However, the mineral concentration of Ca and Mg varied substantially with respect to position of the beans within the canopy. Beans harvested in the middle region had lower calcium and magnesium concentrations than beans from the other two regions for trees in Y3 and Y5 (Table 5).

Table 5. Effects of canopy region on light availability and specific leaf weight of coffee producing branches.

	Light availability (% of full sun)		Specific leaf weight ($mg.cm^{-2}$)		Ca (%)		Mg (%)		Fat content (%)	
Age of the plant	Y3	Y5	Y3	Y5	Y3	Y5	Y3	Y5	Y3	Y5
Upper region	46 a^y	78 a	9.51 a	9.57 a	0.27 a	0.23 a	0.17 a	0.16 a	14.92 a	15.02 a
Middle region	21 b	51 b	10.06 a	10.14 a	0.21 a	0.18 b	0.13 b	0.12 b	14.47 a	14.20 b
Lower region	11 c	4 c	8.32 a	7.32 b	0.25 a	0.23 a	0.17 a	0.16 a	14.23 a	14.10 b
Probabilidad	0.000	0.000	ns^z	0.02	ns	0.01	0.01	0.02	ns	0.03

^{y} *Means within a column separated for Duncan test, P=0.05.* ^{z}*ns = no significant.*

Bean chlorogenic acid, caffeine and trigonelline concentrations were not affected by either production year or canopy region (data not shown). On the other hand, the bean fat content of trees in Y5 were significantly affected by canopy region (Table 5). Beans from the upper region had a higher fat concentration (+1%) than those from the middle or lower region.

DISCUSSION

According to the literature, the incidence of production year, dry matter partitioning and light distribution within the tree on quality has never been studied in coffee trees. In many fruit tree species, the influence of the fruit position in the canopy and light availability on fruit size and quality is well documented (Robinson et al., 1983; De Silva and Ball, 1997; Smith et al., 1992). The results of this study show the importance of the physiological status of coffee trees on bean attributes and sensorial perception of the coffee beverage.

During their productive cycle, coffee trees experience important variations in fruit bearing and die-back due to overbearing is very commonly observed on the most productive plagiotropic branches. Nutman (1933) and Cannell (1974) associated these phenomena with the depletion of carbohydrate reserves, notably of starch, in coffee storage organs (twigs, main stems and thick roots). The difference observed between trees in Y3 and Y5 in terms of dry weight of 200 beans can be likely attributed to low reserves in Y5 trees due to heavy crops the years before.

Due to its architecture and cyclic production, the coffee tree has contrasting fruiting zones according to the position and age of branches in the canopy. They can be reduced to three canopy regions under the present growing conditions for trees in their third and fifth years of production within a 5-year coppicing cycle. Hence, three distinct populations of branches were studied: a population of branches in full vegetative growth with a low fruit load (upper region), a population of highly productive branches with few leaves (middle region) and finally a population of old branches with a very low fruit load but in a vegetative regeneration phase (lower region). In the upper region, it appears that dry matter partitioning was similar for trees in Y3 and Y5. Furthermore, bean biochemical characteristics and coffee quality were also similar for this upper region of trees in Y3 and Y5. These similarities tend to show that the upper canopy region, the fast developing part of the tree, seemed to be favored in terms of carbon allocation.

The intermediate fruiting zone (the most productive one with more than 60% of the harvest) was well exposed to sunlight. Nevertheless, it was also characterized by a very unbalanced fruit to leaf ratio due to a very low leaf area, which should be result in a low light interception. Due to their small number, it is unlikely that surrounding leaves were capable of providing a sufficient amount of assimilates to sustain optimum bean filling and cup quality. According to Kumar and Tieszen (1975) green coffee berries (before ripening) can provide up to 30% of their growth requirements via their own photosynthetic activity. On a heavily fruit bearing tree, coffee berries can represent up to 20-30% of the total photosynthetic surface (Cannell, 1974). In the present study, it was estimated that coffee berries represented up to 60-70% of the total photosynthetic area of branches in this middle region. Therefore, it is highly likely that berries in the middle region, fully exposed to sunlight and forced to grow with a limited carbon supply due to the small number of leaves in their immediate vicinity, developed a greater photosynthetic activity than berries in the other two regions. Furthermore, it has been shown that heavy fruit load enhances coffee leaf photosynthesis (unpublished data). Additional carbon supply may also have been provided through long distance phloem transport from upper canopy region as documented in temperate fruit trees (Génard and Bruchou, 1992). Still, it appears that these additional C supplies were not sufficient in the case of trees in Y5 as differences in terms of coffee quality were observed between this middle canopy region and the upper one with a far lower fruit to leaf ratio.

The lower canopy region of Y5 was characterized by a low fruit to leaf ratio due to a very low fruit load. However, light penetrated poorly in that region, leading to a lower specific leaf weight than in the two other regions and probably a low photosynthetic activity. Cup quality was lower than that of the upper canopy region. It is likely that this lower canopy region, with secondary developing branches and poorly functioning leaves, was a net importer of assimilates and in competition with heavily fruiting branches of the middle canopy and roots as suggested by Cannell (1974). This highlights the needs for further investigation on carbon production and allocation between vegetative and reproductive parts in coffee.

For trees in Y3, such differences between canopy regions were not observed. These trees had a more balanced fruit to leaf ratio than that of trees in Y5. Furthermore, trees in Y3 were less exhausted by previous crops and were likely to have higher carbohydrate reserves. Consequently, the higher leaf area and reserves of these trees did compensate for carbohydrate demand of branches with limited photosynthetic capacity.

The differences due to production year (and hence tree physiological and vegetative status) and canopy region were large and hence should be taken into account when sampling for coffee quality. Although these results need to be confirmed by more detailed observations, they could lead to agricultural recommendations in terms of coffee tree pruning and harvesting. Indeed, agricultural practices limiting annual variations in fruit bearing, lowering nutritional stress and better balancing fruit to leaf ratios could help produced coffee of highest quality.

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Shade: A Key Factor for Coffee Sustainability and Quality

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SUMMARY

For the last 5 years, research has been undertaken on associations of coffee and shade trees in Central America to promote coffee agroforestry systems in the region and to improve coffee farmers' incomes through diversification (timber production), production of high quality coffee and payment of incentives for environmental services in order to compensate for the low coffee prices of recent years. Field measurements have been undertaken to study and model partitioning of light, nutrients and water between coffee and trees, and impacts of shade trees on microclimate, coffee physiology and quality. Farm surveys have also been done to study farmer coffee agroforestry practices and changes in agricultural management in face of the persistent coffee crisis.

These results show that shade creates more favorable microclimatic conditions for coffee cultivation by decreasing leaf temperature of up to 4°C under sub-optimal conditions of low altitude (< 700 m) and by up to 2°C under optimal conditions (> 1100 m). Under sub-optimal conditions, the presence of shade trees reduces coffee heat stress, enhances coffee growth and productivity with an adequate shade level in the range of 20-40%. These results also show that coffee transpiration is lower under shade trees (*Eucalyptus deglupta* or *Terminalia ivorensis*) or artificial shade than in full sun.

These results demonstrate that beneficial effects of shade are not limited to sub-optimal conditions as the presence of shade improves coffee quality, irrespective of the ecological conditions, via a lengthening of the maturation period of coffee berries (up to 6 weeks under shade trees in sub-optimal conditions, and up to 3-4 weeks under artificial shade in optimal conditions). This translates into better bean filling, larger bean size, improved biochemical composition and higher cup quality. Coffee beverage from sun-grown coffee is bitter and more astringent than that from shade-grown ones. Furthermore, beverage acidity and preference are higher for coffee produced under artificial shade or timber trees compared to full sun conditions. Consequently, shade trees improve both the productivity and quality under sub-optimal conditions. Under optimal conditions, the reduction of coffee productivity (~20%) observed with shade can be economically compensated by a decrease in alternate production pattern and a premium paid for higher coffee quality.

The farm survey indicates that shade level and tree density are generally too high in coffee farms for a good compromise between an acceptable reduction in coffee productivity and a diversification of revenues from sales of timber products. Changes in farmers' practices vary according to ecological conditions and coffee prices at farm gate. In optimal conditions where

high prices are rewarding coffee quality, the farmers remain strongly focalized on producing coffee, although cutting costs without compromising too much plantation productivity. On the other hand, the role of trees is been reinforced in sub-optimal lowlands as sales of timber are representing up to 80% of coffee incomes.

These results highlight the fact that beneficial effects of shade are not limited to sub-optimal conditions and that payments for environmental services provided by coffee agroforestry systems are starting to take place in the Central America. Still, additional research is needed to model the effects of agroforestry practices on microclimate, resource partitioning, coffee physiology, productivity and quality in order to provide adequate recommendations for extension services and farmers on the selection and management of associated shade trees according to ecological conditions.

INTRODUCTION

In suboptimal coffee producing areas of Central America, characterized by low altitude and high air temperature, the management of shade trees has long been advocated as the main factor for enhancing coffee plantation sustainability (Beer et al., 1998). Shade trees, especially leguminous species, improve soil fertility (organic matter content and nutrient cycling), decrease soil erosion and nutrient leaching in mountainous areas, greatly reduce excessive solar irradiance and buffer large diurnal variations in air temperature and humidity that are detrimental to coffee physiology (Gutiérrez et al., 1994; Siles and Vaast, 2002).

The role of shade is more controversial in optimal conditions. Until recently, associated trees were generally eliminated in coffee systems upon replanting with highly productive dwarf cultivars at very high densities to maximize productivity in full sun. Due to the world overproduction, current low market prices have led the coffee sector of Central America to realize that intensive coffee monoculture was not economically viable, even in the most favorable ecological conditions, and this has stimulated the search for alternatives to alleviate financial difficulties of coffee farmers. Furthermore, an increased awareness of the negative impacts of agriculture on the environment has also greatly contribute to shift coffee research emphasis from intensive agricultural management to more environmentally friendly practices resulting in the production and marketing of high quality coffee.

For both suboptimal and optimal conditions, it is now recognized by a large majority of the coffee actors in Central America that coffee sustainability and farm economic viability cannot be achieved without inclusion and adequate management of shade trees. Indeed, it has been demonstrated that shade could contribute to the production of high quality coffee in diverse ecological conditions of Guatemala (Guyot et al., 1996), Costa Rica (Muschler, 2001; Vaast et al., 2004) and Honduras (Decazy et al., 2003). The important role of shade trees is likely to be more and more recognized in Central America due to the beneficial impact of coffee agroforestry (AF) systems on the environment and natural resources (preservation of biodiversity, soil conservation, water quality and carbon sequestration) (Somarriba et al., 2004). Consequently, coffee AF systems should help farmers to improve their income via diversification (timber production), production of high quality coffee, and payment of governmental incentives and premium by the coffee industry for environmental services provided by these ecologically-sound coffee systems.

This report presents some results from farm surveys and experiments undertaken during the last five years in optimal and sub-optimal conditions of Costa Rica on the beneficial effects of shade on microclimate, coffee (*Coffea arabica* L.) physiology, production pattern, beverage quality and diversification of farmers' revenues.

MATERIALS AND METHODS

Farm survey

In 2003, a survey was undertaken of around 100 coffee farms in three contrasting coffee regions of Costa Rica where three timber trees species were predominant. The two sub-optimal regions (altitude < 700 m and mean air temperature > 24°C) are La Suiza (Turrialba) and San Isidro (Pérez Zeledón) where *Cordia alliodora* and *Terminalia amazonia* are the predominant timber species associated with coffee, respectively. The optimal region (altitude > 1100 m and mean air temperature < 22°C) was Grecia (Alajuela) where *Eucalyptus deglupta* is the most common timber tree species associated with coffee.

Farm management practices such as shade level, tree density, labor, chemical inputs, and coffee plantation productivity before and after the beginning of the current coffee crisis were collected. Based on coffee and timber prices at farm gate, a rapid assessment of the economic contribution of timber sales to farmers' revenues was done and changes in farmers' agricultural practices in face of the persistent coffee crisis were recorded.

Experimental trials

Over a four year period (2000-2004), two experimental trials were undertaken to document the effects of shade on coffee in optimal and sub-optimal conditions. The trial under optimal conditions (altitude > 1100 m and mean air temperature < 22°C) was conducted on the experimental station of ICAFE (Coffee Institute of Costa Rica) in Barva de Heredia to compare coffee production pattern and beverage quality in full sun versus artificial shade (45%). The second trial under sub-optimal conditions (altitude < 700 m and mean air temperature above 24°C) was conducted on a farm (Verde Vigor SA) in the Southern lowland of Costa Rica to document the effects of associated timber shade trees (*Terminalia ivorensis* and *Eucalyptus deglupta*) on coffee physiology, production pattern and beverage quality in comparison to coffee in full sun. Coffee characteristics (bean physical properties, bean biochemical composition and cup quality) were evaluated according to methodologies developed by CIRAD (Davrieux et al., 2003; Guyot et al., 1993).

RESULTS AND DISCUSSION

Farm survey

Due to the persistently low coffee prices of the last years, coffee productivity has decreased considerably in the two sub-optimal regions (La Suiza and San Isidro) with decreases of 48 and 43%, respectively (Table 1). Comparatively, the decrease in productivity was lower in the optimal region of Grecia with 23%.

According to interviews of producers, these low coffee prices have induced changes in coffee management with a strong diminution in chemical inputs (fertilizers, pesticides and herbicides) and an increase in shade level to minimize the economic risks while taking advantages of timber products. These changes are more noticeable in the sub-optimal regions of La Suiza and San Isidro. In the optimal region of Grecia, coffee remains the main agricultural speculation on the farm and the average tree density is much lower with 78 trees ha^{-1} compared to 184 trees ha^{-1} for la Suiza and 373 trees ha^{-1} in San Isidro (Table 2).

Within the framework of the Clean Development Mechanisms also known as the Kyoto accords, carbon sequestration is one of the environmental services that could be rewarded financially when farmers shift from intensive management in full sun to coffee under shade. The aerial biomass, volume of commercial wood and amount of carbon sequestered in the 3 timber species were quite variable. This is due to the large differences in terms of tree densities observed in this survey (Table 2). Mean aerial carbon sequestration for *C. alliodora* was 39 $\pm$ 27 t C ha^{-1} at a mean density of 184 trees ha^{-1} and an average age of 13 years; for *T. amazonia*, this mean value was estimated 32 $\pm$ 16 t C ha^{-1} at a mean density of 373 trees ha^{-1} and an average age of 8 years; for *E. deglupta*, this mean value was 14 $\pm$ 10 t C ha^{-1} at a mean density of 78 trees ha^{-1} and average age of 8 years. Clearly, carbon sequestration in the aerial part of associated trees is not the only compartment to consider in coffee AF systems as an increase of 2% in organic matter content of the top soil layer could amount to an additional 40-50 t C ha^{-1}. Furthermore, other important environmental services provided by coffee AF systems also have to be considered such as preservation of biodiversity, soil conservation, water quality and landscape scenic beauty (Somarriba et al., 2004).

Table 1. Effects of decreasing coffee prices on plantation productivity in three contrasting regions of Costa Rica.

Region	Production Anterior (kg ha^{-1})	Production Actual (kg ha^{-1})	Decrease in productivity (%)
La Suiza (< 700 m)	1860	960	48
San Isidro (< 700 m)	2220	1260	43
Grecia (> 1100 m)	3120	2400	23

Table 2. Density, age, aerial biomass and light interception of associated shade trees in coffee farms of three contrasting regions of Costa Rica.

Tree species / Region	Density (tree. ha^{-1})	Age (years)	Aerial Biomass (t ha^{-1})	Light Interception (%)
***C. alliodora* / La Suiza (< 700 m)**	184 ± 66*	13 ± 2	77 ± 54	45 ± 14
***T. amazonia* / San Isidro (< 700 m)**	373 ± 191	8 ± 2	66 ± 33	73 ± 15
***E. Deglupta* / Grecia (> 1100 m)**	78 ± 44	8 ± 3	28 ± 20	52 ± 16

* *mean ± standard deviation*

Sales of timber contributed greatly to farmers' revenues, especially in the sub-optimal regions (Table 3). Timber revenues from *C. alliodora* represented 83% of the cumulated revenues of coffee over the 13 years necessary for timber harvesting. In the case of *E. deglupta* and *T. amazonia*, timber sales after 8 years of tree establishment represented 6% and 54% of the cumulated coffee revenues, respectively. These large differences in the timber contribution to revenues are due to large regional variations in tree density, timber production and price, as well as coffee production and price (Dzib, 2003). Due to a higher wood quality, average timber price was 50% higher for *C. alliodora* and *T. amazonia* than for *E. deglupta*. On the contrary, coffee prices were much lower in the sub-optimal regions (34.6 dollars per bag in San Isidro and 36.9 dollars per bag in la Suiza) than in the optimal high-altitude region of Grecia (51.3 dollars per bag). This higher coffee price in the region of Grecia is due to the reputation of high quality of coffee originating from the Central Valley of Costa Rica and helps explain why coffee remains the main agricultural activity of farmers in this region.

Table 3. Revenues from sales of timber and coffee in three contrasting coffee regions of Costa Rica.

Tree species / Region	Timber volume (m^3 ha^{-1})	Timber Revenues (US$)	Coffee Production (kg. ha^{-1})	Coffee Revenues (US$)	% Timber revenues
C. alliodora **/ La Suiza**	123	6 400	960	7 700	83
T. amazonia **/ San Isidro**	69	3 200	1260	6 000	54
E. Deglupta **/ Grecia**	43	1000	2400	16 500	6

Effects of shade on coffee growth and production pattern

Under the sup-optimal conditions of the lowland site (< 700 m and mean air temperature > 25°C) of Verde Vigor in Southern Costa Rica, coffee growth and production was increased by shade compared to full sun conditions (Table 4). The lighter and more uniform shade provided by *E. deglupta* along the year (35% in the dry season and 45% in the wet season) resulted in the highest production (Table 4). On the other end, the denser shade provided by *T. ivorensis* (60% in the wet season) resulted in the highest coffee vegetative growth but decreased productivity as compared to that of coffee under *E. deglupta*. Cumulative coffee production over the three cycles in full sun was 16% and 49% lower than that of coffee under *T. ivorensis* and *E. deglupta,* respectively. The presence of shade trees resulted in higher individual leaf area and coffee leaf area index and lower leaf fall, especially during the dry period. Although shade decreased flowering intensity, final berry load of shade-grown coffee was than higher than in full sun due to the lower berry drop registered during the production cycle under the shade of timber trees as berries were benefiting from higher leaf to berry ratios in their vicinity (Table 4).

Table 4. Effects of management systems (coffee under *Eucalyptus* or *Terminalia* or in full sun) on coffee production (kg of green bean per ha) and vegetative growth (coffee leaf area index: LAI; flowering, leaf to fruit ratio: LA/F; and fruit load) in sub-optimal conditions.

	Production (kg ha^{-1})			% beans with large sizes		Growth 2002			
Coffee Under	**2000**	**2001**	**2002**	**2001**	**2002**	**LAI (m^2 m^{-2})**	**flowers $node^{-1}$**	**LA/F (cm^2/fruit)**	**Berries $node^{-1}$**
Eucalyptus	620 a	1013 b	1890 a	72 a	67 a	2.23 b	9.5 b	11 b	7.6 b
Terminalia	510 a	449 b	1160 b	72 a	67 a	2.78 a	9.7 b	16 a	8.0 b
Full sun	740 a	350 b	700 c	67 b	56 b	1.04 c	10.9 a	6 c	6.2 a

@ values within a line with the same letter(s) do not differ significantly according to the test of Newman-Keuls (P = 0.05).

Under optimal conditions of the experimental station (altitude > 1100 m and mean air temperature < 22°C) of ICAFE in the Central Valley of Costa Rica, artificial shade (45%) increased vegetative growth of coffee plants, individual leaf area and decreased leaf senescence, especially during the dry season (Table 5). Leaf life span was on average of 12 months in shade while that of leaf in full sun was only of 8-9 months. Coffee production was 14% lower under artificial shade than in full sun for the 1999 production, 6% for the second production and 29% for the third production, resulting in a reduction of 18% for the cumulative production over the three years (Table 5). Shade also reduced alternate bearing pattern. In shade conditions, the 2000 production was equivalent to 75% of the previous production (1999) and 80% of the following one (2001). On the other hand, variation in productivity from one year to the next was much higher in full sun conditions as the 2000 production was equivalent to 69% of the previous production (1999) and only 60% of the 2001 production.

Table 5. Effects of light regimes (45% of shade or Full sun) on coffee production (kg of green bean per ha) and vegetative growth (coffee leaf area index: LAI; Average leaf area; and leaf to fruit ratio: LA/F) and percentage of bean with larger bean sizes in optimal conditions.

Coffee Under	Production (kg ha^{-1})			LAI (m^2 m^{-2})		Average leaf area (cm^2)		Leaf to fruit ratio (cm^2/fruit)		% beans with large sizes	
	1999	**2000**	**2001***	**1999**	**2000**	**1999**	**2000**	**1999**	**2000**	**1999**	**2000**
Shade	2250	1700	2130	4.9	4.0	36	42	18	18	63.5	72.1
Sun	2590	1805	3005	4.5	2.6	30	28	14	12	62.5	65.6
P	0.03	ns**	0.001	0.001	0.001	0.001	0.001	0.05	0.001	ns	0.001

*** non-significant (P>0.05).*

Effects of shade on microclimate and coffee physiology

Due to its broad leaves and large crown, *T. ivorensis* provided a denser shade than *E. deglupta* during the rainy season, especially in 2000 and 2001. During the rainy season, the canopy of *T. ivorensis* intercepted up to 60% of photosynthetic photon flux density (PPFD) while *E. deglupta* only intercepted around 30-40%. Furthermore, *E. deglupta* shed less heavily its leaves than *T. ivorensis* during the dry season which resulted in a lower but more constant shade level during the whole year for coffee under *E. deglupta*. Air temperature around coffee leaves was 2-4°C lower under shade of timber trees than in full sun. Still, leaf temperatures remained very high with values of 30-31°C under tree shade and 34°C in full sun around midday[3]. Therefore, the buffering effect of shade trees was not sufficient to alleviate the sub-optimal conditions of this experimental site with temperatures above the optimal range (20-22°C) for Arabica coffee photosynthesis as net photosynthesis (Pn) rates were low with values ranging from 0.5 to 2.5 µmol CO_2 m^2 s^{-1} compared to values of 5-10 µmol CO_2 m^2 s^{-1} commonly reported in the literature [12]. Transpiration rates, monitored via sap flow, demonstrated that on a leaf area basis coffee transpired more in sun full than under shade of trees, especially during the dry season (0.87 l m^{-2} day^{-1} and 0.39-0.45 l m^{-2} day^{-1}, respectively) due to exposition of the sun-grown coffee plants to higher solar radiation and air temperature. This indicates that sun-grown plants were under heat stress, especially during the sunny days of the dry season when higher leaf senescence and leaf drop were observed.

Under optimal conditions, artificial shade (45%) decreased leaf temperature by 2°C around midday and vapor pressure deficit by up to 50% for leaves of branches in the upper part of the coffee canopy. Shade-adapted leaves were more efficient than sun leaves at low solar radiation levels as their Pn rates were higher in the low PPFD range (50-250 µmol quanta m^2 s^{-1}). On the other hand, sun leaves had a higher maximum Pn rates than shade leaves with values of 10 and 15 µmol CO_2 m^2 s^{-1}, respectively. These maximum Pn rates were attained at level of solar radiation much lower (600 µmol quanta m^2 s^{-1} for shade leaves and 900 µmol quanta m^2 s^{-1} for sun leaves) than the ones registered during midday in full sun conditions in the field with PPFD values ranging from 1200-1800 µmol quanta m^2 s^{-1} during the wet season and 1400-2000 μmol quanta m^2 s^{-1}during the dry season. This indicates that coffee leaves, especially in full sun, did not take full advantage on high solar radiation. On the contrary, coffee photosynthesis efficiency was certainly reduced at higher solar radiation due to a decrease in stomatal conductance (Gutiérrez et al., 1994) and photo-inhibition (Mosquera et al., 1999). Coffee transpiration per unit of leaf area was lower under shade than in full sun due to the buffering effects of artificial shade on solar radiation and coffee leaf temperature.

Effects of shade on coffee quality

Under sub-optimal and optimal conditions, shade significantly affected coffee berry ripening process. Coffee berries ripened faster in full sun than in shade due to exposition to higher temperatures. Under sub-optimal conditions, the harvest peak was delayed by about six weeks under the shade of timber trees. During the 2001 production cycle and by mid-November, more than 95% of the coffee berries were already harvested in sun full compared to less than 55% under the shade of timber trees. During the 2002 production cycle, the observations confirmed this delaying effect of shade on coffee berry ripening as 75% of berries were already harvested by late October in full sun while less than 45% were harvested under the shade of timber trees.

Under optimal conditions, the harvest peak was delayed by about a month due to artificial shade. During the first production cycle (1999) and by the forth harvest, more than 85% of the coffee berries were already harvested in full sun compared to 65% under artificial shade. During the second production cycle (2000), the observations confirmed this delaying effect of artificial shade on coffee berry ripening as 82% of berries were already harvested at the third harvest in full sun compared to only 60% in the shade.

This longer period of maturation under shade resulted in a longer and hence better bean filling. This translated into significantly higher percentages of coffee beans with larger sizes (bean diameter > 15/64, *i.e.* > 6.75 mm) under shade in sub-optimal and optimal conditions during the all the production cycles (Table 4 & 5). Bean size is particularly important as it is often the main criterion with bean color and percentage of physical defects on which is based the quality assessment in producing countries and the price to be paid to coffee producers at farm gate.

Shade also had a significant effect on the biochemical composition of coffee beans in sub-optimal as well as sub-optimal conditions. Under sub-optimal conditions, caffeine and fat content were higher in beans of shade-grown plants whereas chlorogenic acids and trigonelline contents were higher in beans of sun-grown plants. Under optimal conditions, the same observations could be observed; higher caffeine and fat content in shade-grown beans and higher chlorogenic acid and trigonelline contents in sun-grown beans.

Under sub-optimal conditions as well as optimal conditions, shade significantly affected beverage quality (Table 6). Negative attributes, such as bitterness and astringency, were higher for coffee beverage prepared from sun-grown beans that from shade-grown ones during all production cycles. Furthermore, positive attributes such as beverage acidity and preference were significantly higher for coffee produced under the artificial shade or shade of timber trees compared to full sun conditions (Table 6).

Table 6. Effects of PPFD regimes (45% of artificial shade and full sun), shade management (coffee under *Eucalyptus deglupta* or *Terminalia ivorensis* or in full sun) and year of production on beverage characteristics.

	Acidity*		**Bitterness**		**Astringency**		**Preference****	
	1999	**2000**	**1999**	**2000**	**1999**	**2000**	**1999**	**2000**
Art. shade	**2.27**	**2.45**	**2.65**	**2.65**	**1.68**	**0.35**	**2.57**	**2.80**
Sun	**1.67**	**2.21**	**2.95**	**2.88**	**1.86**	**0.41**	**2.29**	**2.58**
P	0.001	0.04	0.002	0.01	0.02	ns***	0.01	0.02
	2001	**2002**	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
Eucalyptus	2.27	2.45	1.65	1.65	0.68	0.35	2.70	2.80
Terminalia	2.13	2.41	1.75	1.73	0.70	0.36	2.90	2.78
Sun	1.67	2.21	1.95	1.88	0.86	0.51	2.19	2.28
P	0.001	0.05	0.01	0.01	0.05	0.05	0.01	0.01

*Each value is the average of scoring by 10 judges during 3 tasting sessions. * The scores for acidity, bitterness, astringency and body were based on a scale of 0-5. ** Overall preference were based on a scale of 0-4. *** non-significant (P>0.05).*

CONCLUSIONS

The present results demonstrate that beneficial effects of shade are not limited to sub-optimal conditions as the presence of shade improves coffee quality, irrespective of the ecological conditions, via a lengthening of the maturation period of coffee berries and hence a better bean filling. Still, it must be acknowledged that the improvements in terms of microclimate for coffee growing underneath shade trees are not unlimited. Associated trees generally reduce air temperature by a maximum of 3-4°C. Therefore, shade can compensate an altitude deficit of 200-300 meters in Central America but does not fully alleviate adverse conditions in all coffee producing lowlands of this region.

Under optimal conditions, shade decreases coffee productivity (~20%) but reduces alternate production pattern and improves coffee quality. This translates into more uniform revenues for farmers over the years. Furthermore, the decrease in coffee productivity can be economically compensated by a premium paid for higher coffee quality.

Under sub-optimal conditions, shade reduces coffee heat stress, enhances coffee vegetative growth and productivity with an adequate shade level in the range of 20-40%. The present survey indicates that shade level and tree density are generally too high in coffee farms for a good compromise between an acceptable reduction in coffee productivity and a diversification of revenues from sales of timber products.

Changes in farmers' practices vary according to ecological conditions and coffee prices at farm gate. In optimal conditions where high prices are rewarding coffee quality, the farmers remain strongly focalized on producing coffee, although cutting costs (lowering external inputs) without compromising too much plantation productivity. In these conditions, managing shade of associated leguminous trees (*Erythrina* and *Inga*) to limit chemical weeding and improve coffee soil fertility is an appealing option to coffee farmers as their interest in timber production is very limited due to the apparent low contribution of timber sales to their revenues. On the other hand, sales of timber are contributing greatly to farmers' incomes in sub-optimal lowlands as their efforts to produce coffee quality under shade are rarely and poorly rewarded.

In Central America, there are more and more examples of valuation of environmental services provided by coffee AF systems through local and international initiatives that should help farmers maintain their ways of life. At local level, pilot projects are being implemented to financially encourage farmers to plant trees in coffee plantations and adopt environmentally friendly practices; for example, the national electrical company of Costa Rica is now rewarding farmers for good soil conservation practices in watersheds to avoid siltation of hydro-electrical dams. At the international level, non-governmental organizations (NGO) such as Rain Forest Alliance and Conservation International are launching collaborative programs with local NGOs and cooperatives in many coffee producing countries that promote and reward coffee AF management around protected areas and as an efficient way to limit fragmentation of landscapes for the preservation of biodiversity. On the private sector side, companies such as Starbucks have initiated during the last years programs to reward coffee producers implementing social and environmental practices in their farms. This concept is not new and has been promoted by the "organic movement" for more than a decade in the coffee sector, unfortunately with limited success due to slow expansion of the organic coffee market. Thanks to its less severe environmental requirements and simpler certification scheme, Starbucks is becoming very "popular" in Central America and is currently buying up to 5-10 % of the coffee production of Costa Rica at a premium more than 50% than the New York exchange prices. In the coming years, this company is planning on increasing its purchases in Costa Rica up to 20-30% of the national production and substantially in other Central and Latin American countries.

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Agronomic Performance and Trueness-to-type of *Coffea arabica* Hybrids Mass-propagated by Somatic Embryogenesis

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SUMMARY

In order to validate a mass propagation process of *Coffea arabica* based on the use of liquid nutrient media, the agronomic performance and trueness-to-type of regenerated trees (selected F1 hybrids) was assessed at a large scale. In a first trial representing 3,000 trees, we determined that the frequency of variants increased exponentially with age of the embryogenic suspension. For the five genotypes, somaclonal variation was low (1.3%) in trees produced from embryogenic callus or 3-month-old cell suspensions and increased in frequency with increasing suspension age (6, 10 and 25% in trees produced from cell suspensions aged 6, 9 and 12 months, respectively). Seven types of phenotypic variants were characterized. Based on vigour and productivity of the regenerated plants, it was possible to class the variants in order of severity of physiological disorders: "Colour of juvenile leaves", "Giant", "Dwarf", "Thick leaf ("Bullata")", "Variegata", "Angustifolia", "Multi-stem". The "Dwarf", "Angustifolia" and "Multi-stem" types were the most frequent among produced plants (1.4, 4.8 and 2.9%, respectively). In a second trial, the agronomic performances of 644 trees derived from somatic embryogenesis were compared with those of normal trees produced from microcuttings for the same four clones. Somaclonal variation has never been observed with microcutting-derived trees. The variant aside (2%), for all clones, the trees had vegetative characteristics, productivity, fertility, and biochemical, mineral and beverage characteristics that were identical to those of the controls. We conclude that propagation of coffee by embryogenic callus or young cell suspensions generated few variants. Moreover, detection of 70% of variants is possible at the nursery stage. Somatic embryogenesis can therefore be considered as a possible mass-propagation technique for coffee, for rapid multiplication of heterozygous structures that should lead to substantial genetic gains compared to traditional pedigree selection schemes.

INTRODUCTION

Coffea arabica L. varieties are traditionally propagated by seed. Given the strong hybrid vigour found when complementary genetic pools (Ethiopian x Catimors) are crossed (Bertrand et al., 1999), substantial agronomic progress is expected from F1 hybrids. Efficient somatic embryogenesis micropropagation procedure would provide a means for the large-scale dissemination of hybrid varieties in clonal form. For instance, 19 clones of *C. arabica* F1 hybrids were multiplied to set up assessment networks in Central America (Etienne et al., 2002). However, the processes need to be optimized before the technique can be applied on an industrial scale. The targets to be reached are (i) a reduction in production costs, (ii) a guarantee that the propagated trees are true-to-type.

The existence of somaclonal variations in trees propagated by somatic embryogenesis has been demonstrated in *Coffea arabica*. Söndahl and Lauritis (1992) estimated that around 10% of trees regenerated from embryogenic callus were variants based on phenotypic characteristics. Little information is available to date for coffee trees and woody species in general about the impact of culture conditions on the occurrence of somaclonal variations during somatic embryogenesis processes. Various reviews concluded that somaclonal variations are preferentially induced by certain parameters, such as: (1) explant source, its level of ploidy and its number of chromosomes, (2) hormonal factors, i.e. the concentration and type of growth regulators, (3) genotype factors and (4) the age of the culture.

It is well-known that the critical factor is the involvement of a disorganized growth phase, such as the proliferation of an embryogenic cell suspension (Karp, 1991). The aim of our work, using *Coffea arabica* embryogenic suspensions, was to determine how the age of the suspension and the genotype affect somaclonal variation. This article also examines growth and yield performance, bean chemical and biochemical characteristics, and cup quality for four *Coffea arabica* clones produced by this procedure.

MATERIALS AND METHODS

Plant material

Trial 1. Effect of suspension age. The 5 studied clones were derived from five F1 hybrids of *C. arabica* obtained from crosses between the Caturra, Catimor (T8667) and Sarchimor (T5296) cultivated varieties with wild accessions from Ethiopia and Sudan. Clones from the following five crosses: Caturra x Ethiopian N°531, T8667 x Rume Sudan (tree 1), T8667 x Rume Sudan (tree 2), T5296 x Rume Sudan (tree 1), T5296 x Rume Sudan (tree 2) are referred to as clones H1, H2, H3, H4 and H5. Each clone was propagated by embryogenic cell suspension and the plants were regenerated every 3 months, i.e. after 0 (directly from embryogenic callus), 3, 6, 9 and 12 months of proliferation. For field assessments, five blocks were planted, each corresponding to different embryogenic suspension proliferation times. All the informations about this field trial were given previously (Etienne and Bertrand, 2003).

Trial 2. Agronomic performances. The comparative study used clones derived from four F1 hybrid of *Coffea arabica* and referred as clone 1, clone 2, clone 3 and clone 4. Each clone was propagated by both embryogenic cell suspensions and *in vitro* microcuttings. For each of the eight treatments (two micropropagation techniques x four clones), 100 trees were used for agronomic comparisons as previously described (Etienne and Bertrand, 2001).

In vitro multiplication techniques

The embryogenic cell suspension method involved four stages (Etienne and Bertrand, 2003). In Stage 1, immature leaf explants were cultured for 1 month on medium containing 2.26 μM 2,4-D (2,4-dichlorophenoxyacetic acid), 4.92 μM IBA (indole-3-butyric acid) and 9.84 μM iP (iso-pentenyladenine), then transferred for 6 months to a medium containing 4.52 μM 2,4-D and 17.76 μM BAP. An embryogenic callus developped on the explants. In Stage 2, this embryogenic tissue was placed in liquid medium with 4.52 μM 2,4-D and 4.65 μM kinetin. Subsequently, a cell suspension of embryogenic aggregates was produced. Long-term maintenance of the embryogenic suspension culture was achieved by 1-month proliferation cycles, i.e. twelve cycles were completed for the 1-year-old suspensions. In Stage 3, the embryogenic aggregates were transferred for two months to a temporary immersion bioreactor (RITA®, CIRAD, France), containing a regeneration medium supplemented with 17.76 μM BAP. In Stage 4, the regenerated embryos were cultured with a germination medium containing 1.33 μM BAP. Acclimatizable plantlets were obtained after two consecutive 2-month subcultures in the bioreactor with germination medium.

Trueness-to-type of micropropagated trees in the field (Trial 1)

The identification of variants was based on morphological observations after 8 months in the nursery and two years after planting in the field. The plants regenerated *in vitro* that revealed morphological traits that differed from those of the initial clone when acclimatized in the nursery or planted in the field were referred to as 'somaclonal variants'. These somaclonal variants were identified based on height, morphology, leaf shape, productivity, fruit shape, leaf density, stomatal density and guard cell chloroplast number (Krug et al., 1939; Etienne and Bertrand, 2003).

Growth observations, yield and coffee bean characteristics (Trial 2)

The following measurements were taken:

- Stem diameter (5 cm from the ground) after 36 months in the field,
- Increase in stem height between the ninth and thirtieth month in the field,
- Existence of pollen on the stamens of open flowers,
- Number of chloroplastids in the guard cells (determined on 10 leaves per tree for 12 trees taken at random from each treatment (96 trees in total)),
- Production was measured in terms of grams of fresh berries per tree. The data presented were yields for the second year.

The number of fruits per node was estimated from the eight most heavily bearing nodes.

Frequency of peaberries in a sub-sample of 100 green fruits collected 6 months after flowering from the eight most heavily bearing nodes.

Frequency of floating mature berries in a sub-sample of 200 ripe fruits after immersion in water.

Bean weight of the coffee produced by each tree was estimated by measuring the dry weight of 200 beans from mature berries.

Bean chemical analyses

For 12 trees from each treatment (96 trees in total), 250 g samples of green coffee were collected after screening through a size 17 sieve and eliminating most defective beans. The following traits were measured for each tree separately: Sucrose, chlorogenic acids, caffeine, trigonelline, and fat contents of beans were obtained through chemical analysis after grinding the beans following the method of Guyot et al. (1988). Each chemical analysis was achieved by near infrared spectrometry reflectance on green coffee after grinding (NIR spectrometer system (model 6500, NIRSystem, Inc. 1201 Tech Road Silver Spring, MD 20904) driven by NIRS2 (4.0) software (Intrasoft International LLC, RD 109, Sellers Lane, Port Matilda, PA 16870).

Bean mineral contents

Chemical analysis of potassium, magnesium, calcium, zinc and copper were carried out by atomic absorption spectrophotometry (AAnalysis 100, Perkin Elmer) after wet digestion with a mixture of nitric and perchloric acid (5:1). The aluminium content was measured by the same method after dry digestion. The phosphorus content was determined by a colorimetric method developing molibdene blue by UV/V spectrophotometry at 660 nm (LAMBDA1, Perkin Elmer). Total nitrogen was determined by the Kjeldahl method (Jones and Case, 1990).

Organoleptic analysis

Samples were prepared from very ripe, healthy berries harvested from the upper branches of 12 trees during the harvesting peak. The 2 kg coffee samples were prepared by the wet method (pulping, fermentation and drying). One-kilogram samples of green coffee were collected after screening through a size 17 sieve and eliminating most defective beans. After roasting for 6-7 mn, cup quality tests were carried out on an infusion prepared using 12 g of roasted coffee (Van der vossen, 1985). A panel of eight persons tasted 120ml of infusion. The main taste and flavour attributes (aroma, body, acidity) were estimated using scales ranging from 0 to 5 where 0=nill, 1 = very light, 2 = light, 3= frank, 4= strong and 5 = very strong. There was also an overall standard for cup quality ranging from 0 to 5 where 0= not good for drinking, 1 = bad, 2 = regular, 3 = good, 4 = very good, 5 = excellent.

RESULTS

Types of variants found (Trial 1)

Seven types of variants were found and described (Table 1, Figure 1). Apart from the "Multi-stem" variant (Figure 1H), all the other types of variants corresponded to the descriptions of mutations seen in seed progenies (Cramer, 1913; Krug et al., 1939). Histological markers of the "Dwarf" and "Thick leaf" variants like stomatal density or chloroplast number per guard cell were found. We showed that these two phenotypes and the “Angustifolia” phenotype (Figure 1E) can also be easily characterized by the leaf shape (Table 1). Most variations caused a substantial drop in tree vigour and productivity. However, two phenotypes, one involving a change in juvenile leaf colour (Figure 1B), the other producing a "Giant" phenotype (Figure 1D) had normal vigour as well as productivity.

The “Variegata”, “Dwarf”, “Angustifolia” and “Multi-stem” variants were generally less vigorous than normal plants. On the contrary, the “Giant” and “Thick leaf” variants were remarkable by a taller height. Apical dominance was weak in the "Multi-stem" variant, which was characterized by abnormally high branching as a result of the production of 2 to 4 stems from cauline buds (Figure 1H). This phenotype was expressed from juvenile stages, making it easy to detect in the nursery. The plants died in the field in strong sunlight.

For "Variegata", "Giant", "Bullata" and "Colour of juvenile leaves", the frequency did not exceed 0.3%. The "Dwarf" variant, which is a variant affecting the size and productivity of the tree, exceeded 1%. The "Multi-stem" and "Angustifolia" variants amounted to 2 and 4%, respectively.

Frequency of variants depending on suspension age (Trial 1)

There was no difference between 0 and 3 months of suspension culture in the proportion of regenerated variants produced (Figure 2). However, from 6 months of suspension onward, the average proportion of variants calculated for all clones significantly increased exponentially with suspension age (Figure 2), and can be modelled as: Frequency = $0.99\ e^{0.267t}$, $r^2 = 0.99$ (where t = suspension age). Nevertheless, the use of this model masks the considerable disparities existing between genotypes.

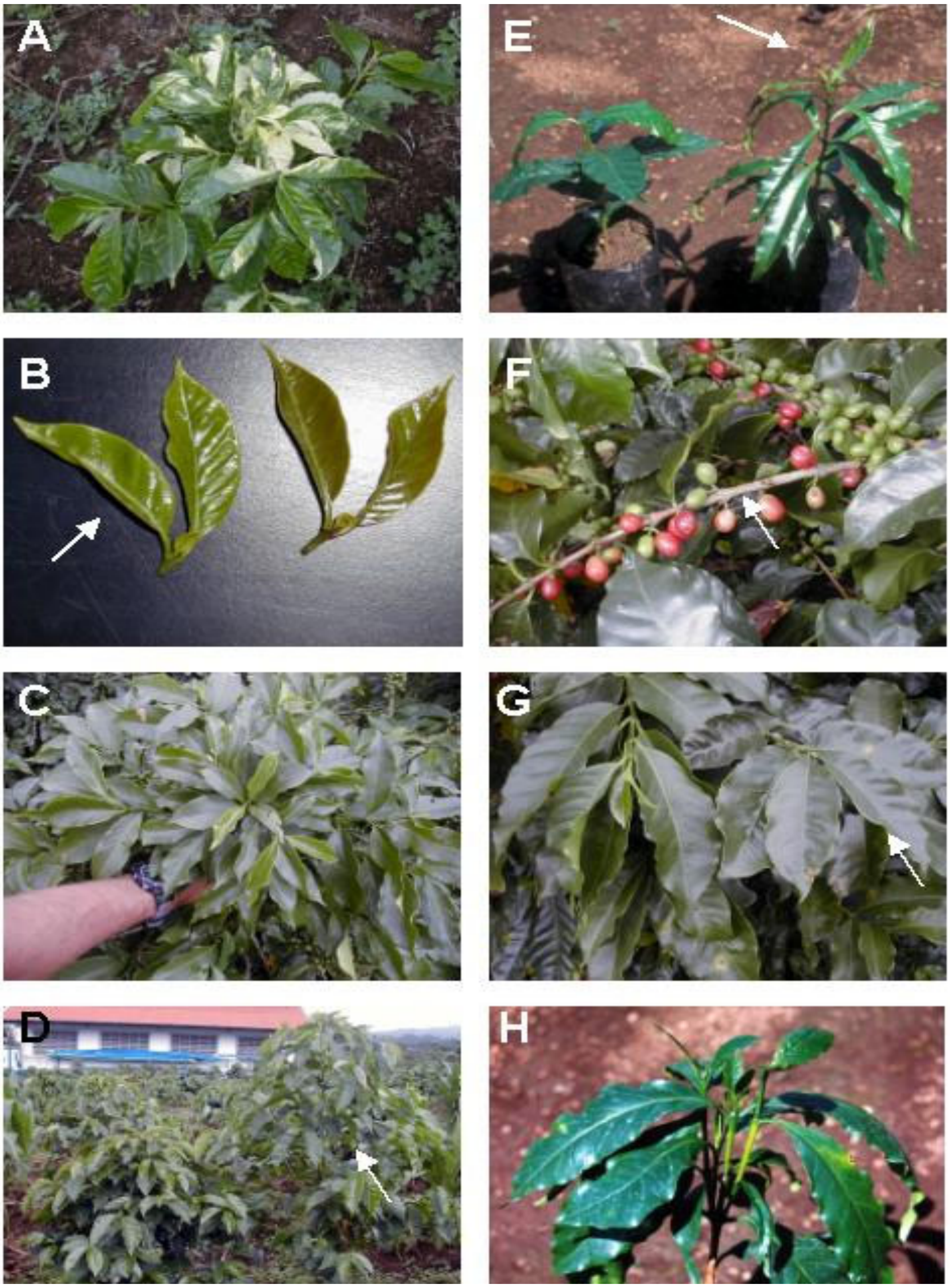

Figure 1. Aspect of the seven phenotypic variations observed in *Coffea arabica* among plants derived from embryogenic cell suspension. The arrows indicate the variant plant material. A) 'Variegata' variant. B) Somaclonal variation for the colour of juvenile leaves (bronze normal leaves on the right and green variant leaves on the left). C) 'Dwarf' variant characterized by a compact phenotype and small leaves. D) 'Giant' variant in the field. E) 'Angustifolia' variant (on the right) with elongated leaves. F) The arrow indicates a branch of the 'Thick-leaf' ('Bullata') variant bearing few fruits of large size. In the background, aspect of a branch from a normal plant. G) On the right, the arrow shows the rounded, lustreless and thick leaves of the 'Thick leaf' variant. On the left, aspect of normal leaves of the same hybrid. H) 'Multi-stem' variant in nursery in which can be observed the emergence of four stems from the cauline bud.

Table 1. Description of seven *Coffea arabica* variant phenotypes based on morphological criteria and productivity. Means followed by the same suffix are not significantly different at P ≤ 0.05.

Variant	Phenotype	Measurement	Value for variants	Value for controls
Variegata	Variegated leaves, decreased tree vigor	Productivity (g plant^{-1})	484.5 b	1298 a
Colour of juvenile leaves	Developing leaves changed from green to bronze in color, tree vigor unaffected	Productivity (g plant^{-1})	1054 a	1098 a
Dwarf	Small leaves, small trees	Leaf length (cm) Leaf width (cm) Productivity (g plant^{-1})	10.40 b 4.45 b 825 b	13.57 a 5.89 a 1179 a
Giant	Normal leaves, taller trees	Tree height (cm) Productivity (g plant^{-1})	260 a 1268 a	195 b 1324 a
Angustifolia	Elongated leaves, fewer or no domatia, longer internodes, taller trees, decrease of tree vigor	Leaf width (cm) Domatias (nb/leaf) Tree height (cm) Productivity (g plant^{-1})	6.50 b 1.72 b 253 a 323 b	7.23 a 10.4 a 190 b 1245 a
Thick leaf (Bullata)	Rounded, lustreless and thick leaves, starry flowers, large-sized fruits	Leaf length (cm) Leaf width (cm) Leaf width/ leaf length Productivity (g plant^{-1})	13.21 b 7.85 a 1.69 b 678 b	14.37 a 6.70 b 2.15 a 1198 a
Multi-stems	Highly branched, died in the field	Nb of stems emerging from the cauline bud Productivity (g plant^{-1})	2 to 4 0 b	1 1590 a

Number of variants observed depending on the genotypes (Trial 1)

The genotypes H4 and H5, which had over 18% of variants (evaluation including plants from all cell suspension ages), were statistically different from genotypes H1 and H3, which had around 5% of variants. Genotype H2, with about 9% of variants, fell between these two groups. However, the differences between genotypes only appeared from 6 months of suspension onward (Figure 2). From 6 months onward, somaclonal variations were then 10% for genotypes H2 and H3, whereas the proportion of variants for genotypes H1, H4 and H5 was similar to that seen at 0 and 3 months. For the 9-month suspension, the proportions of variants ranged from 6.25% for H5 to 14.63% for H2, but the differences between genotypes, were not significant (χ^2_{obs} = 5.42 and $\chi^2_{0.95}$ = 9.49); for the 12-month suspension, the differences between genotypes were significant. For genotypes H4 and H5, the proportions of variants were 95 and 83% respectively. These two hybrids formed a group significantly different ($P < 0.0001$) from the group of genotypes H1, H2 and H3 (proportions of variants of 8.53, 18 and 5.91%, respectively).

Agronomic characteristics (Trial 2)

For the eight studied variables, representing vegetative, production and fertility characteristics, the analysis of variance indicated that there was no significant differences between trees produced from microcuttings and those produced by somatic embryogenesis (Etienne and Bertrand, 2001) (Figures 3A, B). No clone x micropropagation technique interaction was found for 7 of the variables. There was a significant interaction for the percentage of peaberries but it seems to have little meaning since the percentage of peaberries was higher in the microcuttings than in the somatic embryos for clone 3. Flowering was uniform irrespective of clone and micropropation technique. The observation of pollen on the stamens did not reveal any sterile males. The data also indicated the existence of a strong "clone effect" for all the variables considered.

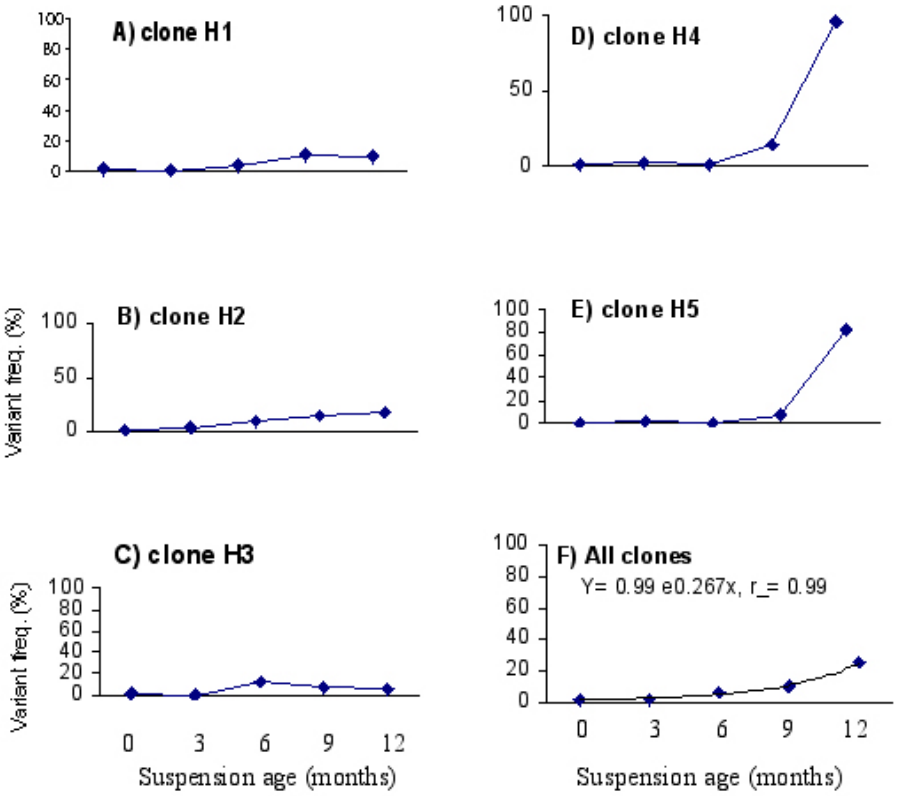

Figure 2. A, B, C, D, E) Evolution of somaclonal variant frequencies depending on suspension age for five genotypes (clones H1 to H5); F) evolution of the average variant frequency obtained with all clones.

Seed biochemical and mineral characteristics, and cup quality (Trial 2)

For the 17 variables studied, representing the biochemical and mineral characteristics of the seeds, along with the organoleptic characteristics of the infusion (Etienne and Bertrand, 2001) (Figures 3C,D), no significant difference was found between plants obtained from microcuttings or from embryogenic cell suspensions. There was therefore no "technique" effect. Differences were observed in a few cases, for biochemical characteristics only, for the same clone and for both techniques. The differences involved caffeine content for clone 1, chlorogenic acid content for clone 2 and sucrose content for clone 2. These slight differences seemed to be down to chance and did not always go in the same direction. They could not be explained by the propagation technique used. Moreover, no interaction was found between the micropropagation technique and the clone used. The analysis of variance for these results also revealed a strong clone effect.

DISCUSSION

This work confirms the existence of somaclonal variations in trees of *Coffea arabica* propagated by somatic embryogenesis, as already reported (Söndahl and Lauritis, 1992). However, the frequency of "off-types" (2.1%) was below the 10% reported by those authors.

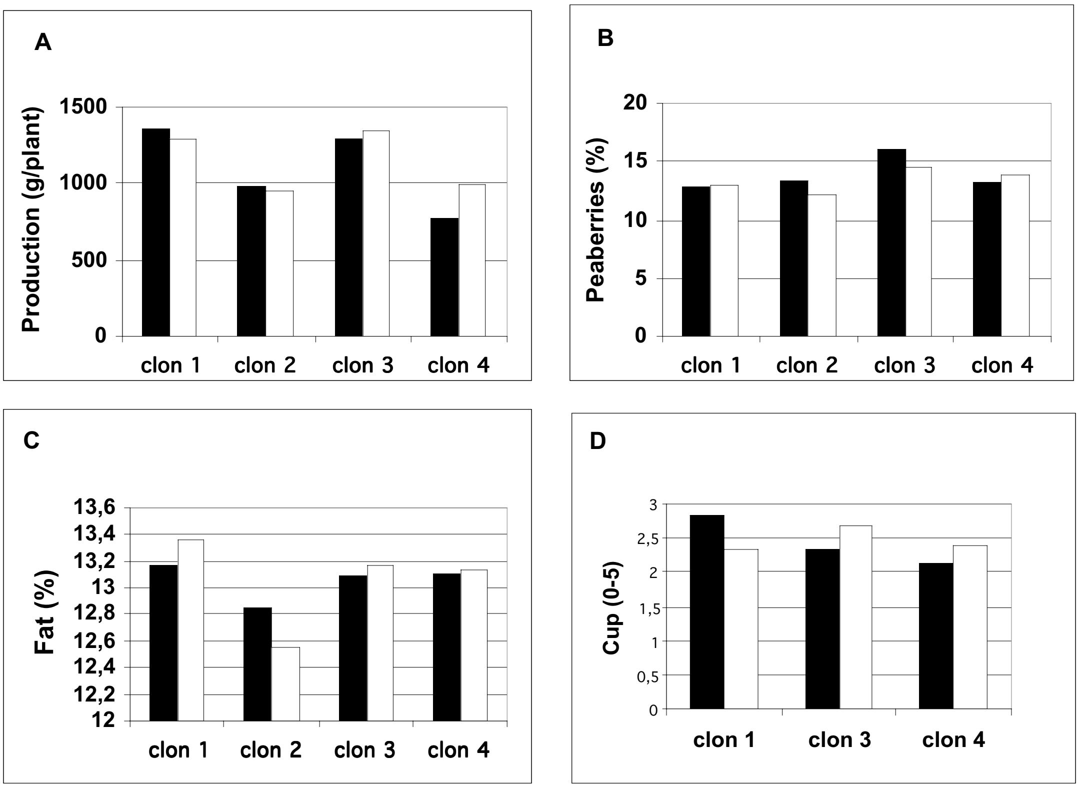

Figure 3. Comparison of some agronomic characteristics (production, percentage of peaberries, bean fat content and beverage quality) for four Coffea arabica clones micropropagated by in vitro microcuttings and embryogenic cell suspensions. Complete data were given previously (Etienne and Bertrand, 2001).

Factors affecting the variant rate

It has frequently been shown that the proportion of somaclonal variants increases with the number of multiplication cycles, or with the length of culture time. This has also been shown for some somatic embryogenesis procedures (Morrish et al., 1983; Symillides et al., 1995; Henry et al., 1996). The existence of somaclonal variants in the progeny of coffee plants propagated by somatic embryogenesis has been documented (Söndahl and Lauritis, 1992; Etienne and Bertrand, 2001; Etienne and Bertrand, 2003). The role of genotype was demonstrated in coffee, but the roles of other culture parameters such as growth regulators and in particular, culture age, were not established. We have shown that the age of *Coffea arabica* embryogenic suspensions affects variant rate. For all genotypes studied, the frequency of variants increased exponentialy. For true-to-type multiplication, it will be essential to restrict embryogenic material multiplication times to less than 6 months. However, the initial stages of cell dedifferentiation and embryogenic callus induction (stage 1) also proved to be mutagenic, as some variants were regenerated from callus of most of the genotypes. Similar findings have been reported for coffee (Söndahl and Bragin, 1991), tomato (Ramulu, 1991) and banana, where it was found to be associated with excessive use of auxin analogs (Shchukin et al., 1997). As was demonstrated in barley cultures (Ziauddin and Kasha, 1990), it is possible that culture age is associated with prolonged exposure to 2,4-D (1 mg/l).

All genotypes in the study exhibited somaclonal variation, however, there were differences between genotypes, primarily in the intensity of the phenomenon. The existence of a genotype effect on somaclonal variation in *C. arabica* has already been shown in F1 hybrids (Etienne and Bertrand, 2001) and in nine widely cultivated varieties (Söndahl and Bragin, 1991). Söndahl and Bragin (1991) showed that plants propagated by somatic embryogenesis, without an embryogenic suspension proliferation stage, all had variants but with high and variable frequencies ranging from 3 to 39%. Hybrids belonging to the same family, such as H2 and H3 (cross T8667 x Rume Sudan), as well as H4 and H5 (cross T5296 x Rume Sudan) performed in a similar way with respect to frequency of variants, the timing of their appearance, and the type of variants observed (Etienne and Bertrand, 2003). These observations support the hypothesis of a marked influence of genotype.

Agronomic characteristics

Apart from examining the trueness-to-type of plants, it is important to test plants obtained by somatic embryogenesis in conventional agronomic trials. Indeed, somaclonal variants sometimes also reveal themselves through more or less intense flowering, or lower yields. For instance, in wheat, lines obtained from somatic embryos produced 11% less on average than the breeder lines, and had 3.8% fewer spikelets per spike, 6.5% fewer kernels per spike (Hanson et al., 1994). Likewise, in tall fescue (*Festuca arundinacea* Schreb.), there are no easily detectable differences for identifying somaclonal variation, but total biomass and seed yields differ between seedling plants and those obtained by somatic embryogenesis (Roylance et al., 1994). Our work on *Coffea arabica* hybrids shows that, if the 2.1% of variants that were easily detectable in the field through their morphology, which differed considerably from normal, were not taken into account, no difference was found in the main agronomic characteristics between trees produced from embryogenic suspensions and trees obtained from microcuttings with the criterions studied. The trees revealed vegetative characteristics, productivity, fertility, bean biochemical, mineral and organoleptic characteristics that were identical to those of the controls. Similar results were obtained with banana (Côte et al., 2000) and barley (Baillie et al., 1992).

All the results obtained show that propagation of coffee trees from young embryogenic cell suspensions generates few variants and that, apart from those variants, the agronomic performance of trees propagated by that technique is identical to that of trees obtained from microcuttings. Somatic embryogenesis can therefore be envisaged as a new propagation technique for coffee, for rapid and mass dissemination of heterozygous structures that should lead to substantial genetic gains compared to traditional pedigree selection schemes.

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Agricultural Extension to Coffee Farmers in Huong Hoa District, Quang Tri province, Vietnam

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SUMMARY

General developments in the Vietnamese coffee sector are described, and elaborated for Khe Sanh an area that produces Arabica coffee. Major changes that the Vietnamese coffee sector has to undergo relate to the improvement of quality of both the product and the production and milling processes. This is especially needed to keep Vietnam competitive in the coffee market when requirements of buyers of coffee become broader than only the intrinsic quality of the coffee. To facilitate adaptation of the Vietnamese coffee industry, agricultural extension to farmers is of utmost importance, but will only be efficient when the current top down approach is changed into more participatory forms of extension. An example of such an approach as implemented in Khe Sanh is discussed with indications how this approach could be made sustainable by actively involve all stakeholders, i.e. farmers, coffee processors, local authorities and local extension services in the process and in the financing of the activities.

DEVELOPMENT OF THE VIETNAMESE COFFEE SECTOR

Until the mid-90s, Vietnam coffee was unknown in the international market. In 1985 Vietnam exported approximately 25,000 tons of coffee. In the following years exported amounts increased slightly, but a real boom came in the late-90s when Vietnam ranked second after Brasil in exported volume.

The reasons for this strong increase are twofold. Firstly, Vietnam is largely an agricultural nation where 70% of the population of 80 million is active in agriculture. The majority of this 70% is cultivating paddy rice in the lowlands. Secondly, Vietnam is divided into three parts, only one part is plain, the two others are midland and mountainous areas. After the end of the war in 1975, the policy of the Vietnamese Government was to relocate people from the over-populated plains to midland and mountainous areas. The mid- and highlands turned out to be not very suitable for Vietnam's traditional crop of rice. Farmers, State-Owned Enterprises (SOE) and officials had to find alternative crops to safeguard economic development in these areas. Coffee was one among many of the alternatives and taken up eagerly by SOEs and farmers because the time from planting to the first harvest is relatively short for a perennial crop and at the time market prices for coffee were very high.

In the late 90s, Vietnam had over 500,000ha of coffee, whereas immediately after the war the coffee area was around 20,000ha (Table 1). The largest part of the rapid expansion took place in the years 1996-1998, reaching up to 100,000ha/year. Quality related problems formed a major drawback of the expansion, with farmers being unaware of e.g. proper practices for drying Robusta cherries, while the processing industry could not keep up with the production increase. When world market prices went down, numerous farmers, especially in the Central Highlands shifted from coffee to other crops and presently the total area is around 450,000 ha.

This is mainly for Robusta coffee, and Arabica is grown on 20,000 ha only.

Table 1. Vietnam; production and export 1982 to 2003.

Year	Area under cultivation (ha)	Productive area (ha)	Productivity (Mt green bean/ha)	Total production (Mt)	Export (Mt)
1982	19,800	9,100	0.51	4,600	4,600
1987	92,300	29,400	1.15	33,820	30,000
1992	135,000	123,000	1.11	136,000	87,500
1997	385,000	155,500	2.57	400,000	375,600
2002	500,000	450,000	1.67	750,000	702,017
2003	450,000	420,000	1.71	720,000	693,863

Source: VICOFA

GOVERNMENT POLICY

Expansion of coffee in Vietnam went so rapidly that also the government was taken by surprise. Although the government initially stimulated coffee production with subsidized credits, things went out of control when the high prices of the mid-90s stimulated a large number of people to go to the mid- and highlands to cultivate coffee. Processing infrastructure and extension facilities could not keep up, resulting in mediocre crop management practices and product qualities at best.

The mid-term development strategy of the government for the coffee sector till 2010 has one overriding principle: quality improvement in both Robusta and Arabica production and processing. Furthermore, Arabica production will be stimulated and expected to reach relative share of 30% of total production, whereas the total area under Robusta is expected to decrease. The mid-term strategy has a strong focus on improved sustainability in terms of environment, economy and societal issues. Practically this means that coffee fields need to have enough windbreaks as well as shade trees system, soil-fertility needs to be enhanced, chemical fertilizer should be used in relation to nutrient removal, pesticide use should follow IPM guidelines. Processing facilities will be required to use techniques to save energy and minimize and recycle wastes. Living conditions of workers and farmers have to be improved, producers should have access to up-to-date training relating, not only to technical issues but also to market information and global developments in coffee.

COFFEE PRODUCTION IN KHE SANH, QUANG TRI PROVINCE

Khe Sanh is a small town in Quang Tri province, situated in Central-Vietnam, around 650 km south of Hanoi. The altitude ranges from 500 to 800m a.s.l. Soil and climatic conditions are suitable, but certainly not optimal, for Arabica cultivation. However, processing and storage faces disadvantages. Annual rainfall is about 2000mm, with a bi-modal rainfall pattern: a small rainy season from the end of April till beginning of June, and the main rainy season from the end of September until the end of December, the latter coinciding with the harvesting season. The annual average temperature is 24-25˚C, with a maximum of around 30˚C. Early mornings often are foggy, and in combination with the rains, the coffee crop survives easily the dry, hot season from June till September without irrigation, even though productivity might be affected.

The total potentia coffee area in Huong Hoa district is around 5,000 to 6,000 hectares. Present acreage is 3,000ha planted by Arabica coffee, and expansion is currently rather slow, due to low coffee prices. Maximum observed fresh cherry yields are in the order of 25 to 30 Mt per ha per year, with the average varying per year from below 10 to around 20 depending on rainfall and productivity of the year before. As the green beans: fresh cherries ratio is about 1:7, this translates to a maximum of 3.5-4.5 and an average of 1.4-2.8 Mt green bean per ha. Processing is wet and semi-wet, resulting in reasonable export prices.

About 70% of the farmers are Kinh, the main ethnic group in Vietnam, while the remaining 30% is of the Van Kieu ethnic minority. About 40% of the Kinh are people that worked in coffee already before the major expansion in the area, and as such have 10 to 20 years experience with coffee. The other 60% of the Kinh farmers are recent migrants from the lowlands where they cultivated rice, or had jobs outside agriculture. They have at maximum only 8 years experience as independent coffee farmers. Both groups of Kinh are clearly accumulating practical experience in management of their coffee crop, but their farming approaches are still seldom fully in line with current sustainability concepts. Their limited experience limits the efficiency of their cultivation as well as the returns on investments made in coffee. The agricultural activities by the Van Kieu ethnic minority are in a process of transformation from shifting cultivation into settled agriculture. This is the result of landownership issues and population pressure, which are limiting the area available to the Van Kieu. Their unfamiliarity with crops like coffee requires intensive (practical) training to improve quality, yields and household resource allocation.

Additionally, international developments necessitate the development of a far-reaching extension program. Coffee consumers do not only require a good quality product, but are also aware of the difficult situation of many coffee farming families as a result of low coffee prices through media campaigns by NGOs like Oxfam. This awareness on the part of consumers resulted in increasing pressure on roasting companies to act and make efforts to improve the burden of the so-called coffee crisis. Coffee roasters, NGOs and producer associations came together to formulate sustainability initiatives such as the “Common Code for the Coffee Community” (4C) and Sustainable Agriculture Initiative (SAI). Although compliance with such codes is expected to result in better coffee prices, Khe Sanh farmers still need better access to information to streamline their production systems with these codes. To solve this problem, agricultural extension is one of the essential tools.

AGRICULTURAL EXTENSION ACTIVITIES IN HUONG HOA DISTRICT

Extension to coffee farmers is the responsibility of the district agricultural extension organisation, which is part of the provincial Department of Agricultural Research and Development (DARD). However, also the local coffee processing companies have a role, because of contracts made with farmers and because of a recent national law that stipulates that companies processing agricultural products have a responsibility in improving working and living conditions of the farmers from whom they acquire these products.

In Huong Hoa area, the district extension service used to follow a strong top-down method regarding agricultural extension, where extension workers were seen as experts and farmers as rather ignorant. The extension workers gave advice to farmers based on information they obtained from often unclear sources, and which was often not relevant for the specific conditions in the district. As a result, very little effect of this extension was observed and farmers were not positive about the extension.

Of the three main coffee processors in Huong Hoa district, one company, called Tan Lam Agricultural Product Joint Stock Company, or in sort TALACO, is partner in a Public-Private Partnership (PPP) project, called ‘Improvement of coffee quality and sustainable coffee production in Vietnam'. The year 2000 to 2002, following the extension program of GTZ. The German Development Service project (DED) started coffee extension in TALACO with 2 FFS in coffee area, responsible of this project is Mr. Herbert Lempke Germany expert and Mr Thiet Vietnamese coffee expert. The result of extension very good. When PPP project start (2002), Extension activity we continues on base result from DED. This project is sponsored by SaraLee-Douwe Egberts and Kraft Foods and involves experts on processing from Germany (from GTZ, the German development aid organisation and EDE, the consulting firm connected to Neumann coffee group) and on agronomy from the Netherlands (from the agricultural research institute Plant Research International, or PRI, part of the WUR, the Wageningen University and Research Center). In the agronomical part of the project, the main focus is on development and introduction of a participatory agricultural extension, in the form of Farmer Field Schools (FFS). Here FFS is used in a broader sense than in the original FAO setup (Gallagher, 1999), which focus 'only' on integrated pest management (IPM), while in Huong Hoa there is more attention to other topics, and in fact focus on integrated crop management (ICM). Those topics were identified by comparing general knowledge about good agricultural practices in coffee with actual occurring farmers' practices. This FFS approach was first introduced to farmers connected to Talaco through land-lease contracts. In 2003, Talaco became the first Utz Kapeh certified processing company in Vietnam, to a large extend because of the efforts of the PPP project, regarding improvements in the processing as well in the extension to the farmers.

As a result of the enthusiasm of participating farmers, the district extension organisation got interested in the approach, and the PPP project positively responded to the request of the district to assist the district extension service in the expansion of the FFS approach to other farmers in the district.

To achieve the expansion, more trainers of FFS were needed than the 2 working for Talaco. Therefore, a total of 17 persons were selected to receive a Training of Trainers (ToT) course to familiarize them with participatory training methods. Participants were required to have a coffee farm, while they should have some educational background in agronomical techniques. Furthermore, the group of trainers should have members from all the local mass organisations with linkages to agriculture or farmers, and represent the various villages in the coffee growing areas. In this way, involvement of the mass organisations was stimulated and a close, personal link of trainers with the local farmers was achieved.

In various combinations of two persons, these trainers started in 2003 to guide 15 Farmer's Field Schools (FFS) in 6 coffee growing communes in the area, with each FFS consisting of 20 to 25 farmers with a total of 328 participants. The FFS are meeting once a month except during the harvesting time from October to December. At the meetings, at least one specific crop management aspect is treated, which is typical for the time of the year of the meeting. Normally, a FFS session consists of a morning session with theoretical background and discussion, whereas practical field exercises take place in the afternoon.

To allow starting up of new FFS with the limited number of trainers, 2 years after being established, FFS will be turned into a study club, where farmers meet and discuss without the guidance of a trainer. In cases where the group can not find the answers they need, a trainer may be hired by the group to work with them.

The site specific agro-ecological and socio-economic conditions make it difficult to directly apply results from research in other areas. To support the FFS program, therefore, several trials are taking place to look into possible solutions to constraints that are closely linked with situation specific farming conditions. These trials have the purpose of influencing farmer's management practices. Therefore the farmers are closely involved in the design, implementation and to a lesser extend in the analysis of trial results, and the trials are taking place on-farm of and generally by farmers participating in FFS. Present trials focus on:

1. Fertilisation prototyping
2. Measurements of leaf chlorophyll content as possible indicator of the need for fertilisation
3. Composting coffee pulp and use of this compost as fertilizer/soil quality enhancer
4. Registration of cropping activities
5. Cherry quality analysis
6. Coffee varieties
7. Influence of shadow trees on coffee quality

SUSTAINABILITY OF AGRICULTURAL EXTENSION

Presently, the PPP project contributes substantially, both financially and technically, to the new extension system. Other major contributors are the mass organisations that pay the salary of the trainers of the FFS. A recurring issue of projects is that the implemented activities fade out after ending of the project, which for the PPP project is foreseen in June 2006. The FFS program has been well received by the farmers, local organisations and coffee processing companies, resulting in a plan being developed by the district extension service to expand the approach even further. In this plan, there will be specific attention to ensure that the financing of the extension activities will at least be partially paid for by the direct stakeholders, which are the local processing companies and the farmers. Also, organizing the extension will become a combined responsibility of the district organizations and the local coffee processors.

Figure 1 compares the old set-up of extension with Talaco as sole processor and the PPP project strongly involved to the proposed new set-up where all processors are involved (at least financially), farmers pay a part of the costs and the PPP project has ended.

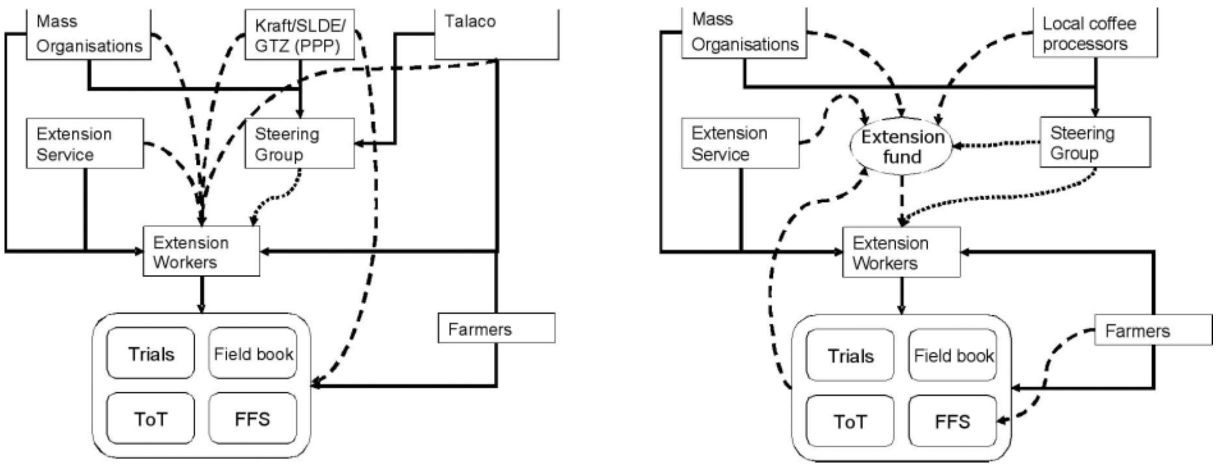

Figure 1. Comparison of old versus new extension set-up in Huong Hoa district (see text): continuous lines indicate linkage through assignment of labour; broken lines: financial linkage; dotted line: linkage through information and decision making.

DISCUSSION AND CONCLUSIONS

Through the activities of the PPP project and collaboration with foreign experts, Talaco has built up a considerable pool of expertise in FFS as a means to agricultural extension to coffee farmers. On a national level, Talaco is considered as a showcase example for other coffee processing companies in the country. This has allowed Talaco to successfully offer cosultancy services on agricultural extension, wastewater treatment, processing practices, recycling, etc to other organisations in Vietnam, with a first venture with farmer cooperatives in Laos as well. This has resulted in income for Talaco, additional to that resulting from selling processed coffee. When this additional income remains at current levels, or even improves, the extension group of Talaco is a net contributor to the profit of the company, and as such will not be seen as a cost, but as an asset to Talaco.

Vietnam, currently among the top 3 largest coffee exporters in the world, is trying to focus on the quality of its coffee and of the production and milling processes. So far, results in general are not significant, which can partially be explained to the lack of knowledge among processors and farmers about how to achieve the desired improvements. In view of the results obtained, the approaches followed in PPP project with Talaco, could serve as an effective model for other coffee producing areas in Vietnam, to provide extension to both farmers and coffee processors. This extension should be considered the first priority to make Vietnam coffee production more sustainable and to allow it to remain competitive in the world market. This is especially needed if Vietnam is to tackle efficiently the challenges posed by new developments, such as formulated in the Common Code for the Coffee Community, and which require the coffee producers and mills to become more sustainable in terms of social, environmental and economic terms.

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Registration of Field Activities: a Tool for Improvement of Cultivation of Arabica Coffee in Huong Hoa District, Vietnam

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SUMMARY

The project “Improvement of coffee quality and sustainable coffee production in Vietnam’, sponsored by SaraLee-Douwe Egberts and Kraft Foods, is introducing crop registration to farmers of Arabica coffee in Huong Hoa district, Quang Tri Province, Vietnam. This crop registration, or Fieldbook, is an addition to the activities of the Farmer Field Schools, a participatory form of extension that recently was introduced in the area. To get a better and quantitative view on input-output relations, farmers have been registering daily cropping activities in at least one of their plots with Arabica coffee. Analysis of this registration gives insight in differences between different forms of crop management and results are used in the discussion among farmers about possible improvements in coffee cultivation practices. Set up of the Fieldbook approach and examples of results of the analysis are discussed.

INTRODUCTION

Currently, agricultural extension to coffee farmers often follows a top down approach, where extension workers bring messages, ideally based upon scientific research, to farmers about how they should improve their crop management. In the last decades, this top down approach has received strong criticism, especially on the failure to address the needs and concerns of smallholder producers, even though in many cases it provided crucial support to (other) farmers on agricultural input supply, planting material, agronomic advice and quality control of harvested produce (Williamson, 1999). However, in the 1990’s, the extension to coffee farmers in many coffee producing countries has been ‘liberalised’ (e.g. Tanzania) and/or the purchasing of coffee was deregulated (e.g. in India), with adverse effects on the efficiency and quality of coffee production (Williamson, 1999). At the same time, coffee farmers are confronted with many challenges regarding demands of buyers, such as compliance with certification requirements (Common Code for the Coffee Community, Utz Kapeh, Rain Forest Alliance, etcetera), continuous low prices for their products, and changes in purchasing systems. To successfully participate in the world market, coffee farmers, especially the smallholders, need extension to continuously improve their crop and farm management and to learn to better adapt to the demands of the end-users of their products.

Especially in annual crops, new methods of extension with a more active participation of farmers have been introduced, such as Farmer Field Schools (FFS), often with remarkable success (van den Berg, 2004). In FFS, farmers are involved in problem diagnosis, planning, testing and evaluation of farming practice options and, ideally, collaboration with research and extension agencies (Williamson, 2002). In these participatory approaches, farmers are stimulated to become more aware of the interaction between their management, the crop and the environment, and to learn from practical testing of different options for crop management practices in which they themselves have actively participated. In most cases, this is achieved through practices and observations in the field combined with discussions among farmers about the effects that farmers observed (Gallagher, 1999).

Optimizing the performance of their crops is a major option farmers have to improve their income and reduce unwanted effects on the environment. A farm may consist of one or several fields that may differ in characteristics, such as age of plants, soil type, possibility to irrigate, distance to the house, etcetera. For different fields different forms of management may be optimal, considering the characteristics of the field and the availability of resources at the farm household, such as labour, finances and access to markets for inputs and outputs. As such, comparison of different forms of crop management, on different fields of one farmer or fields from different farmers, could be seen as an expansion of the FFS approach of comparing practices. However, so far there has been little attention in the FFS community to stimulate farmers to analyze their cropping systems in a quantitative way, in order to make their feelings about the performance of their management more objective and comparable with that of other farmers. Such a quantitative approach however, could be very useful when farmers need to optimise the use of inputs in their cropping systems, since it provides insights in the efficiency of the use of these inputs.

In this paper, an approach to enable such quantitative analysis is discussed. It is developed in a collaborative effort of Plant Research International (PRI), Wageningen, the Netherlands and the Extension Group of Tan Lam Agricultural Product Joint Stock Company (Talaco), a coffee mill in Quang Tri Province, Vietnam. The effort is part of the PPP project “Improvement of coffee quality and sustainable coffee production in Vietnam’, sponsored by SaraLee-Douwe Egberts and Kraft Foods It is expected that the described approach can also be applied in other coffee growing areas, since it is generic and not confined to the Vietnamese situation.

APPROACH

To allow a quantitative analysis of a specific crop management and comparison between fields, the following steps were taken as elaborated in the next sections:

1. development of a robust yet versatile form of describing daily field activities
2. selection and instruction of participants, and general description of the fields
3. data retrieval and digitizing
4. analysis of Fieldbooks
5. communication of results of the analysis

Form for describing field activities

To enable a quantitative analysis, a chronological and quantitative description of all cropping activities (also called operations) in a certain field has to be available. Each activity is characterised by a name or code, a date of execution and the quantity of biophysical input(s) and/or output(s), split into three groups: labour, equipment and materials (following setup by Jansen & Schipper, 1995). Animal traction is left out as a specific characteristic, since it is of very limited importance in the coffee area in Quang Tri and can be included under equipment. When materials are used, the commercial name of the specific material has to be provided (e.g. ‘Vicarben 50 hp’), as well as the unit of measurement (e.g. kg) of the amount that was applied or produced, e.g. to calculate nutrient balances (from nutrient content of fertilisers and crop products). To allow a more specific analysis of labour use, labour input is divided in 4 groups: household adults, household children, hired adults and hired children. To allow economic analysis, the prices paid for the inputs (equipment, materials and hired labour) or obtained for the products have to be provided as well.

The form given to farmers has specific blocks to fill in the required characteristics for each operation group by major type of activity (such as fertilizing, harvesting, biocide spraying) In addition, the name of the farmer and the name of the field have to be noted on the form. The form is designed such that per week only one form is needed by farmers for each field. This works very well, with one exception: for weeks that farmers do not work on the field, they prefer to fill in only a small form stating that they did not execute any activity in the field. They find it a waste of paper to use the full form.

Selection and instruction of participants

Farmers from FFS connected to the project were selected to participate in the Fieldbook activity, divided over the two major production areas (Huong Phung and Khe Sanh), representing current gender distribution among farmers in these areas and current levels of production, which was known by the trainers of the FFS. At the start 21 farmers participated, with 3 farmers registering activities in two fields each, a number that grew to 43 when new FFS started and two farmers from each new FFS were selected to join the Fieldbook (Table 1). The reason for incorporating farmers from each FFS is to make it possible for FFS farmers that do not participate in the Fieldbook activity, to ask their FFS colleagues that do participate about the reliability of the results of the Fieldbook analysis.

Table 1. Number of participants per location, gender and start of participation.

Start of participation	Huong Phung		Khe Sanh		Total		
	♂	♀	♂	♀	♂	♀	All
2002	11	0	4	6	15	6	21
2004	7	1	6	8	13	9	22
Total	18	1	10	14	28	15	43

All participating farmers are literate, so reading of the form and writing on it is not a problem. In the instruction it was made clear that farmers had to fill in the actual inputs used and outputs produced for their specific fields, and that they did not need to provide data on a per ha basis. Apart from the technical instruction, farmers were informed about why the project wanted farmers to keep a Fieldbook (in short: to enable a comparison between farmers and provide input for discussion in the FFS) and that the results would be made public without the names of the participating farmers. Because of the appreciation among farmers of the project's efforts regarding the establishment of the FFS, the respect they have for the head of the Talaco Extension Group and their general interest in improving their cropping systems, it was not difficult to find enough farmers willing to participate. In fact, it was more difficult to tell farmers that they would not participate, due to lack of capacity for processing the data in the project team.

The instruction was done in groups and additionally to individual farmers if they asked for it or when errors in the filled in forms warranted the need for more instruction. In general, farmers had no major problems filling in the form. Some concepts, however, were ambiguous to them. In the beginning many attached a price per hour household labour, equivalent to that of hired labour, while the project wanted to calculate the rewards of household labour without a prior price for that labour. The need for indicating a clear and well defined unit of measurement for used material was at the start not clear to all farmers, and several farmers mentioned 'cans' or similar expressions. Also, several farmers did not correctly fill in the commercial names of materials they used. These problems were solved through discussions in groups and with individual farmers.

Data retrieval and digitizing system

Before a farmer started filling in the Fieldbook, the specific field where cropping activities would be registered was characterised in terms of slope, number of coffee trees, size (ha), and age of trees. The latter are known exactly by the farmers since they lease the fields officially from Talaco, which stipulates these data. Of these data, only the size of the field and the number of trees is currently used in the analysis (see below).

Filling in of the forms is done by farmers themselves or by members of their household on a daily basis. To allow fast detection of errors or dubious or unclear entries, each week a member of the project team collects the form of the last week from each participating farmer and checks the form for possible errors. In general this works very well, although on some occasions farmers still had to fill in the complete week on the form when the project staff came to collect the form. Questions about information on the form collected the week before that arose while typing in the data, are discussed and where possible answered. After receiving a form, a code is written on it that reflects the location, the name of the farmer/field and the year and week that the activities described on it took place. Data on the form, included the code on the form, are typed in on the computer and the coded form is subsequently archived with the other forms of the same field. The code makes it possible to find back the original data in the archive. To allow analysis, data is digitised by project staff into Microsoft Excel® files, one per field. The choice for Excel above database software was guided by the fact that project staff had extensive experience in Excel and hardly any in database software. Initially, the data was typed in without the help of an input-software, which was developed only later and improved the speed and especially the accuracy of the data-entry. The entered data has a row-column structure, where each row describes one activity executed on a specific date, and each column relates to a specific characteristic of that activity. The order of the columns is fixed and similar for all Fieldbook data files. The general data of a field is stored in a specific sheet in its specific Excel Fieldbook file.

Analysis

In the first year, all files were analyzed ‘by hand’ and in the second year a dedicated Excel Macro for the analysis was used. In the analysis, first a chronological, cumulative list of all different inputs are made; which thereafter are used to calculate per type of activity (weeding, pruning etc.) the amounts and costs of inputs and (for harvesting) amounts of cherries and received price for either the calendar year or from the start are calculated. On basis of these data, total use and costs of inputs are calculated, as well as gross income, revenue, operational balance of N, P and K (difference between input through fertilisers and output through harvested cherries). Results of different farmers are combined, in tabular and graphical form after recalculation onto a per ha basis, using the size indication of each specific field. Examples of results are given below.

Communication of results

In a session of the FFS, each field-book farmer received the results of the analysis, where in each graph and table his/her own data was indicated. Anonymous graphs and tables were shown and explained to all FFS farmers, while important differences between groups (mainly based on location) and individual farmers were highlighted. In general, within a short time after presentation all farmers were discussing among each others what caused these differences, and Fieldbook farmers were asked to indicate to others which their results were. Initially, there was quite some distrust among non-field-book farmers about the validity of the data: many thought that the books were ‘cooked’. However, interaction with Fieldbook farmers seems to have convinced them that the results are indeed trustworthy. Farmers are very interested in the results of the analysis: last year they complained that it took us too long to analyze the results.

EXAMPLES OF RESULTS OF THE ANALYSIS

The approach allows for a large number of results to be prepared. Here only a few will be shown, to indicate the types of analysis that are possible.

Biophysical analysis: comparison between forms of management and years

On the fields of three farmers in Quang Tri, comparative experiments take place, where each of these fields is split in two parts. Both are managed by the farmer, according to his own decisions, with one exception: on one part, an 'alternative' fertilization is tested, following suggestions by the project team. In the field of one farmer in Khe Sanh, the alternative management in 2002 gave different results compared to the farmer's management: cherry production was 10 tons per ha higher and more synchronised in time (compare open circles and closed circles for 'alternative' and 'farmer' management, respectively, in Figure 1).

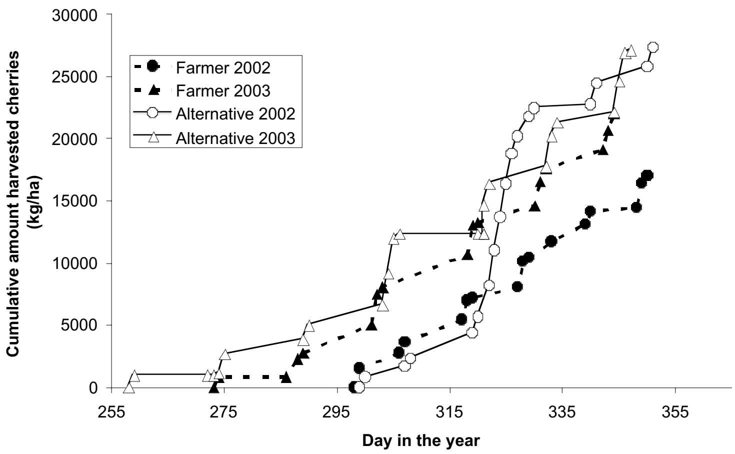

Figure 1. Cumulative amount of harvested fresh cherries according to year(2002, circles; 2003, triangles) and management (farmer's fertilization, closed symbols; alternative fertilization, open symbols) in a particular field in Khe Sanh.

Table 2. Time and amount of Nitrogen fertilization in 2002 and 2003 in the plots with full farmer management ('Farmer') and with an alternative fertilization ('Alternative'), for one specific farmer in Khe Sanh.

Management	2002			2003	
	Day	N (kg/ha)		Day	N (kg/ha)
Farmer	≈150	366		142	110
	350	77		272	77
Alternative	≈150	366		225	81
	194	57		321	96
	266	142			

Although the farmer enjoyed the higher yield, he disliked the synchronization, as this made it more difficult for him to do the harvesting in his other fields with the limited labour force available. In 2003 no big differences were observed in performance of the two forms of management (open and closed triangles, Figure 1). This is mainly related to the smaller differences in amounts and timing of N application between the 'farmer' and 'alternative' management in 2003 (Table 2). Due to drought, the suggested alternative fertilization schedule could not fully be executed as planned in 2003.

Economic analysis: comparison between farmers

Coffee farmers in Quang Tri are generally profit maximisers: yield is less important than income. Therefore, they are extremely interested in the economic performance of their fields. To express this performance, the revenue achieved at each field is calculated according to: $R = G - C = Y \cdot P - C$, where R= revenue, G = gross income, C = total costs of inputs used, Y= yield of cherries, P = price of cherries. In 2002 and less so in 2003, a strong and positive relation existed between yield and revenue (Figure 2).

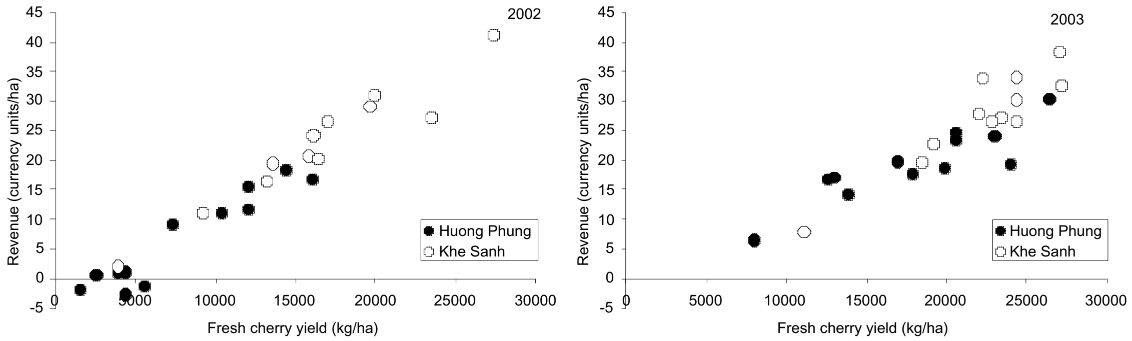

Figure 2. Revenue of individual fields in relation to cherry yield, for two years (2002, left, and 2003, right) and two locations (Khe Sanh, open dots and Huong Phung, closed dots). Data are shown on a per ha basis to allow comparison.

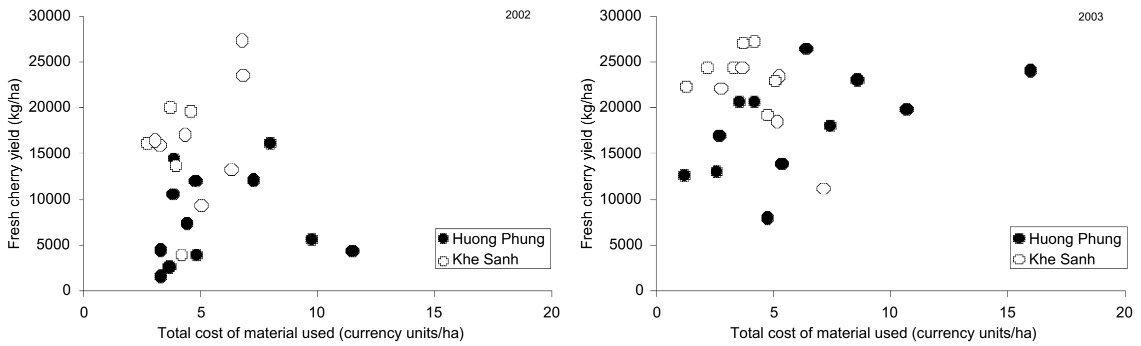

Figure 3. As Figure 2 for relation between total costs of materials used and cherry yield.

There is a difference between the two locations: farmers in Huong Phung, with less fertile soils, younger crops and poorer infrastructure have in general lower yields and lower revenues at similar yields than their colleagues in Khe Sanh. Also, considerable variation exists in the yield-revenue ratio between farmers within each location: especially in 2003, some fields with lower yields had higher revenues and different fields with similar yields showed different revenues. This results mainly from the lack of relation between total costs for material used and yield (Figure 3).

The reasons for this lack of relation are probably twofold:

1. Nutrient management is not always adequate: nutrients are often not applied in a proper mix nor in a proper timing and frequency
2. Other management activities, especially pruning and weeding, are often not conducted properly

Sensitivity analysis

To analyze the sensitivity of the revenue of each field to changes in prices of hired labour and material input, first changes in revenue were calculated according to $R_{\alpha,\beta} = G - (1+\alpha)\cdot L - (1+\beta)\cdot M$, where L= labour cost, M = Material cost, α = relative change in cost of labour, β = relative change in cost of material. The slope of the linear regression of $R_{\alpha,\beta}$ versus α and β indicates the sensitivity of the revenue to the relative changes in costs. Negative sensitivity indicates that the revenue becomes less when prices become higher. A sensitivity of zero means that the revenue is not sensitive at all to changes in price, while at a sensitivity smaller than –1 (e.g. –2) relative changes in the revenue are larger than the relative changes in the price.

Especially at low production levels, the sensitivity for changes in prices for both labour and material can be very high (Figure 1), while at relative high productivity levels there seems to be a tendency that the sensitivity for changes in price of material input increases. This is especially the case in situations where the material is not used efficiently, e.g. due to over-fertilization. The variation in sensitivity for prices of hired labour is related to the efficiency of use of this labour, but also to the fraction that hired labour takes in of the total labour use: the higher this fraction, the more sensitive the revenue for price changes.

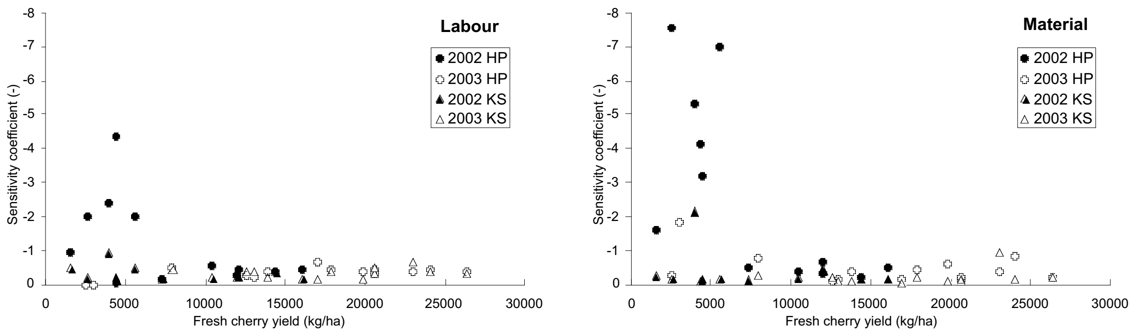

Figure 4. Sensitivity of revenue of observed crop management to changes in prices of hired labour (left) and material input (right) for two locations (HP=Huong Phung, circles; KS=Khe Sanh, triangles) and two years (2002, closed symbols; 2003, open symbols).

DISCUSSION AND CONCLUSIONS

The described relative simple way of collecting data from farmer's management facilitates the analysis of a great number of topics that are of direct interest to farmers. Even though results of the analysis mainly signal possible problems and not always give clear-cut solutions to these problems, it clearly stimulates farmers to discuss about these problems and their possible solutions. In our experience this is shown by the enthusiasm that farmers show when discussing the results. It is difficult to monitor the effects that these discussions have on the behaviour of the farmers, which is due to the yearly variability of the weather as well as to the fact that changing farmers' behaviour takes time. Since the livelihood of the Quang Tri coffee farmers often depends to a large extend on the income generated from the coffee crop, they naturally are hesitant to drastically change their practices on basis of the limited information gathered in the two years as presented in this paper. This is also recognised by farmers filling in Fieldbooks, which have stated that according to them at least 3 to 4 years of data-gathering is required to get reliable results. Therefore, all of them have expressed their willingness to continue with the Fieldbook at least for another few years.

In the approach followed in the PPP project in Quang Tri, trained staff is required to digitise and analyse the Fieldbooks. Training is required in basic Excel procedures, in accuracy and carefulness when typing in the data, and in recognizing unexpected and possibly wrong data. Currently, each week about 1.5 labour days are needed to collect the forms from the farmers, to a large extend because of travel time, and typing in another 0.5 day. In the near future, farmers in Quang Tri will be able to do the digitizing themselves. Currently, the first farmers are buying a computer, most likely not for the specific purpose of filling in Fieldbooks, but the project is already looking for ways to involve them in the Fieldbook work.

In the absence of a full-fledged analysis software, analysis takes about 1 week of labour per year. It is expected that in the beginning of 2005 the analysis software which is under development by the project will be ready to do this job in much less time.

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Developing a Geographical Indication for Arabica Coffee in Bali: Description of the "Terroir" of Kintamani

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SUMMARY

Coffee is in the throes of a crisis caused by surplus production, which has led prices to drop to an all time low. Specialty coffees are weathering the crisis better, among them, the specified-origin coffees. Indeed, their flavour characteristics make them original products that fetch a higher price, as they are much sought-after by roasters and consumers. However, despite of the emergence of these new markets for the specified-origin coffees, there is no real guarantee on the origin at any level of the coffee sector.

The Geographical Indication (GI) is a sign that guarantees the origin of the product, the way it has been produced, and consequently its quality characteristics. We think that GI could be applied to coffee. The development of a GI is mainly based on the identification of the *terroir*. *Terroir* is a French word, which is difficult to translate to English. A *terroir* is a system of complex interactions between a set of operations and techniques practised by man, a cultivated plant and a physical environment to be exploited by a product on which it confers specific original features (Salette et al., 1998). That means that the physical environment is not the only element to be taken into account in defining a *terroir*. Man is another key-word: *terroir* is the expression of a culture and a social organisation.

Kintamani arabica coffee, from Bali, has a great potential for a GI. (1) All the activities of the Balinese from the Kintamani Arabica producing area derived from Hindu philosophy of *Tri Hita Karana*. This philosophy led to a farming system in which chemical fertilisers and pesticides are not used. Kintamani Arabica coffee is produced by generalised organic practices. (2) People is organised according to a specific structure: the "Subak Abian". The "Subak Abian" is in charge of social and religious life. It is also an economic entity which regroups the growers. The "Subak Abian" has the potential to be the basis of the organisation which will support the GI. (3) The Arabica coffee is situated in a well defined environment, the recent areas are 3637 ha located between 8, 17° and 8, 30° South latitude and between 115, 23° and 115, 34° East longitude. The Arabica coffee cultivation becomes very difficult outside that area because of the low altitude or because of the drought which is very long in the eastern side of the Kintamani region. The altitude ranges from 1000 m to 1500 m above sea level. The relief is generally flat, except in the North-West where a typical landscape of terraces can be seen. (4) The Balinese coffee had a very good reputation before the 1950's. Our cup tasting reveals that the Kintamani Arabica coffee has a distinctive characteristic of lemon taste which can explain, in part, this past reputation. We think the reputation of this quality coffee could be recovered through a GI. (5) A quality strategy is being developed in Kintamani region. The picking of only red cherries is strongly recommended and the governmental authorities encourage the wet process. (6) Finally, the Kintamani coffee

growers drink their own coffee. These growers will probably continue to be receptive to the recommendations for the improvement of the quality of a product they appreciate.

INTRODUCTION

Coffee is one of an important estate crops in Indonesia. Recently, in the country is cultivated some 1,1 million ha of coffee husbandry with annual production ranges from 450,000 ton to 550,000 ton of green bean, among them some 120,000 ton for domestic consumption. Coffee is not only to be the main source of income for one million farmers but also an important source of foreign exchange for the country.

The country produces robusta (90%) and arabica (9%) coffees in addition to small quantity of liberica (1%) one. Production area is mainly in Sumatra (almost 60%) followed by Java and Sulawesi islands.

Arabica coffee growing areas consist of Aceh, North Sumatra, East Java, Bali, South Sulawesi, East Nusa Tenggara, and Papua provinces. The coffee is mostly exported to specialty market segment such as Toraja Coffee from Tana Toraja highland (South Sulawesi), Java Coffee from Ijen highland (East Java), Mandheling Coffee from Bukit Barisan highland (North Sumatra), Gayo Mountain Coffee from Gayo highland (Aceh), etc.

During the last five years coffee is in the throes of a crisis caused by world surplus production, which has led prices to drop to an all time low. Specialty coffees are weathering the crisis better, among them, the specified-origin coffees. Indeed, their flavour characteristics make them original products that fetch a higher price, as they are much sought-after by roasters and consumers. However, despite of the emergence of these new markets for the specified-origin coffees, there is no real guarantee on the origin at any level of the coffee sector.

The Geographical Indication (GI) is a sign that guarantees the origin of the product, the way it has been produced, and consequently its quality characteristics. We think that GI could be applied to coffee.

Like trademarks or commercial names, geographical indications (GIs) are distinctive signs, which permit the identification of products on the market. If they are used in the proper way and are well protected, they can become an effective marketing tool of great economic value. GIs indeed convey the cultural identity of a nation, region or specific area. They make it possible to add value to the natural riches of a country and to the skills of its population, and they give local products distinguishable identity. The issue of "extension" of GIs other then wines and spirits, after Doha Round, is of particular interest not only to develop but also developing countries because of the importance of the remunerative marketing of their agriculture, handicraft, and artisan production. In addition GIs have features that respond to the needs indigenous and local communities and farmers. GIs:

- are based on collective traditions and a collective decision-making process;
- rewards traditions while allowing for continued evolution;
- emphasize the relationship between human effort, culture, land resources and environment; and
- are not freely transferable from one owner to another (Addor & Graziolli, 2002)

In Indonesia protection of GI is provided under Trademark Law No. 15 of 2001. Article 56 (1) of the Law mentions that GI shall be protected as a sign which indicates the place of origin of goods, which due to its geographical environment factors, including the factor of the nature, the people or the combination of the two factors, gives a specific characteristics and quality on the goods produced there in. Protection system for GI has not materialized yet in the country.

ICCRI in collaboration with CIRAD has taken initiative to establish Franco-Indonesian cooperation on the identification and implementation of GI protection in Indonesia, with special case on arabica coffee. Arabica coffee was nominated to be an example commodity for the GI project due to its similarity to wine. As a stimulant beverage the taste of arabica coffee determined by a complex of chemical substances involving on the aroma and flavour formation, it is significantly influenced by a "*terroir*", as for wine. The coffee crisis in the beginning of 2000's due to very low price was also similar to the case of wine in the beginning of 1900's.

This paper was aimed to inform the preliminary result of the description of terroir arabica coffee in Kintamani (Bali).

ARABICA COFFEE IN BALI

Bali is a province of Indonesia. Arabica coffee in the province is mostly grown at the altitude above 1000 m, in the highland areas located on the slopes of the volcano Mount Batur. Arabica coffee farms are mainly found in Bangli District mostly at Sub-district of Kintamani and, to smaller extents, in Badung and Buleleng Districts.

According to data from *Dinas Perkebunan* (Provincial Authority for Estate Crops Development) data, area of arabica coffee in Kintamani is 3637 ha currently involving almost 2000 farmers. In 2000 the areas was recorded up to 8230 ha. The significant decrease of the area was mainly caused by very low coffee price as an effect of world coffee crises, as well as the opportunity to obtain better income by converting coffee to citrus and tangerine farms, in addition to a chronic problem of parasitic nematode attack.

The main coffee harvest period is in June, July and August, while tangerine is mostly picked in July and August. Average productivity is 600 kg green coffee per hectare.

Bali is one of a famous tourist destination in the world. Bali coffee along with Java coffee has also been well known in the world market before 1960's. David (1996) in his book mentioned Bali coffee as one of **"coffee geography"** from Indonesia similar to Mandheling, Toraja, Lintong, Gayo, Java, etc.

However, the reputation of Bali arabica coffee was declining then, mainly after the coffee planting in Kintamani was destructed by the eruption of Gunung Agung (volcano of Agung) in 1963. This eruption caused the production and quality of arabica coffee from Kintamini drop significantly for almost 15 years. The government started to redevelop the coffee in the late 1970's and early 1980's, mainly by granting coffee seedlings and extension services as well to the farmers.

Reputation of the Bali coffee will be promoted again by applying fully wash process and introducing good manufacturing practices during the coffee processing. Recently, several buyers interested again to the coffee due to its quality.

TERROIR OF KINTAMANI

Terroir is a French word, which is difficult to translate to English. A *terroir* is a system of complex interactions between a set of operations and techniques practised by man, a cultivated plant and a physical environment to be exploited by a product on which it confers specific original features (Salette et al., 1998). That means that the physical environment is not the only element to be taken into account in defining a *terroir*. Man is another keyword: *terroir* is the expression of a culture and a social organisation.

Referring to the definition, terroir of arabica in Kintamani was described by making surveys on physical environment, traditional knowledge on farming system and social aspects during the year of 2003 and 2004. The result of the description is mentioned below.

Physical Environment

Falcetti (Falcetti, 1994) mentioned that corresponding physical environment elements between the main criteria for composing of *terroir* are climate, relief, soil and inside the soil. Climate consists of rainfall (mm/period) and temperature. Relief consists of altitude (m), slope (% or °) and exposition (°/Nord). Soil and inside the soil consists of texture (name), *granulometrie* (name), *induration* (name or index), solum (m), mineral type (name) and chemical properties (% or p.p.m) and water retention capacity (mm).

Several elements of physical environment of terroir in Kintamani highland as mentioned in Table 1.

Table 1. Physical environment elements of *terroir* in Kintamani highland.

Climate	Rainfall	1250-3500 mm/y, 4-5 dry month/y, dry period June-September, rainfall type C-D (dry).
	Temperature	15-25°C
	Relative humidity	80-99%
Relief	Altitude	1000-1500 m
	Slope	0-60%
	Latitude	8,17°-8,30° S
	Longitude	115,23°-115,34° S
Soil	Geology formation	Qbb (material of tuff with sediment of Mount Buyan Bratan and Batur volcano, quarter age)
	Type of soil	Entisol and Inceptisol, good physical and chemical fertility
	Texture	Sandy-loam
	Solum	50-120 cm
	C-organic	Low
	Capacity exchange of cation	Low
	Period of soil water deficit	July-November

By physical environment as mentioned in Table 1, Kintamani highland is suitable for arabica coffee cultivation.

Traditional Knowledge on Farming System

Terracing

In Bali farmers has traditionally applied terracing on paddy field as well as upland cultivation. Arabica coffee farmers also makes terrace on slope or mainly steep slope. The farmers normally grow elephant grass in order to prevent the terrace from erosion and to supply feeds for their cattle.

Shade trees

On an average farm, a farmer holds area ranges between 0.5 and 1.0 ha. Traditionally, Balinese farmers grow arabica coffee under *Erythrina*, *Leucaena*, *Melia* sp. and *Albizia* as shade trees. Erythrina is widely grown by the farmers due to its function to supply feeds for their cattle during the dry season. Albizia wood can be sold easily as it is a raw material for handicraft carving.

Intercropping

Before 1995, arabica coffee production provided farmers with their main income. Traditionally, most of them grew arabica to be intercropped with other crops such as citrus, pomelo, etc. and the others grew it monoculture under heavy shade.

However, due to the fall in world coffee prices, farmers diversified their production and developed tangerine, which currently provides them a better profit than that of arabica coffee. Tangerine is intercropped with coffee in most of the plots, in which case it imperfectly replaces the traditional shade trees, given that it is smaller in size. Nevertheless, some farmers also grow pure tangerine plots. Tangerine trees are very productive but rapidly exhausted after 4 or 5 years harvesting have to be replaced.

Within the farming systems, tangerine is actually considered a high-yielding but a "risk-taking" crop mainly due to price instability and disease vulnerability. In spite of its current low price, coffee cultivation is maintained as it is considered a "safer" cash crop. This status must be kept in mind as farmers may not willing to take risk at the same time on tangerine and on new coffee marketing schemes.

Integrating coffee with animal husbandry

The farmers usually breed livestock such as two or three bulls graze only grass on the farm, a couple of pigs and some poultries inside the farm. Farmers grow elephant grass on the edge of the plots or on the terrace. Bulls are kept in a mobile wooden stable, which can easily moved to different places inside the farm which usually done by the farmers every six months to one year. This system not only provides enough organic manure but also the dung can be distributed equally in the farm. Pigs need extra food, which the farmer has to purchase.

Animal breeding is a compulsory component of the farming system, as organic manure is an indispensable input on this small, very intensive farm. Manure from farm animals provides organic fertilisation and is reputed to have a preventive effect on citrus disease.

Organic farming

Arabica coffee in Bali has traditionally applied intensive organic farming, even they do intercropping with other crops such as tangerine or citrus. They used to buy organic manure from other region if their own production insufficient to be applied. Most of coffee farmers never applied pesticides to control pest and diseases.

Social

In the Balinese arabica producing area, farmer groups range from 40 to 80 families and area mainly organized according to the traditional **"Subak Abian"** structure.

A Subak Abian is established in a clearly defined geographical area. Every person, either landowner or tenant, who develops an agricultural activity, may be a member. The Subak Abian is not only an economic entity, since it is also in charge of social and religious life. In the Balinese arabica producing area, the population is mostly Hindu.

Consequently, the Subak Abian's objectives derive from Hindu philosophy, which teaches that human beings have to secure and respect three kinds of relationship: with God, other men and the environment. This philosophy is called *"Tri Hita Karana"* means three happiness causes.

The Subak Abian builds and takes care of temple maintenance as well as organizes religious ceremonies; moreover, it is in charge of some social and economic activities such as:

- Organizing collective work (agricultural activities, maintenance of roads and temples),
- Managing the facilities provided to the groups,
- Coordinating meetings with coffee buyers.

The expenditure arising from Subak Abian activities is shared between the different families, which are members of the group. Subak Abian activities in the specific field of coffee marketing are currently limited by the lack of working capital.

Training by Dinas Perkebunan is mainly concentrated on four farmer groups, which has been facilitated with coffee processing facilities. The four Subak Abians are directly involved:

- in red cherry collection and marketing,
- in post-harvest wet processing and green coffee marketing.

In Bali province, arabica producers area also coffee drinkers so that is it easier to make them aware of quality requirements. They could easily be involved in cup tasting activities for instance.

Falcetti (1994) distinguished *terroir* to be homogenous and composite one. Homogeneous *terroir*, when in the same certain terroir can be identified homogeneously to produce a type of characterized product. Composite *terroir*, when in the same *terroir* produces different products, or necessity togetherness of different row materials to produce a complex final product. In case of arabica coffee producing area in Kintamani (Bali) the terroir seem to be homogenous one.

POTENTIAL TO DEVELOP GI ARABICA COFFEE FROM KINTAMANI

Reputation

Bali coffee along with Java coffee has been well-known in the world market before the independence of Indonesia. David (1996) mentioned Bali coffee as one of **"coffee geography"** from Indonesia similar to Mandheling, Toraja, Lintong, Gayo, etc.

Quality planting material

Most of Balinese arabica coffee farmers grow S 795 and USDA 762 varieties as recommended by the Government, which are also widely grown by the planters to produce Toraja coffee in South Sulawesi and Java coffees in East Java. The two varieties are expected to perform unique distinctive characteristics under "terroir" of Kintamani as a special quality sign of the poduct.

Farmer organization

Arabica coffee farmers in Kintamani are organized strongly by Subak Abian, namely a traditional structure on upland areas. Subak Abian plays it role not only on agriculture activity but also on religion and philosophy as well. In Kintamani there are 58 Subak Abian at the moment.

Altitude

Arabica coffee in Kintamani Highland is mostly grown at the altitude 1,200-1,500 m which is expected to perform excellent cup quality.

Farming technique application relatively homogene

Traditionally the farmers grow coffee by using shade trees and holding cattle to obtain organic manure for their coffee.

Efforts on quality improvement

The farmers are willing to improve and to maintain the coffee quality as recommended by government.

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Ecophysiological Variability of Forest Arabica Coffee Populations in Hydraulic Characteristics Along a Climatic Gradient in Ethiopia: Morphological and Physiological Variability

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SUMMARY

The study was conducted in the natural forest ecology of Ethiopia with the objectives to characterize and compare the variability in morphological and physiological characters of Arabica coffee populations. A randomised complete plot design with three replicates was used at each site and the data were analysed using the SAS statistical software. The results depict site variations in plant composition and density, among others. Forest coffee trees were irregularly and closely spaced under dense shadings. Coffees of different sites had distinct vegetative, leaf and seed growth characteristics. Accordingly, compact coffees with short plant height, narrow canopy spread, erect branching, short internode, small leaves and small bean sizes dominated in Yayu and Bonga forests. Conversely, open and intermediate coffee types with wide canopy, large leaves, long internode and spreading branch orientation were more frequent at Sheko and Bale-DoloMena forests. Plant density and shadings remarkably influenced these traits. In other words, low light condition could be the most environmental factor, which influenced the architecture and reproductive growth response of forest coffee trees. Further research on the interaction of diverse coffees and environmental factors should, however, deserve close attentions with the views to target research and development options on the use and conservation of Arabica gene pools in the country.

INTRODUCTION

Ethiopia is the centre of origin and diversity for Arabica coffee. In its birthplace, coffee grows under natural forest story and exhibits features typical shade-adapted C_3 plants, occupying lower to middle strata of the forest canopy layers. It is well known that the suitability of a given location for coffee production is determined by four basic environmental variables: temperature, rainfall, light intensity and soil conditions (Coste, 1992). The rain forests where wild Arabica coffee populations exist with more or less evenly distributed precipitation and a dry season lasting for four to six months but not completely without rain (Wrigley, 1988).

In Ethiopia, coffee grows under diverse climatic and soil conditions. Accordingly, the country is endowed with wide genetic variability of coffee populations, which are locally identified by their vernacular names and preferred for their inherently unique agronomic characters. In this line, Yacob et al. (1996) reported that Arabica coffee materials can be grouped into three macro canopy classes of open, intermediate and compact types with varying shoot and root growth characteristics.

In Ethiopia, coffee is produced in four main production systems: forest, semi-forest, cottage and modern plantations (Workafes and Kassu, 2000). Forest coffee is a wild coffee type grown spontaneously in the humid hot forests where the natural forest cover is more or less intact. However, the original ecology of coffee is disturbed largely due to the escalating deforestation rates. Irregularly spaced dense populations with several a biotic and biotic stresses characterize the forest coffee trees. As a result, growth and development of coffee plants are poor and there is no or little management practices applied to boost productivity (Workafes and Kassu, 2000). But, there are still diverse coffee types in different natural forests, which have adapted the prevailing stresses, though information is scanty mainly on the growth response of coffee plants in relation to the changing environmental variables. This work is expected to shade a light on the spatial and temporal growth responses of coffee plant under specific microclimatic considerations. It would also provide baseline information for future detailed research works on the identification of drought tolerant Arabica coffee populations. Therefore, the primary objective of this study was to characterize and compare the variability in morphological and physiological growth characters of forest Arabica coffee populations under minimally disturbed natural forest ecosystems in south-western and-eastern parts of the country.

MATERIALS AND METHODS

Description of the study area

The study was conducted in four natural forest coffee populations (FCPs), which included Bale-DoloMena (PI), Bonga (PII), Sheko (PIII) and Yayu (PIV). Except PI of south-eastern, the others are found in the more humid south-western part of Ethiopia. Within each FCP, three sites (S1, S2 and S3) were selected and described (Table 1). For this, GPS was used to measure the geocordinates of each site. Moreover, altimeter and clinometer were employed to record altitude and slopes, respectively.

Table 1. Description of the study area.

Forest unit	Site	Abbr.	Latitude (N)	Longitude (E)	Altitude (m)	Slope (%)	
						Range	Mean
Bale (PI)	Majete (S1)	PIS1	6°23′	39°45′	1420	2-3	2
	Majete (S2)	PIS2	6°29′	39°45′	1420	3	3
	Majete (S3)	PIS3	6°29′	39°44′	1490	3	3
Bonga (PII)	Yabito (S1)	PIIS1	7°18′	36°03′	1780	4-6	5
	Arabcasha (S2)	PIIS2	7°17′	36°12′	1520	3-6	4
	Alemgono (S3)	PIIS3	7°19′	36°13′	1660	4-5	5
Sheko (PIII)	Beko 1 (S1)	PIIIS1	7°07′	35°26′	1040	4-18	10
	Beko 2 (S2)	PIIIS2	7°07′	35°26′	1080	5-10	8
	Shime (S3)	PIIIS3	7°04′	35°25′	1180	9-17	13
Yayu (PIV)	Yayu (S1)	PIVS1	8°23′	35°47′	1400	1-8	4
	Yayu (S2)	PIVS2	8°23′	35°47′	1400	2-3	3
	Yayu (S3)	PIVS3	8°23′	35°47′	1400	5-7	6

Data collection and statistical analysis

Coffee spacing was measured and plant density was determined by counting the number of big trees, coffee plants and shrubs within a quadrant of 20*20 m for big trees and 4*4 m for coffee and shrubs. From each site, nine to twelve uniform and young (5-7 years) coffee trees were selected and grouped in to three relatively homogenous blocks by taking into account the existing field variations, mainly land gradients and shade levels. Again, two young primary branches/tree were selected and tagged for measurements on vegetative and reproductive growth responses. The ratio of main stem height to mean length of lateral branches (apical dominance ratio) was determined according to the procedures described by Parent and Messier (1995) as cited by Robakowski et al. (2003).

In addition, healthy and mature leaf samples were collected from the 3rd to 4th nodes on primary branches of the selected coffee trees. Leaf dimensions were immediately measured to calculate the estimate leaf area (length*width*0.66) as described by Yacob et al. (1993). The same leaves were oven dried at 70°C for 24 hrs and dry weight was measured using a sensitive balance. Then, estimated leaf area to leaf dry matter ratio, specific leaf area (SLA) and its inverse, specific leaf mass (SLM) were computed for each site. Moreover, thirty coffee beans from the selected trees were also used to measure seed dimensions (length, width and depth) and determine seed sizes. Finally, the data were statically analysed using the SAS systems for windows v8 and mean comparison was carried out according to Turkey's Studentized Range at 5% probability level.

RESULTS AND DISCUSSION

Plant density

The study sites varied in land nature and plant compositions, among others. Consequently, the slopes ranged from almost flat at Bale to undulating/rolling at Sheko sites, respectively (Table 1). At all sites, big trees, coffee and shrubs occupied such order of canopy strata in the natural forest ecology. Quadrant count and spacing results (Table 2) show that plant density and coffee spacing varied among forest coffee units and within sites. The number of trees was high in Sheko (sites 1 and 2), followed by Bonga (site 1) and Yayu (site 1) forests. It was least at site 2 of Bonga and site 3 of Sheko. But, coffee trees were highest at Yayu (sites 2 and 3) and least at Sheko (sites 1 and 3), respectively. From each forest unit, the widest coffee spacing was measured at site 3 (Sheko), site 2 (Bale-DoloMena), site 2 (Bonga),) and site 1 (Yayu). In contrast, the highest quadrant count on big trees and coffee was observed at site 1 (Bale-DoloMena), site 1 (Bonga), site 2 (Sheko) and site 3 (Yayu), indicating the dense shadings of the sites. The density of shrubs increased from Bale-DoloMena to Yayu forest, probably indicating the levels of human interventions. The vegetative and reproductive growth responses of Arabica coffee trees under such stand structures were different as elucidated below.

Table 2. Mean number of big trees, coffee and shrubs within a quadrant and coffee spacing.

Site	Plant density/quadrant				Coffee spacing (cm)		
	Tree	Coffee	Shrub	Total	Min	Max	Mode
PIS1	10	19	2	31	21	243	83
PIS2	8	7	2	17	27	318	140
PIS3	7	15	4	26	23	390	106
PIIS1	17	18	61	96	18	143	43
PIIS2	5	15	62	82	28	315	87
PIIS3	8	12	36	56	39	266	77
PIIIS1	23	5	7	35	37	214	113
PIIIS2	23	15	0	38	19	247	152
PIIIS3	6	5	0	11	65	272	197
PIVS1	14	13	31	58	27	202	77
PIVS2	11	26	38	75	26	150	74
PIVS3	13	39	27	79	22	170	54

Table 3. Mean values for morphological and physiological characters of forest Arabica coffees at various sites.

Plant character	PIS1	PIS2	PIS3	PIIS1	PIIS2	PIIS3	PIIIS1	PIIIS2	PIIIS3	PIVS1	PIVS2	PIVS3
Plant height (cm)	289.65	333.48	282.74	250.91	247.63	279.09	254.22	270.07	258.17	247.85	284.25	268.90
Girth (cm)	3.12	3.50	3.48	2.63	3.49	3.13	4.02	3.88	4.65	2.93	2.94	2.85
Canopy diameter (cm)	161.15	188.87	199.37	164.87	164.64	170.85	188.47	181.82	192.47	157.53	146.81	145.50
Length of primary branch (cm)	43.01	45.21	48.47	46.83	47.15	48.02	54.48	55.89	52.24	39.11	25.28	31.38
Number of primary branch/tree	30.04	39.59	36.11	24.39	34.96	31.80	31.33	35.88	30.93	30.64	25.14	24.90
Number of nodes/branch	7.13	7.27	7.89	7.87	9.43	10.22	10.84	10.32	10.49	7.59	6.69	6.77
Length of internodes (cm)	6.32	6.51	7.03	6.15	5.13	4.78	5.18	5.52	5.26	5.24	3.87	4.82
Apical dominance ratio	5.79	5.96	4.95	4.59	4.68	5.42	4.06	4.40	4.05	4.59	7.01	5.98
Leaf number	8.34	9.68	11.89	9.40	13.24	10.65	9.90	11.17	11.64	10.86	5.84	7.45
Leaf area (cm^2)	45.97	45.16	55.37	36.47	28.62	32.01	40.43	37.21	39.66	30.09	21.65	28.74
Berry count/branch	7.47	31.36	39.22	12.99	31.13	29.88	18.05	39.28	49.50	13.07	5.56	3.97
Crop to leaf ratio/branch	0.75	3.14	4.05	1.14	2.10	2.75	1.96	3.17	4.13	0.98	0.96	0.50

Vegetative growth

The forest sites had coffee types with distinct crown architectures (Table 3). Consequently, open coffees dominated in Bale and Sheko forests, while the compact types colonized the Yayu forest. Whereas, mixed heterogeneous populations of open, intermediate and compact coffee stands characterized Bonga forest. As the trees were self-sown and freely grown, tall and unmanageable coffee trees were found at all sites, particularly with increasing shade intensity. Accordingly, the tallest (333.5 cm) and the shortest (247.6 cm) coffee trees were noticed in Bale-DoloMena (site 2) and Bonga (site 2), respectively. On the other hand, relatively short and vigour coffee plants were found with reduced plant density and shade conditions.

In general, very tall, thin and flexible stemmed coffees with few primary branches were noticed with increased plant populations and shadings. Accordingly, the highest and the lowest main trunk girth at 5 cm above the ground were recorded at Sheko (site 3, 4.65 cm) and Yayu (site 3, 2.85cm), respectively. These sites were characterized with the respective wide and close spaced coffee trees. In contrast, short, thick and stiff stemmed coffees were observed with reduced shades. This may indicate tree vigour and its resistance from the high risks of damage, mainly due to wildlife and big tree fall. The height of coffee plant was positively correlated with stem diameter, particularly for open coffee types grown under reduced shade conditions. There was a significant variation in the mean canopy diameters of forest coffee trees. As a result, coffee trees with wide canopy spreads were obtained in Bale-DoloMena (site 2) and Sheko (site 3). In contrast, the narrow canopy arrangement was recorded at Yayu forests (Table 3).

The longest primary branches with more number of nodes were recorded at the three sites of Sheko as opposed to the least values recorded at Yayu sites. But, mean internode length was highest at the three sites of Bale- Dolomena and least for Yayu forests. The values increased with increasing shade levels at all forests, except at Yayu sites. At all sites, however, the growth of primary branches was decreased due to aging and cropping. The mean number of nodes of primary branches was high for Sheko, Bonga, Bale-DoloMena and Yayu forest coffee units in that order (Table 3). In other words, coffee trees at sites 2 and 3 of Yayu forest showed the least increments in node number; perhaps due to increased shade conditions to influence yield of coffee cultivars (Taye et al., 2001).

Coffee trees with maximum number of plagiotropic branches were obtained with decreasing plant density cover at all sites. Consequently, high number of lateral branches of varying ages (old, crop bearing and young) was recorded at sites 2 and 3 of Bale-DoloMena, site 2 of Bonga and Sheko forests. The highest proportions of crop bearing branches were determined under moderate shading and reduced spacing. In contrast, the closely spaced coffee trees at site 3 of Bonga and at sites 2 and 3 of Yayu had the least lateral branches. The results largely show the effects of dense shading in enhancing single stemmed, tall to very tall and non-productive coffee trees, particularly in the lower positioned horizontal branches. Hence, the apical dominance ratio (Figure 2) show high values at closely spaced and densely shaded coffee trees at Bale-DoloMena (sites 1 and 2) and Yayu (sites 2 and 3). Here the shoot part of coffee and shade trees was covered with lichen, most probably indicating the high air humidity of the sites. This could reflect the influence of leaf area index and thus productivity of forest coffee stands under specific climatic variables. Hopkins (1995) has reported reduced long-term carbon gain under low light irradiance. Though Arabica coffee is a shade tolerant plant, its growth nature and appearance could not be explained under more heterogeneous forest conditions. Coffee trees also had distinct qualitative growth characteristics (Table 4), suggesting the existence of immense potentials for desirable traits.

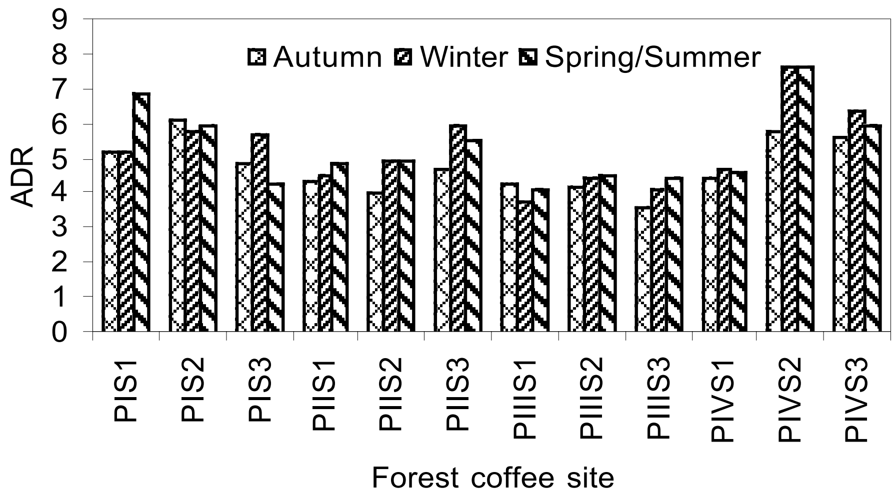

Figure 2. Apical dominance ratio (ADR) of forest coffee trees in dry and wet seasons.

Table 4. Some qualitative characteristics of forest Arabica coffee trees.

Site	Canopy nature	Branching	Leaf tip color
PIS1	I-O	SE-H	Bronze
PIS2	I-O	H-SH	Bronze
PIS3	O-I	H-SH	Bronze
PIIS1	O-I	HE-SH	Green
PIIS2	I-C	SH-SE	Green
PIIS3	I-O	SE-H	Green
PIIIS1	I-O	SE-SH	Bronze/green
PIIIS2	I-O	SE-SH	Green/bronze
PIIIS3	O-I	H-SE	Green/bronze
PIV1	O-C	SE-E	Light green
PIV2	C	SE-E	Light green
PIV3	C	SE-E	Light green

O = open, I = Intermediate, C = compact; H = Horizontal, E = erect, SH = semi-horizontal, SE= semi-erect.

Leaf growth

Maximum mean leaf number was recorded under relatively moderate shading and coffee density at all sites. The highest leaf number was obtained at site 2 of Bonga forest (Table 3). In contrary, leaf drop was high in Yayu (sites 2 and 3) and Sheko (site 2). Heavy crop loads on the widely spaced coffee trees at site 3 of Sheko could also enhanced leaf senescence and subsequent branch die-back. The intact estimated leaf area was high for Bale-DoloMena (45.16-55.37 cm^2), followed by Sheko (37.21-40.43 cm^2) and Bonga (28.62-36.47 cm^2) sites with a leaf shape ranging from ovate to lanceolate. In contrast, leaf area was smallest (21.65-30.09 cm^2) for the lanceolate shaped coffee leaves at Yayu forest sites (Table 3). Leaf shape and size could be associated with the canopy spatial arrangements of coffee trees and may detect water-use efficiency.

Leaf number was significantly reduced in winter season and the reduction was highest at sites 3 and 1 of Bale-DoloMena and site 3 of Bonga, where high incidences of coffee leaf rust and coffee leaf skeletonizer were also observed. Similarly, leaf area was highest in Bale sites as opposed to the least values noted at Yayu forest. Significant change in leaf area was noticed at most sites of Bonga and Sheko. The results decreased in winter and started to increase in spring at most sites (Figure 3), suggesting the influence of climate (temperature and rainfall) on coffee leaf growth. The correlation between leaf number and leaf area did not show similar pattern at various sites and during the study seasons. In general, leaf growth (retention or initiation) of varying sizes may also suggest change in leaf area index and thus, productivity of coffee trees.

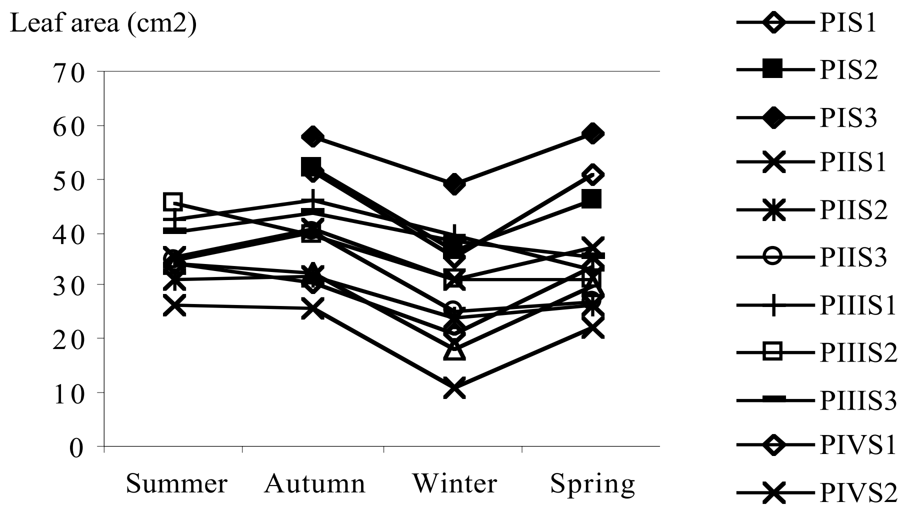

Figure 3. Seasonal change in leaf area of coffee trees at various forest sites.

Though crop to leaf ratio recorded on primary branches was not statistically different within FCUs, increased values were recorded with decreasing plant density. Hence, high values (Figure 4) were obtained at site 3 of Sheko (4.13), Bale-DoloMena (4.05), Bonga (2.75) and site 1 of Yayu (0.98), indicating the more enhanced reproductive growth under moderate shade conditions. On the other hand, the least berry count and highest leaf defoliation was noticed under deep shades. This may come because of low light intensity and low temperature and thus reduced net photosynthetic rate and constrained reproductive growth (Coste, 1992). This corroborates with the previous findings (Tesfaye et al., 2002). In general, there was a trade-off between crop and leaf growths at most sites. Thus, determination on sink-source relationships, which takes in account plant-environment components, should deserve focused attention.

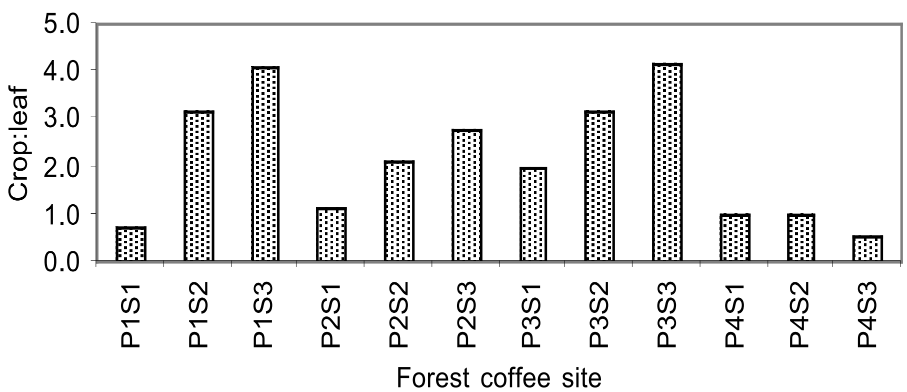

Figure 4. Crop to leaf ratio of coffee trees under different forest conditions.

The destructive leaf growth parameters did not significantly vary at most sites. But, the largest and the smallest mean estimated leaf area and leaf dry weight were recorded at site 3 (Bale-DoloMena) and site 2 (Bonga) forests, respectively. Coffee trees at the three sites of Bonga, however, significantly varied in leaf-dry matter and-size. There was also significant difference in leaf area among Yayu sites. The results show that leaf area and SLA did not generally follow similar patterns at all sites, except at Sheko sites. As a result, the highest (36.9 cm^2/g) and least (28.81 cm^2/g) SLA and the lowest (0.023 g/cm^2) and highest (0.037 g/cm^2) SLM were recorded at Sheko-site 2 and Bale-DoloMena-site 3, respectively (Table 5). The highest leaf dry matter at Bale-DoloMena sites could be attributed to dry season leaf growth nature. The large leaf area, high number of lateral branches and increased fruits on productive nodes may also contribute to the high leaf dry matter yield, reflecting that most assimilates can move to the fruits. This supports the work done by Cannel (1971) who reported high dry matter of fruiting trees than non-fruiting ones due to the high photorespiration in non-bearing trees. The results reveal reduced SLA with reducing overhead and mutual shadings at all sites. This is in line with Hopkins (1995) who has shown a positive correlation between SLA and light use-efficiency. Larcher (2003) has also reported shade leaves with high SLA are better grow in low light habitats. In other words, leaves with high SLM are thick and positively correlated with water-use efficiency under a given radiation load. Yacob et al. (1998) have reported similar leaf growth on Arabica coffee cultivars.

Table 5. Destructive leaf growth characteristic of coffee trees, Spring/Summer 04.

Site	ELA (cm^2)	LFW (g)	LDW (g)	LWR (%)	SLA (cm^2/g)	SLM (g/cm^2)
PIS1	68.78	10.52	2.37	77.50ab	29.26	0.033
PIS2	61.15	9.08	1.95	78.70a	31.45	0.030
PIS3	74.08	10.73	2.58	76.25b	28.81	0.037
PIIS1	48.17a	5.48a	1.65a	68.84b	29.48	0.033
PIIS2	33.19b	3.93c	1.14b	71.07b	29.22	0.033
PIIS3	33.94b	4.45b	1.08c	75.70a	31.40	0.030
PIIIS1	49.41	5.22	1.42	72.68	34.55	0.030
PIIIS2	55.81	6.06	1.40	76.55	39.60	0.023
PIIIS3	50.33	5.46	1.47	72.70	34.57	0.030
PIVS1	54.01a	8.17	1.65	79.40	31.82	0.030
PIVS2	34.13b	6.15	1.15	82.28	37.79	0.030
PIVS3	40.04ab	7.17	1.37	79.89	32.19	0.033

ELA = estimated leaf area, LFW = leaf fresh weight, LDW = leaf dry weight, LWC = leaf water content, SLA = specific leaf area, SLM = specific leaf mass; Figures followed by the same latter(s) within a column are not significantly different from each other at 5% probability level.

Reproductive growth

Fruit and seed growths of coffee trees differed for each FCU and sites. Fruit maturity was fast at Sheko, followed by Bale-DoloMena and Yayu forests. However, it took long time at the relatively high altitude Bonga sites as compared with others. Accordingly, ripe red cherries were collected between November and December 03. Investigation on coffee fruit phenology is being underway. The results on the number of berries on primary branches showed no significant differences among sites, though the value increased with decreasing coffee density. Thus, the highest (49.50) and the lowest (5.56) were counted at site 3 of Sheko and site 2 of Yayu, respectively (Table 3). This was also evident from the crop to leaf ratio results presented in Figure 4. Coffee trees had maximum crop areas of 33, 26, 28 and 26 % at Bale (site 3), Bonga (site 2), Sheko (site 2) and Yayu (site 1) forests, respectively (Figura 5).

Similarly, significantly high proportion of young main stem area was also measured from these sites where minimum coffee density was recorded. The findings could reflect the phenotypic plasticity of coffee plant under light stress environments. Tesfaye et al. (2002) have reported similar shade syndrome on vegetative and reproductive growths of Arabica coffee cultivars in Ethiopia.

Coffee seed characters revealed remarkable variability in seed dimensions and thus seed size. Maximum 100-seed weight was measured for Bale-DoloMena, Yayu, Bonga and Sheko coffees in that descending order (Table 6). On the other hand, coffee bean size was least for Bonga forest and highest for Bale-DoloMena and Yayu forests. This may be associated with the high number of fruits per node and thus increased competition effects. There were also a slight variation in seed weight and volume within each FCU site, reflecting the influence of sit-specific stand structures. This indicates the influence of climatic conditions on fruit growth and bean size (Alemseged et al., 1997; Wrigley, 1988).

Table 6. Bean characteristics of forest coffee trees.

Site	Length (cm)	Width (cm)	Thickness (cm)	Volume (cm^3)	Weight (g)	Density (g/cm^3)
PIS1	1.10	0.63	0.42	0.29	0.19	0.65
PIS2	1.14	0.67	0.44	0.33	0.20	0.60
PIS3	1.12	0.68	0.43	0.33	0.20	0.59
PIIS1	0.85	0.59	0.39	0.20	0.14	0.70
PIIS2	0.95	0.63	0.41	0.24	0.16	0.65
PIIS3	0.96	0.66	0.43	0.27	0.17	0.62
PIIIS1	1.04	0.65	0.43	0.29	0.16	0.56
PIIIS2	0.99	0.65	0.41	0.26	0.14	0.52
PIIIS3	0.95	0.62	0.40	0.23	0.14	0.61
PIVS1	1.05	0.61	0.42	0.27	0.16	0.59
PIVS2	1.05	0.72	0.43	0.33	0.18	0.56
PIVS3	1.09	0.70	0.45	0.34	0.19	0.54

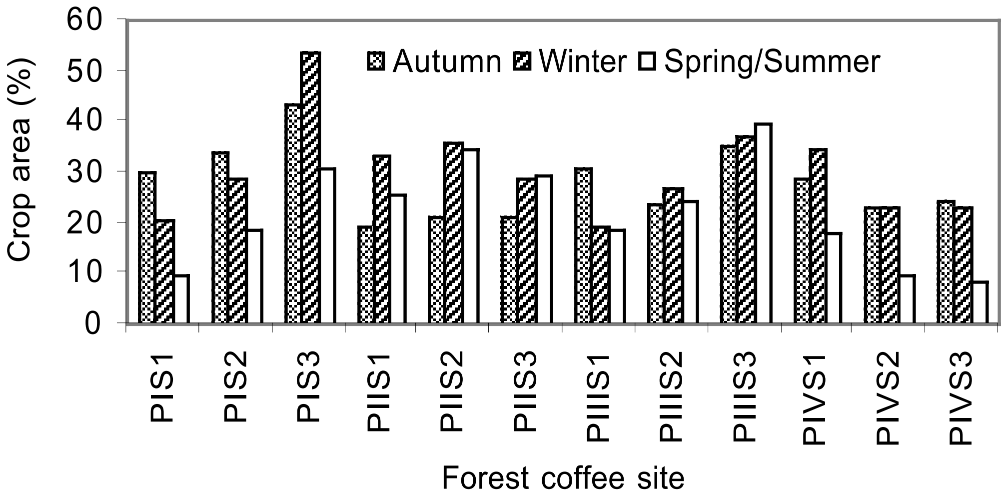

Figure 5. Seasonal change in the main trunk crop bearing area of forest coffee trees.

CONCLUSION

The findings reveal variations in morphological and physiological plasticity of forest coffee trees at different sites and over growing seasons. As a whole, morphologically diverse coffee types occupied specific forest ecology. Accordingly, open coffee types with horizontal to semi-horizontal branching were common in Sheko and Bale-DoloMena while compact coffees of semi-erect branching nature dominated in Yayu and Bonga forest. The selected coffee trees had significant variability in vegetative, leaf and seed characteristics considered under specific sites. In general, significantly high values for most vegetative and seed growth parameters were obtained under moderate shadings, though the magnitude differed from location to location. Moreover, significant seasonal growth patterns were noticed at all sites, though the patterns differ between south-eastern and south-western sites, which reflects, among others, the influence of precipitation and light interceptions. It can be, therefore, concluded that Arabica coffee trees significantly differed in their morphology and stand structures and thus, their natural resource use-efficiency could vary accordingly, which await for future works.

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Initial Farming System Modelling Results for Coffee Farms in Cameroon. Learnings and Prospects

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RÉSUMÉ

L'Est du Cameroun est le second bassin de production de café Robusta du pays et les producteurs y privilégient un système de production extensif. L'étude conduite par l'IRAD et le CIRAD met en évidence que les choix techniques des planteurs sont autant guidés par leurs stratégies personnelles que par la baisse des cours mondiaux. Dans ce contexte, l'utilisation d'un logiciel d'aide à la décision pour modéliser le fonctionnement des exploitations agricoles a permis de mesurer l'impact de plusieurs innovations testées depuis 2000 en milieu paysan. Il apparaît qu'elles doivent être adaptées pour mieux répondre aux attentes et aux contraintes des exploitants. Face à la crise que subissent les producteurs de café, cette nouvelle approche de la caféiculture, basée principalement sur la modélisation de la conduite des exploitations, offre de nouvelles perspectives susceptibles d'améliorer le transfert des acquis de la recherche en milieu réel.

SUMMARY

The East of Cameroon is the second coffee production basin of the country. Coffee producers favour extensive systems of production. The study done by IRAD and CIRAD puts into that farmer's technical choices are guided by their personal strategies as well as by the decline in world prices. In this context, the use of decision-making computer software capable of modelling the functioning of agricultural farms allowed us to assess the impact of some innovations tested since 2000 in some coffee farms. We found that they have to be adapted to better meet the expectations and constraints of farmers. Faced with the crisis affecting coffee producers, this new coffee cultivation approach, based on the modelling of the management of farms, offers new perspectives susceptible to improve the transfer of research knowledge in rural environment.

INTRODUCTION

The Centre and East provinces of Cameroon constitute the second Robusta coffee (*C. canephora* P., var. Robusta) production basin of the country. In 1984, they respectively represent 8% and 18% of the national orchard estimated at 150,000 ha (Anon, 2001). Nevertheless, there is limited information available on the cultivation of Robusta coffee in the peasant milieu and field visits confirmed that, producers prefer extensive systems of production. Despite the depress in world prices, producers continue preferring the monoculture of coffee while adopting an awaiting exploitation position of least cost in their orchards as no acceptable technical alternative has been so far proposed to them by agronomic research (Varlet & Berry, 1997).

Faced with this situation, the agricultural research institute for development (IRAD) and the international cooperation centre for agronomic research for development (CIRAD) conducted, from 2000 to 2004, a research action wherein the objective was to contribute in the improvement of the traditional production system of Robusta coffee.

In order to actualize the available information on coffee farming cultural practices, a survey was carried out on 50 farmers of a village situated in the eastern part of the Centre province. Three innovation techniques were then tested on-farm: the use of selected Robusta coffee, their cultivation in double-line hedges, and their association with food crops cultivated in the space between coffee lines. The agronomic and economic performances of these innovations were evaluated during four years starting after the installation phase of the coffee plants (Jagoret et al., en cours de publication).

After having sorted out the main conclusions of the survey, the present paper develops the results of the use of software "Olympe" in the case of two coffee-based farms and the impact of the proposed innovations on their management.

MATERIAL AND METHODS

Survey

The questionnaire was made up of three parts. The first part was mainly aimed at identifying the farmer. The second part was based on the characteristics of the farmer's coffee orchard and the definition of his technical methods so as to precise the specificities of the orchard and it's mode of management. The estimation of yields per plantation was based on the quantities of coffee commercialized by the farmers. The third part had as goal to characterize the material means of the farmers, their source of revenue and their strategy.

Modelling of the functioning of the exploitations

The software "Olympe" is a simulator that helps in the decision making for a strategic orientation of farm exploitations created by the INRA/ESR institute of Grignon in order to analyze economic results of farm exploitations. A partnership between the INRA/ESR and CIRAD enabled the adaptation and the validation of "Olympe" in the tropical environment.

Firstly, all information required by the software must be introduced: units, production characteristics of annual crops, perennial crops, their specific products and charges (inputs and outputs), working periods, investments, other incomes or expenses, etc. With this information, the performance of the whole farm can be studied or the *ex-ante* assessments on the economic effects of an innovation can be done (Sanchez, 2001). Its interest lies on its rapidity to explore different variants that enables the testing of a project's validity (Penot, 2003).

"Olympe" offers several functionalities (Penot et al., 2003), notably:

- the creation of variants from a fundamental project,
- the evaluation of the consequences of a new investment, the suppression or addition of a production activity, a change in the farmers' agricultural calendar, a technical change, etc.
- the integration in the simulation of risks and the evaluation of consequences, possible events (named hazards), internal (fall in yield) or external (volatility of purchase prices) per exploitation, on the results of the project.

RESULTS

Characterization of Robusta coffee traditional production system in the Centre-East of Cameroon

The average surface area cultivated by the farmer is 4.1 ha of which 1.8 ha is assigned for coffee cultivation. The average surface area and average age of *Robusta coffee* plantations vary however according to the chronology of plots (Table 1).

Table 1. Characteristics of coffee orchards in the Centre-East of Cameroon according to the type of plantation.

	First plot	Second plot	Third plot
Average surface area	1.16 ha	0.9 ha	0.7 ha
Average age	19 years	13 years	8 years
Average density (plants/ha)	1.550	1.500	1.650
Origin of coffee plants:			
Nursery	28%	19%	9%
Old plantations	72%	81%	91%
Establishment of a nursery	12%	9%	4%
Former farm occupancy:			
Forest	36%	37%	42%
Fallow	8%	11%	17%
Food crops	30%	30%	32%
Old cocoa farm	26%	22%	9%

Our investigations confirm the low use of selected plant material and of nurseries: 78% of the coffee orchard is made up of seedlings gotten from old plantations and planted out directly in the field.

The majority of the coffee orchard (82%) benefits from slight shading from fruit trees (banana, plum, palm and citrus trees) or from leguminous plants. 10% of the coffee orchard is grown under high shading of forest species; while 8% are planted without any shade.

As far as agricultural practices are concerned in the Centre-East basin of Cameroon, the upkeep of the coffee orchards is reduced to two monthly weeding per year. No farmer neither fertilizes his coffee trees nor uses herbicides. The removal of parasitical branches is usually done at the same time with the upkeep of the plantation and doesn't consist in a specific intervention.

The regeneration of the coffee trees by rejuvenation is scarcely practiced and the coffee farmers prefer to top the coffee stems. In addition, farmers prefer to extend their farms rather than intensify the agricultural practices: 58% of the plantations were subject to extension and very few were replanted.

About 30% of the farmers are doing a phyto-sanitary protection of their coffee trees, and half of them are applying insecticides only once per year. This is generally done just before harvest so as to clear up the trees from ants. The observations made at the end of 2002 seem to show that the infestation of coffee trees by the berry borer insect (*Hypothenemus hampei* L.) are minimal (12 ± 8%) and doesn't really justify a specific fight.

According to the extensive technical methods adopted by farmers in the Centre-East, the yields of Robusta coffee trees in the Centre-East are low (Table 2).

Table 2. Classes of market coffee per year and average yield.

Classes of yield per hectare	Years		
	2000	2001	2002
< 100 kg	51.3%	44.1%	67.4%
100 kg < < 200 kg	26.8%	32.6%	18.6%
200 kg < < 300 kg	7.3%	14.0%	7.0%
>300 kg	14.6%	9.3%	7.0%
Average yield per hectare	124 kg	124 kg	95 kg

The work realized by the producers in coffee cultivation is mainly done by the available family labour. Mutual aid between farmers is quasi inexistent and few farmers are using paid labour due to lack of funds, as 85% of them are reporting. For 9% of the farmers, the available family labour is sufficient. The tools used in coffee cultivation are rudimentary: a cutlass and a file constitute their essential equipment.

Modelling of two coffee plantation production systems

The decision-making software “Olympe” was used on two Robusta coffee based farms having different strategies. The first farmer’s objective (F1) is the production of food crops for sale. Whereas, the second farmer’s goal (F2) is the production of coffee and its transmission as an inheritance to his children (table 3).

Table 3. Main characteristics of the two computed farms.

	F1	F2
Number of active family members:	1 wife and 7 children	2 wives and 3 children
Farming System:		
Pure traditional coffee farm	0.2 ha	2 ha
Pure plantain	2 ha	1 ha
Cocoyam and plantain	1.2 ha	-
Cocoyam and cassava	0.1 ha	-
Mixed food crops on fallow (maize, cocoyam, cassava, groundnuts)	0.3 ha	1 ha
Mixed food crops on cleared forest (maize, plantain, cassava, groundnuts)	-	1 ha
Pure cocoa	1 ha	0.5 ha
General total	4.8 ha	5.5 ha

The use of “Olympe” implies several steps:

Step 1: Definition of the initial database and the unit system (Figure 1)

Système d'unités

		1 Atelier	2 Entreprise	3 Région	ratio 2/1	ratio 3/2	Monnaie
1	*	Fcfa	Fcfa	KFcfa	1.000	1 000.000	O
2		q	q	q	1.000	1.000	N
3	*	kg	kg	kg	1.000	1.000	N
4		t	t	t	1.000	1.000	N
5	*	baco	baco	baco	1.000	1.000	N
6	*	régime	régime	régime	1.000	1.000	N
7		jt	jt	jt	1.000	1.000	N
8		ha	ha	ha	1.000	1.000	N

Monnaie Utilisée: Fcfa

Figure 1. Example of the different units retained for the study.

Step 2: Definition of the different farming systems (products, expenses, work period, etc…) (Figure 2).

Vivrier annuel — Unités | Tva

.	.	NOM	U.Atelier	U.Entreprise	U.Région	Prix/U.Ent	Tva
1		Maïs spath	baco	baco	baco	2 000.00	Sans
2		Maïs grain	kg	kg	kg	75.00	Sans
3		Maïs autoconsommé	baco	baco	baco	1.00	Sans
4		Arachide coque	baco	baco	baco	2 000.00	Sans
5		Arachide autoconsommée	baco	baco	baco	1.00	Sans
6		Macabo tubercule	baco	baco	baco	2 000.00	Sans

Figure 2. Example of type of annual food crops products.

Step 3: Definition of the farming system details

Each farming system provides products, consumes expenses and needs work. Farming systems are defined in four different ways: annual crops (groundnuts, maize, cocoyam), breeding, perennial crops (coffee and cocoa) and multi-annual crops (banana, cassava).

Step 4: Definition of the farmers' details

Keneke 1

DEFINITION PRODUCTIONS VARIABLES PRODUITS CHARGES DIVERS EXTERNALITES IMMOBILISATIONS FINANCES PRIVE STOCK EN COURS PASSE RESULTATS TRESORERIE

PLURIANNUELLES — PluriAnnuelle | Surface

.	.	NOM	Catégorie	Surface	Plantation	Durée
1		Plantain pur	Pluriannelles	2.00	2003	3
2		Plantain macabo	Pluriannelles	1.20	2003	3
3		Manioc macabo	Pluriannelles	0.10	2003	3
4		Plantain pur	Pluriannelles	2.00	2004	3

Figure 3. Example of a window showing the production surfaces of a specific farmer.

Once the characteristics of each plantation is entered, simulations can be made either from the module "hazard" that notably enables the elaboration of prospective scenarios in function of the module «variants» that from a typical exploitation, enables the creation of many variants as possible (change of technical routes, increase in surface area, etc…).

In the present case, the variant consist of simulating the impact of the putting in place of a one hectare plantation of selected coffee, planted in double-line hedges with food crops in the space between the coffee lines of the two exploitations modelled.

The results allowed by "Olympe" are numerous. In the first place, they concern margins per farming system. Secondly, the software calculates the performances of each farm studied and presents them in different forms (surface, farm account, finances, and agricultural calendar). Comparisons are therefore possible.

The use of "Olympe" enables the notification that, the innovation proposed to the two farmers considered, increases their margin in 2004 (Figure 4). However, the changes in the 2004 agricultural calendar show that, the proposed innovation leads to an additional work at certain periods of the year (Figure 5), which obliges farmers to resort to paid labour, which is a constraint that thus makes relative the interest of the innovation.

Nom	2004
Keneke 1	2 552 000
Keneke 11	2 764 800
Ateba 1	1 341 000
Ateba 11	1 488 150

Figure 4. Evolution of the margins of two *C. canephora* based exploitation with innovation (Keneke 11 et Ateba 11) and without innovation (Keneke 1 et Ateba 1).

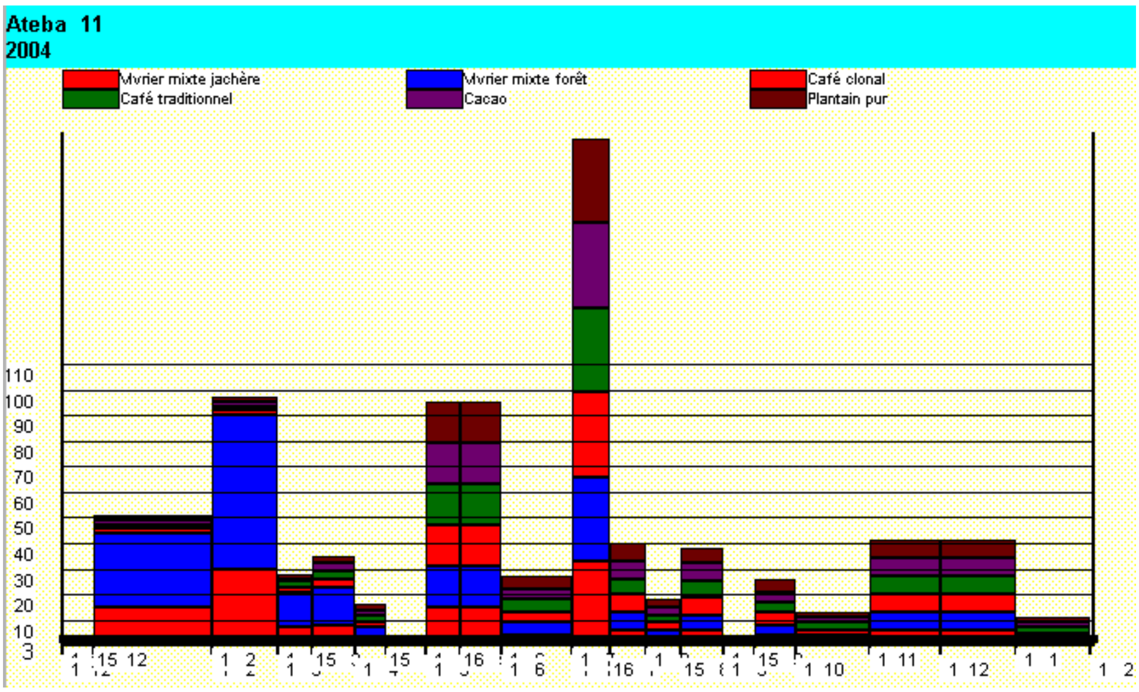

Figure 5. Work time distribution for farmer F2 with innovation in 2004.

CONCLUSION

In the framework of the study carried out from 2000 to 2004 on robusta coffee in the Centre-East basin of Cameroon by IRAD and CIRAD, the use of the software "Olympe" that helps in decision-making enabled the measurement of the impact of three technical innovations proposed to two coffee growers at the level of their finances and of their agricultural calendar.

In the actual context of volatility in world prices of coffee, and the high risks taken by producers, the modelling of the functioning of their exploitations enables agronomic research to provide them with elements of decision that goes beyond the agro-economic performance of the proposed innovations (productivity, vigour, valorisation of a workday). The technical innovations proposed by agronomic research could be as well adapted so as to properly respond to farmers' expectations and constraints, for a better minimisation of production costs and the profitability of the crop cultivated or an adaptation to agricultural calendars.

This new on-farm coffee cultivation approach, principally based on the modelling of the management of exploitations and on the participative analysis of the results, offers new susceptible perspectives to ameliorate the transfer of research knowledge on-farm: best reactivity of agronomic research faced with market evolution, best consideration of constraints and producers' strategies, more rapid adaptation of available knowledge.

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Legume Trees for Best Quality of Coffee Production in Côte d'Ivoire

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RÉSUMÉ

Il est établi que l'azote constitue l'un des éléments majeurs dans la nutrition minérale du caféier. Dans un essai d'association caféier /légumineuses arbustives, à la densité 1 caféier pour 1 légumineuse, l'efficacité de l'azote provenant des émondes et des racines de *Gliricidia sepium* et *Albizzia guachapele* a été comparé à celle de l'urée au niveau du développement et de la production des caféiers.

L'analyse des cinq premières récoltes montre que le traitement *Albizzia* est équivalent à celui de l'urée. En revanche, l'urée est supérieure au traitement *Gliricidia*; la différence est significative. Les gains de production enregistrés en faveur de l'urée sont de 6% et 19% par rapport à *Albizzia* et *Gliricidia*. Toutefois, ces deux légumineuses ont une productivité supérieure au témoin sans engrais et sans légumineuse de 43% et 33% respectivement.

La biomasse fraîche produite par *G. sepium* sur la même période est 1.4 fois plus élevée que celle de *A. guachapele* mais sa décomposition est plus rapide. Ceci pourrait expliquer la différence de rendement entre les traitements des légumineuses.

Il ressort de ces résultats que l'association de ces deux légumineuses au caféier peut permettre de réduire l'utilisation des engrais minéraux azotés et de produire un café de bonne qualité.

SUMMARY

It has been established that Nitrogen is an important nutrient for the coffee tree. In a study to ompare the efficiency of urea and Nitrogen release by *Glricidia sepium* and *Albizzia guachapele* from the roots and prunings used as mulch, coffee trees and N-fixing trees were intercropped at the density of one coffee tree to one N-fixing tree. Growth and yield of the coffee trees were assessed in the differents treatments.

The average coffee yield for the first five years showed that there was no significant difference between the urea and *Albizzia* treatments. However, coffee yield was significantly higher in the urea treatment than the *Gliricidia* one. Coffee yield in the urea treatment was 6% and 19% higher than the *Albizzia* and *Gliricidia* treatments respectively. On the other hand, the *Albizzia* and *Gliricidia* treatments yielded respectively 43% and 33% more than the untreated control (no urea and no legume tree). The fresh biomass produced by *G. sepium* was 1.4 times greater than that produced by *A. guachapele* during the same time period, but its decomposition was faster. This may explain the yield difference between the btreatments with the 2 N-fixing trees.

The results from this study indicated that the association of *G. sepium* and *A. guachapele* to the coffee trees could allow to reduce the use of mineral fertilizer and produce coffee with good quality.

INTRODUCTION

L'engrais azoté favorise le développement des facteurs de rendement chez le caféier, et apparaît comme l'élément majeur pour l'accroissement de la production (Snoeck, 1981). A la dose de 100 kg par hectare et par an dans les sols de Côte d'Ivoire, il permet d'obtenir un gain de production de plus de 40% par rapport au témoin sans engrais.

Mais face aux coûts élevés des engrais chimiques, l'utilisation des légumineuses dans les systèmes de culture comme une source d'éléments nutritifs pour les plantes constitue une alternative judicieuse pour l'amélioration de la productivité. En effet, la décomposition des litières et des émondes, et éventuellement des nodules de légumineuses, peut contribuer à fournir des éléments essentiels au sol et aux cultures afin de réduire l'emploi des engrais chimiques.

Plusieurs expérimentations ont été conduites sur le caféier. Au Venezuela, Aranguren et al (1982) ont observé que les litières de *Erythrina sp* et *Inga sp* associées aux caféiers peuvent compenser les exportations dues aux récoltes, de l'ordre de 17 kg par hectare et par an. De même, Babbar et Zak (1994) ont montré, au Costa Rica, que la minéralisation et la nitrification des engrais sont plus importantes dans les caféières sous ombrage de *Erythrina* sp. que dans les caféières en plein soleil ; en outre, les pertes d'engrais sous forme de nitrates, la forme la plus assimilée, sont faibles sous les caféiers associés aux légumineuses (1995).

Au Burundi, Snoeck et al. (2000) ont démontré que 30% de l'azote atmosphérique fixé par *Desmodium sp* et *Leucaena sp* sont transférés aux caféiers associés. Le transfert de l'azote à travers le paillage des émondes de *Gliricidia sepium* pour contribuer à l'amélioration de la production du caféier et des caractéristiques chimiques du sol, a été également observé au Sri Lanka par Gunaratne et Heenkenda (2000), et par Zahara et Wan Rashidah (2000) en Malaisie.

Par ailleurs, pour déterminer de meilleures pratiques culturales, Boyer (1964) et Bouharmont (1978) ont respectivement mis en évidence en Côte d'Ivoire et au Cameroun, des actions favorables de certaines légumineuses rampantes, dites plantes de couverture, sur le bilan hydrique du sol, la nutrition minérale et la production du caféier. Cependant, ces légumineuses à port bas présentent l'inconvénient d'avoir une mauvaise croissance sous l'ombrage des caféiers et sous l'effet des coupes successives pratiquées.

Pour contourner ces inconvénients, des légumineuses arbustives sont utilisées dans la présente étude: *Gliricidia sepium*, *Albizzia guachapele* et *Albizzia lebbeck*. L'objectif est d'évaluer: i) les effets des légumineuses sur la croissance et la production des caféiers associés, ii) l'économie en engrais minéraux azotés, et iii) le pouvoir fixateur de l'azote atmosphérique par ces légumineuses arbustives.

MATÉRIEL ET MÉTHODES

Deux expérimentations ont été conduites sur la station de recherche de Divo à partir de 1995. Le climat est de type tropical humide; la pluviométrie moyenne annuelle est de 1400 mm avec deux saisons des pluies et deux saisons sèches. Les caractéristiques physiques et chimiques du sol sont les suivantes : argile + limon fin = 28%, C% = 1.19, N% = 0.12, K = 0.30 meq/100 g, Ca = 3.20 meq/100 g, Mg = 0.86 meq/100 g, pH (eau) = 5.9.

La première expérimentation a été réalisée suivant un dispositif en blocs de Fischer avec 4 traitements et 5 répétitions. Deux légumineuses ont été associées aux caféiers: *Gliricidia sepium* et *Albizzia guachapele*.

- T1 : témoin sans légumineuse et sans engrais ;
- T2 : association caféier/*Gliricidia* ;
- T3 : association caféier/*Albizzia ;*
- T4 : engrais azoté (urée) à raison de 100 kg N/ha.

Les légumineuses sont plantées dans les interlignes des caféiers, et à la même densité avec un écartement de 3 m x 2.5 m, soit 1333 arbres à l'hectare. Un an après plantation, les légumineuses sont taillées à une hauteur de 1.50 m du sol, et les nouvelles branches qui sont émises sont coupées tous les 3 à 4 mois pour pailler les caféiers. Les émondes sont pesées avant le paillage aux pieds des caféiers.

Dans le but de suivre les effets des légumineuses sur la croissance des jeunes caféiers, trois paramètres ont été mesurés au cours des deux premières années: le nombre de rejets émis par pied, la hauteur des tiges, et le nombre de nœuds fructifères sur les branches. Concernant les rendements, les productions ont été enregistrées sur une période de cinq ans.

La deuxième expérimentation a porté sur la quantification de l'azote fixé par trois légumineuses arbustives: *Gliricidia sepium*, *Albizzia lebbeck* et *Albizzia guachapele*. Le caféier a été utilisé comme arbre de référence. Les traitements sont disposés en 3 blocs de 4 traitements. Chaque parcelle élémentaire a une superficie de 4 m x 4 m (16 m^2) où des plants issus de pépinière sont plantés à un écartement de 1m x 1m. Les 4 arbres au centre de chaque parcelle élémentaire sur une superficie de 4 m^2, reçoivent 20 kg/ha en trois applications de sulfate d'ammoniaque enrichi avec N^{15} à 10% d'excès atomique. Un an après plantation, les arbres sont taillés à 1m du sol pour la mesure de la fixation de l'azote.

Un test de décomposition sur les feuilles et branchettes des trois légumineuses ci-dessus a été réalisé: la biomasse a été placée dans des sacs de toile de moustiquaire puis déposée sous les caféiers dans les mêmes conditions que les émondes qui servent à pailler les caféiers. Des pesées ont été effectuées à 2, 4 et 6 mois.

RÉSULTATS ET DISCUSSION

La croissance des caféiers

Le Tableau 1 indique que les traitements ne diffèrent pas les uns des autres pour le nombre de rejets par pied. En revanche, le témoin est significativement inférieur à tous les autres traitements pour la hauteur des tiges ($P < 0.05$). S'agissant du nombre de nœuds fructifères, la différence entre le traitement urée et les autres traitements est significative et indique l'azote demeure un élément principal pour le caféier.

Ce résultat corrobore celui obtenu par Snoeck (1981), à savoir que l'engrais azoté stimule le développement des caféiers en entraînant l'accroissement du nombre d'étages sur les troncs, du nombre de nœuds sur les branches et du nombre de nœuds à feuilles et à fruits, des facteurs qui interviennent dans l'augmentation de la production.

Tableau 1. Paramètres de croissance 17 mois après plantation.

Traitements	Nombre de rejets par pied	Hauteur tiges (cm)	Nombre Nœuds fructifères
T1 témoin	3.14 a	71.04 b	6.66 b
T2 G. sepium	2.98 a	91.70 a	7.83 b
T3 A. guachapele	2.95 a	87.80 a	7.57 b
T4 Urée	3.20 a	90.42 a	9.74 a

Classement: a > b La biomasse produite par les légumineuses

La production de biomasse fraîche (feuilles et branchettes) des légumineuses sur une période de cinq ans indique *Gliricidia sepium* produit en moyenne 19.5 tonnes par hectare et par an contre 14.4 tonnes pour *Albizzia guachapele*, soit 1.4 fois plus de biomasse produite par *G. sepium* (Tableau 2). Cela représente annuellement, 14.6 kg et 10.8 kg respectivement, de matière verte par pied de caféier en moyenne. Sur la période de l'étude, les apports d'azote aux caféiers par les légumineuses sont estimés à 158 kg N/ha/an pour *G. sepium* et 116 kg N/ha/an pour *A. guachapele*. Mais les proportions réellement transférées aux caféiers sont souvent bien faibles, de moins de 20% en fonction de la qualité des émondes, des espèces et du type de sol (Haggar et al., 1993; Vanlauwe et al., 1996; Snoeck et al., 2000).

L'étude entreprise sur la décomposition de cette biomasse a montré que *Gliricidia* se décompose plus vite que *Albizzia*; à deux mois le taux de décomposition atteint 70% contre 46% chez *Albizzia.* Cette vitesse de décomposition des feuilles de *G. sepium* a été observée par Zaharah et al (1998) en Malaisie où à moins de 10 jours, les feuilles perdent 60% de leur teneur en azote. La décomposition des émondes et la minéralisation de l'azote dépendent de plusieurs facteurs, notamment la teneur en azote, le rapport C/N, les teneurs en lignine et en polyphénol (NGoran, 1998). La décomposition est lente quand le rapport C/N est élevé, et rapide lorsque ce rapport est faible.

Tableau 2. Biomasse produite et taux de décomposition des émondes.

Légumineuses	Biomasses en t/ha	Taux de décomposition (%) à		
		2 mois	4 mois	6 mois
Gliricidia sepium	19.5	70	83	87
Albizzia guachapele	14.4	45	61	76
Albizzia lebbeck	-	47	55	73

La composition minérale des biomasses

Le Tableau 3 donne la composition minérale des feuilles et des branches. Il indique que la teneur en azote dans les feuilles est presque identique dans les deux types de légumineuses, 3.54% pour *G. sepium* et 3.59% pour *A. guachepele*. En revanche dans les branches, l'analyse décèle une différence significative à $P < 0.05$ en faveur de *Albizzia*.

Concernant les autres éléments, les teneurs en phosphore sont faibles dans les compartiments des deux types de légumineuses. Cependant, le calcium, le magnésium et le potassium ont des teneurs plus élevées chez *Gliricidia* aussi bien dans les feuilles que dans les branches; la différence est significative. Les apports importants de ces bases échangeables par les émondes de *G. sepium* et leur immobilisation dans le sol ont été mis en évidence par Gunaratne et Heenkenda (2000) et par Zaharah et Wan Rashidah (2000).

La concentration du potassium dans le sol risque à terme de provoquer des déséquilibres dans le rapport Mg/K en entraînant des effets néfastes sur le rendement du caféier. La corrélation entre les rendements du caféier et des niveaux du rapport Mg/K a été déjà observée au Burundi par Snoeck et al. (1994) et en Côte d'Ivoire par NGoran (1987).

Les rapports C/N varient de 11 à 12 dans les feuilles et de 27 à 36 dans les branches. Ces résultats montrent la relation étroite entre le niveau du rapport C/N et la décomposition rapide des émondes de *G. sepium.* La composition minérale est comparable à celle trouvée en Malaisie par Zaharah et al. (1998).

Tableau 3. Composition minérale des émondes des légumineuses.

% MS	C	N	Ca	Mg	K	P	C/N
Gliricidia sepium							
• Feuilles	40.3 (*)	3.54	2.20 (*)	0.42 (*)	2.30 (*)	0.14	11.4
• Branches	43.7	1.20 (*)	0.98	0.20	2.50	0.07	36.4 (*)
Albizzia guachapele							
• Feuilles	44.4	3.59	1.60	0.34	1.40	0.10	12.4
• Branches	43.5	1.60	0.68	0.24	1.50	0.05	27.2

(*) La différence est significative à P < 0.05.

La fixation de l'azote

Les quantités d'azote de l'air fixé par les trois légumineuses dans le sol de Divo sont importantes avec pour plante de référence, le caféier: 87% pour *Gliricidia sepium*, 76% pour *Albizzia guachapele* et 81% pour *Albizzia lebbeck*, soit en moyenne 81%.

Effets des légumineuses sur la production

L'analyse du cumul des récoltes sur la période de cinq ans montre que les légumineuses ont amélioré la productivité des caféiers de 33% et de 43% par *G. sepium* et *A. guachapele* respectivement par rapport au témoin sans engrais et sans légumineuse (Figure 1). Les différences sont significatives à $P < 0.05$ avec un coefficient de variation de 14.2%. L'urée est supérieure de 19% par rapport à *G. sepium* et seulement de 5% par rapport à *A. guachapele* Les résultats indiquent que les légumineuses peuvent permettre de réduire les apports des engrais minéraux azotés. Gunaratne et Heenkenda (2000) ont obtenu des résultats similaires sur le caféier en appliquant 10 à 20 kg de biomasse fraîche de *G. sepium*.

Plusieurs facteurs expliqueraient la différence significative entre les deux légumineuses. D'abord, la teneur de l'azote dans les branches de *A. guachapele* est plus importante que celle de G. *sepium*. Ensuite, la vitesse de décomposition de la biomasse chez *G. sepium* limiterait la mise à disposition de l'azote du paillis aux caféiers; il n'y aurait pas une bonne synchronisation entre la fourniture de l'azote et la demande des caféiers comme le soulignent Haggar et al. (1993) et Jensen (1994). Comme autre facteur, la teneur importante de potassium dans les organes de *Gliricidia* qui a pour conséquence, le déséquilibre du rapport Mg/K et l'action néfaste sur la production du caféier lorsqu'il est immobilisé dans le sol. En outre, Zaharah et al. (1998) ont observé que trois à quatre coupes par an sur plusieurs années diminuent la fixation symbiotique de l'azote chez *G. sepium*.

Toutefois, les résultats obtenus montrent que *G. sepium* a sensiblement amélioré la production par rapport au témoin et peut constituer une alternative efficace pour la production durable du caféier. De plus, les effets bénéfiques de cette légumineuse ont été également mis en évidence sur le rendement de l'igname (Budelman, 1989).

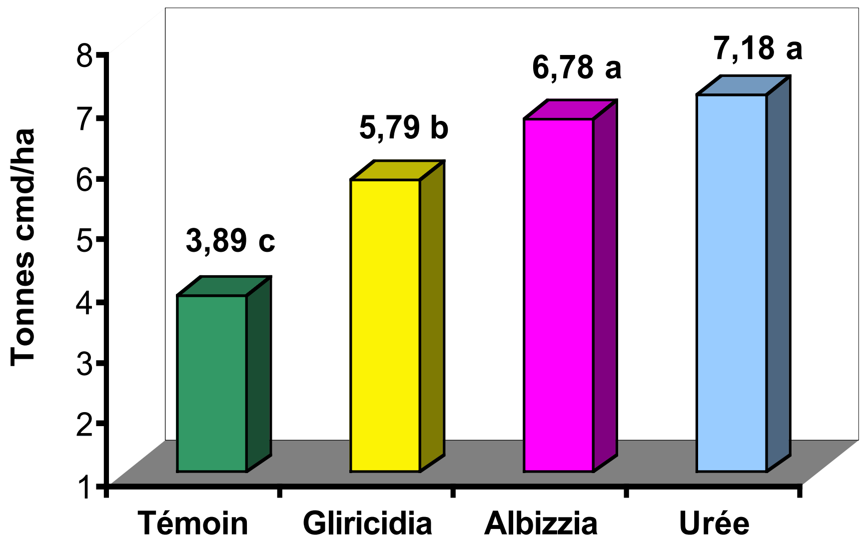

Figure 1. Effets des légumineuses sur le cumul de la production (5ans).

Effets des légumineuses sur la qualité du café

Le Tableau 4 montre les paramètres de la qualité mesurés dans le café marchand de notre étude. Les légumineuses améliorent sensiblement l'acidité qui est caractéristique de la qualité organoleptique du café ; de même, l'augmentation du taux de sucres réducteurs peuvent contribuer à la diminution de l'amertume du café (Picard, 1984; Vithzum, 1976).

Table 4. Effets des légumineuses sur quelques paramètres de qualité du café.

Traitements	Cendres %	Acidité mq/100	Lipides %	Caféine %	Sucres ré-ducteurs %	Protéines %
Témoin	4.31	146	10.48	2.44	0.97	10.0
G. sepium	4.03	208	3.97	2.28	1.03	13.18
Albizzia guachapele	4.13	181	6.57	2.22	1.26	12.56
Urée	4.21	208	7.29	2.36	ND	ND

ND = non déterminé

Par ailleurs, on note une amélioration de la valeur nutritionnelle du café dans les traitements avec légumineuses grâce à l'augmentation du taux de protéines, et à la diminution du taux des lipides. Concernant la caféine, il n'y a pas de variation notable. Toutefois Verlière (1973), dans l'étude sur l'influence de la nutrition minérale sur la composition du fruit, a obtenu un effet positif de l'urée seul et un effet négatif en présence du potassium.

CONCLUSION

Les résultats obtenus dans l'association caféier avec *Gliricidia sepium* et *Albizzia guachapele* par application des émondes sous forme de paillis aux pieds des caféiers sont prometteurs. Ils permettent de dire que ces légumineuses qui fournissent suffisamment d'éléments minéraux au sol et aux caféiers pour améliorer la production et la qualité du caféier, peuvent se substituer aux engrais minéraux azotés, notamment, dans les systèmes de culture traditionnels ne disposant pratiquement pas de systèmes de crédits agricoles appropriés pour les producteurs.

Toutefois, pour une gestion judicieuse et durable du système d'association, il conviendra de suivre d'une part, le maintien des apports des biomasses des légumineuses sur une longue période suite aux coupes successives et d'autre part, l'évolution et les interactions des éléments minéraux immobilisés dans le sol, notamment, le carbone, l'azote et les divers équilibres entre les bases échangeables.

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Principles and Practices of Intercropping in Coffee

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SUMMARY

The paper outlines the underlying principles of successful coffee intercropping systems, gives examples of some common farmer practices and research results. Recommendations are also highlighted.

INTRODUCTION

Intercropping is the growing of two or more crop species simultaneously on the same piece of land (Agboola and Fayem, 1972). There is both inter and intra-crop competition during all or part of the crop growth. Crop intensification is both in time and space dimensions (Andrews and Kassam, 1976). It is widely practiced in most parts of the world and dominant feature in the tropics.

The main expectation from an intercropping system in a perennial plantation is that the overall return from a unit piece of land is increased without affecting either the current or the long-term productivity of the main crop (Liyanange et al., 1984). Therefore, intercropping in perennial crops should be a means of increasing the total productivity of lands that are committed to the base crop for many years. The returns from the additional crops should justify the adoption of the intercropping practice and should contribute to the long-term productivity of the system.

It has been emphasized that one of the main reasons from yield advantages under intercropping is that crops grown in combination may be able to make better overall use of resources than when grown separately (Rao and Willey, 1978). This synergism can occur when the crops have differences in resource use. The biggest complementary effects and thus the biggest yield advantages seem to occur when the component crops have different growing periods or have different growth habits and therefore make their major demands on resources at different times (Rao and Willey, 1978).

When discussing yield advantages the impression may be given that the only advantages of intercropping are higher yields or higher net incomes. A part from this, a major advantage of intercropping is yield stability (Steiner, 1982). There are several reasons why intercrops give more stable yields than sole crops. One basic principle of intercropping is compensation. When one component crop suffers from drought, pests or diseases or does not develop properly, the loss of this crop is compensated at least partially by the other component crop(s) since there is now less competition for resources (Steiner, 1982). Yield stability is also increased by reduction of pests (Norton, 1975), diseases (Bourdon, 1978) and weeds (Moddy, 1975) in intercrops below the level of epidemics or outbreaks.

Coffee Intercropping Systems

Coffee has been a monoculture crop and very limited research on intercropping in coffee has been carried out (Wilson, 1986). This does not mean that farmers have not been intercropping their coffee with other crops. Several food crops such as dry beans *Phaseolus vulgaris*, maize *Zea mays*, Irish potatoes *Solanum tuberosum*, sweet potatoes *Ipomea batatus*, tomatoes *Lycopersicon esculentium*, cassava *Manihot esculenta*, yams *Discoera spp*, sorghum *Sorghum bicolor*, finger millet *Eleusine corcocan*)and pyrethrum *Chrysantemum cinerariefolium* have been observed to be intercropped with coffee (Njoroge and Kimemia, 1993).

In a trial with young coffee in Kenya, intercropped dry beans, *Phaseolus vulgaris*, garden peas *Pisum sativum*, green grams *Vigna mungo*, cowpeas *Vigna unguicalata* and chick peas *Cicer aretinum* significantly depressed the coffee yields by 31, 29, 39, 50 and 30% respectively (Njoroge and Mwakha 1994). However, all the intercrops had a positive net economic benefit. In another trial with young Arabica coffee, it was found that only maize significantly first clean coffee yield (Njoroge et al., 1993). In the same trial, the intercrops did not significantly reduce quality in terms of grade 'A' beans and the organoleptic characteristics. The most appropriate cultivars to intercrop with coffee depended on the ecological site (Njoroge and Kimemia, 1995).

In Kenya it has been observed that during the first 18 months after block stumping of high density coffee, two to four rows of dry bean per coffee inter-row may be successfully grown but the growth and yield of beans intercropped too close to the coffee trees were adversely affected (Mwakha, 1987). Experimental results have also shown that it is possible to intercrop coffee planted at 1330 and 2660 trees/ha during the first two years of change of cycle with Irish potatoes, beans, tomatoes, and cowpeas (Kimemia, 1998).

In Brazil intercropping both young and mature pruned coffee with cotton *Gossipyum hirsutum*, rice, bean, maize and soybeans *Lysine max* showed that intercrops removed large quantities of soil nutrients but did not affect the coffee plant growth (Chaves and Guerreiro 1990). However, the taller crops were noted to affect development and yield of coffee in the same study.

In Cote d'Ivoire it is recommended to intercrop coffee upland rice, maize, yam and groundnut *Arachis hypogaea* (N'Goran and Snoeck, 1987). However, maize was observed to depress the first crop of coffee.

Intercropping coffee with perennial trees is widely practiced in many coffee growing regions of the world. For example coffee is intercropped with oil palm *Elair quineesis* in Zaire, coconut *Cocos nucifera* in Malaysia, rubber *Havea bransielis* in Sri Lanka, bananas in Colombia, cacao *Theobroma cacao,* pepper *Piper nigrum* and *citrus* spp in India. The aim is to increase the farm income and also reduce yield and price related risks (Njoroge and Kimemia, 1993). In Kenya experimental results have shown that the clean coffee yields are not reduced by macadamia, citrus, pawpaws, passion fruit, avocadoes, loquats and mangoes while bananas and guava do reduce clean coffee yields (Kimemia, 2001).

In general, annual and perennial crops can be intercropped successfully with coffee. However, yield depression of the annual crops occurs from the second or third year of tree planting due to shading effects. On the other hand coffee yields are bound to be reduced by the perennial trees due to shading. The choice of the intercrop would therefore be the economic returns to the farmer

Coffee Intercropping Practices

Intercropping in young coffee during the first 18-24 months of establishment for both Arabica and Robusta coffee cultivars, there is ample space between the coffee rows to support an annual intercrop. The intercrops must occupy only the middle 1.0 m space between the coffee rows. The number of intercrop rows should be reduced as the coffee canopy expands. The young coffee should be mulched along the rows, weeded and watered as recommended.

The change of cycle period in mature coffee takes about two years. During this period when the coffee canopy is heavily reduced, it is possible to intercrop annual crops between the coffee rows. The number of rows for the intercrop should be reduced as the coffee canopy expands. For coffee planted at lower densities intercropping can continue for two years, intercropping after the second year affects both the coffee and intercrop yields. At the same time the intercropped food crops hinder proper coffee fertilization and pruning operations.

Characteristics of Suitable Intercrops

In order to reduce any adverse effect of the intercrops on coffee the intercrops should possess the following characteristics:

- The annual crops must be early maturing to fit in the rainy periods only
- Must not be creeping plants unless the crop is trained on stakes.
- Preferably leguminous crops but may be rotated seasonally with non-leguminous crops
- Must not be alternate hosts to coffee pests and diseases
- Must not provide excessive shade to coffee (not more than 30%)
- The fruit trees recommended must have higher canopy than coffee so as to tap light at a higher storey and the canopy must be regulated through pruning.

General Intercrop Management

The number of intercrop rows should be reduced as the coffee canopy closes up. The most appropriate food crops and cultivars to be grown depend on the ecological zone where such a crop does well. Diseases and pests incidence depends on the crop and locality and should be controlled as recommended. The numbers of food crops rows per coffee interrow have to be reduced every season such that no intercrop will be directly under the coffee canopy. This is where the coffee feeder roots are located. Planting intercrops there will increase competition with coffee for moisture and nutrients thus adversely affecting coffee productivity. The food crop yields are also drastically reduced due to shading by the coffee. It is advisable to rotate or plant on alternate coffee rows; alternate non-leguminous and leguminous crops for soil fertility and general environmental sustainability.

Coffee farmers who intend to intercrop are advised to acquire the advisory information on field management of the intercrops. Farms with irrigation facilities can have a wide variety of annual crops to choose from so long as they are medium maturing, non-climbing and medium height.

Coffee Management

To reap he maximum benefits of the intercropping systems, it is imperative that the coffee plants must be managed as recommended. Intercropping may start with already established coffee in which case the system will be fitted within the existing spacing. However, if an intercropping system is envisaged before coffee establishment, then the recommended spacing for the coffee variety and zone should be followed

The coffee trees should be fertilized as appropriate with both organic and inorganic manures. As the amount and type varies with regions, it is advisable farmers to strictly follow the recommendation and even better to base the coffee fertilization on soil and leaf analysis results. Lack of proper feeding of the coffee will result in more competition for nutrients with the intercrops hence a compromise on yield and quality of coffee and the intercrops.

Weeds pose a big threat to coffee and are usually managed by a combination of both mechanical and chemical methods. Where coffee is intercropped with annual food crops, use of herbicides may not be applicable. Weeds are thus controlled by hand weeding, care being taken not to uproot or damage the food crops. In situations where difficult to control weeds like couch grass *Digitaria scalarum* are prevalent, it is recommended to control them first before planting the intercrops.

Coffee is attacked by various diseases and pests which sometimes warrant chemical intervention. It is recommended that as far as possible, pesticides should not be used and cultural and biological methods be adopted. However, when absolutely necessary pesticides maybe used and care should be taken not to harvest the intercrops before the recommended safe period for each pesticide. Care must also be taken to avoid trampling the intercrops while carrying out the spraying.

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Organic Coffee Production: Myth or Reality - a Review

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SUMMARY

Organic coffee is one of several types of speciality coffees selling at a premium over mainstream coffees because of distinct origin and flavour, environment-friendly production, or socio-economic concerns for the smallholder coffee growers. The demand for organic coffee (Western Europe, North America and Japan) exceeds the present supply, which is still small (< 1% of annual world production). More than 85% of organic coffees come from Latin America and practically all is (washed) arabica coffee. The production of certified organic coffee follows the principles of organic farming developed in Europe and the United States out of concern for the perceived negative effects of conventional high-input agriculture on health and environment. It claims superior ecological sustainability in combination with sound economic viability. A rather complex and expensive system of certification has to be passed before such coffees can be sold as truly organic. Growers adhering to the strict rules of organic coffee production may to some extent share the concern of the health- and environment-conscious consumers, but they are motivated primarily by the social and economic benefits from the premium received for certified organic coffee. Nevertheless, there appears to be considerable injustice between the extreme preconditions demanded for "organics" by the largely urban consumer of the industrialized world and the modest rewards received by the organic coffee growers for their strenuous efforts. From an agronomic point of view there is also considerable ground for criticism on the principles of organic farming when applied to coffee. For instance, to sustain economically viable yield levels (1 t green coffee/ha/year) large additional amounts of composted organic matter will have to come from external sources to meet nutrient requirements (especially N and K). Most smallholders will be unable to acquire such quantities and have to face declining yields. Organic farming does not necessarily reduce incidence of diseases and pests below economically harmful thresholds, while the humid conditions of heavily shaded coffee may actually stimulate the outbreak of others. These and other aspects peculiar to the preconditions of organic coffee production are addressed in this review. It is concluded that the concept of organic farming in its strict sense, when applied to coffee, is not sustainable and also not serving the interests of the producer and consumer as much as the proponents would like us to believe. On the other hand, ecologically and economically sustainable coffee production is possible by applying best practices of agronomy, crop protection and post-harvest processing.

INTRODUCTION

Organic coffee is one of several types of speciality coffees selling at a premium over mainstream coffees because of:

- distinct origin and flavour characteristics (e.g. Jamaican Blue Mountain, Guatemalan Antigua, Kenya AA),
- environment-friendlier production systems (Certified Organic, Shade-grown, Bird-friendly),
- socio-economic concerns for the smallholder coffee growers (Fair Trade).

All speciality coffees together represent about 9-12% of annual world coffee production, most of it being of the first kind based on origin and specific flavours. The growing demand for organic coffee (mainly in Western Europe, North America and Japan) exceeds the present supply, which is still less than 1% of annual world production (6.3 million t green coffee in 2003). More than 85% of the organic coffees are produced in Latin America and practically all are (washed) arabica coffees (Rice, 2001; ITC, 2002; Lewin et al., 2004).

Crop yields have increased very significantly over the past century. For instance, average wheat yields in N.W. Europe are now regularly exceeding 8 t per ha against 2 t per ha at the beginning of the 20th century when farmyard manure was still the main external source of plant nutrients (Austin et al., 1989; Curtis et al., 2002). Modern maize cultivars grown under intensive crop management practices may yield six times (6-9 t/ha) more than traditional varieties cultivated with low external inputs (Castleberry et al., 1984). About 50% of these increases are generally attributed to the application of inorganic fertilizers and to the chemical control of diseases, pests and weeds; the other half to breeding for higher yields and improved harvest index, more efficient nutrient uptake and host resistance to diseases and pests (Silvey, 1981; Austin et al., 1989). In the case of coffee, smallholder farms with no access to external inputs produce annually often less than 300 kg green coffee beans per ha, while intensively managed plantations of arabica coffee at conventional spacing may yield annually 2 t per ha averaged over several years and robusta coffee plantations up to 3.5 t per ha. Yields of 5 t per ha or higher have been obtained in some close-spaced and unshaded coffee blocks planted with compact-type arabica cultivars, e.g. in Brazil, Colombia and Kenya (Söndahl et.al., 2004).

Organically produced foods started to gain popularity some 30 years ago, especially with urban consumers in N.W. Europe, North America and Japan, out of concern for the perceived negative effects of conventional (high-input) crop production on the environment and human health. Organic agriculture is claimed to combine superior ecological sustainability with lower health risks and sound economic viability based on the following principles (Rice & McLean, 1999; Rice, 2001; IFOAM, 2000):

1. composted organic matter to improve soil quality (no inorganic fertilizers),
2. soil conservation (contour planting, terracing, cover crops, mulch, shade trees),
3. disease, pest and weed control by “natural” methods only (no synthetic pesticides),
4. minimum use of fossil fuels in the production system,
5. low environmental pollution during post-harvest handling.

Organic coffee production has to follow these practices, such as the regular application of composted organic matter, “natural” methods of disease and pest control and (leguminous) shade trees. IFOAM (International Federation of Organic Agriculture Movements) has formulated basic standards for organic coffees. Some 41 organizations (e.g. Naturland of Germany, ORCA in the USA, SKAL in the Netherlands) have been accredited to certify organic coffee. The procedures of registration, certification and regular inspection are rather cumbersome and expensive. All costs have to be borne by the coffee producers, while the extra premium for certified organic coffee is usually not more than 20% above mainstream coffee prices. Smallholder coffees, that are effectively produced without inorganic fertilizers and synthetic pesticides due to lack of financial resources and therefore organic by default, do not automatically qualify as organic. This is the case, for instance, with most of the arabica coffees in Ethiopia (Taye Kufa & Tesfaye Shimber, 2001).

Some of the assumptions made in organic farming appear to lack scientific proof, such as those pertaining to soil quality improvement and plant nutrient management. Besides, in most conventional farming systems of Europe and North America many new practices have been adopted already, that include the integrated use of organic and inorganic fertilizers (Kilham, 2002). Recently published reports of research projects in N.W. Europe and sub-Saharan Africa on the role of organic matter in sustainable field crop production have offered an opportunity of assessing the validity of strictly applied practices of organic farming. This has formed a useful basis for the evaluation of conventional and organic coffee production systems in respect of ecological and economic sustainability. In the subsequent general discussion all above-mentioned principles of organic farming will be addressed before reaching conclusions on the realities of organic coffee production.

Concepts of soil quality, soil organic matter (SOM) and plant nutrient uptake are presented in Box 1 for easy reference in this review paper.

Box 1. Soil quality and plant nutrient uptake.

Soil quality concerns the total of physical, chemical and biological properties within a particular environment that together provide a medium for plant growth and biological activity, regulate water flow and storage in the environment and serve as a buffer in the formation and destruction of environmentally hazardous compounds (Stockdale et al., 2002). ***Soil fertility*** refers to the supply of nutrients and other components of soil quality that enable abundant growth of crop plants.

Soil organic matter (SOM) consists of (1) a large stable fraction (humus), which is completely amorphous and intimately combined with the mineral portion of the soil, colloidal in character and has properties of water and cation adsorption even better than clay minerals, and (2) a much smaller (< 20%) decomposable (labile or light) fraction of active organic matter, which in combination with the microbial biomass effects nutrient cycling (mineralization) and a better soil structure (increased aggregate stability by fungal hyphae and extracellular polysaccharides). A soil of optimal structure and biological activity requires, therefore, frequent input of fresh organic matter residues to replenish the light fraction of SOM (Shepherd et al., 2002).

Plant nutrients are taken up by the root system from the soil solution as simple inorganic ions: nitrogen (N) mostly as $NO3^-$ sometimes $NH4^+$, phosphorus (P) as $H2PO4^-$, sulfur (S) as SO4 =, potassium as K^+, calcium as Ca^{++}, etc. (Halfacre & Bardon, 1979). The nutrients held in the soil solution form only a very small proportion of the total soil reserve (< 1% for nitrogen and < 0.01% for K). The SOM contains most of the N reserves and a considerable proportion of P and S; about 98% of all K and quantities of other cations are fixed in primary and clay minerals; 50-70% of the P reserves are strongly adsorbed or held in insoluble inorganic forms. Most of the cationic forms of nutrients present in the soil are adsorbed on the surfaces of clay minerals and SOM; these are exchangeable with cations in the soil solution. The soil ***cation exchange capacity (CEC)*** depends, therefore, on the amount and type of clay plus SOM content (Stockdale et al., 2002).

ORGANIC FIELD CROP PRODUCTION IN EUROPE AND AFRICA

Organic versus conventional farming in N.W. Europe

Data from several projects comparing soil quality on organic and conventional farms in the UK were published in the journal Soil Use and Management (vol. 18, 2002). The following summary of main conclusions clearly indicates that the claimed superiority of organic farming, in respect of sustainability and environmental hazards, cannot be substantiated by experimental evidence.

- On organic farms, yields are usually 20-40% lower compared to those on conventional farms. Nitrogen is regarded as one of the key factors limiting productivity. Organic farming systems have the potential to supply large amounts of N to growing crops through the incorporation of crop residues, manures and composts. However, optimum levels of available N are seldom achieved in practice and there is poor synchronization of N availability and crop demand (Berry et al., 2002).
- Composting of manures and plant residues, as is recommended in organic farming for human health and plant sanitary reasons, causes a significant reduction in available N, due to volatilization and transformation into stable organic forms (Berry et al., 2002).
- Nitrate leaching per hectare was found to be similar for organic and conventional farms. However, organic farms leached more N by per kg of wheat grain produced, since yields were 40% lower (Stopes et al., 2002).
- The soil microbial mass, which plays a critical role in nutrient cycling (source of readily available nutrients) and in promoting soil aggregation, was found to be similar for organically and conventionally managed soils. One of the prime determinative factors of the soil microbial status is the type and amount of organic material that regularly enters the soil ecosystem. Apparently, the lower external input of organic matter in conventional farms is supplemented by larger amounts of root exudates and crop residues (roots and stubble) added to the soil from the more productive crop (Shannon et al., 2002).
- Management of plant nutrient availability on organic farms depends largely on chemical and biological processes of SOM, while on conventional farms these soil processes are partly bypassed when readily available nutrients are added through applications of inorganic fertilizers. For example, about 50% of N uptake by a crop on conventional farms are derived from inorganic fertilizers in the year of application with the remainder from mineralization of SOM. There is also no evidence that the fundamental nutrient cycling processes in organically managed soils differ significantly from those in conventionally managed soils (Stockdale et al., 2002).

Sustaining crop production in sub-Saharan Africa

Substantial increases in agricultural production are required in sub-Saharan Africa to feed a rapidly expanding population. However, the technologies of soil fertility improvement leading to the “green revolution” of the 1970’s in cereal crop production of Asia and Latin America have had little impact in sub-Saharan Africa, where mean annual application of inorganic fertilizers is still only 9 kg/ha (nutrients) against a world average of 90 kg/ha (Dudal, 2002). Progressive degradation of soil quality over the past 30 years, mainly caused by lack of external inputs and inadequate soil management practices, has seriously affected agricultural productivity of some 200 million ha in the moist savanna and humid forest zones of West and Central Africa (Keatinge et al., 2001). For instance, average maize grain yields in some areas have declined from 3 t/ha to about 0.7 t/ha (Vanlauwe et al., 2002). SOM is often down to 0.9% or less and nutrient outputs are much greater than inputs. Annual soil nutrient depletion as a result of harvested product and erosion has been estimated at 22 kg N, 3 kg P and 15 kg K per hectare (Smaling et al., 1997, 2002). Extensive research to address these problems, initiated some 20 years ago by the IITA (International Institute of Tropical Agriculture, Nigeria) in collaboration with national and international research organizations, has indicated the potential of reversing these negative trends in soil quality by following an integrated soil fertility management (ISFM) approach (Vanlauwe, 2004). The results have been reported in three separate textbooks published in 2001-2004, two of these being proceedings of workshops held in Cotonou (Benin) and Minneapolis (USA) towards the end of 2000. The main observations and conclusions have been summarized below and confirm unambiguously the essential role of organic matter in rehabilitating soil quality, but also the need for additional plant nutrients from inorganic sources to attain socio-economically acceptable yield levels.

- Cropping systems based on organic matter as the only source of plant nutrients, such as advocated by LEISA (Low external input and sustainable agriculture) are incapable of producing the yield increases required to meet local food demands. For instance in the moist savanna zone of West Africa, maize grain yields of 1500 kg per ha were obtained against 750 kg per ha for control plots without organic matter. With combined inputs of organic matter and an optimum amount of inorganic fertilizer (N and P in particular) sustainable yield levels of 3-4 t per ha maize grain could be achieved (Vanlauwe et al., 2001; Vanlauwe, 2004).
- The bulk of SOM is associated with clay-sized particles, which provide extra charges to the highly weathered soils with inherently low CEC so common in sub-Saharan Africa. Addition of organic matter may, therefore, be effective in enhancing the soil CEC. Organic matter of low quality (C: N ratio > 25) leads to more SOM formation than high quality organic matter. However, significant increases of CEC require very large quantities of organic matter to be incorporated into the soil (Merckx, 2002).
- There is nothing wrong with inorganic fertilizers when properly used. The plant does not care whether the source of nitrate or phosphate ions is inorganic fertilizer or SOM. However, only organic matter provides the source of carbon to the soil micro-organisms, which are essential for nutrient cycling of organic matter and soil aggregation. Inorganic fertilizers also increase SOM, as more crop residues will be returned at higher levels of crop production (Sanchez & Jama, 2002).
- Nutrients from inorganic sources are immediately available usually, while organic matter must first decompose to release N and other nutrients for uptake by crop plants, with the exception of K^+ and other dissolved ions, which are readily leached from organic residues. Organic matter and manures are, therefore, more appropriate as basal inputs, whereas inorganic fertilizers offer flexibility in timing of application in relation to crop demands (Giller, 2002).
- The restoration of soil quality and enhanced crop production in Africa requires the strategic use of organic matter to enhance soil quality, together with the application of inorganic fertilizers in doses tailored to match market opportunities. Other essential factors of the integrated crop management system are: soil and water conservation measures, crop rotation, appropriate tillage (or no tillage) and improved seed (Dudal, 2002).

CONVENTIONAL COFFEE PRODUCTION

The following paragraphs focus on arabica coffee (*Coffea arabica* L.), mainly because almost all publications on this subject deal with this species. However, many of the observations and conclusions equally apply to robusta coffee (*Coffea canephora* Pierre ex Froehn.).

SHADE OR NO SHADE

The natural habitats of all *Coffea* species are the understorey of tropical forests in Africa. Many forms of *C. canephora* can be found in the equatorial lowland forests from Guinea to Uganda, but natural populations of *C. arabica* are restricted to the highland forests of south-western Ethiopia (Berthaud & Charrier, 1988).

Box 2. Some physiological characteristics of arabica coffee.

- The maximum net photosynthetic rate of unshaded leaves is low (7 μmol $CO_2/m^2/s$) compared to that for leaves of other C-3 crops (15-25 μmol $CO_2/m^2/s$).
- The saturation irradiances for leaf photosynthesis are 500 $\mu E/m^2/s$ for unshaded leaves, only 20% of total irradiances at mid-day on sunny days in the tropics; these are even less, 300 $\mu E/m^2/s$, for shaded leaves.
- The net photosynthetic rates decrease markedly at leaf temperatures above 25 °C.
- The proportion of total plant dry-matter production allocated to leaves is 40-50 % (cf. 22% in the case of tea and 20% in oil palm).
- In contrast to most other woody perennials, there is no mechanism of early fruit shedding in coffee to prevent excessive crop load, possibly because there was no evolutionary advantage in the natural forest habitat, where floral initiation is low due to heavy shade. This may lead to excessive fruit set in full daylight and consequent overbearing die-back and biennial bearing, unless controlled by pruning and other crop management practices.

(Cannell, 1985)

Arabica coffee is typically a shade-adapted species (Box 2) and most progenies from natural coffee plants, such as germplasm collections from Ethiopia, become severely stressed when grown without over-head shade and have low yields (Van der Vossen, 1985). However, practically all present cultivars are descendant of early coffee introductions from Ethiopia to Arabia (Yemen), where they were subjected to a relatively dry ecosystem without shade for a thousand years before being introduced in Asia and Latin America around 1700 AD and two centuries later in East Africa. They have retained the physiological attributes of shade-loving plants, but can tolerate drought and full sunlight much better because of a well developed root system, strong plant vigour and the ability to retain leaves longer under conditions of water stress (Van der Vossen & Browning, 1978).

Such coffee plants essentially become self-shading and produce high yields without shade and under intensive crop management, but even with over-head shade they generally yield much more than the forest coffees from Ethiopia.

In South America and East Africa coffee is mostly grown in pure stands without permanent shade, except at very high altitudes. Elsewhere (e.g. Central America, Indonesia, India, Cameroon) it is grown either in pure stands with shade trees or in association with perennial crops (coconut palms, rubber, clove, fruit trees), or in mixed gardens with food crops, bananas (e.g. northern Tanzania) and tree crops. In India and Indonesia the stems of shade trees often serve to support the vines of black pepper and so provide an additional source of revenue to the coffee growers. In favourable ecosystems and with intensive crop management including high external inputs (fertilizers and pest/disease control) coffee will often produce much higher yields without than under shade. Without high inputs or under sub-optimal ecological conditions coffee usually shows better results under shade. Shade is provided by natural forest trees and/or planted trees of various leguminous (e.g. *Inga, Albizzia, Gliricida, Erythrina,* and *Leucaena*) and other (e.g. *Grevillea* and *Casuarina*) species. In Central America the density of shade trees varies from 156-204 trees per ha at lower altitude to 83-100 trees per ha at higher elevations. As a general recommendation, over-head shade should not reduce more than 50% of total irradiances (Söndahl et al., 2004). Where rainfall is limiting and dry seasons are rather long, shade trees may adversely affect productivity due to severe competition for available soil moisture with the coffee. That is why in Brazil and Kenya most coffee is grown without shade. The main advantages and drawbacks of shade in coffee are listed in Box 3.

Box 3. Effects of shade trees on coffee.

Positive

- Reducing the extremes in high (low altitudes) and low (high altitudes) air and soil temperatures.
- Breaking the force of wind and heavy rainfall.
- Controlling erosion on steep slopes.
- Suppressing weeds.
- Producing annually 5-15 t (dry weight) organic matter per ha from litter and prunings.
- Recycling of nutrients otherwise not available to the coffee and reducing nutrient leaching.
- Preventing over-bearing and shoot dieback as a result of reduced light intensity.
- Providing additional revenue from the shade trees (timber, firewood and fruits) and support for secondary vine crops like black pepper and vanilla.
- Potentially reducing incidence of diseases (e.g. leaf rust) and pests (e.g. white stem borer).
- Improving cup quality, particularly in ecologically sub-optimal coffee zones (high temperatures).

Negative

- Progressively lower yields with increasing shade intensity, due to a reduction in flowering nodes, inflorescences per node and flowers per inflorescence.
- Competition for water between shade and coffee trees in seasonally dry regions.
- Damage of the coffee trees by falling branches from the shade trees and occasional tree felling.
- Additional labour costs for regularly pruning of over-head trees to avoid excessive shading.
- Potential increase of some diseases (e.g. South American leaf spot) and pests (e.g. coffee berry borer).

(Beer, 1987; Guyot et al., 1996; Beer et al., 1998; Muschler, 2001)

PLANT NUTRIENT FLOWS IN SHADED AND UNSHADED COFFEE

Crop related nutrient outputs

Coffee makes higher demands on soil quality and more nutrients are removed annually by the harvested products in comparison to other tree crops like Cocoa and Tea (Van Dierendonk, 1959; Anon., 1989). Estimates of nutrients taken up by one hectare of arabica coffee (1300 trees/ha) in 6 t of fresh berries (yielding 1 t green coffee beans and 1.25 t dry pulp and parchment) and in vegetative growth (roots, stems, branches and leaves) are presented in Table 1. N and K are the two dominant nutrients, K being more important in fruit development and N for vegetative growth. The demand for P is much lower, but it is essential for root, flower bud and fruit development. Ca, Mg and other major and micro nutrients, although often essential for a balanced nutrition of the coffee plant, may be left out in this discussion of nutrient flows since the required quantities are usually small to minimal in coffee (Willson, 1985; Mitchell, 1988).

Evidently, the nutrients taken up in the green beans are permanently removed from the coffee field, but in many cases those contained in the pulp and parchment are lost as well. Smallholders often sell the harvested berries to private or co-operative factories for wet processing and even on larger coffee farms, which have their own processing facilities, the pulp is not always composted and returned to the field. In coffee curing plants, the parchment hulled from the green beans usually serves as fuel for the boilers. In the case of dry-processed (natural) coffee, the fruit waste is often also left unused. Some of the nutrients taken up for vegetative growth are returned to the soil in leaf fall, prunings and dying feeder roots. However, a substantial amount (assumed here to be 50% for N and 40% for P and K) remains stored for several years in the permanent framework of roots, stems and branches (Wrigley, 1988; Mitchell, 1988) and will eventually be taken out of the field at change of production cycle by stumping or replanting. The annual nutrient uptake and export from the field by the crop will increase in proportion to higher production levels and the nutrient demand for vegetative growth should also be higher at the closer spacings (3-7000 trees/ha) applied in much of present-day arabica coffee production.

Table 1. Approximate nutrient uptake by arabica coffee producing 1 t green beans/ha/year.

	N kg	P kg	K kg
Green beans (1.0 t dry weight)	40	4	45
Pulp + parchment (1.25 t dry weight)	35	7	53
Vegetative growth	60	5	22
Total	**135**	**16**	**120**
Crop related output (see text)	*105*	*13*	*107*

(Willson 1985; Mitchell, 1988; Wrigley, 1988; Korikanthimath & Hosmani, 1998).

Nutrient outputs due to non-crop factors

In addition to crop-related outputs, nutrients are lost from the coffee agro-ecosystem by leaching (N and K), denitrification and NH3-volatilization. On sloping land with inadequate measures of soil conservation, erosion (run off during heavy rainfall) may cause considerable loss of N and other nutrients. Estimates of the magnitude of such nutrient depletion by non-crop factors are unavailable except for N caused by leaching. In closely spaced (7000 trees/ha) and heavily fertilized (300 kg N/ha/year) coffee plantations in Costa Rica, Babbar & Zak (1995) found annual losses of N to be 9 kg/ha from the top 60-100 cm of soil under shaded against 24 kg in unshaded coffee. Even the latter value is low compared to the 50-100 kg/ha N lost annually by leaching in other tropical agro-ecosystems (Beer et al., 1998). The nutrient outputs for all non-crop factors taken together are here tentatively set at 20 kg N, 2 kg P and 15 kg K per ha in shaded and twice as much in unshaded coffee, independent of yield levels.

Nutrient inputs from shade trees

The litter from shade trees may contribute annually 5-15 t (dry weight) organic matter to one hectare coffee depending on climate, soil quality and external inputs of fertilizers (Bornemisza, 1982; Beer, 1988). In India, 10 t litter from mixed shade trees in regularly fertilized coffee was reported to contain 40-60 kg N, 10-14 kg P and 35-50 kg K (Naidu, 2000). Where the leguminous tree *Erithryna variegata* (dadap) was part of the over-head shade, it contained even 95 kg N. Higher inputs of nutrients from shade tree litter, N in particular, have been reported in Costa Rica, but a large proportion of these must come from soil reserves and the high doses of inorganic fertilizer applied each year to these coffee farms (Beer, 1988). The nutrients gradually released from the decomposing litter add to chemical fertility, but the large annual inputs to SOM by shade trees are even more important in regard to the physical and biological improvement of soil quality (Beer et al., 1998). Inputs from shade litter to organic matter are presumed to be positively related to coffee yield levels, because shade trees will also benefit from higher soil quality and nutrient reserves. Nutrients released annually from the organic matter from shade tree litter are here assumed to be 40 kg N, 10 kg P and 35 kg K at coffee yields of 1 t green beans per ha, and proportionally lower or higher at other yield levels.

Mulches

In unshaded coffee, mulch from grasses, wheat straw and maize stover helps to control soil erosion and weeds, preserve soil moisture and is also an important source of organic matter and nutrients (Mitchell, 1988). For instance, the practice of applying annually large quantities (5-10 t/ha) of mulch cut from elephant (or napier) grass (*Pennisetum purpureum*) on plantation coffee in Kenya adds large amounts of plant nutrients to the soil, K in particular. According to nutrient content data of various mulches and manures provided by Njoroge (2001) 10 t of mulch from elephant grass would contain 150 kg N, 26 kg P and 350 kg K, but from natural grasses or maize stover 140-200 kg N, 13-15 kg P and 88-160 kg K. However, smallholder coffee farmers in Kenya usually have no access to such large quantities and instead prefer to feed whatever there is available to their livestock. Mulching of unshaded coffee is not much practised in most other coffee producing countries. Here again, it is fairly realistic to assume that more mulch is being applied where yields are higher: 10 t mulch applied annually (nutrient input of 150 kg N, 26 kg P and 350 kg K) to coffee yielding 2 t green beans per ha and 5 t mulch at half the yield level.

Weeds

Weeds compete with coffee for moisture and plant nutrients, while some perennial grasses and sedges produce root exudates that are toxic to coffee. Weed control is particularly difficult (and expensive) in unshaded coffee. Control by herbicides has all advantages of zero tillage, including no damage to superficial feeder roots of the coffee (Mitchell, 1988). The use of cover crops, although effective also in controlling weeds, is not common in unshaded arabica coffee because of excessive competition for moisture. In Colombia, selectively eliminating gramineous weeds by herbicides and occasional slashing back the broad-leaved “arvenses” was found to be effective in promoting soil conservation with little loss of nutrients (Cadena & Baker, 2001).

Estimates of nutrient balances

The information on nutrient outputs and inputs, as described above, presumably only covers a few of several factors determining nutrient flows in various coffee agro-ecosystems. Nevertheless, it offers an opportunity of getting a global idea of the annual nutrient balance for shaded and unshaded coffee at different levels of production. The data presented in Tables 2 and 3 are, therefore, intended as an illustration of scale rather than precise measurement. The nutrient output from the crop is calculated from the data presented in Table 1, taking yield levels into account. The non-crop outputs are most likely a gross under-estimation of actual losses in some eco-systems, but exact data are lacking.

In shaded coffee, the nutrient balance is negative for the three major plant nutrients at low to high levels of production. Sustained coffee production will, therefore, require correction of this negative balance by regular application of inorganic fertilizers and/or large amounts of nutrient-rich composts.

Table 2. Estimated annual nutrient flows and balance in shaded coffee per ha.

Yield of green beans t / ha / year	Nutrient output / input	N kg	P kg	K kg
0.5	**Out** (crop)	53	7	54
	(non-crop)	20	2	15
	In (shade litter)	20	6	20
	Balance	***-53***	***-3***	***-49***
1.0	**Out** (crop)	105	13	107
	(non-crop)	20	2	15
	In (shade litter)	40	12	40
	Balance	***-85***	***-3***	***-82***
2.0	**Out** (crop)	210	26	214
	(non-crop)	20	2	15
	In (shade litter)	80	24	80
	Balance	***-150***	***-4***	***-149***

Table 3. Estimated annual nutrient flows and balance in unshaded coffee per ha.

Yield of green beans t / ha / year	Nutrient output / input	N kg	P kg	K kg
1.0	**Out** (crop)	105	13	107
	(non-crop)	40	4	30
	In (5 t mulch)	75	13	175
	Balance	***-70***	***-4***	***38***
2.0	**Out** (crop)	210	26	214
	(non-crop)	40	4	30
	In (10 t mulch)	150	26	350
	Balance	**-100**	**-4**	**106**

In the shaded coffee of India, growers are advised to apply fertilizers at the following annual rates, taking into account nutrient balances and fertlizer-use efficiencies, in 3-4 split applications (Naidu, 2000):

500	kg green beans per ha:	100 kg N,	40 kg P and	85 kg K
1000	“ “ :	150 “ ,	60 “ and	124 “
2000	“ “ :	250 “ ,	80 “ and	210 “

Recycling of nutrients taken up by the fruit waste (pulp and parchment) helps to reduce the negative balance, but the fruit waste requires composting before application to the coffee field, with consequent loss of part of the nutrients during the process. Composted coffee fruit waste was found to contain about 2% N, 0.2% P and 2.5% K (Naidu, 2000; Table 4). At a yield of 500 kg green beans per ha the quantity of composted fruit waste (625 kg dry weight) would recycle 12.5 kg N, 1.3 kg P and 15.6 kg K. This will be proportionally more at higher yield levels, but for each situation it appears that 3-4 times the amount of compost from fruit waste produced by the coffee field will be needed for sustained coffee production.

The nutrient balance in unshaded and mulched coffee, e.g. in Kenya, is highly negative for N in particular, but positive for K, as a consequence of the high K-content of the mulch. Yield responses to mulch application and also to N fertilizers (and P applied as foliar spray) are often considerable, but generally insignificant to K fertilizers (Oruko, 1977). Without mulch or other sources of organic matter, significant yield responses to N, P and K fertilizers are common, but such coffee production systems may not be sustainable in the long term because of a gradual decline in soil quality to be expected for most soil types.

ORGANIC COFFEE PRODUCTION

Organic fertilizers

Coffee fruit waste (pulp) requires proper composting before it can be applied safely to the soil under coffee trees (Korikanthimath & Hosmani, 1998). Other organic residues may be added to the coffee fruit waste to improve the final chemical and physical properties of the compost. Table 4 presents data on the nutrient contents, and for a few also the C/N ratio, of the ingredients for composts and mulches commonly applied in conventional as well as in organic coffee farming. There is large variation in N and K contents between coffee pulp of different coffee regions. Cattle manure has nutrient contents generally inferior to coffee pulp and the data from India indicate that some cattle manures can be chemically of very low quality indeed. Guano is an organic fertilizer of almost unique Peruvian origin and regularly applied to coffee plantations in that country (Krug & De Poerck, 1968; Toxopeus, 2003).

Finca Irlanda, in the southern Mexican state of Chiapas, is reputedly one of the first coffee plantations exclusively producing certified organic coffee, since the late 1960s, on 270 ha of moderately shaded and fairly closely planted (3300 trees/ha) coffee (Pülschen & Lutzeyer, 1993; Nigh, 1997; Wallengren, 1999). The plantation produces annually an average of 1500 t ripe berries, which after (wet) processing yield about 250 t (0.93 t/ha) green coffee and 810 t wet (315 t dry) fruit waste. Compost is prepared from a mixture of the coffee fruit waste (40%) and prunings (10%), cattle manure (20%), sugarcane trash (10%), hoof & horn and fish meals (5%), dolomitic limestone (5%), ground rock phosphate (5%), and some clay. This yields annually about 1000 t of compost for application to the coffee trees at 3.7 t/ha or 1.1 kg/tree (Pülschen & Lutzeyer, 1993). No published data are available on the nutrient content of this compost, but a rough estimate can be made based on the data presented in Table 4. The 3.7 t of compost may thus supply 60-75 kg N, 8-10 kg P and 75-85 kg K to one ha of coffee. According to Table 2, shaded coffee yielding an average 0.93 t green coffee/ha/year will require annually an input of 78 kg N, 2 kg P and 75 kg K to maintain the nutrient balance required to sustain this medium level of coffee production. So, it appears that Finca Irlanda is capable of just doing that based on a compost with 50% fruit and tree waste from the coffee farm itself and the other half consisting of external sources of organic matter and “natural” fertilizers.

Coffee fruit waste left to degrade naturally in heaps will require 6-8 months to turn into stable compost containing about 2% N. Sanchez et al. (1999) described methods of accelerated composting of coffee fruit waste in Mexico and found that a regularly aerated mixture of 40% coffee pulp, 30% sugarcane filter cake, 20% poultry litter and 10% wood chips (bulking agent) resulted in a high-quality compost within 50 days with the following characteristics: water 61%, pH 8.3, N 4.5% and P 2.5% (both on dry weight basis) and a C/N ratio of 7.2.

Table 4. Nutrient content of organic manures and residues.

Type	% of dry matter N	P	K	Ratio C/N	Reference
Coffee pulp, fresh (India)	2.4	0.5	4.2		Korikanth. & Hosmani, 1998
Coffee pulp, composted (India)	2.0	0.2	2.5		Naidu, 2000
Coffee pulp, composted (Mexico)	3.8	0.4		10	Sanchez et al., 1999
Coffee pulp, fresh (Kenya)	3.7	0.4	6.5		Njoroge, 2001
Cattle manure (India)	0.4	0.2	0.2		Korikanth. & Hosmani, 1998
Cattle (Boma) manure (Kenya)	1.3	0.6	1.4		Njoroge, 2001
Cattle manure (Europe ?)	2.0	0.8	1.8		Anon., 1989
Poultry manure (Mexico)	3.4	0.4		9	Sanchez et al., 1999
Poultry manure (Kenya)	3.5	1.4	1.3		Njoroge, 2001
Sugarcane filter cake (Kenya)	1.3	1.1	0.6		Njoroge, 2001
Sugarcane filter cake (Mexico)	1.0			45	Sanchez et al., 1999
Guano, Peru (average values)	12.0	5.0	2.5		de Geus, 1973
Fish meal	10.0	2.6	0.0		Follett et al., 1982
Hoof and horn meal	12.0	0.9	0.0		“

Kamala Bai et al. (2000) reported the results of annual applications of about 5 t compost per ha on soil quality and yield for 43 ha of arabica coffee grown organically under shade in the Karnataka State of south India. The compost was prepared by mixing slurry from a biogas unit (based on coffee fruit waste and cattle manure) with sheep and poultry manure and rock phosphate. Liming to improve soil pH was carried out every 4-5 years. The average yield over nine years (1989-1998) was 1.18 t green coffee per ha, against a mean of 1.32 t/ha before conversion to organic coffee production in 1989. No data on the nutrient content of the compost have been given, but from the yield level it appears that the compost contributed at least 104 kg N, 5 kg P and 101 kg K (cf. Tables 2) to a balanced nutrient supply. The soil was in an optimal condition with pH 6.1, organic matter content of 5.9% in the top 20 cm and all major nutrients above threshold values for adequate soil fertility in coffee. Here again, it should be realized that the applied compost included a considerable amount of ingredients from outside the coffee farm.

AGROCHEMICALS

The rejection of most agrochemicals, on account of supposedly excessive use of non-renewable (fossil) energy resources during manufacturing or unacceptable environmental and health risks (Rice, 2001), severely restricts the application of fertilizers and pesticides in organic coffee production

The use of all types of inorganic N-fertilizers is prohibited according to IFOAM (2000) standards and other inorganic fertilizers are strongly discouraged, except when derived directly from natural deposits. However, claims about excessive use of energy in the manufacturing of inorganic fertilizers are not supported by the facts (Box 4).

The organic farming approach presumes lower yield losses due to diseases and pests in “natural” agro-ecosystems. For coffee, that would be achieved by appropriate management of soil fertility, shade trees, crop sanitation (timely removal of disease-affected and pest-infested leaves, berries or branches) and balance between pests and natural enemies (biological control). Synthetic pesticides will never be permitted, but a number of naturally derived products have been approved for disease and pest control in organic coffee production, including Bordeaux mixture, Neem oil and leaf extracts, Nicotine, Rotenone, Pyrethrum, etc. (Naidu & Raghuramulu, 2000). With all herbicides banned, manual weeding is usually a considerable cost factor in organic coffee production.

Box 4. Facts about inorganic fertilizers and energy use.

Fertilizers
Consumption in 2001: 140 million t; 60% N, 24% P2O5, 16% K2O.
Manufacturing **N*:*** atmospheric nitrogen is fixed by a special process to produce ammonia, which is subsequently converted to urea with a hydrocarbon source of energy (natural gas). **P, K** and other plant nutrients are mined from natural deposits. The ores are further processed to make them more soluble and concentrated for better plant uptake.
Total energy use by the fertilizer industry in 2001: 1.9% of world energy consumption.

Energy
World energy consumption in 2001: 7000 Mtoe = 293 EJ, of which 80% from fossil fuels (oil, gas, coal).
(toe = tonne of oil equivalent; EJ = Exa Joules)

Energy use per capita in 2001:				
	North America	335 GJ	Colombia	28 GJ
	EU	180 "	Guatemala	26 "
	Japan	205 "	India	22 "
	Brazil	45 "	Kenya	21 "
	Indonesia	29 "	Peru	19 "

(IFA, 2002; IEA, 2003)

ECONOMIC VIABILITY OF ORGANIC COFFEE PRODUCTION

Publications on the economics of organic coffee production have been few so far. The results of two case studies comparing the profitability of organic with conventional coffee production in similar agro-ecosystems are summarized in Table 5. Both studies concern arabica coffee grown under shade, the Mexican study using data on yields and production costs taken from Finca Irlanda estate and a nearby conventional coffee plantation (Pülscher & Lutzeyer, 1991). In Costa Rica 10 pairs of smallholder farms (< 7 ha/farm) in 5 different regions were selected, each pair including one organic and one conventional coffee plantation (Lyngbaek et al., 2001). Production costs cover all field operations and post-harvest handling (wet processing and curing) up to the green bean stage.

ICO (International Coffee Organization) average indicator prices for mild arabica on the world market were in 1990 about 90 cts/lb ($ 1.98/kg) of green coffee and 140 cts/lb ($ 3.08/kg) in 1998. Mean farmgate price in 1990 for conventionally grown coffee was according to the Mexican study $1.20 /kg and in Costa Rica $2.18/kg in 1998, which come down to about 60% and 70% respectively of the world market prices. These farmgate prices were used to calculate gross income for the conventional and farmgate + 20% premium for that of organic coffee plantations (columns a in Table 5). As an indication of potential gross and net incomes in years with very high world market prices, calculations have also been made with farmgate prices being 60% and 70% respectively of the mean world market price in 1997 of 192 cts/lb

($ 4.18/kg), adding 10% premium for organic coffee (columns b in Table 5). Premiums for organic coffee are usually lower during years of high coffee prices.

Table 5. Profitability of organic versus conventional coffee production (1).

Arabica coffee under shade		Organic		Conventional	
***Mexico** (1990)*		*a*	*b*	*a*	*b*
Yield of green coffee	kg/ha	900	900	1250	1250
Farmgate price	*$/kg*	*1.55*	*2.75*	*1.20*	*2.50*
Gross income	$/ha	1395	2475	1500	3125
Production costs	$/ha	1482	1482	1392	1392
Net income	$/ha	***-87***	**993**	**108**	**1733**
***Costa Rica** (1998)*					
Yield of green coffee	kg/ha	1100	1100	1400	1400
Farmgate price	*$/kg*	*2.64*	*3.21*	*2.18*	*2.92*
Gross income	$/ha	2904	3531	3052	4088
Production costs	$/ha	1470	1470	1403	1403
Net income	$/ha	**1434**	**2061**	**1649**	**2685**

a = at current farmgate prices in 1990 and 1998; b = at assumed farmgate prices, related to high world market prices in 1997.

Yields were on average 22-28% lower and production costs 5-7% higher in organic than in conventional coffee plantations. Especially cost of labour was 20% higher in organic farms, due to additional manual work in weeding and preparation & application of compost. At the prevailing low prices for coffee in 1990 the conventional farm in Mexico just stayed above break-even point, while the organic farm had a slight negative net income despite the 20% premium received for its coffee. With the higher prices for 1998 both types of farms in Costa Rica had a positive net income, although some 13% lower in case of the organically produced coffee despite the 20% premium also received here. During years of very high world market prices net incomes are substantial in all four cases, but now with organic farms trailing some 23-43% behind conventional farms. In actual fact, the differences should be larger, as the considerable costs for mandatory certification and inspection of organic coffee farms have not been included in these calculations. These have been estimated at $ 0.07-0.11 per kg of green coffee (Rice & McLean, 1999).

A third study on the profitability of organic and conventional coffee is based on data provided by the ISMAM, which is a Maya coffee cooperative in the Chiapas state of Mexico exporting annually some 2.500 t green coffee all produced organically (Nigh, 1997), and presented by E.D.E. Consulting (1997). Only yield data and production costs (including processing to green coffee) are being considered here. Without specification in the report, the much higher yield difference would implicate a comparison between organic coffee production under shade and conventional production without shade. Farmgate prices are taken as 60% of world market prices in 1997 for conventionally produced coffee ($ 2.50/kg, just as in Table 5), but now the premium for organic coffee is put at 20% (as indicated in the E.D.E. Consulting report) resulting in a farmgate price of $ 3.00/kg for organic coffee. The ISMAM data show higher production costs compared to the previous two case studies, particularly for unshaded coffee production. The net income for organic coffee farms is again considerably (44%) lower despite the extra premium (Table 6).

Table 6. Profitability of organic versus conventional coffee production (2).

Arabica coffee		**Organic** *shade*	**Conventional** *no shade*
Mexico/ ISMAM *(1997)*			
Yield of green coffee	kg/ha	920	1610
Farmgate price	*$/kg*	*3.00*	*2.50*
Gross income	$/ha	2760	4025
Production costs	$/ha	2010	2685
Net income	$/ha	***750***	**1340**

DISCUSSION

Maintaining soil quality

Coffee, like many other tropical tree crops, has a high potential for environment-friendly agricultural production especially when grown in a kind of agro-forestry system (Smith, 2000). However, the available data reviewed above show that, even in the most ideal agro-ecosystem, the coffee requires much higher levels of nutrient inputs and crop management to achieve environmental sustainability, than generally assumed by the proponents of organic agriculture (e.g. Van Elzakker, 2001).

While experimental evidence for differences in soil quality and uptake of plant nutrients between organic and conventional coffee farms is rather scarce, the recent results from field crop studies in N.W. Europe and sub-Saharan Africa on these issues contribute considerably to the present discussion. Briefly, the nutrient cycling processes in organically and conventionally managed soils are similar, organic matter is very important in maintaining soil quality, but additional inputs of inorganic fertilizers remain necessary for balanced plant nutrient flows and adequate yield levels. These conclusions appear to apply equally well to coffee.

The estimates presented in this review indicate negative nutrient balances (for N, P and K) in shaded coffee farms at low to high levels of production (Table 2), which require correction by external inputs of nutrients to avoid depletion of natural resources by nutrient mining. Composted coffee fruit waste returned to the field can only supply 25-30% of these additional nutrient requirements. The two organic coffee farms in Mexico and India, referred to in this review, had the means of acquiring nutrient-rich organic matter and manures to make up for the difference and so achieved nutrient balances enabling sustained moderate yields (0.9-1.1 t /ha/ year of green coffee). However, most smallholder coffee growers lack the resources to have regular access to considerable quantities of organic matter or manures and will see their already low coffee yields further decline, especially during the current period of very low world market prices. So, it appears that the larger coffee producers are in a better position to produce certified organic coffee than the resource-poor small farmers, who are actually the declared main target of the organic coffee movements.

Unshaded coffee is bound to develop negative nutrient balances, but the Kenyan example (Table 3) shows that high yields can be sustained indefinitely (>50 years) by a combination of grass mulches, inorganic fertilizers (N and P, adequate K supply from the mulch) and other sound crop management practices, where climate (montane, equatorial) and soils (deep, volcanic origin) are favourable. On the other hand, “organic” coffee production by smallholder farmers in the Buyenzi region of Burundi based exclusively on mulches, cut and carried from nearby fields, became unsustainable in the long term due to gradual depletion of plant nutrients (Metzler-Amieux & Dosso, 1998).

Agrochemicals

All inorganic fertilizers are made out of natural raw materials (Box 4) and provide plant nutrients in the form of simple inorganic ions identical to those released by mineralizing organic matter (Box 1). Prohibition of their use considerably reduces possibilities of applying methods of efficient nutrient management developed in coffee production (Mitchell, 1988), such as synchronizing nutrient availability with crop development and correction of diagnosed nutrient deficiencies by topdressing or foliar applications. The rejection of inorganic fertilizers on account of excessive use of fossil fuels during manufacturing is not supported by the facts, while also demands for minimal use of fossil fuels imposed on organic coffee production appear preposterous in view of the tremendous energy uses per capita in the main consuming countries (EU, Japan and N.America), which are 10-20 times higher than in most coffee producing countries (Box 4).

The hazards of indiscriminate use of chemical pesticides to the environment and the health of coffee farmers are real, but the consumers need not fear because the fruit and parchment skins are already minimizing chances of pesticides contaminating the bean in the field and any pesticide residues still present in the green bean will be destroyed during the roasting process. The successful development of new arabica cultivars with host resistance to coffee leaf rust (*CLR*) and berry disease (*CBD*) enables fungicide-free coffee production in areas, where recurrent severe outbreaks of these diseases would otherwise require frequent fungicide sprays to prevent heavy crop losses, e.g. in India, Colombia and East Africa (Van der Vossen, 2001). Host resistances to other diseases, such as the South American leaf spot (*Mycena citriclor*) on arabica in Central America and black rot (*Koleroga noxia*) in India on arabica and robusta coffee, are either not available or in an initial stage of development. Nematodes (mainly *Meloidogyne* spp. and *Pratylenchus* spp.) can cause considerable problems on arabica coffee in Central America in particular, but also in Brazil, India and Indonesia. Much progress has been made in developing arabica cultivars with resistance to certain nematode species, as well as in utilizing nematode resistant robusta coffee as rootstock for arabica cultivars (Bertrand et al., 2000; Anzueto et al., 2001). Several hundred insect species have been identified as minor and important coffee pests. Among the most damaging and worldwide coffee pests are the coffee berry borer (*Hypothenemus hampei*), stem borers (e.g. *Xylotrechus quadripes*), scale insects (e.g. green scale, *Coccus viridis*) and leafminers (e.g. *Perileucoptera coffeella*). Integrated pest management (IPM) has proved to be much more effective in reducing damage to the coffee trees and crops than frequent routine applications of insecticides. IPM includes early warning systems (monitoring of insect populations) in combination with cultural (pruning and shading), biological (insect traps; introducing insects or micro-organisms parasitic to the pest) and chemical (carefully timed incidental applications with selective and non-persistent insecticides) methods of control (Bardner, 1985; Oduor & Simons, 2003). Complete banning of all synthetic insecticides, as advocated for organic coffee production, weakens IPM for some important pests. For instance, control of the coffee berry borer with bio-insecticides like Neem formulations and sprays with *Beauveria bassiana* is ineffective (Naidu et al., 2001; Baker et al., 2001). Weed control by hoeing or blanket applications with herbicides may increase soil erosion. Mulch suppresses weeds and helps soil conservation, but is not always available in sufficient quantities, and cover crops often compete for soil moisture to the detriment of coffee production. Selective elimination of problem weeds by spot application of a selective herbicide, while allowing limited growth of the others to provide ground cover, promotes soil conservation without reducing yields (PAN-UK, 1998, Cadena & Baker, 2001).

Post-harvest processing

About 40% of the world coffee are processed according to the wet method, including most of the organically produced coffees. These so-called washed coffees are generally of superior quality, although certain Ethiopian or Brazilian dry-processed arabicas are much sought after for their specific taste and flavour (ITC, 2002).

Dry-processed coffees may cause few environmental hazards, but conventional methods of wet processing, to convert the harvest of ripe berries into dry green coffee, require large volumes of water at the initial stages of depulping, fermentation and washing. Even with water recycling, the processing of 6 t harvested fruits will produce, in addition to 1.1 t parchment coffee and 2.7 t fruit pulp, 25,000 litres waste water, which require proper treatment in stabilization ponds before discharge to prevent severe pollution of river waters. The fruit pulp can either be returned to the coffee field after composting or fed into a biogas plant (Adams & Dougan, 1981; Wrigley, 1988). These data are derived from mechanized coffee factories, but also small-scale coffee farmers using traditional hand pulpers do face similar difficulties of discharging the pulp and large volumes of waste water without polluting the environment. Many years of engineering efforts by the coffee research institute Cenicafé in Colombia (Cadena & Baker, 2001) have come up with innovative coffee processing machinery, that reduces water consumption to 10% of that of conventional equipment with no increase in power use and even improves coffee quality. Another important step into the direction of sustainable coffee processing are solar drying units developed in Colombia (Cadena & Baker, 2001) and Indonesia (Mulato, 2004).

Traditional and modern cultivars of arabica coffee

There is a widespread belief with coffee roasters and traders, that traditional varieties of arabica coffee give a better cup quality than the new “hybrid” varieties, because of introgression of disease resistance from robusta coffee (e.g. Illy, 2001).

Although Hibrido de Timor (progenitor for resistance to CLR) arose originally from a natural interspecific cross between *Coffea arabica* and *C. canephora*, the phenotype of this variety is truly arabica. The confirmed good cup quality of CLR-resistant Catimor lines in Costa Rica (Bertrand et al., 2003) and in Colombia (Moreno et al., 1995), as well as the CBD + CLR-resistant hybrid variety “Ruiru II” in Kenya (Njoroge et al., 1990) clearly demonstrates that introgression of robusta genes does not necessarily lead to inferior beverage in arabica varieties. However, coffee quality is also strongly influenced by the agro-ecosystem (climate, soil, altitude and agronomic practices) in which the variety is grown (Söndhal et al., 2004). Lack of inputs and poor crop management, as a result of the current low coffee prices, appear to be major factors for deteriorating quality of arabica coffees in several producing countries.

Organic proponents argue that the new varieties would also need more inputs and therefore be less suitable for organic coffee production. On the contrary, the compact plant stature and disease resistance of these modern cultivars allow closer spacings, resulting in almost complete ground coverage and better uptake of available soil nutrients by denser rooting. The efficiency rate of fertilizer applications is increased, as is demonstrated by higher yields per unit area for high-density coffee at similar rates of fertilizer application common for traditional coffee tree densities (Njoroge, 1991).

Economic sustainability

In Central American agro-ecosystems favourable to arabica coffee, organic coffee under shade produced 20-30% lower yields compared to shaded conventional and 40% lower than unshaded coffee (Tables 5 & 6). The premiums received for organic coffee are obviously insufficient to compensate for the lower yields, slightly higher production costs and fees for certification and inspection by IFOAM-accredited organizations. Net incomes for organic coffee farms were thus 25-50% lower than those of conventionally managed farms, but still fairly remunerative when coffee prices are high (in 1997 and 1998). However, in years of very low world market prices, as in 1990 and again during the current coffee crisis, organic coffee farms appear to end up in the red figures much sooner than conventional farms, despite the price premiums of some 20% for organic coffee.

The organic farming movement appears to offer little in economic and social sustainability to the millions of smallholder farmers elsewhere, who can produce only 200-400 kg/ha/year green coffee under less favourable agro-ecological and socio-economic conditions. Coffee is often their only source of cash income, but this can no longer meet the basic needs of their families because of the persistent coffee crisis (Oxfam, 2002; IISD, 2003). The principles of organic farming may not increase yields substantially and the modest premium does not sufficiently compensate for the additional efforts required to meet the strict regulations for certified organic coffee.

CONCLUSIONS

The profusion of articles on organic coffee in journals, books and on the internet, contain plenty of market-promotional statements, meant above all for the urban consumers of the industrialized world, extolling its benefits for the natural environment, biological diversity and human health, but none provide hard evidence for its alleged environmental and socio-economic superiority over conventional coffee production. The present review has been an effort to fill this gap by assessing the principles and practices applied in organic coffee production against sound agronomic and agro-economic criteria. This has led to the conclusion that the following statement of outspoken proponents in the organic movement “if it is not organic it is not sustainable” (cited in Chapman, 2001) should be revised for coffee into “if it is organic it is not sustainable”, for smallholder coffee production in particular.

Ecologically sustainable coffee production is quite well possible by applying best practices of agronomy, crop protection and post-harvest processing. These include soil conservation measures with or without shade trees, applying organic and inorganic fertilizers to maintain optimum soil quality and crop nutrient levels, planting of disease resistant varieties and applying IPM to reduce crop losses due to biotic stress factors, and the use of novel processing equipment. However, full commitment of all stakeholders in the Coffee Sector is required in helping to restore economic and social sustainability of coffee production, which are so badly eroded by the latest coffee crisis (IISD, 2003, 2004; Baker 2004).

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The Potential Use of Petroleum Spray Oil, D-D Tron Plus, as a Component of Integrated Pest Management in Kenya

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SUMMARY

The D-C Tron Plus, an oil formulated insecticide (Petroleum spray oil) was field assessed for its impact on management of Coffee Green Scale, *Coccus alpinus De Lotto* and its ability to sustain and conserve the Green Scale's biocontrol agents, particularly the predators (lady birds) and parasitoids. The assessment was carried out in two coffee farms from year 2000-2003.

Three rates of D-C Tron plus; 50, 100 and 200 mls per 20 litres of water were assessed. The untreated plots were incorporated as the control. The three rates significantly managed the Green scale's infestations as compared to the control. The same rates and the control, when compared with the banded coffee trees showed significantly equal levels of mean number of ladybirds per tree and parasitism, thus indicating the sustainability of Green Scale's biocontrol agents.

The findings from this study have indicated the suitability of D-C Tron Plus as a biorational pesticide in integrated Pest Management Programs in coffee farming in Kenya.

INTRODUCTION

Coffee Green Scale, *Coccus alpinus* De Lotto is a common and injurious pest of coffee in East Africa (Le Pelley 1968). It occurs in the highlands above 1300 metres from the sea level.

In Kenya, a number of scales are known to infest coffee and other host plants (Acland, 1971; Njeru, 1990; Mugo, 1994). Normally the adult scales are immobile and they remain tightly held to the host plant where they suck the nutrients from the plant sap thus affecting the quality and quantity of coffee produced. Only the crawlers slowly move about and spread the infestation.

Among the coffee scales in Kenya, *C. alpinus* is of economic importance (Njeru, 1990; Mugo, 1994). The symptoms of Green Scale attack is normally recognised because of the leaves or even the whole bushes being blackened by the sooty mould. The presence of climbing attendant ants is also in some cases a good evident of Green Scale attack on the host plant.

The *C. alpinus* is severe in Kenya highlands where coffee is grown during dry period. It is normally more serious on transplanted and newly established seedlings especially at their first two years in the field (Mugo, 1994). Mature coffee trees suffer heavy attack when new suckers are raised for the change of cycle.

Management of *C. alpinus* is mainly attained when an integration of biocontrol agents (Biocontrol), Cultural and chemical is applied. The biocontrol agents of *C. alpinus* include many species of parasitic wasps (parasitoids), ladybird beetles (predators) and entomopathogens (Mugo, 1994). The parasitic wasps*; Metaphycus baruensis Noyes*, M. *swierhii Amanyn, Coccophagus Numbes* and *C. pulvineariae* are most common while ladybird beetles*; Chilocorus nigripes* Mader, *C. quadrimaculatus Weise, C. angolensis* and *Hyperapsis senegalensis* are some major predators of *C. alpinus* in Kenya (Le Pelley, 1968; Le Pelley, 1969; Mugo, 1994).

The efficiency of parasitoids and predators in management of *C. alpinus* infestation in coffee is successfully achieved by keeping away the attendant ants from the Green scales through banding (Anon, 1975, 1989; Mugo, 1994). Culturally all the drooping primary branches are pruned to stop the ants from bypassing the band (Anon, 1975). A number of chemical insecticides are recommended for banding coffee trees infested with *C. alpinus (*Anon, 1989) thus enhancing the effect of biocontrol agents .

Frequent and heavy use of synthetic chemical insecticides to control insect pests in most cases upset the natural balance of the biocontrol agents and the pests. To sustain this balance, use of biorational products as component of integrated biological pest management is important in any sustainable agricultural systems.

In Kenya, no chemical has ever been recommended for spraying against the *C. alpinus* because of its morphology and feeding habit. Recent introduction of D-C Tron plus, a petroleum spray oil, for spraying against *C. alpinus* has attained alot of appreciation because of its several advantages. The D-C Tron plus is a cost effective, biodegradable and environment friendly product for the management of various crop pests and diseases. When compared to the conventional pesticides, this product possess little danger to man and his environment. It is environmentally friendly and compatible with a wide range of integrated pest management strategies. In addition, the product is quite suitable in our current situation since food crops treated with D-C Tron plus, compete favourably in the world market especially this time of "Zero" residue in export commodities.

The D-C Tron is an exempted product from the requirement of Maximum Residue Limit (MRL) when applied to growing crops. This is because the total quantity of the oil in or on all raw agricultural commodities where the product has been used, has no effect to the public health.

The D-C Tron plus, as an insecticide normally kill the pest(s) through suffocation, interference with metabolic processes and behaviour modification (Riehl, 1981; Grassman, 1990; Liu et al., 1999). When applied in the field, it forms a film on the leaves surface. This incase of *C. alpinus* normally affects the settlement of scale crawlers thus increasing their mortality and reducing their spreading rate.

The current work was conducted mainly to evaluate the efficacy of D-C Tron plus against *C. alpinus* and to investigate whether the product had any impact on Green scale biocontrol agents.

MATERIALS AND METHODS

Field Sites

The sampling sites; Kwamaiko and Crops coffee farms, located in Kiambu and Thika Districts, respectively in Central Province were used for this study. Kwamaiko farm is in main coffee growing Agroecozone **(UM2)** with Crops being located in Marginal coffee zone **(UM3).**

The two sites had mature coffee trees with moderate farm management practices being applied. Green scale infestations varied in the two farms. Heavy and moderate infestations occurred at Crops and Kwamaiko coffee farms, respectively.

The sampling for each site was carried out for three (3) years starting from year 2000 to 2003.

Treatments

D-C Tron plus, a petroleum spray oil, at rates of 50, 100 and 200 mls per 20 litres of water were tested in the field against *C. alpinus.* Untreated plots were incorporated as the control. Banding of coffee trees with Dursban 480EC at rate of 700 mls per 20 litres of water was included in our study to compare the effect of spraying on biocontrol agents.

Efficacy Assessment

The efficacy of D-C Tron plus against *C. alpinus* was assessed through the scale's mortality. A Complete Randomized Block Design with four (4) treatments (three rates of D-C Tron plus and the control) replicated four times was used. Each treatment had a plot of nine (9) coffee trees with two rows of coffee between the plots and the blocks as guard rows. When sampling, nine twigs of about six inches each (one twig per tree) with green scale's infestations were sampled fortnightly from each plot. The twigs were each time transported to the laboratory for examination. Both dead scales due to chemical and live ones were recorded. The mean percentage scale's mortality was then computed. Analysis of variance (ANOVA) was applied to determine the efficacy of the D-C Tron plus.

Impact Assessment on Bio Control Agents

The effect of D-C Tron plus application on biocontrol agents of *C. alpinus* was assessed. Unlike in efficacy assessment, Dursban 480 EC at 700 mls per 20 litres of water was included in the trial for banding coffee trees. Banded plots were compared with D-C Tron plus treated ones at rates of 50, 100 and 200 mls per 20 lires of water and the control. A Complete Randomized Block Design with five treatments replicated four times was used. Each treated plot had nine (9) coffee trees with two rows of coffee between the plots and the blocks as guard rows.

From each plot, nine twigs as described in efficacy assessment were sampled fortnightly and taken to the laboratory for examination. Live and dead scales due to parasitism, were counted and recorded. The mean percentage parasitism level was computed using the Analysis of Variance (ANOVA).

The effect of D-C tron plus on ladybirds was assessed by randomly selecting one coffee tree per treated plot. All stages of ladybirds were visually counted and recorded after every two weeks.

RESULTS

Efficacy Assessment

The performance of D-C Tron plus is shown in Table 1. In all the trial sites, the control had lower mean % scales mortality than the treated plots. Except in year 3, there was significantly higher scale mortality for low rate of D-C Tron plus than the control. However, all the D-C Tron plus treated plots never differed significantly in their efficacy from each other. The medium and high rates of D-C Tron plus though performed better than the control did not differ significantly from it. Thus D-C Tron plus at rate of 50mls per 20 litres of water would effectively control *C. alpinus*.

Table 1. Mean Percentage (%) Scale's mortality at Kwamaiko and Crops coffee farms.

Treatment	**Rate Per 20 litres of Water**	**Kwamaiko Farm**			**Crops Farm**		
		Yr.1	Yr.2	Yr.3	Yr.1	Yr.2	Yr.3
D-C Tron Plus	50 mls	28.58 A	31.06 AB	55.38 A	27.79 A	51.22 A	31.67A
D-C Tron Plus	100 mls	29.05 A	35.10 A	54.00 A	24.83 AB	45.58AB	29.78A
D-C Tron Plus	200 mls	26.89 A	33.10 AB	49.68 A	25.79 AB	46.16AB	30.10A
Control	-	22.50 B	29.32 B	49.61 A	22.24 B	29.83B	28.42A
LSD		3.62	4.72	10.69	17.19	19.02	4.38
C.V. (P=0.05)		13.01	17.69	16.66	4.50	35.85	11.86

Means followed by the same letters down the column are not significantly different at P = 0.05

Impact Assessment on Bio Control Agents

The effect of D-C Tron Plus on Green Scale's parasitoids, assessed through % parasitism levels is presented in Figure 1. Both at Kwamaiko and Crops, the mean % parasitism during years 1 and 3, were lower than year 2 for all the treatments. Highest parasitism of 69.41% was found at Crops during year 2 from the banded coffee plots. The lowest 15.83% did occur at Kwamaiko during year 3 also from banded coffee plots. The D-C Tron plus treated coffee plots at both sites generally never differed significantly from the control and banded ones. However at Crops, the banded plots had significantly higher mean % parasitism of 69.41 during year 2 when compared to the control and the D-C Tron plus treatments. The D-C Tron plus treatment rate of 200 mls at Kwamaiko farm showed significantly higher mean % parasitism of 26.97 as compared to the control and the banded plots.

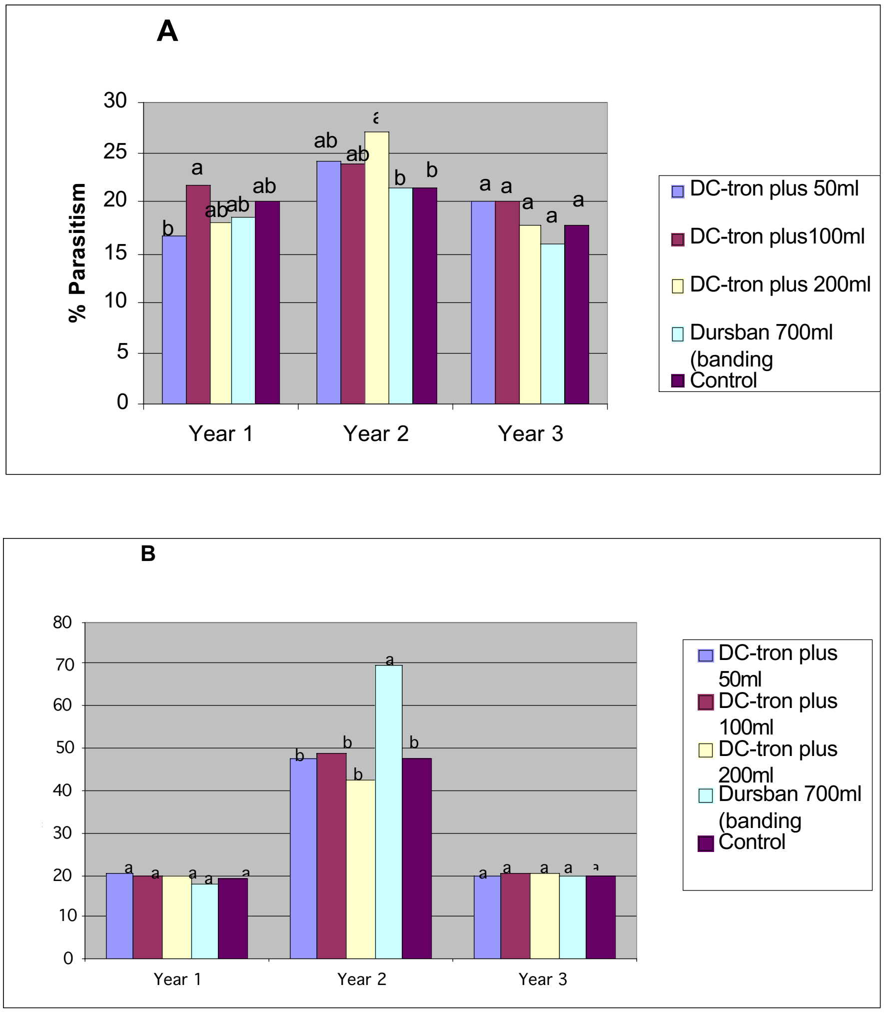
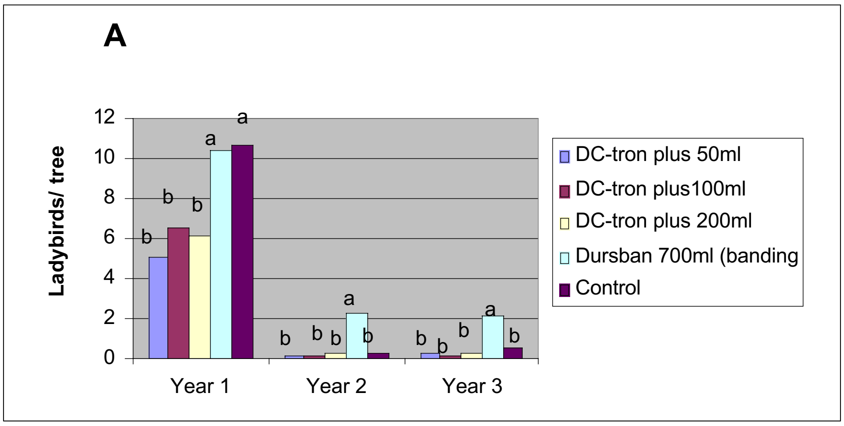


Figure 1. Mean percentage (%) parasitism levels at Kwamaiko (A) and Crops (B) coffee farms under different treatments. Means followed by the same letter do not differ significantly (P = 0.05).

The D-C Tron plus effect on ladybirds, was determined by the mean number of ladybirds per tree. The results of this assessment are presented in Figure 2.

Low mean number of ladybirds per tree occurred during years 2 and 3 on both study sites. During year 1, the ladybirds were numerous at the two sites with highest mean of 34.25 attained at Crops from controlled plots. The lowest mean number of 0.09 ladybirds per tree was observed at Kwamaiko from the D-C Tron plus treatment rate of 100 mls during year 3. At Crops, the D-C Tron plus treated plots never differed significantly from the control and the banded plots except in year 3 when banded plots showed significantly higher mean number of ladybirds per tree. Similarly at Kwamaiko, during years 2 and 3, banded plots had significantly higher mean number of ladybirds per tree than the control and D-C Tron plus treated plots. However, during year 1 at Kwamaiko, the banded and controlled plots had significantly higher number of ladybirds per tree than the D-C Tron Plus treated plots.



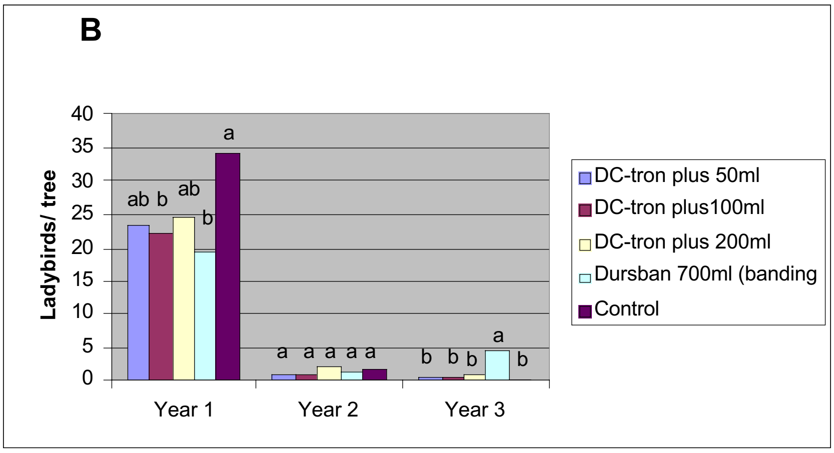


Figure 2. Mean number of ladybirds per tree under various treatments at Kwamaiko (A) and Crops (B) coffee farms. Means followed by the same letter do not differ significantly (P= 0.05).

The results from this impact assessment indicated that the D-C Tron Plus sprays had no significant effect on Green Scale's biocontrol agents.

DISCUSSION

The three rates of D-C Tron Plus as indicated in Table 1 effectively controlled the Green scales. The Management of *C. alpinus* in Kenya is normally carried out by using various insecticides for banding. Foliar spray of any insecticides against *C. alpinus* has never been there and the D-C Tron plus now become the first product to be recommended.

The assessment of D-C Tron plus sprays effect on *C. alpinus* biocontrol agents showed the potential this product has as a biorational pesticide compatible with integrated pest management strategies. During this study, significantly higher mean % parasitism from banded plots occurred at Crops when compared to the controlled and the D-C Tron plus treated plots. This was possible because according to Mugo (1994) efficiency of parasitoids is attained when attendant ants are kept away from the scales through banding. In some cases, the D-C Tron plus had higher mean % parasitism than the control though not significantly better. This experience could have been due to the negative effect of D-C Tron plus on the movement of attendant ants to attend the scales. This effect makes the parasitoids more efficient, probably because the oil sprays according to Liu et al. (1999) are known to cause some behaviour modification which could have happened to the attendant ants.

The results from Figure 2 showed that the predators (ladybirds) preferred mostly he banded coffee plots as compared to the D-C Tron Plus treated and the controlled plots. This support Anon (1975) and Mugo (1994) findings that banded trees keeps away the attendant ants, thus promoting the predators occurrence on Green Scales infested trees. Findings during year 1 at Kwamaiko, had some indications that the banded and the controlled plots had significantly higher number of ladybirds per tree than the D-C Tron Plus treated plots. This situation as observed occurred due to scales mortality from the D-C Tron plus treated plots that caused hosts (Green scales) scarcity. As a result of this, the ladybirds migration searching for the host was likely to have occurred on the controlled and the banded plots where the host prevailed thus increasing the population levels of the ladybirds.

The ability of the D-C Tron Plus to control the *C. alpinus* and subsequently to sustain and conserve its associated biocontrol agents makes this product a suitable component of integrated pest management in coffee farming.

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Agri-Sector Analysis: Competitivity, Technology Demand and Quality for the Coffee Sector of Sao Paulo State, Brazil*

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SUMMARY

In order to identify the demands for possible increasing of share on the Brazilian agribusiness, the coffee sector of Sao Paulo State, Brazil, was analyzed here. Beside this, an accurate understanding of coffee sector is of interesting for policy makers, economic development, trade policies, health, beverage quality and equity objectives. Using Delphi method we verified that the expansion of this sector, through aggregation of new markets, should be carried out by an improvement of cup quality, environmental and social responsibilities, and more investment for the development of new coffee products.

INTRODUCTION

Presently, programs of Research and Development – R&D – at Public Institutions of Sao Paulo State, Brazil, have been carried out with limited financial and human resources, mainly those related to applied research. Then, the prioritization of R&D demands is very important for scientific and technological management. Above that, the productive sector of coffee chain of Sao Paulo State has lost market share in the Brazilian agribusiness, mainly regarding to volume and value of grain production. Consequently, the identification of the actual needs for knowledge and technologies – and their prioritization – is necessary to direct agriculture research, technical assistance and other government policies.

The main objectives of this study are to analyze the coffee sector of Sao Paulo State, Brazil, in order to have a better understanding of its constraints and opportunities, and to identify its demand for possible increase of its share on the Brazilian agribusiness. Specific objective for analyzing the coffee sector is the understanding of competitivity.

This paper identifies research priorities, which should receive especial attention during next years, having in view an increase of the sector competitivity. Also it identifies R&D demands for Sao Paulo State and the order of priority of the technologic and non-technologic strategies for increasing Sao Paulo State share on Brazilian agribusiness.

METHODS

Two basic aspects were evaluated here: competitivity and demand prospection. The methodology consist of (Castro et al., 1995 and 1998; Mecasis, Agropolos, 1999; Townsley, 1996): (a) *a diagnostic analysis*, with the objective of identifying the major limitations of sector components, and the needs for knowledge and technologies (current demands), that could reduce the impact of those limitations, and improve quality, production efficiency and equity along the channel; and (b) *a prognostic analysis* using the Delphi method, which

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consists of the application of iterative questionnaires until a consensus within its audience of specialists has been reached.

Technologic strategies are prioritized for the following five groups: I) Development of cultivars adapted to different environments and plantation systems; II) Development of methods, procedures and agriculture insumes for plant protection; III) Agronomic practices (fertilization and irrigation); IV) Others agronomic practices; V) Harvest, post-harvest and industrialization. Non-technologic strategies are prioritized among the following set: origin guarantee, market development, farms funding, farm inspection, tax incentive, logistic support, legislation and standardization, major sectional organization of the productive chain, institutional marketing, support for quality programs, and registration of sanitary products.

Technologic strategies would produce specific benefits to each producing region of the Sao Paulo State, while non-technological ones will benefit all producing regions of Sao Paulo State.

RESULTS

In the coffee sector of Sao Paulo State we verified that the main successfully strategies of competitivity are destined to achieve quality certification and social responsibility certification – environmental preservation, workers health, food security and non-use of child-work. These strategies allow the differentiation of products and have been adopted by big companies.

Prognostic analysis was performed by 200 invited coffee specialists, that answered iterative questionnaires, and 40,5% of answers were returned.

Using Delphi method, important research subjects for increase of the competitivity of Sao Paulo coffee sector are indicated in Table 1, technologic strategies prioritized for that sector are indicated in Table 2, and non-technologic ones are indicated in Table 3.

Concerning the research subjects that should receive especial attention next years, the priority order is: 1º-Genetic improvement, 2º- Sustainable coffee production systems, 3º- Development of new products and markets, 4º- Coffee quality and standardization, and 5º- Biotechnology (Table 1).

Besides these priorities, the following topics were analyzed: the importance of the size of coffee farms for the sector competitivity, the management of coffee cooperatives, and the sector organization.

Table 1. Prioritization of important research subjects for increase of the competitivity of Sao Paulo State coffee sector.

Important research subjects (81 questionnaires)	**Prioritization** (frequency of answers)				
	1º-	**2º-**	**3º-**	**4º-**	**5º-**
Genetic improvement	**40**	19	4	12	0
Sustainable coffee production systems	26	**24**	17	8	3
Development of new products and markets	11	11	**20**	18	13
Coffee quality and standardization	6	11	20	**23**	16
Biotechnology	4	8	12	10	**40**

Table 2. Technologic strategies prioritized for increase of the competitivity of Sao Paulo State coffee sector.

Strategic group	**Order of priority**	**Technologic strategies** (81 questionnaires)	**Total of indications** (frequency of answers)
Group I	**1º**	Coffee varieties with multiple resistance (rust, nematodes, leaf miner and others)	**50**
Development of cultivars	**2º**	Selection having in view coffee plantations more thickened (for small-scale farmer, smallholders, and regions where the soil has major aggregated value)	**35**
	3º	Coffee varieties with resistance and/or tolerance to abiotic stress	**33**
	4º	Development of coffee varieties with desirable beverage quality and special technological characteristics (low level of acidity for blends, porosity for "express coffee")	**33**
	5º	Section having in view regional evaluation of coffee varieties	**29**
Group II	**1º**	Bio-control of the main pests of coffee plant and their natural enemies	**52**
Methods, procedures and agriculture insumes for plant protection	**2º**	Microclimatic interactions in different handling conditions	**46**
	3º	Development of pheromones	**45**
	4º	Development of traps	**40**
	5º	Resistance of pests and pathogenic agent to agricultural defensives	**35**
Group III	**1º**	Sustained management of soil fertility	**40**
Agronomic practices (fertilizatio n and irrigation)	**2º**	Manuring and nutrition of coffee varieties	**30**
	3º	Nutrition and coffee quality	**28**
	4º	Pruning and mineral nutrition of coffee plant	**27**
	5º	Organic fertilization: green manuring and utilization of agri-industrial and urban residues	**24**
Group IV	**1º**	Integrated management of pests, diseases and nematodes	**44**
Others agronomic practices	**2º**	Organic and ecological coffee plantation	**43**
	3º	Production system to improve the beverage Quality of coffee	**36**
	4º	Recuperation of degraded soil	**28**
	5º	Spacing and density of planting	**28**
Group V	**1º**	Development and improvement of technologies for drying	**44**
Harvest, post-harvest and industrialization	**2º**	Development of technologies to improve the productive efficiency and the beverage quality of coffee	**43**
	3º	Development of new technologies to use defective coffee beans	**36**
	4º	Improvement of work conditions of coffee gatherer (security equipment and worker health)	**28**
	5º	Development of technologies to utilization of agri-industrial residue (straw and dregs)	**24**

Results demonstrated that the most important factor for the survival of coffee sector is the production of high quality beverage and with efficient technical and administrative management, and independent of the farm size.

Inadequate management of many coffee cooperatives results in high costs and interests for the coffee producer. In this way, new organizational models are necessary for an agri-industries control by small farmers, which could permit an origin certification and insertion of their coffee into a differentiated market.

The number of class associations in the coffee productive chain has increased lately. This intensification should contribute for sector survival and for the competitivity of coffee business. Farmer organizations, particular those of smallholder, results in more negotiation power, and therefore are very important for their survival.

Table 3. Non-technologic strategies prioritized for increase of the competitivity of Sao Paulo State coffee sector.

Order of priority (81 questionnaires)	**Non- technologic strategies**	**Total of Indications**
1º	Market development	30
2º	Major sector organization (integration and co-ordination)	31
3º	Support to certification (origin guarantee)	36
4º	Support to quality programs	29
5º	Farm funding	20

CONCLUSIONS

Expansion of coffee sector of Sao Paulo State and increase of its share on the Brazilian agribusiness, throw aggregation of new markets, should be carried out by an increase in the beverage quality of coffee, more environmental and social responsibilities, and more investment in new coffee products.

Toasted and ground coffee industrial segment should aggregate more value, via development and improvement of technologies of drying and technologies of utilization of defective coffee beans. Development of technologies would improve the productive efficiency and the beverage quality of coffee. The special coffee segment (*gourmet*), traditionally exported, would be improved by an increase of internal coffee consume.

In Sao Paulo coffee regions, where soil and climate are favorable and allows coffee production without an irrigation system and harvesting in periods with low index of humidity, the maintenance or the increase of the competitivity are related to differentiation of the coffee production. In some Sao Paulo coffee regions, the search for competitivity should consider a technical assistance, introduction of new techniques for coffee prepare, such as cherry coffee beans without pulp, and the development of new scientific research teams.

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Effect of Rooting Media, Hormone and Half-node Cutting Types on Vegetative Propagation of *Coffea canephora* Pierre ex. Froehner

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SUMMARY

An experiment was initiated at the premises of Cocoa Research Institute of Nigeria (CRIN), Ibadan to evaluate the effect of rooting medium, hormonal treatment and use of half node on the Vegetative propagation of *Coffea canephora Pierre ex. Froehner*. There were three factors of media, hormone and cutting type of three, two and two levels respectively. Media evaluated were sawdust, topsoil and sawdust/topsoil. Two types of cuttings, full node and half node treated or not treated with indole butyric acid (IBA) were also investigated, giving twelve treatment combinations, replicated three times. Result obtained from all the parameters evaluated viz number of cutting sprouted, number callused, number rooted and percentage survival revealed no significant difference in all the treatments except on the root length, where IBA treatment had significant influence at ($p = 0.05$). The least value of percentage sprout of 40 was recorded in with and without hormone full node cuttings treatment in topsoil medium. The results obtained from this study have therefore shown that any of the media may be used in vegetatively propagating coffee with or without hormone and that the use of half node cutting which can give more planting materials is also possible and practicable as against hitherto used multiple or full node cuttings.

INTRODUCTION

Coffee is one of the important export crops worldwide. To improve the production of this important crop therefore, efforts have to be made right from nursery level to harvesting stage to ensure qualitative production. Coffee seedlings distributed in Nigeria to farmers until recently are propagated by seeds (Adenikinju et al., 1989). Propagation of *robusta* coffee by seeds may lead to decline production as the plant is self-sterile (Pochet, 1987). In the light of the above, research efforts were made in the past to explore the use of vegetatively propagated materials as planting materials (Oyebade, 981). However the types of cuttings used by the author were multi-nodal i.e. cuttings of about 15-20 cm in length containing three or more leaves. (Omolaja and Obatolu, 1999) exploited further the use of hormonal treated cuttings at different concentrations and found that 4000 mg/l of IBA was the most successful.

The advantages of vegetatively propagated *robusta* coffee are multi-various ranging from shorter nursery period; more vigorous cuttings; early fruiting; disease resistance (for resistant clones); guaranteed genetic stability and improved yields. In order to maximize these advantages and find an easily adoptable method of vegetatively propagating coffee, experiment was initiated at the Cocoa Research Institute of Nigeria (CRIN) to look at the possibility of half node cuttings that can guarantee more planting materials, avoidance of hormonal treatment in rooting medium/media in the Southern parts of Nigeria.

MATERIALS AND METHODS

The experiment was initiated at the Headquarters of Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria to evaluate the rooting performance of hormone treated full and half node cuttings of *Coffea canephora Pierre ex Froehner* set on different rooting media.

The treatments evaluated were cutting type (full and half node cuttings); hormone treatments (with or without 4000 gm/l Indol – 3 – butyric acid quick dip and rooting media (forest topsoil, weathered sawdust and sawdust over topsoil at ratio 1:3.

Orthotropic shoots of clone 108 of *Coffea canephora Pierre ex froehner* was harvested early in the morning and the base of the harvested shoots were dipped in water to reduce the rate of evapo-transpiration. They were taken to the nursery were the cuttings were prepared according to the method of Pochet (1987). The cutting was done using sharp budding knife. For the half node, a full node was split into two. The cuttings were immersed in water for a period of 30 minutes.

The rooting media were filled into a black polythene bag of dimension 30 cm x 6.25 cm which is capable of giving up to 200 cuttings per square metre. They were then arranged on a prepared bed of dimension 2 m x 1 m. Flexible sticks of about 1.5 metre in length were bent over the bed on which transparent polythene sheet was then spread on the bent sticks after the pots with cuttings have been arranged and thoroughly watered. The polythene sheet was then buried along the edges of the bed – to ensure humidified environment for the cuttings.

The treatments were factorially laid out in Completely Randomized Design (CRD) and replicated three times. Each replicate contains 10 cuttings, giving a total of three hundred and sixty cuttings. The cuttings were examined fortnightly for any sign of water stress and where observed, the cuttings were watered and the polythene sheet closed back. After sixty day of setting the cuttings, they were examined for sprouting and rooting (2) quoted between 8-12 weeks for rooting to take place in *Coffea canephora*. The following parameters viz percentage sprouted, callused, rooted, root length (Primary and Secondary) and survival count were evaluated.

RESULTS AND DISCUSSION

Results as shown in Table 1 on percentage cutting sprouted revealed no significant difference in the various treatment combinations evaluated with full node cutting in sawdust on topsoil medium, with or without hormone recording 73 percentage. However this result is not significantly different from half node cutting, with or without hormone in similar medium, which was 70 percent. The little difference in sprouting could be due to exposure of the internal tissues in half node cutting (Pochet, 1987). The better rooting performance of sawdust on topsoil medium (1:3) could be due to the fact that weathered sawdust encourages rooting while the forest topsoil supplies the necessary nutrients for further growth of the cuttings (Pochet, 1987; Coste, 1992), have mentioned sawdust as a good rooting medium for coffee. The lower percentage sprouting in topsoil medium of between 40-60% may be due to some inherent pathogen in the medium and lateness in root initiation compare with sawdust medium. Other parameters like percentage callused, rooted and survival followed similar trends. However there was a higher root length recorded for full node cuttings in sawdust on topsoil medium with hormone, the hormone could have enhanced the level of root initiation at the concentration used (400 mg/l) as was experienced by (Omolaja and Obatolu, 1999).

This study has revealed that raising *robusta* coffee cuttings can easily be done by the local farmers without exploiting the conventional, more expensive propagator method. Hence, the half node cutting, found to be successful, if practiced by farmers will result in higher planting materials and reduced cost. The use of half node without hormone in sawdust on topsoil medium (1:3) is therefore recommended, as the method used is easily adoptable by local coffee farmers.

Table 1. Mean Values for Parameters Measured.

Treatments	Percentage sprouted	Percentage callused	Percentage rooted	Percentage survival	Root length (cm)
$m_0c_0h_0$	40	40	40	40	1.62
$m_0c_0h_1$	57	60	60	60	5.60
$m_0c_1h_0$	60	60	60	60	5.03
$m_0c_1h_1$	70	70	70	70	7.05
$m_1c_0h_0$	73	73	73	73	6.60
$m_1c_1h_6$	60	60	60	60	5.02
$m_1c_0h_1$	73	76	76	73	8.12
$m_1c_1h_1$	70	70	70	70	6.27
$m_2c_0h_0$	70	73	73	73	5.03
$m_2c_0h_1$	60	60	60	60	6.23
$m_2c_1h_0$	57	57	57	57	2.90
$m_2c_1h_1$	67	67	67	67	6.67
SE (P – 0.05)	NS	NS	NS	NS	2.80

M = media used: m_0 (topsoil); m_1 (sawdust on topsoil) and m_2 (weathered Sawdust). C = cutting type: c_0 (full node) and c_1 (half node). H = hormonal treatment: h_0 (without hormone) and h_1 (with hormone).

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Genetic of Rooting and Sprouting Abilities on Cuttings Propagation of Robusta Coffee Clones (*Coffea canephora* Pierre var. *robusta* Cheval)

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SUMMARY

A study to evaluate the genetic of rooting and sprouting abilities on cuttings propagation of robusta coffee was carried out at Kaliwining Experimental Station (45 m a.s.l.) at Jember, East Java. The experiments were conducted under rainy season as well as the dry one by using randomised complete block design with 14 clones and 4 replications. Cutting materials consisted of a node with 4-5 cm length of internodes. Each clone consisted of 100 cuttings in one replication without using any growth regulators. Cutting materials were planted on cutting bed. Observation was done after three months. The observed parameters were percentage of rooted cuttings, number of roots, total of root length, number of sprouts and total of sprout length.

The results showed that the percentage of rooted cuttings on rainy season is higher than that of on the dry one, in contrast the rooted cuttings possessed less number of roots and shorter length of roots as well as lighter roots dry weight. The success of cuttings propagation was significantly affected by genetic factor (clone), especially on the characteristics of percentage of rooted cuttings, total roots length and number of roots. BP 409 was considered the most difficult clone to be propagated by cuttings. Percentage of rooted cuttings and total roots length showed high heritabilities, that the two characteristics might be used as selection criteria in order to find high yielding robusta coffee clones which are able to be propagated by cuttings easily.

The highest general combining ability (GCA) of the two mentioned characteristics was belonged to Q 121 clone. The highest specific combining ability (SCA) of the percentage of rooted cuttings was performed by crossings of BP 409 X BP 42, Q 121 X BP 961 and BP 961 X BP 358. Crossings of BP 409 X BP 358 and BP 42 X Q 121 performed the highest SCA on total length roots.

INTRODUCTION

Vegetative propagation is an essential thing to be applied on robusta coffee planting in order to get high yield and uniform quality of beans. Propagation of coffee clone by cuttings bears several advantages such as genetic uniformity, less expensive than grafted seedling and faster growth (Nur & Sulistyo, 1987). At the same density, planting material from cuttings performed higher yield 75-89% than that of from seedling (Snoeck, 1988).

Distribution type of feeder roots of mature coffee bush from cuttings (BP 358 clone) were not significantly different to that of from seedling (BP 358 X BP 42), namely some 80% of the roots grew in the zone of 30 cm depth and 110 cm from the trunk (Nur & Zaenudin, 1986). Adaptability of cuttings robusta planting to water stress depends on its clone (genetic factor), for instant BP 409 clone performed more tolerant to the mentioned condition than that of BP 358 and BP 288 clones (Nur & Zaenudin, 1992).

Field experience showed that each clone of robusta coffee performed different response on rooting ability as well as its sprout formation. This report was aimed to inform the genetic background of rooting and sprouting abilities on robusta coffee propagated by cuttings.

MATERIAL AND METHOD

The study was carried out at Kaliwining Experimental Station of ICCRI located at Jember (East Java) on 45 m altitude with dry climate type. This study used a node of ortothrophic branch with 4-5 cm internodes length. Cuttings were planted into a mixture of sand, topsoil and cow dung manure with proportion of 2:1:1 without using any plant growth regulator. In order to maintain humidity and temperature, the cuttings beds were covered with transparent plastic sheet for some three months.

Fourteen clones of robusta coffee consisted of nine promising clones (BP 397, BP 418, BP 436, BP 534, BP 913, BP 920, BP 936, BP 939, and SA 203) and five recommended clones (BP 42, BP 358, BP 409, and BGN 371) were used to study variability, genetic variance and heritability. Cuttings propagations were conducted on dry and rainy season by using randomised complete block design with four replications.

Parameters observed in this experiment were percentage of rooted cuttings, number of roots, total roots length, root dry weight, number of sprouts and total sprouts length.Genetic variance of each characteristic was estimate by the following model.

$$\mathbf{Y_{ijk} = \mu + M_j + (B/M)_{kj} + K_i + (K{*}M)_{ij} + e_{ijk}}$$

Where, $\mathbf{Y_{ijk}}$ (mean of i-th clone and j-th season), $\boldsymbol{\mu}$ (general mean), $\mathbf{M_j}$ (effect of j-th season), $\mathbf{(B/M)_{k\,j}}$ (random effect of k-th bock on j-th season), $\mathbf{K_i}$ (effect of i-th clone), $\mathbf{(K{*}M)_I}$ (interaction effect of i-th clone and j-th season), $\mathbf{e_{ijk}}$ (experimental error).

Genetic variance (σ^2_G) was estimated by clone variance, whereas environmental variance (σ^2_L) was estimated by season variance. The following are formulae to estimate each variance.

$$\sigma^2_L = (\sigma^2_{(M)} - \sigma^2_{(K*M)})/ik,\ \sigma^2_G = (\sigma^2_{(K)} - \sigma^2_{(K*M)})/jk,\ \sigma^2_T = \sigma^2_G + \sigma^2_L,$$

$$\mathbf{H^2} = \{\sigma^2_G / (\sigma^2_G + \sigma^2_L)\} \text{ X } 100\ \%$$

Where, $\sigma^2_{(M)}$ (mean of sum square of season), $\sigma^2_{(K)}$ (mean of sum square of clone), $\sigma^2_{(K*M)}$ (mean of mean square of interaction between clone and season), $\sigma^2_{(G)}$ (genetic variance), $\sigma^2_{(L)}$ (season variance), $\sigma^2_{(T)}$ (total variance), $\mathbf{H^2}$ (*broad sense heritability*).

Classification of heritability according to McWhirter (Griffing, 1956) is high ($\mathbf{H^2} \geq 0{,}50$), medium ($0{,}20 \leq \mathbf{H^2} \leq 0{,}50$), and low ($\mathbf{H^2} < 0{,}20$).

General combining ability (GCA) and specific combining ability were estimated by making partial diallel 5 X 5 crossing consisted of F1 and its reciprocals of five clones (BP 409, BP 42, Q 121, BP 961 and BP 358). Estimation of GCA and SCA was carried out according to Griffing (1956) method 4.

RESULT AND DISCUSSION

Varibility of rooting and spouting ability between robusta clones used in this experiment is mentioned in Table 1. BP 409 performenced the lowest percentage of rooted cuttings, whereas the highest one was belonged to SA 203. BP 409 also performenced the lowest of number of root per cuttings, total root lenght per cuttings and root dry weight.

Table 1. Mean of observed characteristics of each robusta clone.

Clone	PRC	NRC	RLC	RWC	NSC	SLC
BP 42	40.6^{bc}	3.1^{abc}	7.2^{abcd}	12.8^{a}	1.6^{a}	2.7^{a}
BP 358	48.0^{bc}	2.8^{ab}	9.6^{d}	10.9^{a}	1.6^{a}	3.8^{bc}
BP 397	37.1^{b}	$2,3^{a}$	7.9^{abcd}	12.9^{a}	1.7^{a}	4.2^{c}
BP 409	10.4^{a}	2.1^{a}	5.4^{a}	9.0^{a}	1.6^{a}	2.4^{a}
BP 418	43.7^{bc}	3.1^{abc}	7.7^{abcd}	12.9^{a}	1.7^{a}	2.9^{a}
BP 436	43.6^{bc}	2.8^{ab}	7.4^{abcd}	10.9^{a}	1.8^{a}	2.7^{a}
BP 534	36.4^{b}	3.0^{abc}	6.0^{ab}	12.3^{a}	1.7^{a}	2.3^{a}
BP 913	50.1^{bcd}	3.7^{de}	7.2^{abcd}	11.2^{a}	1.8^{a}	3.5^{ab}
BP 920	38.0^{b}	3.2^{abc}	6.8^{abc}	12.3^{a}	1.8^{a}	2.8^{a}
BP 936	64.0^{cd}	3.6^{bcde}	8.6^{bcd}	9.5^{a}	1.6^{a}	3.4^{ab}
BP 939	55.5^{bcd}	3.6^{bcde}	6.7^{ab}	10.0^{a}	1.7^{a}	3.3^{ab}
SA 203	53.3^{bcd}	3.4^{bcde}	7.9^{abcd}	14.4^{a}	1.6^{a}	5.5^{d}
SA 237	74.3^{d}	3.8^{e}	8.7^{cd}	13.5^{a}	1.8^{a}	5.5^{d}
BGN 371	56.8^{bcd}	3.6^{cde}	6.9^{abcd}	11.1^{a}	1.7^{a}	3.6^{b}

PRC - Percentage of rooted cuttings. RWC - Root dry weight per cutting (gr). NRC - Number of roots per cuttings. NSC - Number of sprouts per cutting. RLC - Total root length per cutting (cm). SLC - Total sprouts length per cutting (cm). Figures at the same column followed by the same letter are not significantly different at 5% level according to DMRT.

As mentioned in Table 2 season influenced to cuttings propagation. Percentage of rooted cuttings in the rainy season was higher than that of dry one, however dry season was recorded more favourable for root and sprout growth.

Table 2. Mean of rooting and sprouting characteristics observed on each season.

Rooting characteristics	Rainy season	Dry season
Percentage of rooted cuttings	52.0^{a}	41.1^{b}
Number of roots per cuttings	2.6^{a}	3.6^{b}
Total root lenght per cuttings (cm)	6.9^{a}	7.9^{b}
Roots dry weight per cuttings (gr)	11.7^{a}	19.4^{b}
Number of sprouts per cuttings	1.8^{a}	1.6^{b}
Total sprouts lenght per cuttings (cm)	2.1^{a}	4.8^{b}

Figures at the same row followed by the same letter are not significantly different at 5%.

Table 3 showed the genotypic (clone) and season variances of rooting and sprouting characteristics on robusta coffee. Based on the variance analysis, heritability of each characteristic was estimated. Percentage of rooted cuttings and total of root length performed high heritability, whereas root dry weight and number of sprout per cutting performed the lowest one. The medium heritabilities were identified on number of roots and total sprouts length.

Table 3. Genotype (clone) and season variances of each cutting characteristic of robusta coffee.

Characteristics	Var. Clone	Var. Season	Var. Total	Heritability, %
Percentage of rooted cuttings	200,6302	55,4440	256,0742	78,34
Number of roots	0,2511	0,4983	0,7494	33,51
Total of roots lenght (cm)	0,8811	0,4478	1,3290	66,30
Roots dry weight (mg/cuttings)	0,5198	21,6516	22,1714	2,34
Number of sprouts	0,0023	0,0220	0,0243	9,59
Total of sprouts length (cm)	0,8885	3,7795	4,6680	19,03

Percentage of rooted cuttings and total roots length are expected to be important characteristics on breeding program mainly dealing with the cuttings propagation. More genetic information on combining ability of the two characteristics was explored too as mentioned in Table 4 for GCA and Table 5 for SCA.

Table 4. General combining ability (GCA) of rooting and sprouting characteristics.

Clone	PRC	NRC	RLC	NSC	SLC
BP 409	-6.083^{d}	0.087^{b}	-0.392^{b}	-0.003^{a}	-0.422^{cd}
BP 42	-3.583^{cd}	-0.242^{bc}	-0.900^{b}	0.056^{a}	0.162^{b}
Q 121	**8.083^{a}**	-0.026^{b}	**1.446^{a}**	-0.036^{a}	**1.020^{a}**
BP 961	-1.500^{c}	**0.799^{a}**	**1.138^{a}**	0.018^{a}	-0.555^{d}
BP 358	3.083^{b}	-0.617^{c}	-1.292^{b}	-0.036^{a}	-0.205^{c}

Figures at the same column followed by the same letter are not significantly different according to Critical Different Test at 5 % level.

Table 5. Specific combining ability (SCA) of rooting and sprouting characteristics.

Clone	PRC	NRC	RLC	NSC	SLC
BP 409 x BP 42	**4.167^{a}**	-0.110^{cd}	-0.096^{bcd}	0.017^{bc}	-0.087^{bcd}
BP 409 x Q 121	-3.750^{bc}	-0.465^{de}	-0.754^{cd}	-0.017^{c}	-0.171^{cde}
BP 409 x BP 961	-1.667^{ab}	**0.910^{a}**	0.179^{bc}	-0.183^{d}	**0.292^{ab}**
BP 409 x BP 358	1.250^{ab}	-0.335^{de}	**0.671^{ab}**	**0.183^{a}**	-0.033^{bcd}
BP 42 x Q 121	3.750^{bc}	**1.077^{a}**	**1.329^{a}**	-0.050^{c}	**0.546^{a}**
BP 42 x BP 961	-6.667^{c}	-0.710^{e}	-0.625^{cd}	0.108^{ab}	-0.092^{bcd}
BP 42 x BP 358	-1.250^{abc}	-0.256^{cd}	-0.608^{cd}	-0.075^{c}	-0.367^{de}
Q 121 x BP 961	**4.167^{a}**	-0.702^{e}	-0.033^{bcd}	**0.125^{a}**	-0.487^{e}
Q 121 x BP 358	-4.167^{bc}	0.090^{c}	-0.542^{cd}	-0.058^{c}	0.113^{bc}
BP 961 x BP 358	**4.167^{a}**	0.502^{b}	0.479^{b}	-0.050^{c}	**0.288^{ab}**

See Table 4.

The highest GCA of percentage of rooted cuttings and total root length was belonged to Q 121 clone. Q 121 is expected to be an important parental in order to do breeding for improving of cuttings propagation. The clone also performed the highest GCA of sprout length per cutting.

The highest specific combining ability (SCA) of the percentage of rooted cuttings was performed by crossings of BP 409 X BP 42, Q 121 X BP 961 and BP 961 X BP 358. Crossings of BP 409 X BP 358 and BP 42 X Q 121 performed the highest total length roots.

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Effect of Coffee Seeds Pre-germination Practice on Tap Root Development

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SUMMARY

Pre-germination (germinating seeds before sowing) is a common practice among the extension agents of coffee and Tea Authority (CTA) of Ethiopia. However, the effects of such practice and nursery soil preparation on taproot development were not studied. In this study, bulks of seeds of 15 released selections were pre-germinated between sacks with and without treating with fungicides. Concurrently, part of the untreated bulk were seeded directly on conventional seed-beds. Polythene tubes with course (unsieved) and fine soil were used to grow the pre-germinated seeds.

Highly significantly large percentage of hypocotyls were initiated from seeds sampled from untreated bulk as compared to seeds sampled from the treated bulk seeds, but highly significantly more percentage of rotten seeds were also observed in the bulk seeds untreated with fungicides (3.84%) than in the treated bulk seeds (2.01%). Large percentage of cotyledon and first pair of true leaves were initiated much earlier from direct sowing than from pre-germination practice. Percentage of multiple and crooked tap roots under fine and course soils and seed-bed were significantly higher from the pre-germination than from direct sowing. Relatively large percentage of seedling stand, however, was recorded from the pre-germinated and planted seeds than from directly seeded as expected, because no screening was made for nonviable seeds before direct sowing. From these observations it was concluded that pre-germination was the primary cause of malformed root system and eventual early tree death in the field.

INTRODUCTION

Pre-germinating of coffee seeds was a common practice by the development agents of the agricultural bureau. It is practiced mainly to compensate the delay in the time of sowing due to delay in seed-bed preparation and to avoid unviable seeds. However, effects of such practices were not studied. In East Africa, pre-germinating coffee seeds using wet sacks, sand media, etc., was found to reduce germination time by three weeks compared to six to eight weeks of germination on conventional direct seed-bed, and the pre-germinated seeds did not reach the cotyledon stage any quicker than seeds sown on direct seed-bed (Fernie, 1961). According to Fernie (1961), pre-germination practice in coffee necessitates transplanting of the germinated seeds on exact stage of the radicle and on specific dates. He noted that sowing *in situ* in permanent bed minimized root malformation to a large extent compared to transplanting. Similarly, Silveira et al. (1964) reported that deformed roots were more frequent with pre-germinated seeds than with direct sowing.

The present study was prompted by the problem of tree death noted under field condition and this was suspected to be associated with malformed root system arising from pre-germination, poor seed-bed preparation and other factors. The objectives of this study were: (Copal and Ramaiah, 1971) to see the effects of pre-germination and different soil preparation practices on proper formation of taproots, and (Fernie, 1961) to see the effect of fungicidal treatment of the seeds on pre-germination.

MATERIALS AND METHODS

Bulked seeds of 15 released coffee berry disease (CBD) resistant cultivars was divided in to two equal batches and kept between wet sacks for pre-germination (also known as cheating). One batch received weekly fungicide (Captafol 80% WP at the rate of 3kg/ha) spray while the other batch was left without captalfol spray, but water spray simultaneously till germination commenced. Concurrently, seeds from the bulk were directly sown on seed-bed and in polythene tubes filled with coarse (unsieved) and fine (sieved) soils. Later, pre-germinated seeds were also planted on seed-bed and sieved and unsieved soils. The experiment was conducted in the nursery under 50% shade at Jimma agricultural research Center.

The treatments were recorded for percent germination, rotten seeds, initiated cotyledon and true leaves, and malformed root system. The data were analyzed using the procedure of two-stage nested design by considering seed batches as fixed and soil media as random variables.

RESULTS AND DISCUSSION

Differences between batches (sprayed and unsprayed) were significant for all the characters measured while differences between soil medias (seed-bed, course soil and fine soil) were significant only for percent germination and radicle length (Table 1). The mean scores of the unsprayed batch were considerably higher for seed germination (7.9%), rotten seeds (3.84%), and radicle length (1.64cm) than that of the sprayed batch (Table 2). This result clearly suggested that fungal rotting could be avoided by spraying the seeds with fungicides and the fraction of rotten seeds (2.01%) observed with sprayed batch might have been attributed to seeds containing poorly developed embryos and endosperm. On the other hand, it appeared that spraying retards the germination of healthy seeds as reflected by radicle length and percent germination.

Table 1. Mean squares from the analysis of variance for different characters.

Source of variation	Mean squares					
	Germina-tion	Rotten seeds	Radicle length	Multiple taproots	Crooked taproots	Seedling stand
Batch	167.38^{*}	20.00^{**}	14.70^{**}	6.99^{**}	5754.17^{**}	96.63^{**}
Media	22.72^{**}	2.13	1.45^{*}	0.25	36.46	8.56
Error	2.59	0.75	0.45	0.89	210.10	9.53

$^{*, **}$*Significant at 0.05 and 0.01 probability levels, respectively.*

Table 2. Treatment means for different characters.

Treatments	Seed Germination (%)	Rotten Seeds (%)	Radicle Length (cm)
Sprayed batch	2.62	2.01	0.43
Unsprayed batch	7.90	3.84	1.64
L.S.D 0.01	3.82	1.76	1.17

The development seedlings with multiple and crooked taproots were strikingly frequent with pre-germinated batches, sprayed and unsprayed, as compared to direct sowing in all fine soil, coarse soil and conventional seed beds (Table 3). These results suggested the significant advantage of direct sowing over pre-germination be it sprayed or not for fungus and that pre-germination under wet sacks is a dangerous practice.

Table 3. Mean percentage values of different treatment combinations for the characters measured.

Treatment	Fine soil			Fine soil			Conventional seedbed		
	MTR	CTR	SS	MTR	CTR	SS	MTR	CTR	SS
Sprayed batch	36	65	92	36	66	94	20	45	87
Unsprayed batch	26	67	89	28	74	87	20	86	85
Direct sowing	1	24	-	6	20	-	0	30	82
LSD – 0.05	7.4	21.5	4.8	7.4	21.5	4.8	-	-	-
– 0.01	10.1	29.5	6.7	10.1	29.5	6.7	-	-	-

MTR= Multiple taproot, CTR= Crooked taproot, SS= Seedling stand.

Fast seedling development was also observed with direct sowing compared to pre-germinated seeds (Figure 1). In the first week of observation, about 20% of the total seeds under direct sowing reached cotyledon stage while in all other treatments with pre-germinated seeds only less than 3% of the total seeds reached cotyledon leaf stage. Similar trend was observed for true leaves stage. This finding is very much in conformity with that of Fernie in East Africa (Fernie, 1961).

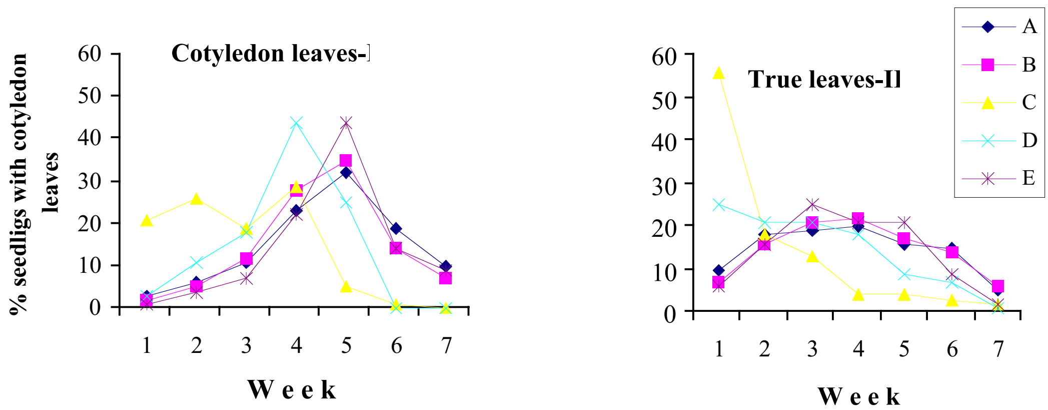

Figure 1. Weekly increment of seedlings with first pair of cotyledon (I) and true (II) leaves for treatments A = sprayed, pre-germinated and planted in polythenes, B = unsprayed, pre-germinated and planted in polythenes, C = direct sowing on seed-bed, D = unsprayed, pre-germinated and planted on seed-bed, and E = sprayed, pre-germinated and planted on seed-bed.

The advantage of screening non viable seeds through pre-germination was demonstrated by the high percentage of seedling stand per plot as compared to direct sowing. The advantage, however, was overwhelmingly outweighed by the disadvantages of malformed root system emanating from unavoidable malpractices of the operation. Any hour of delay in transplanting the pre-germinated seeds as reported in East Africa will aggravate the situation and such sensitive operation is impractical for large scale plantation.

Based on the observed large number of deformed root systems, we concluded that pre-germination was a major cause of early (fourth or fifth bearing) tree death in the field. About 80% of the weak necrotic plants uprooted from the farmers field and CIPA (coffee improvement project areas) at Yirgacheffe had deformed (forked, goose-necked and double goose-necked) taproots. In general, for the production of healthy and strong seedlings, we strongly recommend that coffee should be seeded directly in seed-bed or polythene tube and if seed viability is doubtful, two seeds per hole should be seeded and then thinned to one plant. This will allow the seedlings to develop normal root systems vis-à-vis healthy shoot systems provided proper seed-bed preparation and nursery management is practiced.

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Testing of Selected Coffee Cultivars for Root Development at Bebeka State Farm

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SUMMARY

Bebeka is one of the big coffee (*Coffea arabica* L.) plantations in Ethiopia. There are two sites of this farm known as D10 and F10, which are characterized by different soil types. The soil at D10 is reddish-brown, deep and friable (ideal coffee soil) and that of F10 is ashy, sandy-gravel and shallow with some clay pan formation beneath the ground. Seven cultivars were planted at both sites using RCB design in two replications with 20 trees per plot. The objectives were to see varietal differences in root development on different soil types. The selections were evaluated for yield, survival rate, girth, tap root length, length of laterals and root dry weight.

Differences between cultivars were significant ($P < 0.05$) for yield and other characters except tap root length. The compact cultivar 74112 consistently showed lower mean performance followed by the high altitude cultivar 7332 than others for almost all characters at both sites. Cultivar x location interaction was not significant for all the characters measured suggesting the consistent response of the cultivars to both sites. However, the average performances of the cultivars were consistently greater at D10 than F10 suggesting that the soil at F10 had some degree of obstruction on the characters measured. In general, from the results of the present field and the previous nursery experiments, it was concluded that: (Mesfin Ameha et al., 1989) healthy and vigorous seedlings could be obtained by using seed-beds prepared from mixtures of fine forest soil and sand at 2:1 ratio, respectively, (Bayetta Bellachew et al., 1993) the presence of varietal differences and low yield at both sites (6.45 and 6.13 Qt/ha at D10 and F10, respectively) suggested the need of searching for high yielding and adaptable cultivars for Bebeka area, and (Fernie, 1970) the obstruction effect of the soil at F10 on root development and other characters could be improved by using healthy and vigorous seedlings, larger hole size (60 x 60 x 60 cm) and proper management practices.

INTRODUCTION

Bebeka is the biggest coffee state farm among others, which covers about seven thousand hectares of land. It is located 32km south of Mizan Teferi town at an altitude between 900 and 1200 m (Bayetta Bellachew et al., 1993). It is surrounded by dense forest, which contains diverse wild species of coffee (*C. arabica* L.), spices and other plants. The climate is hot and humid (Lakew Belayneh, 1986; Paulos Dubale and Tesfaye Shimber, 1994). The annual average rainfall is over 1750 mm while monthly average minimum and maximum temperatures are about 16°C and 31°C, respectively. The soil is generally said to be deep, rich in organic matter, and loamy-clay type with PH ranging from 4.5 to 5.5. There are also small patches of swampy areas not suitable for coffee. Generally, however, Bebeka is said to be marginal for coffee production due largely to its low altitude, high temperature and erratic rainfall distribution (Fernie, 1970; Paulos Dubale and Tesfaye Shimber, 1994).

At Bebeka coffee plantation, low yield and tree death are some of the major problems. The problems associated with varietal adaptation, disease and climate have been studied, but problem associated with varietal differences in root development and the effects of soil types on the ability of the roots to penetrate deep in to the ground was not investigated. Root development is very important to coffee tree growth and productivity and soil is said to play an important role in varietal performances (Paulos Dubale and Zebene Mikru, 1994). There are two major sites in Bebeka state farm known as D10 and F10, which are characterized by different soil types. The soil at D10 is reddish brown, deep and friable (ideal coffee soil) covering majority of the farm and that of F10 is ashy, sandy gravel and shallow with some clay pan formation beneath the ground, which makes it difficult for root penetration and moisture conservation (Paulos Dubale and Tesfaye Shimber, 1994). The same coffee variety performed differently at the two sites and poor root development owing to soil problem was the most suspicious for the poor performance of the coffee trees at F10. The objectives of the present study, therefore, were to see varietal differences in root development and effects of soil type on root development and yield performance at Bebeka state farm.

MATERIALS AND METHODS

Seven coffee cultivars which were developed at Jimma Agricultural Research Center (JARC) were selected for this study (Table 1). Seedlings were raised in polythene bags filled with mixtures of forest soil and sand in 2:1 ratio, respectively, as recommended during the first phase of this study, seedling evaluation of cultivars for root and shoot development (Mesfin Ameha et al., 1989).

The cultivars were planted at two locations known as D10 and F10 in Bebeka state farm using RCB design in two replications with 20 trees per plot. The trees were grown without shade and all the experimental plots were uniformly and properly treated using Bebeka's management practices. Data were collected for yield, survival rate, stem diameter (girth), taproot length, length of laterals, and root dry weight using the established procedure at JARC. The data were analyzed using the procedures of factorial design in RCBD to compare the different treatments.

RESULTS AND DISCUSSION

Mean squares due to cultivars were significant ($P < 0.05$) for yield and survival rate and highly significant ($P < 0.01$) for girth, length of lateral roots and root dry weight and not significant for taproot length (Table 1) suggesting the presence of considerable variations between the seven cultivars for almost all the characters measured. Differences between sites were, however, significant only for survival rate ($P < 0.05$), length of laterals ($P < 0.05$) and root dry weight ($P < 0.01$) indicating that site variation was a factor among others for tree death and root development problems. The variation between cultivars and between sites, however, was not considerable for tap root length unlike the investigator's expectation. Most probably, the 60 x 60 x 60cm hole size dug for field planting might have avoided some soil pans that could impede taproot pen trance and prompt varietal as well as site differences.

Interaction between sites and cultivars was not significant for all the characters measured indicating that the cultivars had consistent performance at both sites. This was well demonstrated by the consistently superior mean performance of F-59, 20071 and 744 and the inferiority of 74112 and 7332 for all the characters (Table 2). Probably the variation between these groups of cultivars could be attributed to adaptation problem emanating largely from distance in geographical origin and climate since the later cultivars were collections from higher altitudes of Illubabor region while the former cultivars were from Kaffa region, which is geographically closer and ecologically very similar to Bebeka. In view of this, development of varieties using landrace collections from the vicinity of Bebeka or other similar areas could be the best breeding approach. It is also interesting to note that the over all mean of the cultivars were consistently greater at D10 than F10 for all the characters measured. This result may suggest that F10 has some degree of obstruction on the development of the characters mainly on survival rate, length of lateral roots and root dry weight.

Table 1. Description of cultivars.

Cultivar	Origin		Growth habit	Major characteristic
	Altitude (m)	Area of collection		
7332	1900	Gera, Keffa	Open	CBD resistance
74112	1710	Mettu/bishare,Illubabor	Compact	CBD resistance
7440	1700	Washi, Keffa	Open	CBD resistance
7454	1700	Washi, Keffa	M. open	CBD resistance
744	1700	Washi, Keffa	M. open	CBD resistance
20071	1575	Bero/Maji, Keffa	M. open	High yield
F-59	1650	Bonga, Keffa	M. open	High yield

Table 2. Mean squares for the characters measured from seven cultivars at two locations.

Source of variation	DF	Yield (gm)	Girth (cm)	Survival rate (%)	Taproot length (cm)	Length of laterals (cm)	Root dry wt. (kg)
Replication	1	562322.28	0.561	463.08	122.32	275.95	0.05
Cultivar (A)	6	2147971.87*	8.516**	857.27*	92.36	2766.28**	0.78**
Site (B)	1	42121.28	1.128	1507.49*	54.05	3068.13*	1.23**
A x B	6	968162.70	0.293	236.20	90.44	717.55	0.05
Error	18	627181.98	0.259	242.29	141.09	353.64	0.11
CV (%)		53	7	32	18	12	33

*, ***Significant at 0.05 and 0.01, probability levels, respectively.*

Table 3. Mean performance of the cultivars at D10 and F10 sites for different characters.

Cultivar	Yield (Qt/ha)		Girth (cm)		Survival rate (%)		Taproot length (cm)		Length of laterals (cm)		Root dry wt. (kg)	
	D10	F10	D10	F10	D10	F10	D10	F10	D10	F10	D10	F10
7332	3.56	2.76	6.883	5.584	23	25	68.7	56.3	155.4	111.2	1.04	0.45
74112	2.47	1.79	5.743	5.743	45	30	56.8	70.0	129.5	77.3	0.44	0.26
7440	4.13	8.81	8.180	8.159	52	44	73.3	71.0	166.2	145.7	1.16	0.73
7454	5.13	7.01	7.073	6.914	52	58	76.5	62.4	147.4	145.1	0.88	0.67
744	5.65	8.08	8.588	8.150	65	30	65.5	65.5	208.9	163.5	1.81	0.97
20071	8.77	7.16	8.701	9.085	69	45	58.0	61.3	170.0	183.8	1.41	1.13
F-59	15.44	7.27	9.442	8.980	84	55	75.0	67.9	168.8	173.2	1.83	1.44
Mean	6.45	6.13	7.800	7.391	56	41	67.7	64.9	163.8	142.8	1.22	0.80
$LSD_{0.05}$	3.30		0.51		15.57		NS		18.81		0.33	

Based on the results of the present field and previous nursery experiments, the following conclusions were made: (Mesfin Ameha et al., 1989) to raise healthy and vigorous seedlings with well developed root system, it is advisable to use seed-beds/polythene tubes filled with mixture of finely prepared forest soil and sand at 2:1 ratio, respectively, (Bayetta Bellachew et al., 1993) the presence of varietal differences in adaptation and generally low yield at both sites (6.45 and 6.13 Qt/ha at D10 and F10, respectively) suggested the need of searching for adaptable cultivars using landrace collections from low altitude areas of the region, and (Fernie, 1970) the slight obstruction effect of the soil at F10 on root development and other agronomic traits could be improved by using healthy and vigorous seedlings, larger hole size (60 x 60 x 60 cm) and proper management practices.

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Response of Coffee Seedlings to Organic Manure Amended with Phosphate Fertilizers in Two Soil Types in Nigeria

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SUMMARY

Coffea canephora (Pierre Ex. Froehner) seedlings response to organic manure fortified with phosphate fertilizers in two soils (Alfisol and Ultisol) was evaluated in the greenhouse. Ground cocoa pod husk (GCPH), ground cowdung (GCD) and two phosphate fertilizers [single super phosphate (SSP) and sokoto rock phosphate (SRP)] were used. The manures supplied 10 kgNha^{-1} while the phosphate fertilizers supplied 10 Kg P_2O_5 ha^{-1}. The results indicated that phosphate fertilizers sustained better seedling performance in both soils. The SSP was significant on height, leaf area and dry matter yield ($P \leq 0.05$) in Alfisol while SRP was superior in all the parameters in Ultisol. SSP fortified organic fertilizers increased soil available P in Alfisol and decreased in Ultisol.

INTRODUCTION

Coffee production had declined drastically over the years due to a number of reasons among which are government policies, soils and other factors. Most soils upon which coffee is grown are generally poor in basic nutrients such as nitrogen and phosphorus. Therefore, fertilizer application can improve coffee production. To ensure sustainable coffee production, alternative sources of nutrition are required to complement inorganic fertilizers (Dudal and Deckers, 1991). The contribution of organic matter to soil productivity is well known (Oladokun, 1986). P is mostly supplied through single super phosphate, triple super phosphate and other inorganic sources that have their environmental implications on the underground water and soil acidity. However research into the use of rock phosphate especially Nigerian rock phosphate as an alternative source of P is very recent. Therefore, the present study evaluated coffee seedling response to organic fertilizers amended with different phosphate fertilizers.

MATERIALS AND METHODS

Greenhouse experiments were carried out in 2000 and 2001. Soils used for the studies were obtained from two coffee growing areas in Nigeria.Soil samples were collected at 0-20 cm depth at two locations (Ibadan & Uhonmora). Four kilograms of soil were placed in 15 x 45 cm sized polyethylene bags, watered and coffee seedlings at two-leaf stage were transplanted into each bag, Nine fertilizer treatments of Single superphosphate (SSP) at 10kg P_20_5 ha^{-1} = 25 mg SSPkg^{-1} soil; Ground cowdung fortified with SSP 10 kg P_20_5 ha^{-1} (GCD*); Ground Cocoa pod husk fortified with SSP 10 kg P_20_5 ha^{-1} (GCPH*); Ground Cowdung sole = 250 mgkg^{-1} soil; Sokoto rock phosphate at 10 kg P_20_5 ha^{-1} 15 mg SRPkg^{-1} soil; Ground Cocoa pod husk sole = 500 mg GCPHkg^{-1} soil; Ground cowdung fortified with SRP at 10 kg P_20_5 ha^{-1} (GCD**); Ground Cocoa pod husk fortified with SRP 10 kg P_20_5 ha^{-1} (GCPH**); and Control were applied. The organic fertilizers supplied 10 kg N/ha. Treatments were arranged in a CRD, replicated three times. Routine analyses were carried out with IITA methods (International Institute of Tropcal Agriculture, 1982). Dry matter yield and nutrient compositions were determined. The Relative Agronomic efficiency (R.A.E) of SRP to SSP was calculated according to (Obigbesan & Udosen, 1995). The Internal efficiency (I.E) of the fertilizers (SSP & SRP) was determined with method (Dwivedi et al., 1989). ANOVA was carried out and the means separated with DMRT at 5% level.

RESULTS AND DISCUSSION

The soils were low in basic nutrients (Table 1). The pH of the soils lies in the range of (5.85-6.50). The exchangeable bases for the soils were suitable for coffee growth (Akinrinde, (1987). The N and P levels of GCD were superior to GCPH (Table 1). SRP nutrient value is higher than SSP (Table 1). SSP at 10 kg P_2O_5/ha significantly increased seedling height (40.35 cm) above other treatments in the Alfisol (Table 2). The least height (18.75 cm) was obtained with GCPH**. Seedling height was not significantly different in Ultisol as a result P sources (Table 2). SRP treated seedlings were taller than other treatments. Seedlings treated with GCD performed better than those treated with GCPH in both soils (Table 2). This was due to the high nutrient values of GCD over GCPH (Table 1). The effect of P-fortified organic fertilizers on coffee leaf area was similar to that for plant height (Table 2). SSP at 10 kg P_2O_5 ha^{-1} or P-fortified organic fertilizers significantly improved seedling leaf area in an Alfisol than SRP (Table 2). The seedling dry matter yield was significantly affected by SSP application or P-fortified organic manure in Alfisol (Table 3). Application of SRP decreased dry matter yield of coffee seedlings. P-fortified organic fertilizers were found to enhance coffee dry matter yield (Patel, 1970). There was no significant difference in an Ultisol on coffee dry matter yield when phosphate was applied. (Table 2). The decrease observed in these parameters did not manifest at the final harvest. The P-uptake of coffee seedlings when SSP was applied was significantly higher than other applications (3.29 mg/pot). This was followed by GCD*. However, the Internal Efficiency (IE) of SSP was not significant when compared with SRP that gave about 29% reduction. In Alfisol, GCD** gave significant organic carbon (26.3 g/kg soil), while SRP gave 10.2 g/kg soil (Table 3). GCD and GCPH with or without phosphate fertilizers increased organic carbon in ultisol. The R.A.E of SRP with or without organic manure was greatly improved in coffee.

Table 1. Selected physical and chemical characteristics of soils and fertilizer materials.

Soil Parameters	Alfisol	Ultisol	GCPH (%)	GCD (%)	SSP (%)	SRP (%)
Sand (gkg^{-1})	694.00	609.80	-	-	-	-
Silt (gkg^{-1})	149.60	151.40	-	-	-	-
Clay (gkg^{-1})	156.40	238.80	-	-	-	-
Textural class	SL	SCL	-	-	-	-
PH (H_2O)	6.65	5.85	-	-	-	-
Org. C (gkg^{-1})	9.10	8.40	24.32	17.45	-	-
Total N (gkg^{-1})	1.80	1.90	1.02	1.83	-	-
Avail. P ($mgkg^{-1}$)	8.76	10.38	0.14	0.45	18.02	33.47
Exch. K^+ ($cmo1kg^{-1}$)	0.40	0.68	4.30	2.13	-	-
Exch.Ca^{2+}($cmo1kg^{-1}$)	2.96	4.87	1.20	1.64	27.00	44.23
Exch.Mg^{2+}($cmo1kg^{-1}$)	1.28	2.96	0.24	0.56	-	0.95
C : N ratio	5.06	4.42	20.10	17.45	-	-

SL – sandy loam, SCL – sandy clay.

Table 2. The Influence of P- fortified organic fertilizers on growth parameters.

Treatment	Height (cm)		Leaf area (cm^2)		DMY ($gpot^{-1}$)		P–uptake ($mgpot^{-1}$)	
	Alf	Ult	Alf	Ult	Alf	Ult	Alf	Ult
SSP	40.35^{a}	43.20^{ab}	87.16^{a}	89.90^{a}	7.83^{a}	7.73^{b}	3.29^{a}	1.93^{c}
GCD*	32.25^{b}	54.50^{a}	86.40^{a}	98.70^{a}	7.19^{a}	12.03^{a}	2.37^{b}	3.12^{b}
GCPH*	30.97^{b}	42.90^{ab}	66.80^{b}	79.50^{a}	4.39^{b}	11.12^{a}	1.14^{d}	3.00^{b}
GCD	29.77^{bc}	40.20^{ab}	81.69^{a}	65.80^{ab}	4.50^{b}	6.82^{b}	1.38^{d}	1.84^{c}
SRP	23.75^{c}	55.80^{a}	49.05^{cd}	88.40^{a}	3.72^{c}	12.08^{a}	1.52^{c}	3.26^{b}
GCPH	23.47^{c}	36.70^{b}	54.39^{c}	62.10^{ab}	2.93^{d}	15.72^{a}	0.73^{e}	4.24^{a}
GCD **	23.40^{c}	38.40^{b}	55.11^{c}	81.60^{a}	2.81^{d}	8.70^{b}	0.31^{e}	2.17^{b}
GCPH**	18.75^{d}	29.90^{b}	41.35^{d}	62.50^{ab}	1.97^{e}	10.90^{a}	0.61^{e}	2.94^{b}
CONTROL	25.50^{c}	31.70^{b}	71.04^{b}	68.50^{ab}	4.52^{b}	7.47^{b}	1.54^{c}	1.87^{c}
MEAN	27.58	41.48	65.89	77.41	4.32	9.58	1.46	2.71
S.E	12.15	17.02	25.63	32.92	3.62	5.58	0.31	0.26

GCD = CD + SSP, GCD* = CD + SRP Alf - Alfisol*
GCPH= CPH + SSP, GCPH* =CPH + SRP Ult - Ultisol*

Table 3: Effect of P-fortified organic fertilizers on available P, organic carbon fertilizer internal efficiency (I.E) and relative Agronomic efficiency (R.A.E).

Treatment	Organic carbon (gkg^{-1})		Soil available P ($mgkg^{-1}$).		I.E		R.A.E (%)	
	Alf	Ult	Alf	Ult	Alf	Ult	Alf	Ult
SSP	11.70a	9.80b	10.91c	4.27a	2.38a	4.01a	-	-
GCD*	12.00b	11.70b	19.64b	2.93b	-	-		-
GCPH*	13.40b	17.90a	33.82a	3.38b	-	-	-	-
GCD	12.00b	17.20a	4.36d	4.09ab	-	-	-	-
SRP	10.20b	13.00b	3.27d	3.47ab	2.45a	3.71a	47.54	156.27
GCPH	13.10b	14.80b	4.36d	2.67b	-	-	-	-
GCD **	26.30a	12.40b	8.73c	2.94b	-	-	-	-
GCPH**	10.90b	16.30a	8.73c	2.64b	-	-	-	-
CONTROL	7.10b	8.12ab	4.36d	1.95bc	-	-	-	-
MEAN	12.97	13.46	10.91	3.15	2.41	3.86	-	-
S.E	5.34	2.79	3.33	0.73	0.48		-	-

Values with the same letters in the columns do not differ significantly at $P \leq 0.05$ (DMRT).
GCD = CD + SSP, GCD* = CD + SRP Alf - Alfisol*
GCPH = CPH + SSP, GCPH* = CPH + SRP Ult - Ultisol*

CONCLUSION

Seedlings performed better in growth parameters and RAE of SRP was higher in Ultisol than in Alfisol. Hence SRP can substitute for SSP in coffee production in an Ultisol.

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Effects of Phosphorus Fertilizer Placement on the Growth of Arabica Coffee Seedlings

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SUMMARY

In Ethiopia coffee is grown to a large extent on Nitosol. This type of soil is deep and has no serious physical problems; it is however, poor in some major nutrients. Phosphorus is highly fixed in the soils, where dominated by kaolinitic clays. The ease of P uptake depends on fertilizer placement, rate and time of phosphorus application in the soil. Commonly P fertilizers are applied by broadcasting in ring around the coffee tree and may or may not be incorporated with the soil. Therefore, determination of the proper placement of fertilizer is useful. Field experiment was conducted to determine the effect of p placement on the growth of coffee seedlings (variety, F-59) at Jima Agricultural Research Center (Melko), on Eutric Nitosol. The effectiveness of localized spot applications at different horizontal and vertical distances was studied for three phases. Four horizontal distances (15, 30, 45, and 60 cm) and three vertical depths (7.5, 15, and 22.5 cm) were used for P placement and a conventional application method was also included for comparison to determine the effect of phosphorus (P). A recommended fertilizer rate of 77 kg P ha^{-1} (13.7 gm per tree) and 170 kg N ha^{-1} (50 gm per tree) was applied. The root biomass and distribution of roots at different depths were investigated. The status of P in the soil and in the plants were analysed for total and available (Bray I) P. The results of first and second phases of the experiment indicated that the effect of P placement on different growth parameters showed significant differences in root dry matter ($p < 0.05$). Horizontal placement at 45cm was the optimum placement. Covariance analysis of the last phase for the mean height, girth and leaf number between initial and final measurement showed significant responses with r value of 0.93, 0.47 and 0.86 respectively. The highest available P was recorded at 80 days when P was placed at 45cm away from tree trunk and at 15cm depth, whereas the check (ring application) has shown the maximum P - concentration in all applications time except 40 days.

INTRODUCTION

The effect of phosphate fertilization in crop production depends upon factors controlled by the phosphate absorption characteristics of the plant root as well as factors controlled by the phosphate adsorption characteristics of the soil for phosphate (Barber, 1977). About 70 to 80% of the applied P is unavailable to coffee plants due to high fixation. The availability of P in coffee fields mainly depends on mobility and dissolution of applied P (Krishnapp Naik et al., 1989). Fertiliser, applied in the zone of high root activities will be more efficiently utilized by the tree and the quality of fertiliser applied could also be reduced instead of by broadcasting them over the entire area of plantation (Patel and Kabra, 1976; Barber, 1980).

Banding of P as opposed to broadcast be also suggested on tropical soils, which have high fixation capacity to reduce P fixation (Sobulo, 1978). The methods of phosphorus fertilization influence the amount of phosphorus need for good yield (Sadaphel, 1980). Crops may respond much better to band than broadcast phosphorus, especially on soil testing low phosphorus or soils where high P fixing capacity precludes easy manipulation of P level (Fox and Kang, 1978; Tanner, 1984). The method of application is a compromise between the volume of soils in which the fertilizer is placed (and where the root can find it) and fixation capacity of the soil (Sadaphel and Sing, 1971). Under wide range of soil and climatic condition band application of super-phosphate accelerate the rate of phosphorus uptake by different crops (Malavolta and Neptune, 1977; Delvalle et al., 1974; Sobulo, 1978). In wet season, the diffusion of P and the exposure of high proportion of feeding roots in banding zone increase due to high soil moisture content, to areas beyond the band (Olson et al., 1961).

Phosphorus is a limiting nutrient hence, the status and magnitude of P fixation in the different coffee growing area of the country was investigated (Paulos, 1994; Picolo and Gobena, 1989; Sahlemedhin and Ahmed, 1983; Bekele and Höfner, 1993). There is no enough information on the best P placement method, thus, it is very essential to know the best application method of P in coffee soils amended with high dose of various water-soluble phosphate fertilizers for maximum yield of coffee.

MATERIAL AND METHODS

An experiment was conducted at Melko (Jimma), on the southwest of Ethiopia. The soil was eutirc nitosol series (Paulos, 1994). The treatments were various distances of phosphorus placement, using one and half year old coffee seedling (var. F-59) transplanted from nursery field, were conducted the activity in to three phases. A recommended fertilizer rate 77 kg P ha^{-1} (13.7 gm per tree) was applied. Nitrogen at the rate of 170 kg N ha^{-1} (50 gm per tree) was applied before applying the treatments each phase. The treatments and plants were completely randomized and replicated three times having three observations per treatments in all phase.

The first phase of the trial was conducted during the wet season. The treatments were applied using four horizontal placement (i) placement in hole 15, 30, 45, and 60 cm directly below the plant from the base of the plant and covered with soil at the depth of 5 cm. (ii) conventional approach, ring application at a radius of direct to the canopy from the base of the tree and covered with soil at a depth of 5 cm. (iii) Control (with out phosphorus fertilizer).

The second phase of the experiment was started during the dry season, and conducted on the same soil and fertilizer rate. The treatments were vertical placement, at a depth, in a hole 7.5, 15, and 22.5 cm deep, and 32 cm far away from the base of the tree. Check (ring application) and control (with out fertilizer) applied the same treatment as in first phases.

The third phase was based on the results of previous trial namely horizontal and vertical distances. The treatments combinations were horizontal placement of P 30, 45 and 60 cm distance from the tree trunk and vertical placement 7.5, 15 and 22.5 cm Depths. Control (unfertilized) plots and ring applications (conventional fertilization) were also included in the experiment. Watering in both experiments was under irrigation (by siphoning), except the first phase.

Soil samples was collected at a distance of 32 cm from a tree trunk at a depth of 15 cm. Plant sampling for analysis was done every 20 days interval parallel to plant sampling (leaf), Height, girth and leaf number. At harvest, shoot were removed and the fresh weight of shoot were separately measured leaf area were also measured. Roots were quickly washed and their fresh weight was measured, the root length was estimated and then dried along with shoots at 70^{o} C .The dry leaves, shots and roots were weighed. The samples were weighed, and grounded to 2 mm screen, plant p concentration on a 0.25 gm samples digested in H_2 SO_4/

H_2O_2 acid using molybdenum blue calorimetric procedure. Soil P was analysed for P-available.

Table 1. Effect of horizontal placement of P on mean biomass yield of coffee seedling at Melko.

Treatments (cm)	Shoot growth				Root growth	
	Plant height (cm)	Stem diameter (cm)	Leaf area (cm^2)	Shoot dry matter (gm)	Root Length (cm)	Root dry matter (gm)
15	63.30	1.20	1665.7	36.1	694.3	5.3bc
30	63.30	1.15	1650.5	30.8	503.4	4.4c
45	62.90	1.15	1609.4	37.1	676.4	7.5a
60	62.00	1.18	1663.3	34.0	523.4	6.7ab
Control	64.80	1.23	1627.8	39.1	567.1	5.1bc
Check	63.20	1.22	1410.9	32.4	514.7	6.3abc
LSD						
0.05	ns	Ns	ns	ns	ns	1.9
S.E $\pm$	2.1	0.1	218.7	4.6	95.0	0.6
C.V. %	5.7	10.6	23.6	22.8	28.4	17.8
Mean*	44.3	0.8	1121.8	12.4		4.6

**Pre-treatment at two leaf stage.*

Table 2. Effect of vertical placement of P on mean biomass yield of coffee seedling at Melko.

Treatments (cm)	Shoot growth				Root growth	
	Plant height (cm)	Stem diameter (cm)	Leaf area (cm^2)	Shoot dry matter (gm)	Root Length (cm)	Root dry matter (gm)
7.5	100.1* (79.4)**	2.3 (1.4)	11633.8	202.3	3398.0	52.9a
15	95.0 (75.3)	2.1 (1.2)	10677.1	261.0	2919.0	39.8ab
22.5	999.7 (76.5)	2.4 (1.4)	12266.1	340.5	2759.1	36.0b
Control	89.9 (68.0)	2.0 (1.2)	9336.8	211.6	2386.6	31.3b
Check	94.8 (71.1)	2.1 (1.3)	112453.9	243.9	2865.0	29.6b
LSD						
0.05			n.s.	n.s.	n.s.	14.7
S.E $\pm$	7.2	0.2	2115.2	54.7	617.4	6.4
C.V. % E	7.1	8.0	14.5	18.6	14.5	11.1
S	10.0	11.1	32.1	28.6	38.1	30.0
Mean***			6.9	0.2	150.5	0.04

**Final measurement*
***Initial measurement*
****Pre-treatment at two leaf stage*

RESULTS AND DISCUSSION

The results of first and second phases of the experiment indicated that the effect of P placement on different growth parameters showed significant differences in root dry matter ($P < 0.05$). Horizontal placement 45 cm from the tree trunk and 15 cm depth was the optimum placement (Tables 1 and 2).

Table 3. Effect of P placement on mean biomass yield of coffee seedling at Melko.

Treatments Vertical-Horizontal placement (cm)	Shoot growth				Root growth	
	Plant height (cm)	Stem diameter (cm)	Leaf area (cm^2)	Shoot dry matter (gm)	Root Length (cm)	Root dry matter (gm)
7.5-30	69.25(58.17)	1.63* (1.25)**	306.00(142.33)	100.3	3839.3	19.7
7.5-45	69.95(58.33)	1.69(1.39)	298.83(147.17)	105.5	4299.2	32.1
7.5-60	70.92(60.83)	1.60(1.33)	295.67(147.50)	91.4	4257.3	24.3
15-30	64.33(54.83)	1.58(1.22)	235.16(131.00)	98.1	2696.0	29.1
15.45	72.33(61.17)	1.73(1.38)	274.83(183.67)	118.1	3614.7	32.7
15-60	71.40(62.00)	1.67(1.34)	227.83(159.17)	118.1	5084.7	25.5
22.5-30	71.83(61.67)	1.74(1.38)	347.83(169.33)	117.3	4421.3	30.4
22.5-45	64.83(53.33)	1.55(1.29)	301.00(156.83)	95.01	3168.8	23.0
22.5-60	71.83(61.50)	1.77(1.49	331.00(175.67)	105.1	2982.0	32.0
Control	68.08(58.33)	1.62(1.30)	32.83(128.67)	102.7	4273.3	29.0
Check	68.37(57.50)	1.65(1.30)	293.50(139.33)			
S.E ±	3.88(3.53)	0.19(0.12)	38.51(25.78)	18.0	792.4	4.0
C.V. %						
Per observation	11.53(13.16)	15.06(18.35)	33.34(33.98)	40.7	33.8	38.7
Per plot	9.68(10.35)	12.37(15.10)	22.33(29.22)	29.7	35.5	24.5

Table 4. Effect of vertical P-placement (depth) on the content of available P.

Treatments Vertical-Horizontal placement (cm)	Available P, in % distance (cm)				
	0	7.5	15	22.5	30
7.5-30	1.06	1.73	1.03	0.68	1.26
7.5-45	0.91	0.86	0.69	0.91	1.03
7.5-60	1.14	1.61	2.68	1.38	0.76
15-30	1.96	0.95	0.71	0.47	0.35
15-45	0.83	0.35	0.12	1.07	0.23
15-60	1.43	0.59	0.47	0.59	0.83
22.5-30	1.67	0.12	0.59	0.70	0.66
22.5-45	0.70	0.81	0.92	0.48	1.25
22.5-60	0.48	0.81	0.59	0.59	0.37
Control	0.57	1.36	2.13	0.48	0.48
Check	0.59	0.96	2.64	0.56	0.86

The effects of P placement on the dry and fresh weight of are given Table 3. There was no significant difference between treatments in fresh weight of shoot and dry of seedlings. However, analysis of variance test for the effect of P placement on root ($p < 0.05$) indicated a significant increases in weight due to treatments. Apparently the relative rate of shoot growth was higher than that of the roots.

An average incremental height for the last phase trial was attained of about 10.49 cm during the period. The difference in mean plant height between seedlings receiving different placement of P was negligible. Therefore, means of the treatment were compared with check plants and the difference between the two widened as the seedling grow larger. The change in stem diameter with initial to final time was 0.33 cm and also low and non significant. Covariance analysis of the last phase, for the mean height, girth and leaf number (between initial and final measurement) showed significant responses with r-value 0.95, 0.47 and 0.86 respectively. The average incremental leaf number 133 was attained during the period. The difference in mean plant number between seedlings receiving different placement of P was not significant.

Table 5. Effect of different time of soil sampling on P-placement on the side of applied P.

Treatments Vertical-Horizontal placement (cm)	Available P, in% distance (cm)				
	20	40	60	80	100
7.5-30	1.74	2.20	2.08	1.69	0.04
7.5-45	1.68	2.20	1.91	1.45	0.54
7.5-60	1.64	1.94	1.83	0.64	0.54
15-30	1.98	0.99	1.53	1.22	1.14
15-45	2.19	1.31	1.83	2.86	0.79
15-60	1.18	0.79	1.48	2.83	2.31
22.5-30	1.52	1.91	1.74	1.10	0.79
22.5-45	1.68	1.39	2.26	1.24	0.57
22.5-60	0.99	1.57	1.91	0.84	0.67
Control	1.42	1.05	1.48	1.04	1.11
Check	3.06	2.00	1.06	1.54	2.09

Table 6. Effect of different time of soil sampling on P-placement.

Treatments Vertical-Horizontal placement (cm)	Available P, in% distance (cm)				
	20	40	60	80	100
7.5-30	1.58	1.48	1.56	1.40	0.24
7.5-45	1.98	1.61	1.76	1.40	0.44
7.5-60	1.47	1.51	1.66	1.17	0.59
15-30	1.81	1.24	1.74	1.14	0.59
15-45	2.09	1.01	1.40	2.68	0.95
15-60	1.58	0.88	1.30	2.09	1.95
22.5-30	1.21	1.44	1.48	0.92	1.01
22.5-45	1.47	1.22	1.57	1.19	1.06
22.5-60	0.78	1.35	1.48	0.79	1.06
Control	0.99	0.92	1.35	0.84	1.44
Check	2.80	1.44	1.57	1.75	2.26

The highest available P was recorded at 80 days when P was placed at 45 cm away from tree trunk and at 15 cm depths. Where as the check (ring application) has shown the maximum P-concentration in all applications time except 40 days.

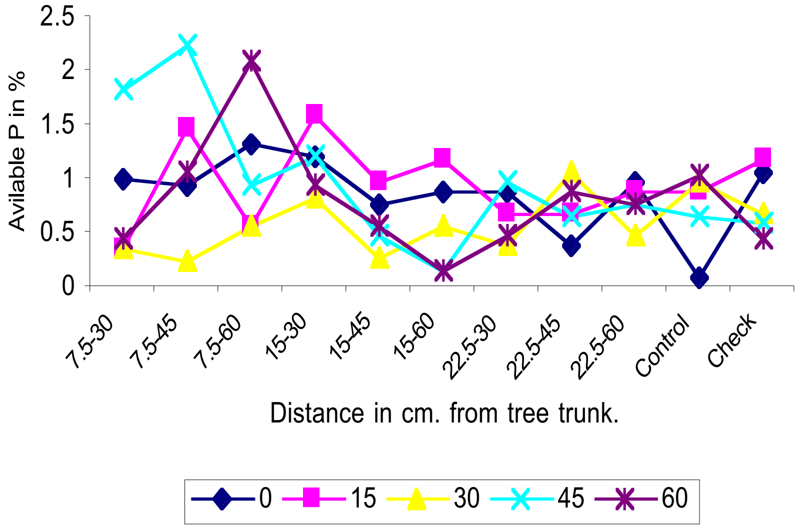

Figure 1. Effect of horizontal P-placement on the available phosphourus conten in %.

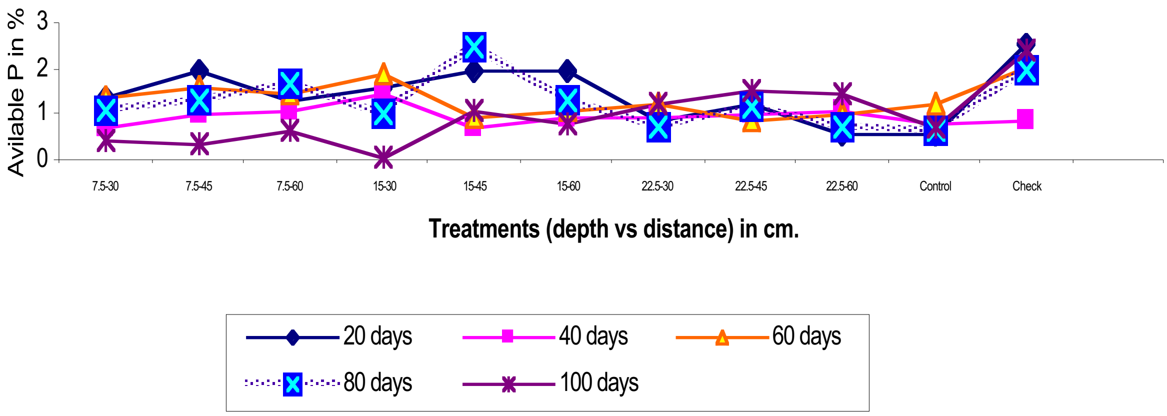

Figure 2. Effect of time of soil sampling on the available phosphourus conten in % on the P-placement.

CONCLUSION

A non significant growth characteristics in plant height, stem girth, leaf area ratio and root length were observed between P placements for all phases of trial except root fresh and dry weight parameter. The highest available P was recorded at 80 days when P was placed at 45 cm away from tree trunk and at 15 cm depths. Where as the check (ring application) has shown the maximum P concentration in all applications time except 40 days.

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Response of Coffee Seedlings to Organic fertilizer Grown in an Alfisol in Nigeria

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SUMMARY

The effects of three organic fertilizer *Chromolaena odorata*, cowdung and *Pennisetum purpureum* were evaluated on the growth of coffee seedlings in the greenhouse. The organic fertilizers were applied at rates equivalent to 0,5 and 10 tha^{-1} to coffee seedlings. The treatments were arranged in a complete randomized design, replicated four times. The results showed that, *C. odorata* was significant higher in all the parameters measured than cowdung and *P. purpureum* at 5 tha^{-1} ($P \leq 0.05$). Combination of *C. odorata* with either of the two increased coffee growth and the soil chemical properties. Therefore, 5 tha^{-1} of *C. odorata* and cowdung mixture was found most suitable for Coffee Seedlings production.

INTRODUCTION

Tropical soils are known to be low fertility due to low activity clay minerals. One way of restoring the fertility is through the use of organic materials (Haris et al., 1987). Current coffee production is aimed at improving production and quality through organic farming (Organic production htm, 2003). Agro-input for sustainable coffee production according to Nutman (Nutman et al., 2002) are fertilizer and manure. Recently, focus has been on the use of organic materials as fertilizer (International coffee organization htm, 2003; Obatolu et al., 1989). Economic depression in Africa has reduced farmers' ability to purchase much needed inputs for crop production (Michori et al., 1981). This has also affected seedling establishment and yield (Obatolu et al., 1989). Therefore, if coffee production have to meet world production forecast (International coffee organization htm, 2003), there is the need to find alternative means other than use of mineral fertilizers. The use of organic materials has been reported (Obatolu, 1987). Most coffee farmers in Africa cannot cope with the phenomenal increase in price of mineral fertilizers. The accumulation of toxic elements in beans has become a basic consideration in USA, Europe, and Asia where organically produced food materials carries a special premium (Organic production htm, 2003). This study examined the effect of three organic materials used as fertilizers on the growth of seedlings grown in an Alfisol in Nigeria.

MATERIALS AND METHOD

Green house study was conducted on C. *canephora* (Pierre Ex.Froehner) seedlings. Organic materials were collected from Ibadan and have been characterized (Obatolu et al., 1989). An Alfisol was used and routine analysis carried out (Table 1). The pH was determined using glass electrode pH meter, particle size analysis (Jackson, 1958), Total nitrogen (Bray and Kurtz, 1945), while exchangeable K, Ca, Mg were extracted by 1N NH_4OAc and K, Ca was read on flame photometer and Mg on atomic absorption spectrophotometer.

There were six treatments of *C. odorata* (C), *P. purpureum* (P), cowdung (D), *C. odorata* with *P. purpureum* (CP), *C. odorata* with Cowdung (CD) and *P. purpureum* with Cowdung (PD), and control (CRL). The treatments were arranged in a complete randomized design with four replicates. The *C. odorata, P. purpureum* and cowdung were processed before application at a rate of 0,5 and 10 tha^{-1} in a 5 L pot containing 4 kg soil. Growth parameters were taken on plant height, stem girth, leaf area, leaf number monthly and dry matter yield. The results obtained were subjected to ANOVA.

Table 1. Characteristics of Ibadan soil (0-30 cm).

				Exch. cations					
Sand (g/kg)	**Silt** (g/kg)	**Clay** (g/kg)	pH (H2O)	K (cmol/kg)	Mg (cmol/kg)	Ca (cmol/kg)	Total N (g/kg)	Avail P (mg/kg)	Org. (g/kg)
722	74	214	6.2	0.09	0.12	1.70	0.22	4.0	1.5

Table 2. Effect of organic fertilizers on some growth parameters of coffee seedlings at first rate of application.

Treatment	Height (cm)	Girth (mm)	Number of leaves.	Leaf area (cm^2)	DMY (g/pot)
C_1	22.83a	1.65a	9.00a	30.75a	24.33a
D_1	17.06b	1.60b	8.06c	20.87bc	20.00b
P_1	15.33d	1.50c	7.30c	19.56c	15.66b
C_1D_1	11.11f	1.40e	7.00d	22.20b	20.20b
C_1P_1	16.16c	1.60b	8.00bc	22.29b	13.66d
D_1P_1	15.33d	1.30f	8.00bc	22.10b	21.10b
CRL	14.33e	1.45d	8.23b	24.10b	15.00b

Table 3. Effect of organic fertilizers on some growth parameters of coffee seedlings at second rate of application.

Treatment	Height (cm)	Girth (mm)	Number of leaves	Leave area (cm^2)	DMY (g/pot)
C_2	20.32a	1.40c	8.00c	29.65a	22.33a
D_2	12.22e	1.30d	7.00e	15.50d	16.20c
P_2	15.00bc	1.30d	6.00f	16.22d	14.52c
C_2D_2	16.33b	1.52a	9.00a	24.72c	20.00b
C_2P_2	14.00d	1.30d	8.66b	25.52b	23.66a
D_2P_2	14.33d	1.45b	8.33c	24.11c	15.00e
CRL	14.33d	1.45b	8.32cd	24.10c	15.00e

Means in a column with similar letter(s) are not significantly different at ($P \leq 0.05$) DMRT.

RESULTS AND DISCUSSION

The soil was found to be moderate in basic nutrients (Table 1). Addition of the organic fertilizers improved the availability of plant nutrient in the soil. This was evident on the significant growth of the coffee seedling ($P \leq 0.05$). The result of growth the parameters (Tables 2 & 3) of each or the combined fertilizers showed that, *C. odorata* treatment performed significantly ($P \leq 0.05$) at 5tha^{-1} than cowdung, *P. purpureum* above the control (Table 2). Combination of *C. odorata* with either of the two and cowdung with *P. purpureum* were significantly better than *C. odorata* with *P. purpureum* above the control. However, *C. odorata* with *P. purpureum* showed higher dry matter yield than the other two (P ≤0.05).

Application of each or the combined organic fertilizers at 10 tha^{-1} showed a similar trend. *C. odorata* treated seedlings performed better than the other two organic fertilizer (P ≤0.05). Addition of *C. odorata* with cowdung were better in stem girth and number of leaves, *C.odorata* with *P. purpureum* showed higher leaf area and dry matter yield than the control. The *C. odorata* treatment at 5 tha^{-1} increased in the growth parameters than at 10tha^{-1}.Similarly,combinations of *C. odorata* with cowdung and cowdung with *P. purpureum* at 5tha-1 were better above the other treatments. At 10 tha^{-1}, cowdung with *P. purpureum* gave the highest dry matter yield. Better seedlings were observed in pot treated with *C. odorata* and cowdung with their combinations due to their high manurial potentials. Therefore, 5 tha^{-1} of *C. odorata* and cowdung mixture was found most suitable for seedling production.

CONCLUSION

The results showed that, *C. odorata* with Cowdung mixture applied at 5 tha^{-1} would conveniently be a better alternative for raising coffee seedling production in the nursery.

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Analysis of Coffee Trade in Selected Coffee Growing Areas of Nigeria

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SUMMARY

This study investigated the effect of coffee traders' trade practices on the economic and technical efficiency of coffee trade in the coffee growing areas of Nigeria. Eighty traders were randomly interviewed in two states where they were concentrated. The data were analysed using Chi – square statistics and percentages. The trade was found to be technically and economically inefficient. A negative (average) gross margin of ₦33,297.57 (US $256.14) is one of the indicators of inefficiency. Type of coffee buyers, traders' produce point of purchase and grade rating were found to have significant impact on coffee traded quantity and prices. It was recommended that the government need to introduce and control a virile coffee trade regulation.

INTRODUCTION

Marketing is known to be vital to the economy of all countries of the world since it performs some fundamental functions. An efficient marketing system will locate areas where produce are surplus (usually areas of production) and bring them to areas where they are in short supply (Abbott and Makeham, 1979). This provides earnings for the traders (marketers) who facilitate the transfer of produce from the farmers (i.e. the producers) to the users (i.e. the processors and/or the consumers). The consumers will gain satisfaction while the processors will enjoy the availability of raw materials and also the farmers too will earn income.

The marketing of coffee has been hampered over the years due to low price being offered to farmers and traders (Oduwole and Sanusi, 2001). Hence, an investigation was carried out to ascertain the determinants of coffee marketing in Nigeria from November 2000 to December 2001. The preliminary findings necessitated this study. Some coffee exporters and merchants (in large towns e.g. Lagos and Ibadan) were interviewed. These traders stated that poor bean quality and scattered sale points were the major constraints facing the Nigerian coffee trade. Therefore, this study assessed the effect of coffee traders' trade practices on the economic and technical efficiency of coffee trade.

METHODOLOGY

Eighty (80) traders were randomly selected and interviewed in the coffee growing states of Kogi and Taraba. The interview was conducted using well-structured questionnaires. The two states happened to be the areas where there was a sizeable number of coffee traders, which was due to the fact that Kogi and Taraba States were the main (*robusta* and *arabica*) coffee producing states in Nigeria.

The data generated were analyzed using chi-square statistics and percentages. The hypotheses tested were:

1. Null Hypothesis – no significant relationship exists between purchase point, purchase price, purchase source, quantity bought, quantity sold, selling price, produce grade rating, grader, stocking and buyer.

$$H_o: P_l = P_p = P_s = Q_b = Q_s = S_p = G = G_r = S = B = 0$$

where: P_l, P_p, P_s, Q_b, Q_s, S_p, G, G_r, S & B are the variables named respectively above.

2. Alternative Hypothesis – A significant relationship exists between the variables.

$$H_a: P_l \neq P_p \neq P_s \neq Q_b \neq Q_s \neq S_p \neq G \neq G_r \neq S \neq B \neq 0$$

RESULTS AND DISCUSSION

The null hypothesis (H_o) which stated that (selling) price was independent of buyer was rejected and the alternative (H_a) which stated otherwise was accepted, $P > 0.10$ (Table 1). Also, the H_o that viewed quantity sold as uninfluenced by the buyer was rejected while the H_a that stated otherwise was accepted, $P > 0.10$ (Table 1). The hypothesis (H_0) that (purchase) price was independent of (purchase) source was rejected while the alternative (H_a) which stated otherwise was accepted, $P > 0.10$ (Table 1). The statistics for quantities purchased - source of purchase relationship was significant at $P < 0.05$ (Table 1). Therefore, the H_0 that quantity bought was uninfluenced by purchase source was accepted. Also, H_0 that purchase point did not affect purchase price was rejected and H_a which stated otherwise was accepted, $P > 0.10$ (Table 1). Purchase point and quantity purchased interaction was significant at $P = 0.10$ (Table 1). Hence, H_o which stated that point of purchase did not influence the quantity bought was rejected and H_a which stated otherwise was accepted.

Table 1. Chi-square Statistics of Factors of Coffee Trade.

Variables	*Degree of freedom*	*Chi-square*	*p-value*
Purchase Price – Purchase Source	4	13.7671	0.992
Quantity Bought – Purchase Source	8	2.2330	0.041
Purchase Price - Purchase Point	8	3.6477	0.175
Quantity Bought – Purchase Point	12	7.6512	0.100
Stocking – Selling Price	2	0.1670	0.080
Selling Price – Grade	4	6.4628	0.773
Purchase Price – Grade	4	1.9679	0.235
Quantity Sold – Grader	8	8.0854	0.435
Quantity Bought – Grader	12	28.2768	0.994
Grade – Grader	8	5.6410	0.640
Selling Price – Buyer	4	3.5424	0.525
Quantity Sold – Buyer	4	3.5792	0.530
Selling Price – Quantity Sold	**4**	3.1009	0.456

Source: Field Survey, 2000/2001.

Furthermore, the hypothesis (H_0) that selling price was uninfluenced by produce stocking was accepted, $P < 0.10$ (Table 1). Also, the null hypothesis (H_0) which stated that selling price was independent of grade was rejected while the alternative hypothesis (H_a) was accepted, $P >0.10$ (Table 1). H_o that purchase price was uninfluenced by grade was rejected and H_a which stated otherwise was accepted, $P > 0.10$ (Table 1). H_o that quantity sold was independent of the grader was rejected and H_a which stated otherwise was accepted, $P > 0.10$ (Table 1). H_o which stated that quantity bought was not dependent on grader was rejected and the H_a was accepted, P > 0.10 (Table 1). Finally, the null hypothesis (H_o) that grade rating was independent of grader was rejected while the alternative (H_a) which stated otherwise was accepted. Stocking practices, graders, grading, buyers, purchase locations, and sources of purchase adversely affect the quantity of coffee bought and sold as well as coffee trade income. Produce grading was found to be carried out by quite a number of graders such as the farmers themselves, government officers, and brokers. The above factors were responsible for the low bean quality complaints against coffee beans in Nigeria by the city merchants and exporters. There is possibility of bias in classifying coffee into grades as a result of the person who is grading the produce. Hence, selling price, purchase price, quantity purchased and sold were influenced by grade classification of the grader.

56% of traders held produce in storage while 44% do not stock produce. This is why selling price – stocking relationship was insignificant. However, from observations, the storage practices of the traders who store coffee are quite poor leading to deterioration in coffee grade quality. This is one of the factors responsible for traders being offered low prices.

A substantial proportion of those who did not store produce cited unstable (bean) prices as the reason for their decision. Those who held stock gave the same reason. On the average, 19.5 tons of coffee was held in stock over a 3-year period by a (storage practicing) trader with (an average) storage cost of ₦52,020.83 (US $400.16) and an average (stocked) produce loss of 2.1%. The coffee trade could be said to be technically inefficient. A 5.8% produce loss in transit is rather on the high side. If other losses of 2.1% produce loss in storage and a 1.6% produce loss in transit from store to point of sale were added, the amount of wastage will further increase. Also, the defects in offering low quality beans for sale as a result of improper grading, which were reflected in the influence of buyer type on quantity sold, selling price and grade; is another indication of technical inefficiency.

At a purchase price of ₦54,982.10 (US $422.94) per ton, (an average) 34.84 tons of coffee was bought for sale by (an average) coffee trader (Table 2). At (an average) selling price of ₦66,887.0 (US $514.52) per ton, (an average) 23.38 tons of coffee was sold (Table 2). This implies that (on the average) traders could not sell 11.46 tons of coffee. The above yielded a (negative average) gross margin of (US $256.14) ₦33,297.57 (Table 2). The trade was economically inefficient due to the negative gross margin. A negative gross margin is not far fetched since about 90% of the traders have other businesses in which they were engaged.

Table 2. Average Gross Margin of Coffee Trade in Nigeria (1998-2000).

Variable	Amount	
Purchase Price	₦54,982.10	$422.94
Quantity Purchase	34.84 tons	-
Purchase Cost	₦191,880.20	$1,476.00
Selling Price	₦66,887.00	$514.52
Quantity Sold	23.38 tons	-
Revenue	₦158,582.63	$1,219.87
Gross Margin	₦33,297.57)	($256.14)

Source: Field Survey, 2000/2001.

57.5% of traders were of the opinion that the constraints facing coffee trade is imperfections in coffee bean prices. From the above, it can be deduced that market instability with particular reference to bean price is the most crucial problem of coffee trade. To tackle the problem(s), 38.75% of the traders recommended the introduction of (coffee) trade regulations and control by government to be administered by government or coffee union while 16.25% said that government should re-invent the Commodity Board.

CONCLUSION AND RECOMMENDATIONS

To reduce/eliminate coffee trade inefficiencies, the role players in the coffee trade chain need be educated on proper storage practices. Also, there is need to change the method of (on-farm) post-harvest processing from dried beans to wet beans for enhanced produce quality in which the Cocoa Research Institute of Nigeria (CRIN) should play a leading role. Finally, there is need for trade regulation and control by a government parastatal (e.g. the Ministry of Trade and Commerce) in conjunction with the National Coffee and Tea Association (NACOFTAN) and CRIN.

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Impact of Coffee Marketing Problems on Coffee Production in Nigeria

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SUMMARY

Coffee marketing in Nigeria has been hampered over the years due to low prices being paid to farmers. This study appraised the effect of coffee marketing problems on coffee production in Nigeria. 150 questionnaires were administered on randomly selected coffee farmers in Abia, Taraba and Kogi States of Nigeria. Analysis showed that the average age of farmers was 54 years while the average age of coffee farms was 30 years. An average of 0.83 tons was realised per hectare of coffee farm. With 53.5% of produce available for sale been eventually sold at a price of ₦51,690.00 (US $397.62); farmers earned ₦25,384.69 (US $195.27) gross margin per season. Markov (Chain) analysis revealed that farmers with large unsold quantities of coffee beans would increase from 16.5% in 1998 to 23.3% in year 2005. A major recommendation was that farmers should organise themselves into farmers' cooperative to take advantage of bulk produce sale.

INTRODUCTION

Marketing becomes highly important with increasing commercialisation of a subsistence economy (Sanusi and Okoruwa, 1999). This is because it provides foreign exchange for export oriented economies, earns income for producers and traders alike as well as relocate agricultural produce from areas of surpluses to areas of shortages (Abbott and Makeham, 1979).

In terms of production, trade and marketing, tree crops are of immense value to the countries of the world (Sanusi et al., 2001). The foreign exchange earned by Nigeria from cash crops such as cocoa, coffee, groundnut, etc contributed to the provision of infrastructural projects such as the Cocoa House in Ibadan and Ahmadu Bello University in Zaria. According to Seudiu (1996), coffee is an important (primary) product produce in and exported from Africa to the developed countries of the world. Coffee is known to be the main foreign exchange earner for many African, South and Central American countries. It provides job for about 20 million people worldwide (Gordon, 1988). According to Sanusi et al. (2001), the Nigerian and world coffee markets' crisis caused by the extinction of the Nigerian Marketing Board and the ineffective administration of the coffee agreement by the International Coffee Organisation respectively left coffee trade without effective regulation nationally and internationally (Sanusi et al., 2001).

The economic significance of coffee cannot be over-emphasised because of its usefulness as a beverage in the home, a raw material in the industry and a commodity of trade in the world market (Sanusi et al., 2001). Thus the coffee industry could be a vital and useful avenue for realising the objective of poverty alleviation and employment generation in Nigeria, since its cultivation, processing and commerce will provide gainful employment for people (Sanusi et al., 2001). Hence, this study examined the effect of coffee marketing problems such as low coffee bean prices and unorganised marketing on the production of coffee in Nigeria.

METHODOLOGY

Primary data was used in this study. The study covered (selected) major and minor coffee producing states i.e. Kogi, Abia, Taraba, Ondo, Ogun, Ekiti and Oyo States of Nigeria. In Oyo, Ogun, Ondo and Ekiti States; coffee cultivation have been abandoned to such an extent that few stands of coffee planted more than 40 years ago could be found on the plots. One hundred and fifty (150) respondents were randomly sampled in Abia, Kogi, and Taraba States. 80 response sets were eventually used for analysis. Data were analysed by frequency, percentages, gross margin and Markov Chain technique.

RESULTS AND DISCUSSION

About 68% of the farmers had one form of formal education or the other (Table 1) while the average age of the farmers is 54 years and that of the farm was 30 years. This implies that the coffee farming population is on the fringe of inactive years.

Table 1. Socio-economic characteristic of farmers.

Characteristics	Frequency	Percentage	Average (years)
Formal Education	54	67.5	6.7
No Education	26	32.5	0
Total	80	100.0	6.7
Age (Farmer)	-	-	54
Farm Age	-	-	30

Source: Field Survey 2000/2001.

Statistics indicated that 71.85%, 44.92% and 49.27% of the total farmland area available to farmers were planted to coffee in Kogi, Abia and Taraba States respectively (Table 2). For the three States, about 58.44% of available farmland were planted to coffee (Table 2). The average yield/ha in the three States were 0.84, 0.66 and 1.08 tons respectively, i.e. an average of 0.83 tons for the three States (Table 2). The average price/ton was ₦58,410 (US $449.31); ₦26,000 (US $200); ₦70,080 (US $539.08) in Kogi, Abia and Taraba States respectively and an average of ₦51,690 (US $437.62) for the three States.

Table 2. Average values of volume of produce, available farmland, area planted to coffee, unsold produce quantity and price by state (1998-2000).

State	A	B	C	D	C/B (%)	D/A (%)		Price/ton (‘₦000)
Kogi	8.62	14.35	10.31	5.14	71.85	59.68	0.84	58.41
Abia	3.11	10.53	4.73	1.20	44.92	38.73	0.66	26.00
Taraba	2.94	5.50	2.71	1.83	49.27	62.09	1.08	70.68
Total	4.89	10.13	5.92	2.62	58.44	53.58	0.83	51.69

A – vol. of output (tons), B – available farmland (ha), C – area under coffee (ha), D – unsold coffee (tons). Source: Field Survey 2000/2001.

Kogi and Taraba State farmers had a “fair” price/ton of coffee, which made them continued coffee production over the years. In Abia State, most of the farmers abandoned their (coffee) farms with some replanting coffee with rice because of the low prices offered for the coffee. This low price did not encourage production in the State. On the average, about 54% of the produce available for sale were sold in the three States (Table 2).

The gross margin (GM) was found to be ₦25,384.69 (US $195.27) per season (Table 3). Markov Chain forecast showed that with the trend exhibited by the Nigerian coffee industry, if not curbed, farmers with large unsold quantities of coffee beans would increase from 16.5% in 1998 to 23.3% in year 2005 (Table 4).

Table 3. Average gross margin per season (1998-2000).

Description	Amount	
Revenue	₦139,563.00	$1,073.56
(Less) Cost	₦114,178.31	$878.29
Gross Margin	₦25,384.69	$195.27

** ₦130 ≅ US $1. Source: Field Survey 2000/2001.*

Table 4. Unsold processed coffee by farmer classes (1998-2005).

Year	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
S_1	58.8	58.0	57.7	56.6	56.5	56.1	56.1	56.0
S_2	25.3	24.0	22.4	20.9	20.9	20.8	20.7	20.7
S_3	16.5	19.8	21.2	22.5	22.6	22.9	23.2	23.3

Source: Field Survey 2000/2001

CONCLUSION AND RECOMMENDATION

A 58.4% available farmland planted with coffee by farmers was far less than the FMC&T (Federal Ministry of Commerce and Tourism, 1995) figures of earlier years. Furthermore, effective hectarage was found to be between 15% to 20% which was not different from previous figure of 20% (Federal Ministry of Commerce and Tourism, 1995). 80-85% were not maintained, abandoned and overgrown with weeds. The launching of a nationwide rehabilitation programme was recommended in the past (Federal Ministry of Commerce and Tourism, 1995) as solution. The Cocoa Research Institute of Nigeria (CRIN) conducted this for farmers in 1996/1997. However, the gains have been marginal. With 68% enlightenment rate, younger farmers were successfully attracted into coffee cultivation. Evidence was that average farmers' age of 70 years quoted by FMC&T (Federal Ministry of Commerce and Tourism, 1995) dropped to 54 years. Also, the average farm age of over 40 years quoted by FMC&T (Federal Ministry of Commerce and Tourism, 1995) dropped to 30 years. However, other parameters have not changed. Effective hectarage and available farmland under coffee had not appreciated. In Abia State, for example, a total number of 400 farms quoted by FMC&T (Federal Ministry of Commerce and Tourism, 1995) in 1994/1995 dropped to 271 in 1999 with only 21.75% of the farms' land planted to coffee (Sanusi and Lawal, 2002).

This study revealed that: (i) the produce were scattered in the producing areas which made assembling for effective marketing difficult; (ii) there was an absence of adequate market information leading to unnecessarily wild price speculations by farmers. Hence, there was high produce price fluctuations – ₦100,000 (US $769.31) per ton a times and ₦30,000 (US $230.77) per ton at other times. These factors drastically reduced the margin accruable to the farmers, thereby pauperising the coffee farming household. The farmers should be encouraged/supported to form their own cooperatives as a matter of priority. This is to facilitate: (i) easy assembling of produce for effective marketing; (ii) provision of loans to the farmers; (iii) regular seminars/training on standard marketing practices, market information and technology transfer in terms of agronomic practices.

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Effect of Shade on the Growth and Yield of Young Arabica Coffee Trees in Kenya

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SUMMARY

A study was undertaken to investigate the effect of shade on coffee plant growth and yield. Six shade trees were studied. *Mimosa scrabella* affected coffee plant growth, yield components and yields while the other shade trees had no significant effect. Mimosa reduced incidences of crinkle leaf and weeds significantly. The evaluated shade trees except mimosa could be suitable shade trees for coffee.

INTRODUCTION

Coffee which is a major cash crop in Kenya is grown by both small scale farmers (55%) and large scale farmers (45%). The original plantings were done under shade from various trees mainly *Grevellea robusta* and *Cordia abysinica* among others. Coffee being an understorey tree was assumed to be able to do better under shade. Robertson (1954) reported that coffee at medium and lower elevations does better and gives higher yields when grown under light shade. Shade has been observed to even out yields over time and reduce overbearing dieback (Huxley, 1970). It also evens out ambient air temperatures and thus reduces the "hot and cold" phenomenon observed mainly in the upper coffee zone (Tapley, 1961). The hot and cold problem is a big hindrance to coffee production in the upper coffee zones in Kenya. Shade trees have the disadvantage of competing with coffee for water and nutrients besides reducing the amount of photosynthetically active radiation (PAR) reaching the coffee trees (Willey, 1975). This can reduce coffee yields. The crucial consideration for shade in coffee is to identify a tree that will have minimal adverse effect on the coffee plant growth, yield and quality but provide all the other beneficial effects of shade. Currently, it may not be possible to get an ideal shade tree, but possibly with genetic engineering this can be achieved. The current study was aimed at screening some of the existing trees as suitable shade trees in Kenyan coffee.

MATERIALS AND METHODS

The trial was sited at Coffee Research Substation Kit ale (1 00'N, 35 12'E, 1890m above sea level and an average rainfall of 1100 mm, most of it falling between April and September). The soils at the site are humic nitosols.

The test coffee cultivar was the compact, disease resistant Arabica hybrid Ruiru 11, planted in 1994. Six shade trees namely; *Cordia abysinica, Leucaena divesofilia, Mimosa scrabella, Grevellea robusta, Markhamia lutea* and *Albizzia schimperiana* were used.

Coffee was managed as recommended and raised on single stem with minimum pruning mainly to remove dead and interlocking branches (Njoroge, 1991). The shade trees were trained on single stem, allowing the canopy to start developing above the coffee canopy (above two meters). The shade trees were not fertilized or manured. Suckers developing at the base of some trees like markhamia were removed.

Data on coffee tree height, diameter, primary branch length (fourth primary from the tree top), number of primaries, number of nodes on the fourth primary and leaf area (second opened leaf on the fourth primary from the top) were recorded at the end of the first production cycle. Ripe coffee was picked from the central coffee trees and weighed after every picking. The total cherry weigh per plot converted to clean coffee at the ratio of 6:1. Coffee bean quality was not assessed during this production cycle due to lack of processing facilities

The trial was laid in a completely randomized block with three replicates.

RESULTS

After six years, coffee plants grown under mimosa and cordia shade were significantly shorter than those grown in the open (Table 1). Coffee plants under albizzia shade were the tallest. During the same period shading coffee plants with mimosa resulted in significantly thinner coffee stems than the unshaded coffee (Table 1). All the other shade trees did not affect significantly the coffee stem diameter. Unshaded coffee had significantly shorter primary branches than the shaded coffee (Table 1). The leaf area and internodal length were not significantly affected by the shade treatments. During this production cycle, coffee shaded by mimosa yielded significantly less than unshaded coffee. The other shade trees did not significantly affect the yields of clean coffee.

Table 1. Effect of shade trees on Arabica coffee plant growth, yield components and yields of clean coffee, Kitale, Kenya.

Shade tree	Tree height (cm)	Stem diameter (cm)	Primary branch length (cm)	Leaf area (cm^2)	Number of bearing primaries	Number of non-bearing primaries	Yields of clean coffee (kg/ha)
Cordia	180 c	4.98 a	43.6 a	24.43 a	106 a	7 ab	1870 ab
Leucaena	206 ab	5.00 a	45.5 a	15.67 a	112 a	7 ab	2464 a
Mimosa	144 ab	3.77 b	39.4 a	26.04 a	76 b	4 b	1049 c
Grevellea	190 bc	4.89 a	40.7 a	21.54 a	106 a	8 ab	1907 ab
Markamia	195 abc	4.81 a	38.4 ab	20.06 a	100 ab	7 ab	2011 ab
Albizia	208 a	5.52 a	44.4 a	32.05 a	112 a	8 ab	1662 bc
No shade	199 ab	5.09 a	27.4 b	16.78 a	110 a	11 ab	2052 ab
Mean	189	4.86	39.9	22.42	103	7	1859

Means followed by the same letter down the column are not statistically significant according to Turkey's Honestly Significant Difference P = 0.5

The shade trees exhibited different growth rates as shown by their breast height bole diameter (bhbd). Mimosa and grevellea had the significantly the biggest bole diameter of 29.7 and 26.62 cm respectively while leucaena had the least at 9.87 cm after six years. There was no significant difference in percent light interception by the shade trees which intercepted 40-60% with an average of 53%.

The shade trees affected weed growth and there was significantly less weed growth in the plots under mimosa shade as compared to the unshaded coffee (Table 2). The other shade trees did not significantly influence the weed levels

Coffee plants under cordia and mimosa shade had no signs of crinkle leaf while those coffee plants in the open had severe to very severe crinkling of the leaves (Table 2).

Table 2. Effect of shade trees on weed cover, occurrence and severity of 'crinkle leaf' syndrome on coffee plants Kitale Kenya.

Shade tree	% Weed cover	Occurrence of crinkle leaf*
Cordia	43.3 ab	None
Leucaena	45.9 ab	Mild
Mimosa	15.0 ab	None
Grevellea	45.0 ab	Mild
Markamia	55.0 a	Mild
Albizia	55.0 a	Mild
No Shade	61.7 a	Severe
Mean	45.7	

Means followed by the same letter down the column are not statistically significant according to Turkey's Honestly Significant Difference P = 0.5.
**Crinkle Leaf scoring*
None 0%
Mild 1-20%
Severe 21-50%
Very Severe >50%

DISCUSSION

The use of shade has been observed to alter the growth habit of the coffee plant. Sturdy (1935) observed an increase in internodal length and leaf area. This was confirmed by Hollies (1967) who reported that individual leaf areas increased with shade (artificial). During the current study, the leaf area and internodal length were not affected by shading but coffee plants grown under Albizzia shade were significantly taller. Coffee trees grown under mimosa shade were shorter and thinner, with less bearing primary branches and less coffee yield. The mimosa shade tree exhibited faster growth as exhibited by the breast height bole diameter. As there was no competition for light, then the adverse effects could have been attributed to competition for moisture or production of allelopathic compounds. The other shade trees did not influence the coffee yield. Amoah et al. (1997), reported that shade trees did not affect the coffee growth and yield of robusta coffee at establishment. Crinkling of coffee leaves due to changes in diurnal temperatures affects coffee leaves and reduces the photosynthetic apparatus. It is a major problem in the upper coffee zones where diurnal range of temperature is more than the tolerable range of 19°C for coffee (Mwangi, 1983). By reducing the temperature range, shading reduces significantly the occurrence and severity of crinkle (Tapley, 1961). Similar reduction of crinkle leaf was observed when young Arabica coffee was intercropped with fruit trees (Kimemia, 2001).

In this study, shading coffee particularly with mimosa greatly reduced weed incidences and species. The increased shading do effect weed growth and the leaf fall from the shade trees form mulch which all interferes with weed growth. The possibility of allelopathic compounds from the mimosa plant or reduced soil moisture may also have contributed to the low level of weeds under the mimosa shade.

These initial results indicate the possibility of interplanting young coffee with *Cordia abysinica, Leucaena divesofilia, Markhamia lutea* and *Albizzia schimperiana* to provide shade and control crinkle leaf in the upper coffee zones in Kenya.

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The Effect of Leaf on Half-Node Stem Cuttings on the Propagation of Robusta Coffee (*Coffea canephora*) in Nigeria

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SUMMARY

Robusta coffee (*Coffea canephora*) has been hitherto propagated successfully by single node stem cuttings in Nigeria. Recently, the demand for rooted stem cutting out spanned the available stem cuttings materials on field; hence a trial was initiated at Cocoa Research Institute of Nigeria, Ibadan to investigate the propagation of robusta coffee by half node stem cuttings. Leafy and non-leafy half node stem cuttings of two improved clones of *C. canephora* (C111 and C36) were evaluated for sprouting and rooting successes at fortnightly intervals for four months. The experimental design was Randomized Complete Block Design (RCBD) with four replicates. Data collected were analyzed statistically using analysis of variance (ANOVA) and the means were separated using Least Significant Difference (LSD). Results showed that leafiness had significant effects on sprouting and rooting ($p \leq 0.01$). The leafy half node cutting had sprouting percent of 70.31 and 60.94 at 7 and 15 Weeks After Set (WAS) respectively while the non-leafy half node had sprouting per cent of 0 at both periods. The percentage sprouting of clone C111 was significantly higher than C36 at $p \leq 0.05$.

INTRODUCTION

Coffea is usually propagated by seed, although it has been successfully propagated by stem cuttings, marcotting and budding (Opeke, 1987; Cambrony, 1992). Recently, the importance of vegetative propagation has increased greatly due to the increasing demand for tree crop improvement (Dhyani and Khali, 1993). Vegetative propagation is the basis of the establishment of clonal plantations, making both cultivation and harvesting easier and ensuring a good biological standardization of the product.

The rooting of stem cuttings represent an important means of vegetative propagation to obtain plants with desired genetic traits within a short period. It is one of the quickest and easiest tools for the multiplication of perennial species like Coffee (Arya et al., 1993; Goel and Bethl 1995). For rooting of *Coffea* cuttings, the single node cutting had been the practice in Nigeria. At present, the demand for rooted stem cutting out-spanned the available stem cutting on the field. Rene Coste (1992) reported on the trials in Madagascar where half-node *Coffea* stem cuttings were used to enhance rapid multiplication of vegetative propagules. The potentials of this method were corroborated by Cambrony (1992). The need to explore the possibility of half-node stem cutting as a means of propagating robusta coffee in Nigeria in order to meet the high demand for improved planting materials that will breed true to type necessitates this study. The objective of the study therefore is to evaluate the effect of leaf in the sprouting and rooting of half-node stem cuttings of robusta coffee (*Coffea canephora*).

MATERIALS AND METHODS

Non-lignified orthotropic branches of clones C111 and C36 were cut, using secateur, from coffee germplasm plot at the Cocoa Research Institute of Nigeria headquarters, Ibadan in between 2002 and 2003. The collected branches were about 30cm in length.

The cut end was dipped in a bucket of water in order to prevent dehydration. The cuttings were cut into smaller size of 2cm length with one node. The single node cuttings were dissected into two symmetrical halves, using budding knife, to obtain half-node stem cuttings. For each of the two clones, 50 per cent of the half-node cuttings had their leaves detached completely while the other 50 per cent had their leaves reduced to one-third of the original size in order to reduce evapo-transpiration. The experiment is factorial, comprising of two factors (clone and leafiness) each at two levels to give four treatment combinations laid in a Randomized Complete Block Design replicated four times. The half-node stem cuttings were planted in a black polythene pots filled with forest topsoil. The pots were arranged under natural shade created by mature cocoa trees in West 4 plot of the Institute. The stem cuttings were watered to full capacity and covered with transparent polythene sheet suspended by flexible stick obtained from the branches of *Gliricidia sepium*. The polythene sheet was weighed down with soil round at the edges to prevent it from being blown away by wind. Caution was taken to ensure that the polythene sheet was not perforated so as to create a humidified condition necessary for the cuttings. At regular intervals, the polythene sheet was opened at one side for watering in order to maintain the humidified condition.

At 7WAS the polythene sheet was removed, the stem cuttings were weeded manually, watering was done using a watering can and data were taken on sprouting of the cuttings. Hardening of the cuttings commenced at 7WAS adopting the method of Omolaja and Obatolu (1999). Data on sprouting success was taken at fortnightly intervals until 15WAS. The data was transformed using log (x + 1) and then subjected to analysis of variance (ANOVA). Afterwards the means were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

The average sprouting success of half-node stem cuttings of *Coffea canephora* is shown in Table 1. It was observed that leafiness is a critical factor in the sprouting and rooting of *C. canephora* stem cuttings. In both clones (C111 and C36) non-leafy stem cuttings did not sprout. This result agreed with an earlier observation made in Madagascar (Rene Coste, 1992) that *C. canephora* stem cuttings without leaf showed zero percents of sprouting and rooting. The reason for this could be due to the vital function of leaf as a site for the manufacture of food and other physiological processes, such as respiration, that occur in plants.

Table 1. Average sprouting success of *Coffea canephora* stem cuttings at fortnightly interval.

Clones & Leafiness	(WAS)				
	7	9	11	13	15
Clll, leafy	70.31	67.19	64.06	62.50	60.94
CIII, Non-leafy	0	0	0	0	0
C36, leafy	25.31	20.31	20.31	20.31	20.31
C36, Non-leafy	0	0	0	0	0

Differences in the clones, leafiness and in the interaction of clones and leafiness were highly significant ($p \leq 0.01$) (Table 1). Clone C111 gave better sprouting and rooting successes than clone C36. This agreed with earlier report by Rene Coste (1992) that clones of *C. canephora* differ in their sprouting and rooting abilities. This is however contrary to the report by Omolaja and Obatolu (1999) who reported that there was no difference in the rooting ability of stem cutting of two varieties of *C. canephora* (Pierre Quillou and Java). At 7WAS, C111 gave a sprouting success of 70.31 per cent, which declined to 60.94 at 15WAS. In C36 the percent sprout were 25.00 and 20.31 at 7WAS and 15WAS respectively. The decrease in percent sprout with time was due to the inability of some sprouted cuttings to root which resulted in their death as reported by Puri and Verma (1995). Despite the absence of synthetic rooting hormones, couple with the fact that the cuttings were half-node which made it more fragile than single or multiple nodes cuttings, a percent sprout of 60.94 was obtained for C111. Although this percent sprout is less than 90 percent rooting success reported by Rene coste (1992) in Madagascar, it is however higher than 55 percent sprout and comparable to 60.00 percent obtained for stem cuttings treated with 2000 mg/l humic acid and 8000 mg/l Naphthalene acetic acid (NAA) respectively as observed by Omolaja and Obatolu (1999). The presence of leaf is therefore recommended as a treatment for rooting stem cuttings of *C. canephora*. The result of this work can easily be adopted by the farmers in that it was done under conditions similar to that on farmers' farms. It is however desirable that further investigation be conducted using larger samples of stem cuttings to compare the earlier recommendation of 8000 mg/l IBA for the treatment of one-node stem cuttings of *C. canephora* in Nigeria condition with half-node stem cuttings production without IBA treatment.

Table 2. Mean square estimates of sprouting of *Coffea canephora* stem cuttings at fortnightly interval.

	Periods (WAS)				
Parameters	7	9	11	13	15
Clone	2053.23	2197.26	1914.06	1779.75	1650.31*
Leaf	9084.47**	7656.25**	7119.14**	6857.91**	6601.56**
Interaction	2053.23	2197.26	1914.06	1779.78	63.47

*** : $p \leq 0.01$.*
** : $p \leq 0.05$*

CONCLUSION

The presence of leaf in the rooting of half-node stem cuttings of *C. canephora* is a critical factor without which rooting will not occur. Hence every stem cutting to be rooted should have leaf.

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Integrated Fertilisation of *Coffea Robusta* by Coffee Husks Compost and Two Leguminous Plants in Togo (Fertilisation Intégrée de *Coffea Canephora* par le Compost de Coques de Café et deux Légumineuses Forestières)

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SUMMARY

Coffee is one of the main cash crops grown in Togo. Coffee husks, an important residue (15 000 tons.year^{-1}) from coffee shelling are not used as manure for the soil in coffee farms. From 1999 to 2003, we investigated the possibility of dissolving raw Togolese phosphate using of organic acids released in the course composting coffee husks. Coffee husks, raw phosphate, chicken droppings, straw and clay from anthill were all mixed up in small compost pits. The composts thus obtained had far more concentrations in major mineral elements (nitrogen 0,77%, available phosphorus 299,76 ppm and potassium 0,753%) than required to nourish the coffee-tree. On the one hand, many tests of efficiency of these composts on both the growth and production of coffee tree, on the other hand the Leguminous plants effect evaluation on coffee tree production, confirmed the feasibility advantage in using coffee husks and Leguminous plants to maintain soil fertility in coffee based cropping systems.

INTRODUCTION

Le café est le 3ème produit d'exportation du Togo. La baisse continue des prix d'achat aux agriculteurs limite la capacité financière de ceux-ci à se procurer de l'engrais minéraux indispensables à la fertilisation des plantations. La conséquence de cette situation est la diminution des rendements liée à la dégradation progressive de la fertilité des sols dans les caféières. Or le Togo dispose d'importants gisements exploités de phosphate naturel de qualité (36,3% de P_2O_5) et plusieurs Légumineuses forestières associées aux caféiers constituent une source d'azote à peu de frais. Aussi les coques de café représentent – elles un résidu de récolte riche en potassium (3,743%) facilement récupérable estimé à 15 000 tonnes par an. En vue d'améliorer la fertilité des sols et stabiliser les rendements de café en absence d'engrais chimiques, il nous a paru judicieux d'étudier deux modes de fabrication de compost avec les coques de café additionnées ou non de phosphate naturel, de tester les composts obtenus sur la croissance de jeunes caféiers en pépinière et de comparer les effets du compost, des Légumineuses et l'engrais chimique sur le rendement des caféiers adultes.

MATÉRIEL ET MÉTHODES

Les essais ont été conduits à la station expérimentale de Tové située à 205 m d'altitude, 06°53' de latitude Nord et 00°39' de longitude Est. Les espèces végétales étudiées sont *Coffea canephora var robusta, Leuceana leucocephala et Glyricidia sepium.*IIG 55. Deux modes de fabrication (F1 et F2) de compost avec les coques de café additionnées ou non de phosphate naturel ont été essayés. Des échantillons composites de sol et de compost ont été prélevés et analysés au Laboratoire des Sols de l'ITRA à Lomé. Le diamètre au collet, la hauteur et les biomasses (fraîche et sèche) ont été évaluées sur de jeunes plants de caféiers et par traitement. Le test d'évaluation de la production de caféier adulte a été conduit sur une caféière âgée de cinq ans. Les traitements sont en blocs randomisés et répétés 5 fois. La parcelle élémentaire comporte 48 caféiers dont 24 utiles. Soit 21 m sur 12,5 m. La superficie totale de l'essai est de 1,05 ha. Le témoin absolu (sans engrais et sans Légumineuses) et le témoin de référence (engrais à la dose vulgarisée) ont été comparés au compost, aux Légumineuses seules et aux Légumineuses additionnées de demie dose d'engrais. Ce schéma a affiché les traitements suivants: T1 = Témoin absolu; T2 = NPK 20-10-10 à 400 kg/ha (155 $g.plant^{-1}$ x 2); T3 = Compost F1 à 8 $tonnes.ha^{-1}$ (3 $kg.plant^{-1}$ x 2); T4 = *L. leucocephala* var hawaï géante: 166 $plants.ha^{-1}$; T5 = *G. sepium* ILG 55 : 166 $plants.ha^{-1}$; T6 = T4+1/2T2; T7 = T5+1/2T2**.**

RÉSULTATS ET DISCUSSION

Compostage des coques de café

Les composts obtenus après quatre mois ont les caractéristiques suivantes:

Tableau 1. Caractéristiques des types de compost.

Type de compost	Eléments minéraux			
	Azote (%)	Phosphore total (ppm)	Phosphore assimilable (ppm)	Potassium
Compost sans phosphate naturel	0,776 a	1088 a	268 a	0,863 b
Compost avec phosphate naturel	0,765 a	5117,330 b	363,330 b	0,533 a

Les moyennes suivies des mêmes lettres dans les colonnes ne sont pas significativement différentes (test de Student-Newman-Keuls au seuil de 5%).

Les teneurs en phosphore (assimilable et totale) sont significativement plus élevées au niveau de tas additionné de phosphate naturel. Ce qui implique un enrichissement du compost par une partie du phosphate naturel au cours du processus de compostage.

Effet du compost sur la croissance de jeunes caféiers

Hauteur et diamètre au collet des jeunes plants de caféiers

Les plants qui ont été élevés sur le compost fait de coques de café et de phosphate naturel présentent une meilleure croissance en hauteur (Tableau 2).

Tableau 2. Hauteur et diamètre au collet des jeunes plants de caféiers, 4 mois après leur repiquage.

Type de substrat	Diamètre au collet (cm)	Hauteur (cm)
F1 sans phosphate naturel	2,38 a	15,32 a
F2 avec phosphate naturel	2,17 ab	22,30 b
T(terreau)	2,37 a	17,26 ab
CV	19,76%	19,06%

Les moyennes suivies des mêmes lettres dans les colonnes ne sont pas significativement différentes (test de Student-Newman-Keuls au seuil de 5%).

Biomasse

Les caféiers conduits sur le compost de type F2 ont développé les plus grandes quantités de biomasse fraîche et sèche (Tableau 3)**.**

Tableau 3. Biomasse totale des jeunes plants de caféier, 4 mois après leur repiquage.

Type de substrat	Biomasse fraîche totale (en g)	Biomasse sèche totale (en g)
F1 sans phosphate naturel	334 b	67 b
F2 avec phosphate naturel	776 a	194 a
T (terreau)	330 b	72,5 b
CV	20,79 %	21,88 %

Les moyennes suivies des mêmes lettres dans les colonnes ne sont pas significativement différentes (test de Student-Newman-Keuls au seuil de 0,05).

L'effet du compost de coques de café sur la croissance en diamètre et en hauteur et sur la biomasse des plants de caféier indique que les coques de café jusqu'alors perdues (15000/tonnes/an en moyenne) peuvent être utiles aux exploitations caféières..

Effet du compost et des Légumineuses sur la production de café

Après deux années de production, la parcelle a subi la rigueur de la sécheresse et a dû être recepée en 2000. La récolte de 2001 a été insignifiante. L'analyse statistique des productions cumulées des 4 principales récoltes n'a pas montré de différences significatives entre les traitements. Rapportées à l'hectare (Tableau 4), les productions du café induits par les deux Légumineuses forestières et le compost permettent de faire un clair rapprochement par rapport au rendement avec à l'engrais. Il est intéressant de mettre en évidence d'autres formes de fertilisation du caféier, autres que celle exclusivement à base d'engrais minéral en caféiculture togolaise La meilleure Légumineuse a donné un rendement de 965 kg.ha^{-1} de café marchand Il est remarqué que l'addition de la demie dose d'engrais minéraux a amélioré le rendement sur le traitement Glyricidia (1099 kg.ha^{-1}). Le rendement de 882 kg.ha^{-1} de café marchand du compost a confirmé l'utilité de coques de café pour fertiliser les caféières togolaises.

Tableau 4. Rendements en kg/ha de café marchand dans différentes conditions de nutrition.

Traitement	Rendement kg.ha^{-1}				
	1998	1999	2002	2003	Moyenne
L. leucocephala	1052	800	956	1036	924 ns
G. sepium	907	483	1335	1135	965 ns
Leuceana +1/2NPK	631	530	1270	1062	873 ns
Glyricidia +1/2 NPK	1227	1106	1047	1016	1099 ns
Compost	670	925	890	1046	882 ns
NPK 20.10.10	832	518	1194	1204	937 ns
Témoin	690	710	540	508	612 ns

Effet sur quelques paramètres de la fertilité des sols

Après 4 campagnes, des indicateurs d'évolution de fertilité des sols ont été observés sur toutes les parcelles élémentaires. La diminution du taux de matière organique a été maximale sur le traitement NPK (–1,169%). Elle a été faible sur les traitements compost et Légumineuses (–0,247%). La teneur en phosphore totale a diminué en moyenne de 112 ppm sur tous les traitements. Celle en phosphore assimilable a augmenté de 15 ppm sur les traitements compost et Légumineuses; elle par contre diminué sur le témoin absolu et sur NPK de 0,5 ppm.

Sur ces mêmes traitements la capacité d'échange cationique a aussi diminué de 4%, alors qu'elle a augmenté de 21% sur les traitements Compost et Légumineuses. Aucun des traitements n'a pu entretenir le taux de saturation (Tableau 5).

Tableau 5. Evolution quelques caractéristiques des sols dans différentes conditions de nutrition.

Paramètres	Caractéristiques après l'application des traitements						
	NPK 20.10.10	Compost	Témoin	1/2NPK + Gly	1/2NPK + Leu	Gly	Leu
Mat. Org %	–1,169	–0,55	–0,569	–0,448	–0,182	–0,006	–0,058
Azote tot %	–0,0382	–0,0.64	–0,0037	–0,0099	+0,0218	+0,0128	–0,0463
P tot ppm	–158	–127	–108	–48	–93	–139	–110
P ass ppm	+1	+14	+2	+17	+12	+8	+22
K méq/100g	–0,06	+0,055	+0,031	–0,051	+0,015	–0,22	+0,0462
CEC méq/100g	–0795	+2,014	–0 ,02	–6,615	+2,333	+1,687	+2,005
Saturation%	–56,77	–65,9	–62,23	–33,4	–62,4	–65,81	–63,05

CONCLUSION

Cet essai a permis de montrer que le compost des coques de café et les légumineuses forestières sont des éléments à la portée du petit producteur pour entretenir la fertilité des sols en caféiculture. Ils peuvent servir d'alternative à l'utilisation des engrais chimiques en conditions de chute des prix de café et permettre de conserver le verger en périodes défavorables.

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Adaptation of Arabica Coffee Land Races along Topographic Gradients in Southern Ethiopia

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SUMMARY

A systematic survey was made in the major coffee growing areas of Southern Ethiopia with the major objective to establish systems shift and adaptation of Arabica coffee land races along topographic gradients. Frequency distribution and weighted means of landforms, soil types, shade trees and river recurrences were considered. Landrace coffee types: *Kurumie* (compact), *Deiga* (intermediate) and *Wolisho* (open) were categorized along topographic gradients. The results depict that short river recurrences in Sidama were more dominant than Gedeo zone. Flat lands dominated convex and concave land configurations. In the order of magnitude Cambisols dominated all other soil types. The compact local coffee types flourish ideally on moist flattop and bottom soils, intermediate and open types adapt and perform well on eroded lands and drier soils and steep slopes besides top and bottomlands. There was strong correlation between canopy diameter and growth of lateral branches for all coffee classes, which dominated at each farm. Rainfall patterns, soil types and slopes were more determinant factors than altitude in dictating *in-situ* Sidamo and Yirgachefe Arabica coffee adaptations. As a whole, intermediate and open coffee types favored homogenous stands on relatively drier soils against heterogeneous coffee populations on almost flatlands and young soils, justifying their variability in adaptations and stand structures along soil moisture gradients.

INTRODUCTION

Sidama and Gedeo zones represent the major coffee growing and densely populated areas in south Ethiopia with the respective density of 451 and 590 persons per km^2 (CSA, 1998). The land is irregular as mountains, valleys, steep and gentle slopes and almost flatland, characterize it. Raunet (1977) has reported the dominant soil association; altitudes ranges and vegetations. Chaffey (1982) did the general vegetation cover from remote sensing and Westphal (1975) described the cropping system of the area.

However, whether these works used the consistent cropping patterns of the region is strongly questionable. To date, no focused work on soil-plant components with the emphasis on the adaptations of local coffees in the region. This study was intended to verify whether or not there is ecosystem variability and Arabica coffee land race shifts in the major coffee growing areas of southern Ethiopia. Similar, concepts were promoted elsewhere by Crawley (1986) in which case ecological stresses precondition the particular shifts in question. According to Coste (1992) and Wrigley (1988) Arabica coffee can be classified into compact, intermediate and open cultivars. Brown-Bridge and Eyasu (1972) have identified three commercial coffee types in South Ethiopia. Similarly, Yacob et al. (1996) have also reported that Arabica coffee land races of the study area are known by different vernacular names (*Kurmie, Wolisho* and *Deiga*) and categorized into three macro morphological classes. These include *Kurumie* (compact types) has small leaves, fruits, compact canopy and short heights. On the other hand, *Wolisho* (open types) has the longest leaves, fruits, bigger canopies volume, stiff stem and tallest heights. *Deiga* (intermediate types) lie in between the two classes. Therefore, the major interest of this study was to establish the adaptation patterns of Arabica coffee land races along topographic shifts in Sidama and Gedeo zones of south Ethiopia.

MATERIALS AND METHODS

The study was conducted in the major coffee growing areas of south Ethiopia. A car drive stops at an intervals of 5-10 km were made on Awassa-Moyale highway between Awassa-Yirgalem (Sidama zone) and Dilla-Yirgachefe (Gedeo zone) to determine the occurrence frequency of landforms (flat, convex and concave), soil associations, vegetations and coffee land races along the roadsides. River recurrences were also recorded and kilometer changes of the speed-covered were determined. This was based on a car speed kilometers hr^1 wristwatch second count from start to the end of the land formation. In this case, the indirect wristwatch tidal multiplied by the car speed would give the km covered for specific variant character. The coverage distance change would give rise to the soil and landform magnitudes.

Moreover, based on the preset phenotypic characteristics of the local coffee types (Yacob et al., 1996), systematic on farm morphological classification and frequency distributions were determined at each farm. Canopy diameter was the average measures taken in 2-directions on the widest sides of lateral branches. In addition, vertical number on each coffee type was counted and its relationship with canopy size was considered from the computed regression equation and linear correlation to assess the magnitudes of successions and growth performance along topographic features.

RESULTS AND DISCUSSION

There were strong Arabica coffee landrace, soil association and landform shifts in the surveyed areas (Table 1). There was more regular frequency of plateaus and bottom almost flatlands than convex and concave land configurations. Furthermore, almost flat landforms were associated with more soil depths than the two configurations (Table 1). This could be among the most probable reasons for the more Arabica coffee heterogeneity in the coffee farms around Yirgalem areas more than that of Gedeo (Table 1). This also justifies the inherent variability among local coffee types in shoot and root growth natures to perform better under a given ecological settings. Above all, soil moisture regimes can detect plant distribution and composition. This seems to be accompanied by the regular land deterioration evidenced by severe erosion due to shorter rivers recurrence frequency within the Gedeo zone than Yirgalem, Aleta Wondo and Yirgachefe (Table 2). The severity of erosion has long been recognized within the Gidabo Basin (Raunet, 1977), although the contribution of rivers albeit to the land configuration was not attributed to the phenomenon. It is also very lately that the rainfall patterns and the higher elevations coupled with the irregular and broken landforms could aggravate the severity of erosion in the region (Raunet, 1977; Westphal, 1975).

The dominant shade trees presented in Table 3 include *Acacia* sp., *Croton machrostachys, Albizia* sp., *Ficus* sp., *Podocarpus gracilior* and *Cordia africana* in that order along altitudinal variations. Accordingly, *Acacia* sp. and *Croton* were dominant at relatively low and high altitude areas. This agrees with Yacob et al. (1996) who have identified leguminous trees as ideal shade sources for sustainable coffee production. However, Eucalyptus tree is also widely expanding in the area and investigation on its ecological and economic aspects should deserve attentions. The present finding supports the work done by Cook et al. (1987) who reported that forest and vegetation shift principle was registered in the temperate regions as a consequence of climatic stress and forest decline was expressed in terms of tree ring to discover climatic stresses.

Table 1. Landforms, soil types and altitudes.

Location	Landform	Distance covered (km)	Freq. (%)	Soil association (km)	Freq. (%)	Altitude (m.a.s.l.)
Yirgalem-Awassa/tobacco Monopol	Flat	17.6	27	Cambisol (7.2)	12	1800-2000
				Fluvisol (10.4)	13	
	Concave	2.9	3	Cambisol (2.9)	5	2000
	Convex	10.4	16	Cambisol (7.4)	23	1930-2000
				Lithosol (3)	4	
AletaWondo to Aposto	Flat	38.7	65	Lithosol (2.7)	8	1750-1950
				Cambisol (18.4)	43	
				Fluvisol (4.4)	9	
	Concave	20.3	18	Plansol (13.7)	15	1880-1980
				Lithosol (2.4)	4	
				Cambisol (4.2)	9	
	Convex	24.8	43	Cambisol (20.9)	39	1750-1900
				Nitosol (3.9)	6	

Table 2. Recurrent rivers along Awassa to Yirgachefe highways.

Location	River name	Altitude (m)	Distance (km)	Distance change (km)
Dale	Chale	1885	0	
	Cola	1830	2	2
	Bisandima	1880	5	3
Aleta	Bukisa 1	1900	6	1
	Bukisa 2	1900	7	1
Dilla	Chicha	1650	3.7	0.7
	Kilkila	1620	5.7	1.8
	Bedela	1620	5.7	0
	Darso	1640	9	3.3
	Finchua	1820	14	5

Table 3. Average number of coffee shade trees between Awassa and Yirgalem towns.

Distance (km)	Altitude (m)	*Acacia sp*	*Albizia sp.*	*Croton*	*Cordia*	*Ficus*	*Podocarpus*
9	1790	71	5	14	5	16	-
12	1890	57	12		3	-	-
15	1920	43	33	13	-	10	-
17	1945	7	6	6	-	-	-
18	1940	3	3	-	-	-	-
24	1950	18	18	14	-	-	5
28	1900	19	19	55	-	-	5
40	1835	31	31	112	-	19	32
Total		**249**	**127**	**214**	**8**	**45**	**42**

Table 4. Mean frequency of local coffee types along soil types and altitudes.

Coffee farm	Altitude (m)	Soil type	Soil depth (cm)	Coffee type	(n)[a]
Melka Alati	1690	*Cambisol*	A-79	*Kurmie*	26
			B-26	*Deiga*	40
			C-20	*Wolisho*	8
Jirreme	1740	*Cambisol*	A-40	*Kurmie*	59
			B-21	*Deiga*	124
				Wolisho	18
Wenenatta	1790	*Lithosol*		*Kurmie*	31
				Deiga	31
				Wolisho	NF[§]
Ferro	1810	*Cambisol Fluvisol*	A-79	*Kurmie*	25
			B-72	*Deiga*	75
				Wolisho	NF
Afursa Worabi Worabi	1880	*Regosol*	A&C - 350	*Kurmie*	26
				Deiga	23
				Wolisho	NF
Gidabo	1910	*Cambisol*	A-23	*Kurmie*	17
			B_1-46	*Deiga*	NF
			B_2-174	*Wolisho*	87
Bultuma	1980	*Nitosol*	A-68	*Kurmie*	62
			B-185	*Deiga*	NF
				Wolisho	184
Sockicha	2000	*Nitosol*	A-95	*Kurmie*	180
			B-137	*Deiga*	NF
				Wolisho	279
Homa	2000	*Cambisol Fluvisol*	A-70	*Kurmie*	34
			B-125	*Deiga*	8
			C-80	*Wolisho*	9
Bankbusa	2080	*Regosol*	A-75	*Kurmie*	NF
			C-140	*Deiga*	NF
				Wolisho	65

a = mean number of observations; NF § = not found.

Table 5. Associations between canopy diameter and number of verticals on local coffee types.

Coffee farm	Altitude (m a.s.l.)	Coffee type	Observation number	Canopy spread (m)	Vertical Number	Regression equation	Correlation value (r)
Melka Alati (River side)	1690	*Kurmie*	26	3.4	24	Y= -14.3x + 11.5	0.57**
		Deiga	40	3.0	12	Y= 11.6x + 8.2	0.80**
		Wolisho	8	4.0	11	Y= 6.7x + 1.2	0.70NS
Jireme	1740	*Kurmie*	59	3.3	17	Y= -44x + 18	0.85**
		Deiga	124	3.8	27	Y= 41.9x – 3.8	-0.40**
		Wolisho	18	3.7	8	Y= 9.9x – 0.4	-0.04NS
BankBusa	2080	*Wolisho*	65	3.1	4	Y= -5.1x + 2.9	0.66**
Hama	2000	*Kurmie*	34	3.0	8	Y= 2.4x + 3.43	0.50**
		Deiga	8	2.9	8	Y= -6.0x + 4.9	0.92**
		Wolisho	9	3.2	7	Y = -9.3x + 5.2	0.44NS
Afursa Worebi	1880	*Kurmie*	26	1.8	5	Y= -53.5x + 32.5	0.98**
		Deiga	23	2.3	6	Y= -3.9x + 4.3	0.50*
Sockicha	2000	*Kurmie*	180	2.2	9	Y=-3.2x + 5.8	0.69**
		Wolisho	279	2.4	8	Y= 4.1x + 1.5	0.16**
Bultuma	1980	*Kurmie*	62	4.1	11	Y= -11.3x + 5.4	0.86**
		Wolisho	184	3.6	10	Y= -16.3 x + 7.2	0.80**
Gidebo	1910	*Kurmie*	17	3.3	11	Y= -45.1x + 17.2	0.94**
		Wolisho	87	3.0	8	Y= -8.4 x + 4.4	0.98**
Wogido	2060	*Kurmie*	31	3.3	6	Y= 0.5x + 1.6	0.93**
		Deiga	31	3.7	8	Y= 44.7x –10.0	0.76**
Ferro	1810	*Kurmie*	25	3.4	6	Y= 4.8x + 0.4	0.30NS
		Deiga	75	3.4	6	Y= 1.8x + 1.2	0.62**

The most recurring Arabica coffee land races were the intermediate-*Deiga* morphological classes in the Gedeo zone of high altitude area where there was higher extinction rate of open-*Wolisho* and compact- *Kurmie* classes in the zone (Table 4). Erosion severity and landform shifts could attribute significantly to such adaptation differences along the rainfall gradients (Figure 1). In addition, the increased number of crop bearing branches in the intermediate classes and its highly significant correlations with canopy spreads (Table 5) could explain their better growth performances and productivity than the other two land race classes. The compact classes also produced more primary branches at some farms. This in part reflects variability in coffee morphology and stand structures due to plant density cover in different forest ecology as Taye et al. (un pub.) reported it. Crawley (1986) proposed the competitive exclusion principle where the best competitors will give long enough to oust all others, where the ultimate domination of one species will induce the extinction of the other.

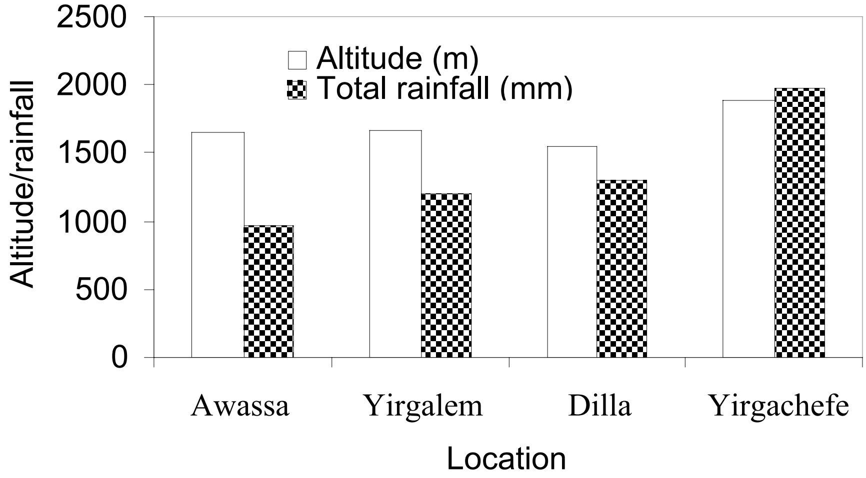

Figure 1. Altitude and long-term annual rainfall of the study areas.

Hence, in the present study there are indications that under more favorable conditions all the three Arabica coffee classes could coexist simultaneously, particularly on bottom almost flatlands giving rise to rather a heterogeneous stand. The eventual and frequent extinction rate give rise to a homogenous coffee stands, which may indirectly explain the homogenous Yirachefe coffee stand with its best quality favorable again for uniform roasting, though more characterizations and cropping systems remain for future work.

CONCLUSION

The results show strong Arabica coffee land races adaptations along the *in-situ* farm topographic gradients. Accordingly, the vigorous and open types have wider adaptation from wet to dry sites, while the compact types flourish in wet areas. Most of the farms possessed only one or two classes and the intermediate classes dominated the open and compact classes. Shifts in soil types (depth and moisture contents) dictate adaptations of Arabica coffee land races to favor or disfavor heterogeneous and homogenous coffee stand structures. This suggests the roles of soil moisture status and growth natures of coffee types. Thus, the *in-situ* and *ex-situ* conservation of Arabica coffee genetic-base must be localities that favor the balanced stands of the three coffee classes with distinct characteristics. The finding may shade a light on the major site features that would help to target appropriate soil and water conservation measures, develop suitable cropping patterns and design conservation approaches for the local coffee gene pool in the area.

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Eco-physiological Variability of Forest Arabica Coffee Populations in Hydraulic Characteristics along Climatic Gradients in Ethiopia: Moisture Dynamics in Soil and Plant Systems Under Field Conditions

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SUMMARY

The study was undertaken in the natural forest coffee populations with the primary objective to investigate the diurnal and seasonal moisture dynamics in the soil-plant systems. Soil moisture was measured using a theta probe and volumetric method. A pump up pressure chamber (Scholander bomb) was used to measure the predawn and mid-day leaf water potentials (LWP). The measurements were made over seasons (between August 2003 and August 2004) in the wet and dry seasons. The results indicated that soil and leaf water contents varied over seasons and locations. Accordingly, soil water content followed the order of summer > autumn > winter season in the south-western sites (Bonga, Sheko and Yayu). In contrast, it was higher in winter than summer season at Bale-DoloMena sites of south-eastern Ethiopia. Similarly, LWP changed with soil moisture patterns, though the values varied among seasons and sites. Consequently, the least and highest LWP were recorded in the dry and wet seasons, respectively. At most sites, the variation between the predawn and mid-day LWP was highly significant in the wet season. In contrast, this was not significant during the dry season, which most probably suggest the isohydric behavior of coffee trees. At all sites, coffee trees did not show symptoms of drought during the course of study. As a whole, the present preliminary findings would provide insights into the variability and influences of climatic patterns, site features and phenotypic growth of coffee populations. Therefore, further studies on the amplitude of drought stress adaptations of wild Arabica coffee populations with the special emphasis on the hydraulic gradients in the soil, plant and atmosphere components should continue with the purpose to identify drought tolerant coffee accessions.

INTRODUCTION

Water availability is one of the most important factors controlling the distribution of plant species at the global scale. Soil water facilitates the absorption of minerals by plants while plant water content helps in maintaining the right type of turgidity for growth. The movement of water from the soil into the roots is mainly affected by the extent to which the roots spread (Coste, 1992). The coffee tree has a limited surface area but widely spreading surface roots, and therefore has generally low rates of water uptake (Wrigley, 1988).

Arabica coffee needs total annual rainfall of 1500 to 1800 mm, which is evenly distributed over the growing period of 8 to 9 months (Coste, 1992). A dry period of 3-4 months is also physiologically important to break bud dormancy and trigger the reproductive growth processes. The water requirement of a coffee plant also depends on climatic variables (atmospheric humidity, light, wind and cloud cover), soil properties, cropping patterns and management regimes. However, the occurrence of frequent drought is one of the factors that threatened the genetic pool of Arabica coffee in the major coffee growing areas of Ethiopia. This is more aggravated, among others, by the escalating deforestation of the natural forests and expansion of coffee cultivation to marginal areas. There are still diverse coffee types, which are adaptable to the prevailing environmental stresses including the recurrent drought situations. However, detailed information is scanty mainly on the interaction between water supply and demand for the diverse Arabica coffees grown under wide agro-ecological zones of the country.

Plant moisture stress requires the understanding of atmospheric demands on the plant, plant regulation and soil moisture supply. Hence, leaf water potential was found to be the most suitable technique for assessing the internal water balance by integrating soil moisture tension, the resistance to water movement within the plant and the demand for transpiration imposed by the environment. The internal water balance in coffee is influenced by soil moisture, soil type and root resistance (Coste, 1992). Plants attempt to maintain water balance at decreasing soil moisture by stomatal closure, increasing permeability to water in the root zone or both. According to Tausend et al. (2000), the specific morphological differences of coffee reflect the hydraulic architecture of the plants, by their influence of the boundary layer resistance as well as by the determination of the hydraulic resistance for the soil-root-shoot-leaf resistance.

In this regard, study on the response of Arabica coffees along climatic gradients and complex production systems are amongst the high priority areas identified in the strategies and priorities of the national coffee research of the country. Within the context of water deficit stress adaptation of wild Arabica coffee populations the specific objective of this study was, therefore, to examine the seasonal and diurnal moisture dynamics in the soil-plant systems under the natural forest habitats of south-western and south-eastern Ethiopia.

MATERIALS AND METHODS

The study was carried out in the natural forests of Bale-DoloMena (PI), Bonga (PII), Sheko (PIII) and Yayu (PIV). Except, PI of south-eastern, the others are located in south-western part of the country. According to Paulos and Demel (2000), these forests are characterized with varying rainfall gradients with the bimodal and mono-modal distributions in the south-eastern and south-western parts of the country, respectively. The long-term rainfall amounts followed the descending order of Yayu>Bonga>Sheko>Bale-DoloMena. Three sites (S1, S2 and S3) were selected within each forest population. The study areas were described in our report on the morphological and physiological variability of forest Arabica coffee populations along a climatic gradient (Taye et al., un pub).

At each site, nine to twelve young (5-7 yrs) experimental coffee trees were selected along the existing variations within a site. The tip of lateral branch with two pairs of leaves was removed from the upper canopy of the selected trees to measure leaf water potential (LWP) during predawn (5:30 to 6:30 hours) and mid-day (12:00 to 13:30 hours). This was done using a portable pump up pressure chamber (Scholander bomb). Simultaneously, soil moisture beneath the canopy of coffee trees was measured by using a theta probe type ML 2x. Moreover, surface soil samples were collected before the day cycle starts and soil fresh was immediately measured. Then, oven-dried soil dry weight was recorded to determine the water in the soil (percent of dry weight) under field conditions.

In addition, healthy and mature coffee leaves were collected (before sunrise) from the 3rd to 4th nodes on primary branches and leaf fresh weight was immediately measured. Subsequently, the sample leaves were oven dried at 70°C for 24 hours and dry weight was measured to calculate the osmotic leaf water content (percent of dry weight). The data were collected over seasons: summer-August/September 03, autumn-November/December 03, winter-February/March 04 and spring-May/June 04. But, at PI sites, the last data were collected in the first week of August 04 (summer season). In here, winter and summer represent the driest seasons in the south-western and south-eastern sites, respectively. Finally, the data were analyzed using SAS software and mean comparison was carried out according to Tukey's Studentized Range at 5% probability level.

RESULTS AND DISCUSSION

Soil moisture dynamics

Significantly different soil moisture was measured due to seasons and sites. Except at sites 2 and 3 of Bale, there were highly significant seasonal soil moisture differences at the other sites. And the results followed the order: spring >autumn>winter, indicating similar seasonal soil moisture patterns in the south-western sites. Accordingly, the highest (39% vol.) at Bonga (site 2) and the least (10%vol.) at Sheko (sites 2 and 3) were measured in May/June 04 and February/March 04, respectively. In contrast, the results at Bale sites were higher in winter as compared with the summer season (Figure 1). From the theta probe soil moisture readings (Figure 1) and soil water (percent of dry weight bases) (Figure 2) at Bale sites, significantly maximum values were obtained in winter, spring/summer and autumn seasons in that order. Though, the difference between spring and autumn seasons was high at Yayu, there was similar trend for all sites (Figure 2). This is quite in line with the long-term rainfall patterns in south-western and south-eastern parts of the country (Paulos and Demel, 2000).

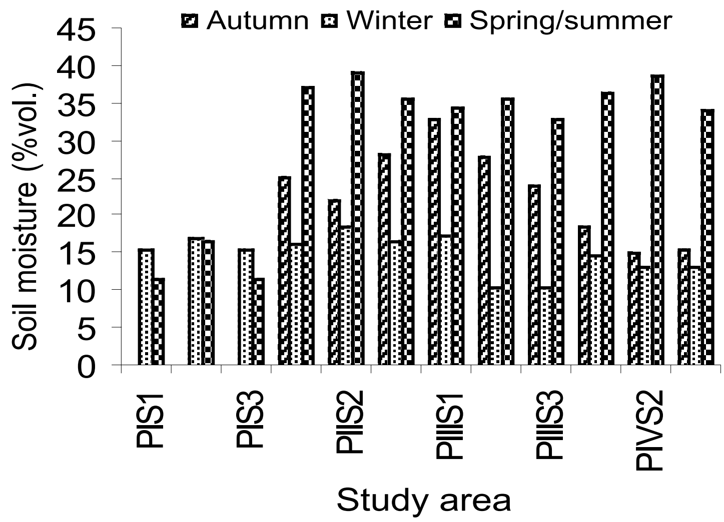

Figure 1. Seasonal soil moisture dynamics in the different forest coffee sites.

Moreover, the results revealed significant differences among sites within each forest population. Hence, the least values were recorded during the dry season at site 1 (Bale), site 1 (Bonga), sites 2 and 3 (Sheko) and sites 2 and 3 (Yayu) forests. Except site 3 of Sheko, these sites had high plant density covers and hence, the results may in part reveal soil moisture competition by the closely spaced coffee trees and shade trees during the dry season. Whereas, the low soil moisture status at site 3 of Sheko could be associated with the specific site features shown in our report (Taye et al., un pub). Soil properties particularly depth and texture may contribute to such soil moisture variability and it is foreseen. In addition, the high soil moisture at site 2 of Bonga could reflect the contribution of the plant density and morphological growth natures of coffee trees (Taye et al., un pub). Because, moderate over shadings help to reduce the hydrostatic gradients in the soil-plant-atmosphere continuum. Soil cover from annual broad-leaved weeds and litter falls the deciduous shade trees can also minimize water demands and conserve soil moisture. Larcher (2003) has shown that the rainwater may be intercepted with the dense upper canopy layers and lost due to evaporation.

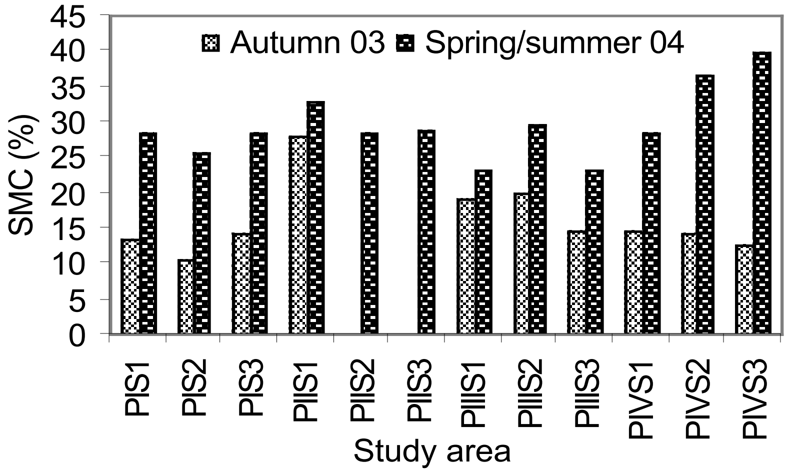

Figure 2. Soil moisture content (SMC-percent dry weight) in the dry and wet seasons.

Leaf water content

Both seasonal and diurnal LWP results followed similar patterns with the seasonal soil moisture status recorded at each site. Accordingly, , significantly lower diurnal LWP values were measured at the south-western sites in winter as compared with spring season. Moreover, the least (greatest water tensions) results were obtained at Bonga (sites 1 and 3) and Sheko (sites 2 and 3) in winter season when little diurnal differences were noticed (Figure 3). This could be due to the limit of the Scholander bomb (21 bar). Similarly, coffee trees at Bale-DoloMena sites had significantly low LWP values in the dry summer season (August 04) when the diurnal LWP differences were also minimal as compared with the winter season (Figure 3). Except at sites 1 of Bale-DoloMena and Sheko forests, significant variation in predawn LWP was found between the winter and summer season. Accordingly, maximum values were measured during the later season at south-western sites as opposed to the lower results recorded in summer at south-eastern Bale-DoloMena sites (Figure 3). This demonstrates the variability in rainfall patterns, site factors (Taye et al., un pub) or drought adaptations of coffees, which awaits for future work.

In addition, the diurnal (predawn and mid-day) LWP patterns varied among seasons and sites. Hence, the maximum mid-day LWP values showed highly significant seasonal variations at all sites, except site 2 of Bale-DoloMena forest. At Bale-DoloMena sites, the values display a decreasing pattern from autumn to summer seasons. In contrast, there was a highly significant change in mid-day LWP across seasons at the south-western sites where the least and highest values were measured in winter and summer seasons, respectively (Figure 4). But, no significant difference in the mid-day LWP was noticed between dry and wet seasons at the two sites of Bonga (sites 1 and 3). This could also be associated with the morphology of coffee trees (reduced side growth and leaf number) and high density of shade trees (Taye et al., un pub), which can reduce the seasonal water fluctuations in the soil-plant-atmosphere interfaces. In general, forest coffee trees had little diurnal LWP variations at most sites especially in the dry season. Moreover, the difference between the predawn LWP was not significant among at Bale-DoloMena sites. As a whole, the present LWP findings may suggest the homeostatic behaviors of coffee trees under increased soil moisture tensions.

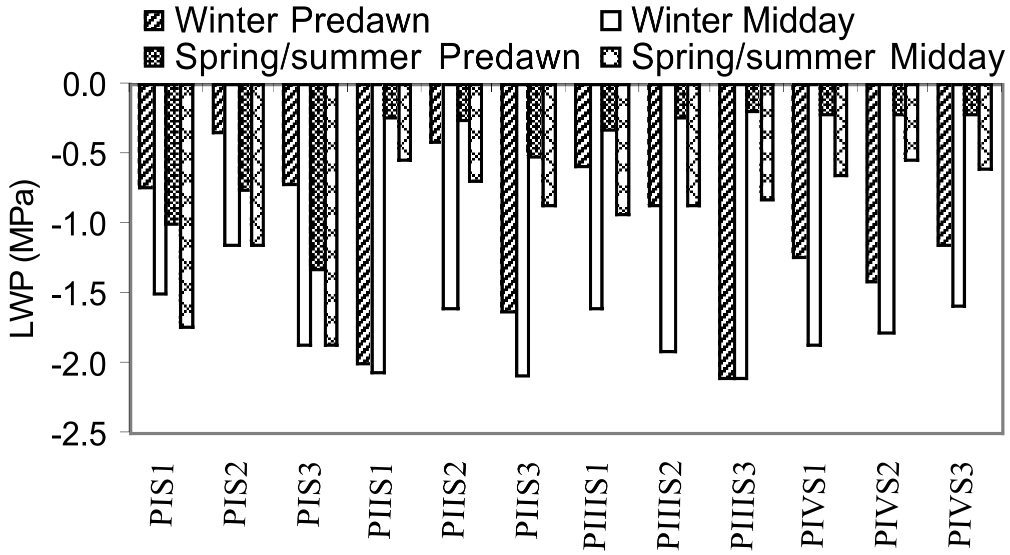

Figure 3. Seasonal and diurnal leaf water potential (LWP) dynamics in the natural forest Arabica coffee trees.

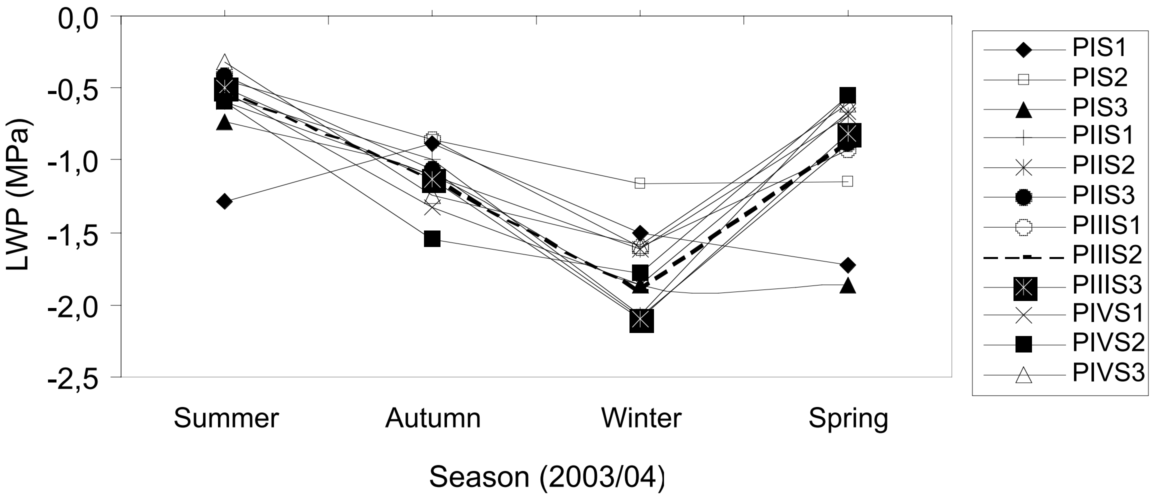

Figure 4. Mid-day leaf water potential (LWP) patterns of forest coffees over seasons.

The osmotic leaf water (percent of dry weight) results also revealed variations between autumn and spring/summer seasons, particularly at Bale (sites 1 and 3) and Yayu sites (Figure 5). Similar to LWP, high leaf water content was determined in the spring/summer season all sites. The results may reflect the impact of climatic variables, shades or adaptations of coffee accessions. The roles of shading to increase air humidity and reduce the vapour pressure gradients between the atmosphere and the leaves and thus, reduced the evaporative soil moisture demand has been documented by Wrigley (1988). In general, the findings strongly suggest the contributions of stand structures to detect plant water demands. As a result, under the present soil-plant moisture status, coffee trees did not show symptoms of drought at all studied sites, which calls for a focused research on plant-environment interactions.

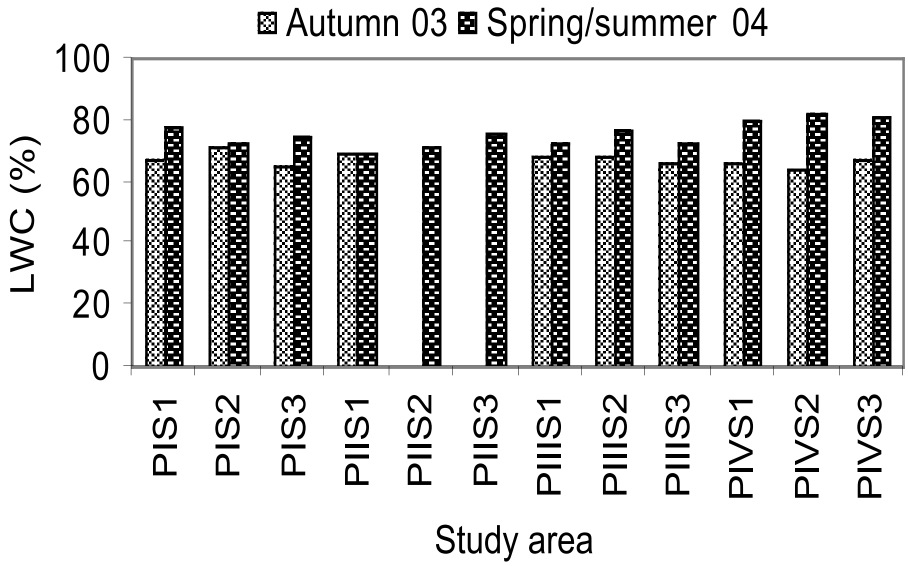

Figure 5. Seasonal leaf water content (LWC, percent of dry weight) of Arabica coffee trees under different natural forests.

CONCLUSION

The results show maximum soil moisture contents on the order of spring>autumn>winter seasons in south-western areas. Conversely, at Bale-DoloMena sites, soil moisture was slightly lower in summer as compared with the winter season. Unlike the dry seasons, significant diurnal LWP fluctuations were noticed in the wet seasons. This suggests the homeostatic response of coffee trees due to increased dry soil moisture tensions. Moreover, coffee trees did not display symptom of drought under the present soil-plant water status recorded at all sites. This could be largely attributed to the light stimulated plant growth responses under forest ecology and thus, reduced hydrostatic gradients. The coffee trees may also tolerate more soil water deficits than the prevailed situations. Taken together, it can be concluded that the findings would provide baseline information to demonstrate location specific climatic variables, site features (stand structures, land configuration, soil types) and growth natures of coffee populations. Hence, further research on the eco-physiology of forest Arabica coffees with the special focus on their natural resource use-efficiency and growth responses under different climatic variables and soil water deficits is crucial to identify drought tolerant coffee accessions.

ACKNOWLEDGMENTS

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Yield Response of Arabica Coffee Cultivars under Various Tillage and Transplanting Practices in South-western Ethiopia

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SUMMARY

The experiments were carried out at Tepi and Gera Research Centres with the primary objective to investigate the influences of different tillage and transplanting techniques on the yield response of Arabica coffee cultivars. The treatments were arranged in split-split plot design with three to four replicates consisted of 12 trees per plot. In this case, tillage practices, coffee cultivars and depth of transplanting were assigned as main-, sub-and sub-sub-plot treatments, respectively. Four years mean clean coffee yields were recorded and analysed using SAS software. The results at Tepi revealed that tillage had significant ($P \leq 0.05$) effects during the initial crop year. Coffee cultivars significantly ($P \leq 0.01$) differed and the compact cultivar (74110) gave the lowest yield response throughout the study period. The effect of planting depth was, however, not significant. As a whole, conventional holing, compact coffee cultivar and collar level planting gave the least average yield levels from the respective main treatment groups. The open coffee cultivar (75227) significantly ($P \leq 0.01$) out yielded the other coffee cultivars under all tillage practices. The other main and interaction effects did not show significant under the low land Tepi conditions. The results at Gera highland also indicated non-significant differences due to the main and interaction effects for all years, except the significant ($P \leq 0.05$) variation displayed among coffee cultivars during the early crop stage. Unlike at Tepi, tillage had little effect on coffee yield and the compact coffee (74158) was more productive at Gera, suggesting the agro-ecological specific yield advantages of tillage systems and coffee cultivars. At both sites, the main treatment effects, however, did not show consistent yield patterns over years, largely due to the biennial bearing nature of coffee trees. In essence, the contributions of tillage and transplanting practices were more noticed during the early crop stages. Therefore, taking into account, among others, suitable coffee cultivars, available power sources, ecological and socio-economic aspects, soil-plant manipulations should be exercised at the times of field planting with the views to ensure maximum stand establishments and thereby, increase coffee productivity.

INTRODUCTION

In Ethiopia, the predominant use of unimproved management practices during land preparation as well as at the time of field transplanting could be among the major reasons that could adversely influence field establishments of coffee trees and ultimately contribute to the low per unit area national average coffee yield of the crop ranging from 450 to 472 kg ha^{-1} clean coffee (Workafes and Kassu, 2000). In this regard, optimum time of transplanting, land preparations and hole size have been recommended (Yacob et al., 1996). In addition, the available information revealed that deeper hole digging as early as possible in the dry season is the best practice to ensure better soil conditions for the transplants, particularly in drought prone coffee growing areas. But, the mechanical effort required and labour shortage seems to restrict its wider adoption, largely under a small scale farming systems. Moreover, most coffee farmers claimed on the development of problematic weeds that are difficult to control, specifically during the early stages of the plantation before the canopy covers the ground surface. The magnitude of the problem is closely associated with the practice of transplanting coffee seedlings in holes prepared without applying any soil manipulation practices and with little focus on shoot and root growth natures of coffee cultivar that would determine its productivity under the prevailing ecological factors. Yacob et al. (1993, 1996) have reported three broad canopy classes of open, intermediate and compact coffee types, largely to target improved management packages that would help boost coffee productivity.

Under no-tillage system, soil crusting, cracking and high infestation of grassy weeds are some of the major constrains noticed during the early growth stages of coffee seedlings and subsequently caused poor yield performance of coffee trees. In other words, with concerns about increased death of young trees, weed problems and declining net income of the users associated with the escalating price of herbicides and the labour intensive noxious weed control have encouraged small-scale coffee farmers to initially till their farms and subsequently apply slight seasonal cultivations. This is usually accomplished either by manual hand hoeing or fork digging or by oxen driven ploughing. In addition, in large-scale coffee plantations this is accomplished by tractor cultivation.

In this context, the merits and demerits of various tillage systems (Robertson et al., 1975; Munawar et al., 1990; Rowland, 1993) and transplanting methods (Coste, 1992; Wrigley, 1988) have been documented elsewhere, in association with farming operation calendar, use of the available natural resources and farm inputs, soil conditions, field transplanting operations, plant survival rate and growth performances and economic aspects. Under our conditions, despite a paucity of information on the right soil-plant manipulations and suitability of coffee trees to develop the different concepts of tillage techniques which takes into account soil-plant components, coffee growers apply the traditional practices as strategy to improve early field establishment of coffee seedlings. The specific objective of the experiment was, therefore, to investigate the impacts of different tillage and transplanting practices on the yield response of improved Arabica coffee cultivars in different agro-ecological areas of South-western Ethiopia.

MATERIALS AND METHODS

The field experiments were conducted at Tepi and Gera Research Centres that respectively represent low and highland coffee growing areas of South-western Ethiopia. The geographical description of the study sites along with the long-term mean rainfall and temperature is presented in Table 1. The treatments were arranged in a split-split-plot design with three to four replications of 12 trees per plot was used at both locations. At both locations, tillage systems, coffee cultivars and transplanting practices were assigned as main-, sub-and sub-sub-plot factors, respectively. The different tillage treatments consisted of manual digging, oxen plough, tractor cultivation, and conventional holing on un-tilled plots. Three coffee berry disease (CBD) resistant Arabica coffee cultivars of varying canopy architectures (open, intermediate and compact) were planted at the different depth of transplanting treatments (collar level, about 5 and 10 cm deeper than the collar point). For this, a uniform hole size of 40 x 40 cm was dug at the respective recommended spacing of 2, 1.8 and 1.6 m^2 for open, intermediate and compact coffee cultivars (Yacob et al., 1993). Except the experimental variables all routine field activities were uniformly applied through out the study period. After a year of transplanting, field survival and early growth responses were recorded and reported (Taye et al., 2001). At both locations, four years (Tepi, 1999/00-2002/03 and Gera, 1998/99-2001/02) crop yield was harvested from each plot and the average clean coffee yield ha^{-1} was analysed using the SAS system for windows v8 and treatment mean separation was made according to Fisher's least significant test at 5% probability level.

Table 1. Description of the study Research centers.

Center	Latitude	Longitude	Altitude (m.a.s.l)	Temperature (^{0}C)		Rainfall (mm)	Agro-ecological zone
				Min.	Max.		
Tepi	7^{o}3'N	38^{o}0'E	1200	15.4	29.9	1685.9	Hot to warm humid low to high altitude
Gera	7^{0}7'N	36^{0}0'E	1940	10.4	24.0	1877.8	Tepid to cool sub humid low to high altitude

RESULTS AND DISCUSSION

Main treatment effects

Tillage practices

The results analysis of variance at Tepi depict that the various tillage practices had no-significant effects on coffee yields during the last three consecutive crop years. But, significant ($P \leq 0.05$) yield difference was obtained in the first crop year. At Gera, tillage systems did not show significant influences throughout the study years. In other words, tillage had slightly increased coffee yields at Tepi than Gera, indicating its site-specific yield advantages as it has been reported in Brazil (Haare, 1966). At Gera, relatively high coffee yield was obtained from conventional holing on untilled plots during the good crop year, tough it resulted in the lowest yield responses during the bad crop years at both locations (Tables 2 and 3), indicating its inferiority particularly during stress seasons. Poor soil conditions, which can impede the side and vertical root growth and enhanced growth of noxious grassy weeds, could be among the probable reasons for poor stand establishment (Taye et al., 2001) and subsequent imprints on the present low crop yield performances. In contrast, the other tillage practices had high yields, though the patterns varied over crop years. Here, broad leaved annual weed species dominated, requiring easy but frequent cultural control measures. Munawar et al. (1990) have reported such a shift in weed species composition with tillage system. The same authors have also elaborated the use of herbicides in zero or minimum tillage systems, but save time, fuel, and labour for increasing soil water supplying capacity to crops. This is quite in agreement with the early performances of the seedlings due to the same soil manipulation techniques (Taye et al., 2001). This suggests that the later yield levels of the perennial coffee trees much depends on the intensity of management practices applied during the early stages.

Coffee cultivars

The yield results at Tepi show highly significant variations among the three Arabica coffee cultivars for all years, except the last crop. As a result, the lowest mean clean coffee yield was obtained from the compact coffee (74110) as opposed to the open (75227) and intermediate (7440) cultivars (Table 2). This corroborates with the adaptation and high yield performances of open and intermediate CBD resistant coffee selections with more favoured vegetative growths in the humid hot to warm low lands. Similarly, significant yield difference was obtained at Gera due to coffee cultivars in the first crop year with high yields recorded from the intermediate (7440) and compact (74158) coffee cultivars (Table 3). However, no significant yield difference was noted with increasing ages of coffee trees. Unlike at Tepi, the dwarf cultivar (74158) gave high crop yield at Gera environments, which suggests *inter alias* the availability of adequate soil moisture for shallow rooted compact coffee cultivars. This is in line with the work of Yacob et al. (1996) who have reported variations in the adaptations of morphologically diverse Arabica coffee types. Taye et al. (2001) have also found similar growth responses of young coffees, indicating site-specific performances of coffee cultivars.

Table 2. Mean yield (kg ha^{-1} clean coffee) of Arabica coffee under different tillage and transplanting practices at Tepi Research Center (1999/00-2002/03).

Treatment	Crop year			
	1999/00	2000/01	2001/02	2002/03
Tillage	*	NS	NS	NS
Oxen cultivation	1723.00a	1403.33	1738.00	545.67
Manual digging	1635.67ab	1470.00	1693.33	551.00
Conventional holing	1459.00b	1622.33	1649.33	498.33
SE (±)	209.30	215.71	85.79	150.55
CV (%)	47.80	53.50	58.80	103.90
Coffee cultivar	**	**	**	NS
75227 (open)	2452.67a	1673.67b	2193.00a	548.00
7440 (intermediate)	1689.33b	2096.00a	1646.67b	693.67
74110 (compact)	675.67c	673.00c	1241.00c	353.33
SE (±)	112.99	253.76	62.23	153.43
CV (%)	47.80	62.90	43.30	105.90
Transplanting depth	NS	NS	NS	NS
Collar level	1506.67	1434.00	1667.67	430.00
5 cm deeper than collar	1646.67	1626.00	1725.00	654.00
10 cm deeper than collar	1664.00	1382.67	1688.00	511.67
Mean	**1605.78**	**1480.89**	**1693.56**	**531.89**
SE (±)	156.80	133.48	132.88	107.67
CV (%)	35.80	33.10	28.80	74.30

*NS, *, ** = Not significant and significant at 5% and 1 % probability levels, respectively. Means followed by the same letter within each column are not significantly different at 5% probability level.*

Transplanting depth

Depth of transplanting had no significant effects on coffee yield at Tepi and Gera. The high coefficient of variation at Tepi in the last crop year could be due to other external sources to result in more heterogeneous stands and thus may confound the effects of the main treatments with increasing tree ages. The result obtained at Gera is in agreement with the previous yield report (IAR, 1996) due to transplanting hole sizes. This may partly reflect high organic matter content of the soil and thus, enough soil moisture and plant nutrients in the surface soils as it has been reported by Paulos (1994). However, maximum value was noted with increased transplanting depth during the initial and last cropping years (Tables 2 and 3). This could be explained in terms of efficient-use of the available natural resources, particularly by shallow rooted compact coffee cultivar. This supports the yield advantages of coffee reported in Brazil (Haarer, 1962) with increased depth of field transplanting. The present findings also conform to better growth of coffee seedlings observed in drought prone areas of western Hararghe and with the work at Jimma, Gera and Tepi Research Centre (Taye et al., 2001) where good stand establishments were noticed due to deeper plantings. Coffee farmers transplant self-sown bare or with a root ball coffee seedlings in hole or along the furrow without considerations of hole sizes, time of hole preparation, transplanting methods and depth of root-collars. They buried coffee seedlings deeper than a collar level with the views to ensure better anchorage and high field survival rate. This could be associated to the enhanced growth of adventitious and feeder roots that would enable maximum exploitation of soil moisture and nutrients.

Table 3. Mean yield (kg ha^{-1} clean coffee) of Arabica coffee cultivars as affected by tillage and transplanting practices at Gera (1998/99-2001/02).

Treatment	Crop year			
	1998/99	1999/00	2000/01	2001/02
Tillage practice	NS	NS	NS	NS
Manual digging	414.00	387.00	1405.67	2877.00
Conventional holing	343.33	440.67	1314.00	2648.33
Oxen-plough	327.00	368.67	1334.33	2711.33
SE (±)	36.57	169.94	122.41	328.53
CV (%)	32.60	39.50	27.10	35.90
Coffee cultivar	**	NS	NS	NS
741 (open)	256.00b	359.33	1344.00	3059.67
7454 (intermediate)	416.33a	334.00	1498.67	2317.00
74158 (compact)	412.00a	503.00	1211.33	2858.00
SE (±)	51.15	90.62	142.84	393.71
CV (%)	42.50	68.10	31.70	43.00
Transplanting depth	NS	NS	NS	NS
Collar level	349.66	404.00	1341.67	2706.33
5 cm deeper than collar	372.66	393.33	1361.00	2783.00
Mean	**361.16**	**398.67**	**1351.34**	**2744.67**
SE (±)	25.92	35.50	97.05	148.60
CV (%)	23.60	32.60	26.30	19.80

*NS, ** = Not significant and significant at1% probability level, respectively. Means followed by the same letter within each column are not significantly different at 5% probability level.*

Treatment interaction effects

At Tepi, no-significant yield variations were occurred at all orders of interaction, except the highly significant differences noted during the first crop year due to the integration of tillage and cultivars. As a result, the open coffee cultivar (75227) significantly out yielded the other cultivars under all tillage practices. The intermediate and compact coffee cultivars followed in that order (Figure 1). Above all, manual digging significantly enhanced the response of the short cultivar. Variations arising from all interaction effects were also non-significant at Gera, indicating the less contribution of tillage treatments to bring about a change in the soil-plant systems under humid Gera condition, which is quite in line with the work done by Taye et al. (2001). This could in part be attributed to the better soil and climatic conditions as it has reported by Paulos (1994) and Yacob et al. (1996).

In other words, the influence of soil and plant manipulations could be explained in terms of better anchorage and maximum exploitation of soil moisture and plant nutrients. This supports the notions of coffee farmers who practice seasonal digging or hoeing to minimize the evaporation of soil moisture through upward capillary movements. They also argued that seedlings planted at shallow depths would be easily uprooted and face high risks of drying in dry seasons. Northwood and Macartney (1971) pointed out the merits of cultivation to offer ideal aeration and moisture status for plant growth. This also conforms to the report (IAR, 1996) that indicates high field establishment and coffee yield due to increased planting hole sizes. According to Taye et al. (in press), Arabica coffees of distinct growth natures also varied in their adaptations along moisture gradients, indicating that soil-plant-water relationships are amongst the major area of focus in coffee cultivation.

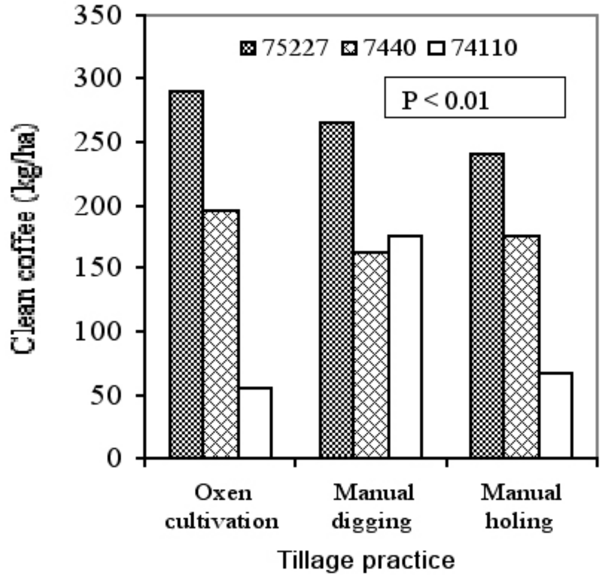

Figure 1. Interaction effect of tillage and coffee cultivars on the early stage mean clean coffee yield at Tepi (1999/00).

CONCLUSION

The long-standing labour intensive hole digging during the driest months and the collar level plantings were found to be inferior at the different agro-ecologies. In contrast, the other soil-plant manipulations had high crop yields, particularly in the early stage. But, the magnitude of the response differed between locations, mainly due to coffee cultivars. Moreover, there was no any predictable yield pattern for each main treatment effect, largely due to the biennial bearing nature of coffee trees. From the findings it can be concluded that depending on the size and slopes of the farm and cheap power sources, initial tillage practices and deeper planting of coffee seedlings can be practiced during the establishment of coffee plantation by resource-poor and large-scale coffee producers. It is also worth considering the agro-ecological suitability ranges of Arabica coffee cultivars. However, further study on the responses of coffee cultivars vis-à-vis short- and long-term climatic variables is crucial. In addition, evaluations of the treatments on soil properties and economic feasibility are focused research areas.

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Farmers' Cropping Pattern in Sidama and Gedeo Zones, Southern Ethiopia

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SUMMARY

In an effort to survey the cropping pattern in Sidama and Gedeo zones, five-km drive stops were made starting from Awassa tobacco monopoly to Yirgalem-Dilla-Yirgacheffa and Cheleleketu. The dominant food and horticultural crops and their association in the field were determined in the four localities. The objectives of the study was to describe the existing farmers' indigenous knowledge of cropping patterns and thus provide baseline information for future researcher and development interventions that would help to optimize resources at a farm level and ensure maximum productivity in the highly populated Sidama and Gedeo areas. The results reveal that coffee is the often-leading crop in the study areas, which was mixed-cropped with other perennial and annual crops in different combinations through out the cropping seasons. Coffee, cereals, *enset*, fruits, vegetables, pulses, chat, root crops, and sugarcane combination dominated in all localities. The farmers grew almost all crops for the purpose to ensure family food supply and as cash sources. This is confirmed by developing a frequency of crop "matrix". Farmers possessed small farm size and they practice multiple spatial and temporal cropping. Accordingly, the commonest mixed intercropping was two and three crop combinations. Sole crop and mixed intercropping of five and six crop combinations were low. In general, there is a shift in the crop types and crop combinations at each site, largely indicating the influence of climate and soil factors and the long standing farmers' experience to identify suitable crop types and crop husbandry practices.

INTRODUCTION

Cropping pattern is defined as the yearly sequence and spatial arrangement of crops or of crops and fallow on a given area. Knowledge on cropping system in the tropics is required for various social, cultural, demographic, ecological and economical reasons. Above all ecophysiological imposition by the climatic constraints puts most agricultural activities into a stand still. Few works (Hackett, 1990) in the tropics appreciated the dominant role of ecological factors play to limit crop adaptation and productivity.

The performance and yield of a forage plant is its genotypic expression as modulated by continuous interactions with the environment (Carvalho and Schank, 1989). Hackett (1990) also elaborated the simultaneous parts to be played by ecophysiological factors such as soil aeration, soil depth and water deficit. He suggested crop environment matrix (CEM) to specifically categorize the significant roles each of the matrix components can contribute to specific parts of ecosystem and crop management. Carvalho and Schank (1989) acknowledged that one of the most widely limiting environmental factors limiting production on global basis is water. There fore similar studies one required in Ethiopia in Gidabo basin. The rational for staggered cropping system adapted in the area is heavily dictated by shifts in rainfall, land forms and soil types and the long standing crop cultural practice of the region. The role-played by population pressure to adopt the present cropping system is also highly considered. However, it has been long recognized was edaphic, hydrologic and mineralogical ratio variations have critical role to dictate plant species succession at both micro and macro levels (Crawley, 1986).

The objective of this study was to establish presently observed dominant crops, cropping pattern, the association of coffee with other associated crops in mixed-cropping and develop crops association 'matrix'. This would help to provide an insight into farmers' indigenous cropping pattern for future research and development interventions geared to improve and/or generate agronomically and economically sound technologies for Sidama and Gedeo zones of Southern Nations, Nationalities and People Regional State.

METHODOLOGY

Site description and data collection

Starting from Awassa tobacco monopoly to Yirgalem-Dilla-Yirgacheffa and Cheleleketu towns with an altitude range from 1500 to 2020 m mean above sea level (m.a.s.l), a car drives were made to follow up the association of landforms, soil type, crop combinations and crop management practices of the region. On each survey occasion, a five-km drive stop transact survey was made by a three team research group, car km gauge and wrist watch velocity distance and time motions were used to synchronize occasional car drive stops. Each of the three team research group independently and randomly scored the major crops in a farm, cropping patterns at various strata viz. high strata (trees) and low strata crops (cereals, beans and root crops) were partitioned during the survey period. As individual farmer holding had fences or boarder demarcation, the major crop types and their combination patterns were counted and determined from each fenced out farm.

The study was undertaken during the first peak rainy season when most of the annual crops and vegetables are on the farm with the perennial plants. As a result, percentage and frequency means were used to estimate and aggregate the dominant crops, their combination patterns, land and soil shifts along a topo-climo sequence at four major localities along the Awassa Moyale high way roads. Based on this, it was tried to develop a crop association matrix with the views to provide baseline information for future research and development interventions.

RESULTS AND DISCUSSION

The present cropping pattern and crop association results reveal that out of the four occasions aggregated in the study area, coffee dominated in the crop frequency count, followed by enset and cereals at three locations. Fruits and vegetable distantly followed the three major crops (Table 1; Figure 1). In other words, shifts against coffee farms could be seen along the altitude (1500 to 2000 m.a.s.l.) and rainfall gradients. This is to disfavour coffee landraces to favor introduced coffee berry disease (CBD) resistant selections as a result of the prevailing CBD pressure that wiped land races is only a speculation with stronger indication towards local germplasm shift for extinction for good. In another survey (Taye et al., un pub.) it was found that the threat of compact Arabica coffee land race extinction shift to favour and give ways to tolerant flexible stemmed intermediate and open stiff arabicas of Yirgachefe. Crop shifts come about due to site character (Cook et al., 1987) and various environmental stresses, the stresses complemented to include water, temperature and light (Kuuluvainen, 1988).

Table 1. Mean frequency count of major crop types and their association 'matrix' at four localities in Sidama and Gedeo zones.

Location	Crop type	Coffee	Enset	Cereal	Veg.	Fruit	Pulse	Sugar	Chat
Awassa-Yirgalem	Coffee	-							
	Enset	15	-						
	Cereal	12	17.7	-					
	Veg.	0.4	0.4	0.3	-				
	Fruit	7.6	6.43	8.0	0.14	-			
	Pulse	0.3	0.3	0	0.14	0	-		
	Sugar cane	0.9	1.4	1.86	0	0	0	-	
	Chat	1.9	1.0	1.28	0	0	0.42	0	-
	Root crops	0.3	0.1	1.14	0	0	0	0	0
Yirgalem-Dilla	Coffee	-							
	Enset	25.42	-						
	Cereal	28.29	23.57	-					
	Vegetable	2.86	2.28	2.28	-				
	Fruit	10.28	9.28	11.14	1.0	-			
	Pulse	3.28	1.86	3.0	1.43	1.57	-		
	Sugar cane	1.0	0.85	0.71	0.14	0.71	0.14	-	
	Chat	2.71	2.28	2.14	0	1.86	0.14	0.14	-
	Root crops	0.42	0.43	0.28	0.28	0.14	0	0	0
Dilla-Yirgachefe	Coffee	-							
	Enset	28	-						
	Cereal	33.7	25.2	-					
	Vegetable	5.7	4.8	3.5	-				
	Fruit	17.3	10.2	14.5	1.5	-			
	Pulse	4.7	2.5	4	0.7	3.0	-		
	Sugar cane	2.0	1.17	1.7	0.7	0.5	0.17	-	
	Chat	0	0	0	0	0	0	0	-
	Root crops	3.8	2.7	3.7	3.7	1.5	0.7	0	0
Yirgachefe-Cheleleketu	Coffee	-							
	Enset	33.7	-						
	Cereal	25.7	12.0	-					
	Vegetable	9.7	10.0	7.7	-				
	Fruit	6.0	3.0	3.7	0.67	-			
	Pulse	1.33	0.67	2.0	0	0	-		
	Sugar cane	1.0	1.0	0.7	0.33	0	0	-	
	Chat	0.33	0.33	0.33	0	0	0	0	-
	Root crops	2.33	2.0	1.33	1.33	0	0	0.33	0

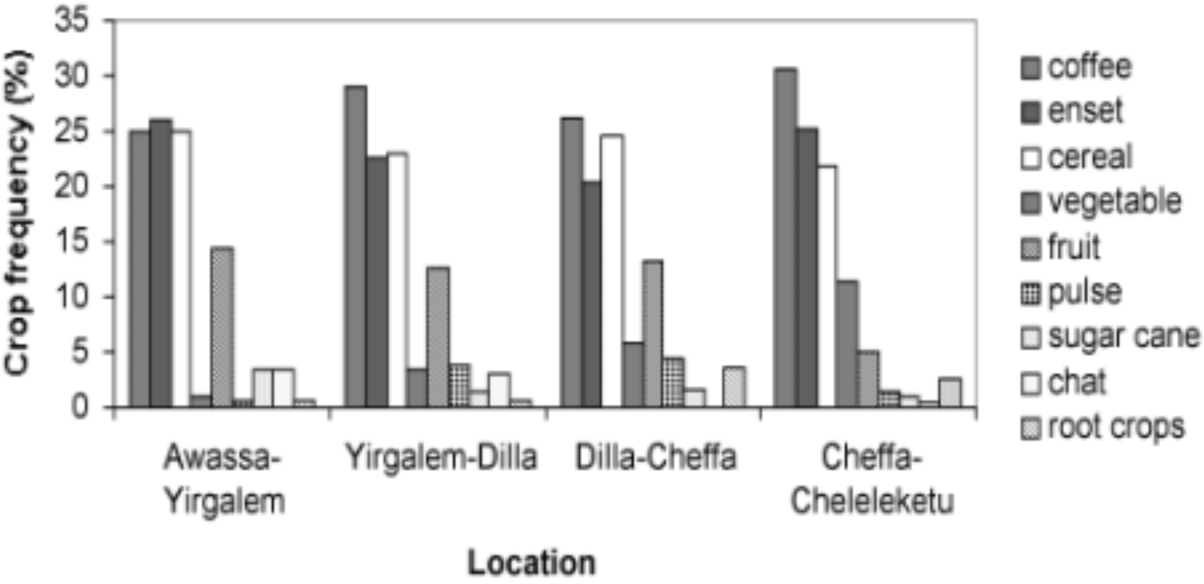

Figure 1. Average frequency (%) of major crops across the study locations.

In the present study attempts were made to determine the most favourably combining crop types with Arabica coffee in the two zones. In this regard, Arabica coffee is most favourably combined with false banana-*enset (Ensete ventricosum)*, cereal crops and fruits; consistent with few works conducted earlier (Hackett, 1990; Westphal, 1975). The association of coffee with the other crops was expressed in 'matrix' style across the four localities (Table 1), which shifts the occurrence frequency along the climo-toposequence of the specific points, though the likelihood of the frequency of obtaining coffee was high in most cases. The common root crops and vegetables include potato, yam, cabbages, hot pepper, whereas fruits involve mango, avocado, pineapple and citrus, though their distributions vary over locations, reflecting the suitability if the sites. Above all, the unique feature of the study area was the presence of the *enset* with coffee in all farms studied (Table 2) as it has reported by Westphal (1975). This probably attributed to the use of enset as shade for coffee and its less competition between the two crops for the available above- and below- ground natural resources (CO_2, light, moisture, and nutrients) under the current farmers practice. Cereals are produced for seasonal family food supply second to *enset,* while fruits are meant for local market as income source and home consumption and thus, are used for maximum cropping as indicated earlier in the association 'matrix'. In all farmers` fields, coffee and sugar cane combinations were very much few (Table 2), indicating the perception of the farmers towards the high competition effects of these crops for soil moisture and plant nutrients with subsequent poor performances. However, few farmers grew coffee with maize and other morphologically similar crop types, which is a focused research area. The frequency of getting chat (*Catha edulis*), stimulant cash plant, in association with coffee was also not much higher. Though some of the farmers' plants chat as an alternative cash source in areas where coffee production was not successful, most likely due to the constraints associated with adaptations or mismanagement.

Table 2. Association of coffee and other crops between Awassa and Chelelektu (Sidama and Gedeo zones).

Location	*Coffee and associated crops (%)*							
	Enset	*Cereal*	*Vegetable*	*Fruits*	*Pulses*	*Sugar cane*	*Chat*	*Root crops*
Awassa-Yirgalem	38.9	31.5	1.1	20.0	0.7	2.6	4.8	0.7
Yirgalem-Dilla	34.8	38.8	5.1	12.4	3.9	1.2	3.3	0.5
Dilla-Y/cheffe	29.4	35.4	5.9	18.2	4.9	2.1	1.0	4.0
Y/cheffe-Cheleleketu	42.1	32.1	12.1	7.5	1.7	1.2	0.4	2.9
Mean	**36.3**	**34.5**	**6.1**	**14.5**	**2.8**	**1.8**	**2.4**	**2.0**

The small land size owned by the farmers because of the high population pressure seems not as such contribute to food shortages in the area. Although the cropping system and their stand were not properly identified, stripping and mixed intercropping fashions seem to dominate the smallholdings of the area. Sequential cropping and relay intercropping were also used occasionally if the situations permit. Accordingly, the commonest mixed intercropping was two and three crop combinations. In contrast, sole cropping and mixed intercropping of five and six crops combinations were low. There were also big trees associated with most of the shade tolerant crops. This follows similar patterns across the study areas; though the magnitudes vary (Figure 2) perhaps reflecting site-specific yield advantages constrained by either a biotic or biotic stresses. Moreover, this could be partly related to the bimodal rainfall pattern (Figure 3) and other farm resources that enable the farmers to practice spatial or temporal cropping systems. Taking together, there is a shift in the crop types and crop combinations over sites, largely indicating the influence of climate and soil factors and the long standing farmers' experience to identify suitable crop types and crop husbandry practices and thus, maintained local crops and farmers' indigenous technical knowledge. However, this should be further examined and complemented in the agricultural development of the area.

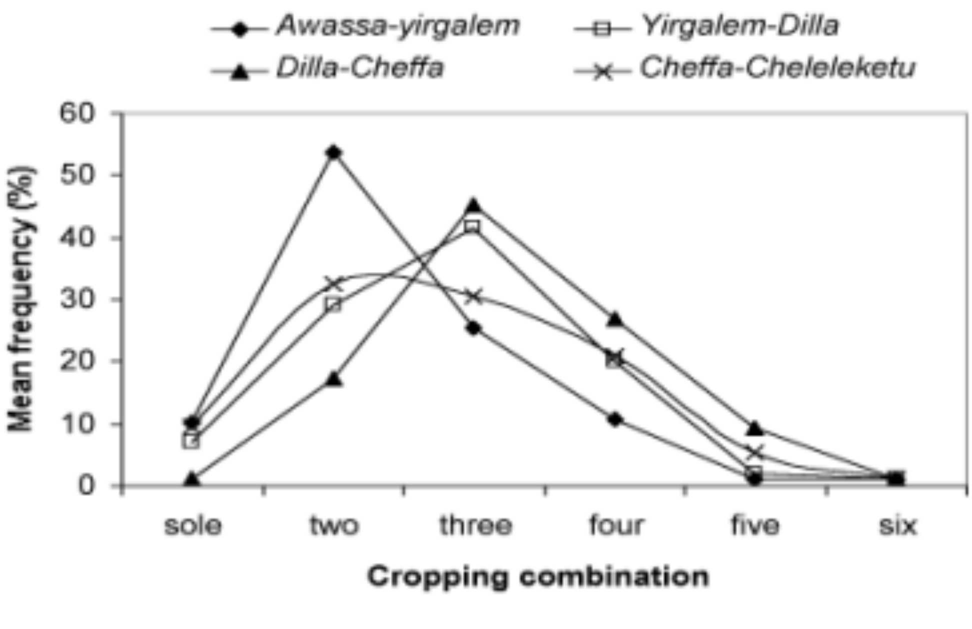

Figure 2. Frequency of farmers' crop association within a farr Sidama and Gedeo Zones.

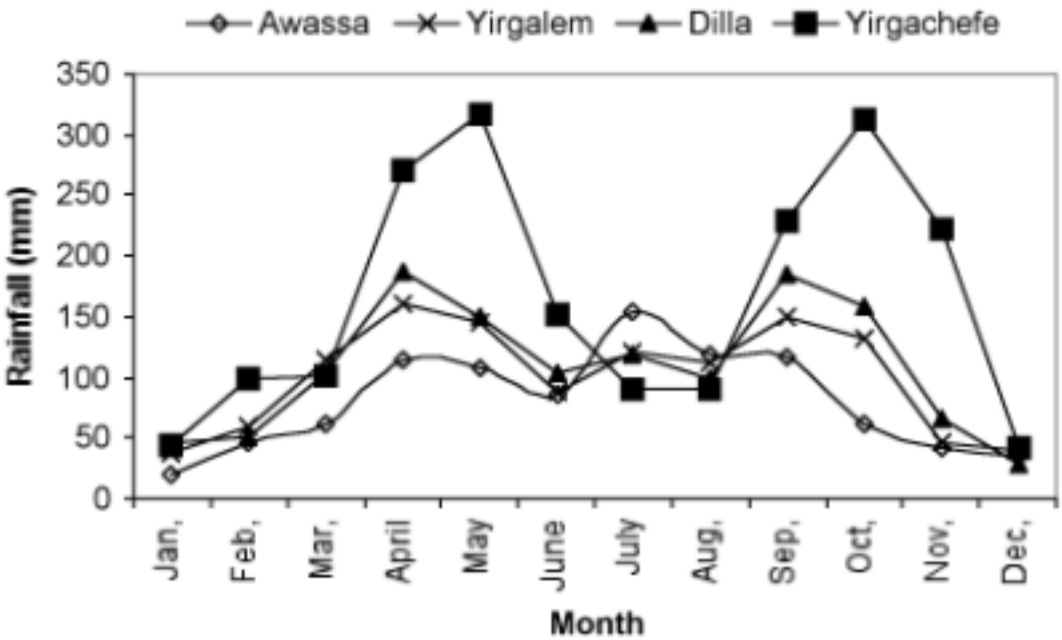

Figure 3. Long-term monthly mean rainfall distribution at the study areas.

CONCLUSION

There seems to exist certain consistency in coffee-*enset*-cereal-fruit-vegetable-pulse-chat-root crops and sugar cane cropping pattern. Coffee is a leading crop, followed by *enset* and cereals. Association of crops determined by altitude, seasons and the complementary and competition effects, which expressed their existence in crop association 'matrix'. Despite the high population pressure and small farm size, farmers are applying their indigenous knowledge against the existing challenges so as to stabilize yield and ensure family food supply. Cropping patterns hardly exceed two to four crop combinations. Mono cropping and multiple cropping beyond four crops are quite rare. There is a certain crop shift along site topographic and rainfall regimes. This, however, calls further works either to improve or develop appropriate cropping pattern, which takes into account farmers` experience, crop morphological characteristics and stand structure and ecological variables. To exhaust the present findings more transects within farm and along roadsides remain to be done during the different seasons of crop years. As to what extent ecophysiological variables, socio-cultural and economic factors to dictate the present cropping pattern is remain uninvestigated.

ACKNOWLEDGMENTS

The paper is fully dedicated to the late **Yacob Edjamo** for his keen interests to emanate the idea of farming systems study in the area in general and this work in particular. Accordingly, he was one of the principal investigators of this study without which it would have not been possible.

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Fat Content: a Quality Indicator for Central America Coffees?

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SUMMARY

In most major agricultural commodities (i.e. wheat, corn, sugarcane) chemical content analysis is widely used in order to efficiently describe the quality of product on trade between producers and buyers. In several studies in Central America involving different edapho-climatic conditions, crop management practices and varieties, fat content from green coffee beans samples was assessed. Then fat content was correlated with beverage quality by expert judging panels. Results showed that fat content is highly affected by the plant physiological condition. Green coffee from highlands, shade conditions or harvested on plants exhibiting good fruit: leave ratio had higher fat content. Beans with higher fat content showed a reduction on volume increase during roasting and more homogeneous color. In the studies, fat content was higher in samples that showed better beverage quality. In Central America, quality is commonly assessed by cupping or defects classification system of green coffee samples. In future, systematic determination of fat content could complement actual quality appreciation systems and help the roaster to minimize its variation on final blend offer to costumer.

MATERIALS AND METHODS

In several studies from distinct coffee locations involving different edapho-climatic conditions, crop management practices and varieties, fat content (FC) and beverage quality from green coffee samples were assessed by chemical analysis and by expert judging panels respectively. A preference score ranging from 0 to 5 (where 0:nil and 5:very good) was used during the cupping sessions.

RESULTS

In "Catuai" cultivar, FC increase significantly with elevation. At higher elevation, higher was the FC and better the classification by the cupping panel (Figure 1).

A second study with CR-95 cultivar (Figure 2), trees under shade conditions (45%) and harvested during earlier and full fruit ripening showed higher FC and were preferred in sensorial analysis than those from sun full conditions and later ripening.

In a third study with CR-95 cultivar (Figure 3) (in sun full conditions) in a year of high yield, samples from trees with 25% and 50% of initial fruit load (fruit thinning was performed manually a few days after flowering), showed higher FC and better preference note than those without thinning.

Samples with higher FC showed a reduction on volume increase during roasting and more homogeneous color (Data no shown).

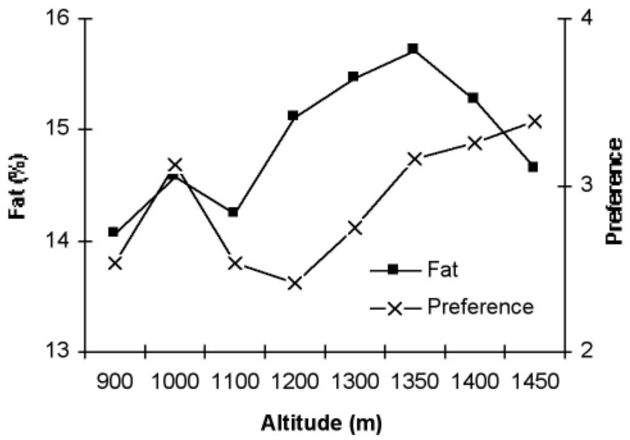

Figure 1. Fat (%) and cupping preference of green coffee from different elevation in Alajuela, Costa Rica (cv. Catuaí).

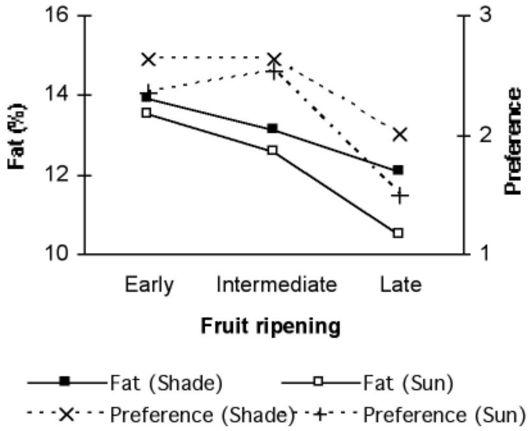

Figure 2. Fat (%) and cupping preference of green coffee from different shade conditions and harvest time. Heredia, Costa Rica (cv. CR-95).

Figure 3. Fat (%) and cupping preference of green coffee from trees with different fruit load. Heredia, Costa Rica (cv. CR-95).

DISCUSSION

In these studies, it appears that in green coffee samples from trees growing under stress conditions (high average temperature because of low elevation and/or sun full exposition or high yield) the FC of green coffee decreased. It also seems that high FC and good cupping preference score can be correlated. In Central America as worldwide, quality is commonly assessed by cupping or by defects classification system of green coffee. In future, determination of FC could complement actual quality appreciation assessments.

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The Coffee Industry of Ghana – A Breeder's Perspective

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SUMMARY

Production of Robusta coffee beans in Ghana has been low, ranging from a peak of 6,700 metric tonnes (MT) in 1967-68 to 6000 MT as at 1996. The major factors which have been identified for the low production of the crop are poor yields attributed to unselected planting material, inadequate husbandry practices, old age of trees and poor marketing. The government in 1991 embarked on a programme to revive the coffee industry. Coffee cultivation was to be revitalised through improved pricing, liberalised markets and improved extension and research to raise production to 50,000 MT. This paper discusses the structure of the coffee industry, efforts made at increasing production and improving trade and factors that mitigate the achievement of the set goals. Research activities to alleviate these problems are highlighted.

INTRODUCTION

Robusta coffee is grown in the same areas as cocoa in the high forest zone of Ghana. However, coffee being financially less attractive and more labour intensive has become a minor crop. Since it is generally less demanding than cocoa in its requirements for good soils and well-distributed rainfall, it is relegated to the poorer lands. Smallholdings are scattered throughout the cocoa growing areas (FAO, 1989). The major factors identified for the low cultivation and production of the crop were lack of price incentive for coffee farmers, poor yields attributed to unselected planting material of unknown origin, inadequate husbandry practices and old age of trees. Efforts therefore made by Government to revitalise the coffee industry included a review of the internal marketing of coffee, increased research, extension and planting material production and increase in annual production.

THE STRUCTURE OF THE COFFEE INDUSTRY

Climate and Soils

Coffee growing areas are within the high forest zone, which covers the south west of the country and a narrow strip along the eastern border. Rainfall within the zone averages 2000mm in the southwest corner and gradually decreases northwards and eastwards to about 1300mm where the high forest zone merges into the savannah woodland zone. There are two rainy seasons from March to July and September to November. There is a short dry season of about one month in July/August and a longer one of three months from November to February. The soils within the forest zone are well-drained, deep clay-loam soils, which are slightly acid and have moderate water holding capacity.

Area under cultivation

According to a countrywide survey over the period 1970-80, the area under cultivation was around 13,346 hectares. After the severe drought and bush fires of 1982-83, sample surveys taken in 1985 revealed that as much as 76 percent of the cultivated area was destroyed by the bush fires, leaving only 3,170 hectares under cultivation (World Bank, 1990). Another sample-survey by the Cocoa Services Division of COCOBOD in 1996 gave the land area under smallholdings to be 8,723 ha. About 173 ha new plantings were cultivated by smallholders between 1996 and 1999. Given the low world market price of the commodity since 1999, it is unlikely any new plantings have been made from 1999 to date. The effective area under the management of Private Estate Developers as at June 2002 was estimated as 1,100 hectares by the Association of Coffee Estate Developers (personal communication). The total area under coffee cultivation by smallholder and Estate Developers could probably be about 10,000ha.

Yields and Production

Sample surveys before 1989 found that coffee yields were generally low, ranging between 100 and 200 kg/ha clean coffee on smallholdings. High coffee yields of about 600kg/ha was however obtained from the best blocks of the COCOBOD Plantations due to better husbandry practices and access to essential inputs. Production of coffee beans in Ghana ranged from a peak of 6,000 to 6,700 metric tonnes (MT) between 1967 and 1996 to the lowest of 123 MT in 1983/84. The good price incentives enjoyed by farmers in the 1990`s contributed to peak coffee exports of 10,000 MT of clean coffee in 1997/98. There has been a gradual reduction in coffee exports from 1998 to a low of 1,084 MT in 2002/03.

Processing

Coffee processing in Ghana is done by the dry method. Sun-dried coffee cherry is hulled, hand picked and the clean coffee bagged in 61.5kg gross weight (60kg net). The coffee is usually graded and sealed by the Quality Control Division of COCOBOD.

Marketing channels (Main buyers and major exporting companies)

Private buyers control both the local and external coffee trading after the coffee trade liberalisation of 1992. Of the seventy-six licensed companies registered in 1992 only 45 were in existence in 2003. Seventeen purchased coffee in 2001, 9 in 2002 and 8 in 2003 (COCOBOD, 2001, 2002, 2003). OLAM Limited, Metal Impex and the Ghana National Procurement Agency were the major exporting companies. The European Union (EU) and Africa are the main export destinations since 2000.

EFFORTS TO REVAMP COFFEE PRODUCTION

Areas for improvement

Smallholder Coffee Rehabilitation and Planting

COCOBOD, which at the beginning of the Project in 1991 was the sole purchaser and exporter of coffee beans in Ghana, was by the end of 1991 to have raised the coffee bean producer price to the equivalent of 65 percent of the free on board (FOB) price ex-Ghana ports. In addition, COCOBOD was to have relinquished its monopoly on bean purchases and exports through licensing of private dealers. This was to provide farmers with an incentive and confidence to invest in coffee farm rehabilitation/replanting or new-plantings, particularly where cocoa has been devastated by the cocoa swollen shoot virus disease. Existing Cocoa Extension Agents were to be trained in coffee cultivation to impart technical advice to farmers directly. 1500 ha of existing holdings were to be rehabilitated and a further 3000 ha either replanted or newly planted over a period of six years.

Production and multiplication of planting material

A Coffee Working Group involving the Private Sector, Research and Extension and Financing Banks was formed in 1997 after the review of the sector in 1996. The constraint identified was the lack of good planting material in sufficient quantities. It was projected to establish 1-hectare Wood Gardens at each of the 8 selected coffee centres using 200,000 rooted elite material be supplied by the Cocoa Research Institute of Ghana (CRIG). With the necessary facilities and infrastructure (education of farmers; availability of inputs; favourable marketing; propagating bins and irrigation facilities) in place, it was anticipated that the eight Wood Gardens could produce 8,000,000 planting material each year to meet the planting material requirements of growers. This quantity was to be adequate for 4,000 ha of new plantings per year and 40,000 ha in 10 years. Together with existing plantings, the target production of 50,000 tons of clean coffee a year was to be achieved, from an average yield of 1 ton /ha from Estate (Private) and Smallholder farms.

ACHIEVEMENTS OF THE PROGRAMME

The project, which started in 1991, had its effective implementation period between 1997 and 1999 due to initial administrative problems. The coffee trade was however, liberalised in 1991 and farmers received 65% of FOB prices. An average of 0.7 ha Wood Gardens were established by October 1999 at each of the 8 centres from 136,126 rooted material supplied by CRIG. Additional 65,000 rooted cuttings were supplied in 2000 to complete the planting of the 8-ha Wood Gardens. Owing to the initial slow multiplication of planting material, 500 ha of farms were re-habilitated and 173.23 ha of new plantings were achieved between 1997-1999 out of the target of 3,000 ha. Additional propagating facilities have not been provided although the Wood Gardens were in place by the end of 2000. With the slump in world market price of coffee, however, production has rather suffered a decline from 6,825 MT in 1999/00 to a low of 1,084 MT in 2002/03.

CONSTRAINTS

1. The supply of planting material is limited by lack of propagators for clone multiplication
2. The low financial returns resulting from poor world prices have rendered investment in the coffee industry unattractive, leading to farmers switching to other crops.
3. There is lack of credit for inputs and hiring of labour for farm operations.
4. Buying companies have to travel long distances to purchase the limited crop at very high cost, which makes most buyers unwilling to purchase coffee at the farm gate.
5. The unavailability of credit for Licensed Buying Companies to finance coffee purchases and the high interest rates by Commercial Banks make coffee marketing unprofitable.
6. Although coffee is grown throughout the cocoa growing zone of the country, only 4 out of the over twenty licensed cocoa buying companies are also licensed to purchase coffee.
7. The reorganisation of extension with the transfer of cocoa and coffee extension services to the Ministry of Food and Agriculture (MoFA) has resulted in a weak coffee extension since MoFA now has to deal with all other crops in addition to cocoa and coffee.

THE WAY FORWARD

The coffee industry has been characterised by low production since 1962. Cocoa licensed buying companies are widespread and their operations are close to the farm-gates, hence, companies licensed to buy cocoa should be licensed to buy coffee as well. Only then will coffee farmers, who are also cocoa farmers, continue to cultivate the crop. With the poor performance of both cocoa and coffee extension services under MOFA, these services could be transferred back to COCOBOD.

The issue of planting material availability has not been solved, due to lack of propagators for clone multiplication. The high cost of production and transportation of planting material produced by vegetative propagation, and its slow multiplication rate make the use of such planting material very expensive and unattractive to farmers. Research to produce seed planting material, which will be cheaper and available in large quantities, to augment existing clone planting material supply is underway. In addition, research by CRIG has developed some technological packages for increased productivity.

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Agronomic Characteristics of Drought Tolerant Robusta Coffee Genotypes

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SUMMARY

Increasing trends towards dry weather affect coffee cultivation through high seedling mortality during establishment, poor plant growth and low yield. Identifying drought tolerant genotypes with good yield potential suitable for environments with unpredictable rainfall are major objectives in Robusta coffee breeding in Ghana. This study investigated associations among six agronomic traits and drought tolerance. Eighteen genotypes of Robusta coffee (*Coffea canephora*) with varying characteristics comprising 12 core selections and six introductions were investigated in three environments from 1996 - 2003. The genotypes were assessed for drought tolerance on a visual scale of 0-5 (resistant/tolerant – susceptible). Genetic correlations among drought tolerance scores and agronomic traits were calculated from a combined analysis of variance and covariance from the same data. Drought tolerance ability showed significant genetic associations with fruits per node (r_G = 0.52*) and percent fruit-set (r_G = 0.61**). Very strong associations were observed between drought tolerance and early yield (r_G = 0.64**) and mean five-year yield (r_G = 0.74***). The findings suggest that drought tolerant and high yielding genotypes can be identified at the early fruiting stages mainly by their fruit-setting ability. Fruit setting ability of trees could therefore be used as criterion for screening large numbers of genotypes for drought tolerance.

INTRODUCTION

Water deficit stress is the most important factor limiting coffee yield in most coffee growing areas. The effect on yield depends on the drought effect on the plants before flowering, during fruit-set, and fruit development. Improved screening methods for detecting tolerance at both vegetative and reproductive phases would be valuable in a coffee-breeding program. Visual scoring method of leaf scorching is used for vegetative stage drought tolerance in robusta coffee. In the absence of water deficit stress, however, such method cannot be useful. Other methods are not sufficiently convenient and not easy to measure (Da Silva Ramos and Carvalho, 1997). Agronomic characteristics of most crops were found to have an effect on their tolerance to drought stress (Annicchiarico and Pecetti, 1995). The apparent ease and suitability of these studies to select drought tolerant genotypes have elicited interest in the use of correlation methods as means of screening germplasm of various crop species for drought tolerance (Ehdaie et al., 2001; Reddy et al., 2001).

The objectives of this study were to: (I) assess the response of a range of coffee genotypes to water deficit stress; (II) relate the results to plant reproductive characters; and (III) determine the use of the genetic associations in the selection of drought tolerant Robusta coffee genotypes in the early stages of the breeding programme.

MATERIALS AND METHODS

Plant Material, Experimental Design and Traits Observed

The study was conducted at three rain-fed sites, representing a wide range of soil types, fertility levels and rainfall regimes from 1996-2003. The genotypes comprised 12 clones extracted by individual selection from a population of five half-sib families introduced from Cote d'Ivoire and six clones introduced from Togo. Field planting was done in Fisher blocks consisting rows of eight single plants. Both inter-row and inter-plant spacing were 2.44 m. In every environment, the blocks were arranged according to a randomised complete block design in four replications. Planting all three environments was done in June 1996. No fertiliser was applied and crop management practices were not varied for all locations. One or two stems per hill were capped to 1.8 m.

At flowering in December 1999/January 2000, ten random plants per clone, and three random branches at the middle of each plant were tagged for studies on flowering and fruiting. The total number of flowers at the sword stage to a week after flower opening at each node and fruits that remained on the branches six months after flowering were counted and summed up for all three branches. These were used in estimating the number of flowering and fruiting nodes per branch, and the number of flowers and fruits per node. Percent fruit set was estimated as the proportion of flowers that set fruit and remained on the branches at six months from flowering multiplied by 100. Assessment of plants for drought tolerance was done at the end of February 2001 when coffee leaves appeared scorched due to severe moisture stress at all three sites. Leaf scoring of the plants was done on a scale of 0-5: resistant/tolerant – susceptible on all plants at all three sites. Coffee yields (fresh weight) were recorded for all individual trees each year from 1998/99 to 2003/04. Values recorded in 2000/01, when data for yield determinants were also recorded, and mean five-year yields (1998/99-2002/03) were used for this study (Table 1).

Table 1. Traits measured and abbreviations.

Yield and yield components	Abbreviations
Yield in 2000/01	Yield 3
Drought reaction	TDR
Mean five-year yield	MY5
Percent fruit-set	%FS
Number of fruits per node	F/N
Number of fruiting nodes per branch	FN
Number of flowering nodes per branch	FLN
Number of flowers per node	FL/N

Statistical Analyses

Genetic correlations were calculated from combined analyses of variance and covariance from the same data. The form of the analysis and the expectations of the composition of the mean squares of these analyses are presented in Table 2. The analysis of covariance between paired characters was of the same form as the analysis of variance with analogous expectations for the mean sum of products. Genotypic correlations between traits were computed on location mean basis as:

$$R_G = Cov_{(xy)\,b} / (var_{(x)\,b}\, var_{(y)\,b})^{1/2}$$

Where $Cov_{(xy)\,b}$ is the genotypic covariance component for traits x and y, $var_{(x)\,b}$ and $var_{(y)\,b}$ are the genotypic variance components respectively for traits x and y (Falconer, 1989). For correlations involving drought assessment scores, inverse value of genotypes mean was used.

Table 2. Form of analysis of variance and expectations of mean squares.

Source of Variation	Degrees of Freedom^{+}	Mean square expectations (Location mean basis)
Locations (E)	e-1	$\sigma^2 w + g\,\sigma^2_E$
Genotypes (G)	g-1	$\sigma^2 w + e\,\sigma^2_G$
Genotype x Location	(g-1)(e-1)	$\sigma^2 w$

$^{+}$*e = number of locations = 3; g = number of genotypes = 18.*

RESULTS AND DISCUSSIONS

Visual drought tolerance scores were positively associated with F/N ($r_G = 0.52^*$), %FS ($r_G = 0.61^{**}$) and Yield 3 ($r_G = 0.64^{**}$) (Table 3). Also observed was a strong positive association between drought tolerance and MY5 ($r_G = 0.69^{***}$). Strong relationships were observed among F/N, % FS and Yield3 ($r_G = 0.75^{***}$ - 0.85^{***}); and between %FS and Yield 3 ($r_G = 0.85^{***}$), and % FS and MY5 ($r_G = 0.70^{***}$). F/N, however, showed significant but low genetic correlation with MY5 ($r_G = 0.48^*$). Negative but non-significant associations were observed between FL/N and all the traits, except F/N with which positive but non-significant relationship was observed.

Table 3. Genetic Correlations of drought reaction with yield and its components among 18 Robusta coffee clones in three environments.

	TDR	FLN	FL/N	FN	F/N	%FS	Y2000
FLN	0.09ns						
FL/N	-0.04ns	-0.08ns					
FN	0.32ns	0.83***	-0.07ns				
F/N	0.52*	0.28ns	0.41ns	0.55*			
%FS	0.61**	0.21ns	-0.27ns	0.58**	0.75***		
Yield3	0.64**	0.41ns	-0.02ns	0.74***	0.75***	0.85***	
MY5	0.69***	0.10ns	-0.23ns	0.39ns	0.48*	0.70***	0.83***

*Error df = 34, ns = non-significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.*

The very high genetic correlations observed among TDR, %FS, Yield 3 and MY5 shows that percent fruit-set and cherry yield are most sensitive to moisture stress. Flowering of coffee in both 2000 and 2001 occurred at the beginning of a three-month dry season. Average monthly rainfall received during the period of moisture stress (December-February) in 2000 at Bechem, Fumso and Tafo were 10.5, 8.8, and 45.7 mm respectively. In severe stress situation in 2001, values of 8.1, 3.1 and 19.1 mm were recorded. Cannel (1975) reported that, the period of rapid growth in coffee is between 10 and 17 weeks after flowering during which a lot of water is required by the fruit locules, which contains 80-85% of water, for the development of the bean. Moisture stress during this period therefore resulted in very high fruit drop (Huxley and Ismail, 1969).

From the analyses of variance, highly significant differences were observed among genotypes in their tolerance to drought, fruit set ability and yield (not shown), implying that selection for high performing genotypes for these characters is possible. Wide range of attributes, between and within species of plants under moisture stress, including arabica coffee, has been reported

(Garrity et al., 1983; Omanya et al., 1996; Da Silva Ramos and Carvalho 1997). Some of these attributes could be responsible for drought tolerance ability in drought-tolerant Robusta coffee genotypes as well.

Percent FS and F/N were both positively associated with Yield 3 and MY5, but the comparatively stronger associations between % FS, and Yield 3 and MY5 clearly shows that fruit-set is indeed the most important character related to reproductive stage drought tolerance in robusta coffee. Fruit-set was estimated from data recorded on four-year old coffee plants under normal moisture stress in three diverse environments. It is therefore a reliable method of evaluation in near optimum and stress environments. Our results should therefore form an important base for a pre-selection index for high yielding and drought tolerant coffee genotypes during the initial screening of genotypes for characters of agronomic importance.

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Understanding the Coffee Farmer and his Environment

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SUMMARY

Colombian coffee farmers were questioned about their perceptions and problems regarding their environment. Responses indicated that a wide range of coffee farmers, from smallholders to estates, consider that biodiversity on their farms is seriously declining. They also cited a number of environmental concerns, including water scarcity, deforestation, soil erosion and agrochemical abuse. Most farmers expressed interest in any schemes to tackle some of these problems. The results are discussed in relation to requirements for future large-scale uptake of sustainable coffee schemes.

INTRODUCTION

Sustainable coffee projects and products have increased dramatically in the past few years (Giovannucci & Koekoek, 2003). With the recent drafting of sustainability standards for mainstream sector (Common Codes for the Coffee Community, 2004), it seems likely that activity in this sector will continue to grow.

Sustainable coffee projects have examined a wide range of coffee growing practices in order to establish minimum standards that may variously emphasize aspects of biodiversity, farming practices, health and safety procedures, minimum rights for workers and so on. Although many of the measures are aimed at improving quality of life, scant attention has been paid to understanding what the farmer thinks about this. In consequence we know rather little about what coffee farmers' own particular priorities might be and much less is there documented evidence of these perceptions available for a wider audience.

Previous projects however, suggest that when farmers are consulted, they usually have interesting or surprising things to say (Bentley & Baker, 2002). Studies of farmers tend to show that they are often well aware of environmental problems and may even be carrying out remedial actions by themselves (e.g. Ngailo et al., 2003). The work presented in this paper aimed to discover more about Colombian coffee farmers' perceptions in relation to their environment (with particular reference to biodiversity) in the hope that new insights will help inform future strategies for improvement of sustainable coffee farming, especially towards the development of an agenda that farmers could recognise and identify as being useful to them and of which they might eventually take ownership.

MATERIALS AND METHODS

The fieldwork was carried out on coffee farms in Caldas, Colombia and employed farm semi-structured interviews. Researchers from Cenicafé and coffee extensionists developed the project in two contrasting municipalities of the department of Caldas:

- *Manizales*: the veredas (a division equivalent to a UK parish) of Manzanares, Santa Clara and Morrogordo. These districts comprise many smallholder communities and have substantially traditional shade coffee growing technology. These farmers can be considered as being part of a peasant economy.

- *Palestina*: the veredas of EL Higuerón, La Muleta, La Plata and Los Alpes. This zone is characterised by intensive farms with little or no shade. Here coffee growers have an entrepreneurial approach to coffee production.

Figure 1. Colombia with approximate study zone marked.

RESULTS

The farmers

The veredas had a total of 477 farmers, of which 80 were sampled. 44% of those questioned had less than 5 ha of land, thus classing them as smallholders, 34% had more than 10 ha. 40% had less than five years of education, 31% had 5 to 11 years. Their farms covered a range of production styles, from moderately intensive (4000 trees/ha with some shade) to highly intensive (6000+ trees/ha full sun).

The concept of biodiversity

Nearly two thirds of farmers had heard of the term ‘biodiversity’ though 72% of these were not entirely clear about what the term entails.

70% thought biodiversity was ‘very important’ and 30% ‘important’ in relation to maintaining an environmental balance and more specifically, water sources.

Changes in biodiversity

Almost all farmers questioned considered that both animal and plant abundance is in decline. About three quarters of those questioned considered that mammal species had declined and 27% that bird numbers had also diminished. Farmers considered that these declines were due to deforestation (38%) over-hunting (25%), environmental contamination (25%) and growth in agriculture (12%). As for plant species, shade trees were the most commonly cited (63%) as being in decline with intensification of farming as the main reason for this. When asked to quantify the decline in biodiversity, 67% felt it was 'very serious' (*muy grave*), 22% serious, and 11% moderate.

Farmers saw both beneficial and damaging effects of biodiversity. For beneficial, over half (53%) felt it enhances quality of life, and lesser percentages cited food, biological control and pollination as other beneficial services. On the damaging side, 74% cited pests and diseases, whereas 22% 'competition' against the crops they are growing, i.e. they regard weeds as being a biodiversity-related problem. Farmers also pointed out that not all species were in decline, 55% felt that bird numbers were increasing and 45% that weed species were increasing. 51% attributed these observations to changes in patterns of crop growing, whereas 38% cited herbicides and 9% mentioned climate change.

Nearly all farmers identified environmental problems, both on their farm (97%) and in the immediate vicinity of their *vereda* (100%). At progressively larger scales, farmers' perception of the level of biodiversity changed. Thus at the departmental (state) level, 54% classified biodiversity as high, at the municipal level, 17% thought it was high, where as at their own vereda and farm level only 12 and 11% respectively thought that biodiversity was high. Therefore it seems that when areas analysed are smaller they tend to see less biodiversity.

Environmental problems

Water pollution was the most predominant farm problems cited (45%), followed by agrochemical problems (40%), litter (10%) and soil erosion (5%). Most farmers (71%) admitted to contributing to environmental problems, 51% through contamination with agrochemicals, 31% just through normal day-to-day farming practices and 18% specifically through water pollution due to washing coffee.

Future collaboration

Two thirds of farmers (65%) said that they already carry out some conservation, including tree planting (38%) conservation of water sources (26%) and refrain from using dangerous chemicals (15%). Most (90%) affirmed that they would be willing to do more to protect biodiversity, including maintenance of wild (uncultivated) land (54%), tree planting (15%) and less use of chemicals (31%). 81% would work to attract more fauna, including maintenance of food plants sources in the field, and the establishment of some plants specifically to attract certain species.

Although nearly all farmers (94%) were willing to collaborate in some way to protect the environment by carrying out work of some description on their farms, none (0%) were willing to fund this work through extra taxes, donations etc. These farmers were also willing to make their farm more sustainable in exchange for a premium by planting shade trees and generally protecting the natural flora and fauna of the farm, but even so were unwilling to do anything that would materially sacrifice coffee productivity, because they think that the gross income due to farming would be reduced. In their perspective, to reduce productivity is a real threat to the economic sustainability of coffee production and hence to their quality of life. When questioned about the level of premium that farmers would expect to receive for making their farms sustainable, amounts the cited varied between a 16 to 33% premium over their current parchment coffee sale price.

DISCUSSION

The Colombian coffee farmers questioned in this survey covered a wide range of farm sizes and educational levels. Nevertheless they displayed a level of unity in their broad understanding of some key environmental problems. Many farmers recognise that the quality of their immediate environment is under threat. Pesticides, water resource problems, soil erosion and deforestation are all major concerns. Indeed many accepted that they themselves are at least partially responsible for some of these problems and that farming in their localities had reduced levels of biodiversity below that of the region as a whole.

It was encouraging to find that farmers have both a good level of awareness of the problems and are prepared to participate in any future plan to improve things. Perhaps less encouraging is that they expect to be well compensated for any major changes to their current coffee growing practices. It would seem that joint activities where farmers contribute their labour free of charge might be the most cost-effective way to bring about measurable improvements.

However with at best only modest premiums likely from any future area-wide coffee sustainability schemes, it is therefore important that project implementers look for innovative ways to bring about change. An important first step is to consult coffee farmers about their perceptions and priorities to guide programmes towards the most plausible implementation pathways. From our experience of this project we suggest:

- Itemization and prioritisation of farmers' main problems will permit decision makers to construct a list of topics most likely to be welcomed by farmers
- The priorities will be similar whatever the size of farmer
- It is likely that these priorities will vary little within a region (though this needs further testing)
- A project should start implementation with a few key topics of most concern to farmers, to give the highest likelihood of uptake and hence establish a foundation of success upon which further activities could be built
- Initial success will lead to greater ownership of the process by farmers and enhance the likelihood that the projects themselves can be self-sustaining

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Studies on Genetic Variability for Root Characteristics and Water Use Efficiency in Robusta Coffee

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SUMMARY

Thirty five promising robusta accessions were assessed for the genetic variability in root characteristics, water use efficiency and associated traits. By adopting gravimetric techniques, the plants raised from single nodal cuttings of selected accessions were grown in large containers and maintained under the moisture regime of 70% field capacity. The results indicated significant genetic variability with regard to root proliferation, water use efficiency and related traits. The total transpiration was high in genotypes having relatively high root biomass. However, mean transpiration rate and water use efficiency showed negative relationship. The relationships of water use efficiency with total dry matter production and photosynthesis were positive. Based on root biomass and total biomass and water use efficiency, the accessions 1932 (Madagascar), 879 (Java) and 3399 (Costarica) were found to be the most desirable genotypes and could be used as parents in crop improvement programmes.

INTRODUCTION

Most of the coffee growing areas of south India receive Southwest monsoon. a minimum period of three months drought coupled with high temperature and poor sub soil moisture during the summer season substantially reduces the yield. Hence drought tolerance is important aspect of coffee productivity. Screening of coffee cultivars based on osmotic adjustment reveled that robusta coffee is susceptible to drought and arabica coffee is more tolerant to drought (Venkataramanan, 1985).

The crop reduction will be high in robusta due to drought (Venkataramanan, et al., 2004). For this reasons, maintenance of a relatively high water status of shoot by increased water uptake is desirable. This can be achieved by traits like, high root to shoot ratio (Sharp and Davies, 1989), high total root length (Ingram et al., 1994) and high root elongation rates or by reducing the water loss (e.g., waxiness, root to shoot signaling, leaf rolling etc, Sharp et al., 1988). Another approach to increase the productivity under limited water conditions would be to select genotypes with high water use efficiency (WUE). It is also possible to attribute the differences in productivity among cultivars or genotypes at a given level of evaporation to the differences in WUE, provided HI (Harvest Index) is constant i.e. Y= water use X WUE X HI (Passioura, 1983). Hence, identifying genotypes with desirable root characteristics for moisture condition and high WUE would be very useful. In view of this, an experiment was conducted to study the genetic variability in root growth characteristics and to look into the relationship between roots associated traits and WUE using 35 accessions of *Coffea canephora* at Regional Coffee Research Station, Chundale.

MATERIALS AND METHODS

Coffea canephora is a highly cross-pollinated species. To get true to types of plant materials for water use, WUE and other related physiological traits in this experiment, suckers were used for propagation. Suckers were collected from 35 robusta accessions (Table 1) inclusive of exotic species identified as drought resistance (DR) collections and robusta selections. The collected suckers were planted into poly bags and maintained in nursery trench up to 8-10 months for better establishment. The established 10 months old plants were transplanted in to the battery containers (20 kg capacity) filled with soil mixture containing of soil, FYM and sand at the ratio of 6:2:1 respectively.

Thirty days after transplanting, water stress was imposed to maintain 70% FC by withholding the irrigation. The robusta clones were maintained under Rain Out Shelter (ROS) to prevent external water entry and also under Agro shade net, was used to protect from direct sunlight during daytime. To maintain the requisite soil water status, the pots were weighed once in two days for a period of five months. To evaluate the performance of accessions, primary growth parameters such as shoot dry weight (SDW), root dry weight (RDW), total dry matter (TDM) and cumulative water added (CWA) were recorded during the experimental period. Based on these primary observations, the parameters like cumulative water transpired (CWT), water use efficiency (WUE), leaf area duration (LAD), mean transpiration rate (MTR) and net assimilation rate (NAR) were computed.

Table 1. List accessions were used in this experiment.

No.	Accessions	No.	Accessions	No.	Accessions
1	**Java**	13	**DR-3**	25	**DR-15**
2	**Madagaskar**	14	**DR-4**	26	**DR-16**
3	**Saigan**	15	**DR-5**	27	**DR-17**
4	**Uganda 880**	16	**DR-6**	28	**DR-18**
5	**Uganda 1979**	17	**DR-7**	29	**DR-19**
6	**Costarica 3399**	18	**DR-8**	30	**DR-20**
7	**Ivary cost 1509**	19	**DR-9**	31	**SIB-4**
8	**Uganda 1977**	20	**DR-10**	32	**SIB-7**
9	**Guatemala 1**	21	**DR-11**	33	**Robusta bold**
10	**Ivary cost 3**	22	**DR-12**	34	**Robusta high yild**
11	**DR-1**	23	**DR-13**	35	**Dwarf CxR**
12	**DR-2**	24	**DR-14**		

RESULTS AND DISCUSSIONS

Root characteristics are considered to be important for survival and better performance of perennial crops like coffee. Therefore, identification of efficient clones/accessions with respect to ideal root traits is very much essential. There was a significant genotypic variation in root dry weight ranging from 1.63-10.71 g/plant amongst the 35 different accessions. The Java had the highest root dry weight and DR-9 had studied the least root dry weight (Table 2).

Table 2. The genotypic variation in root & shoot dry weight, root to shoot ratio and total dry matter grown under 70% FC.

Parameters	Range	Mean	C.V(%)
Shoot dry weight (g/plant)	10.13-38.0	18.57	24.88
Root to shoot ratio	0.16-0.50	0.28	15.71
Total dry matter (g/plant)	11.75-47.69	23.78	25.06

Genotypes were classified in to six groups based on root dry weight (Table 3) and root to shoot ratio (Figure 1). Most of the accessions showed increased root biomass under moderate moisture stress conditions, because severe stress inhibits both root and shoot growth (Sharp and Davies, 1979). The frequency was more in the category of 4 to 6 grams of root dry weight per plant (Figure 1).

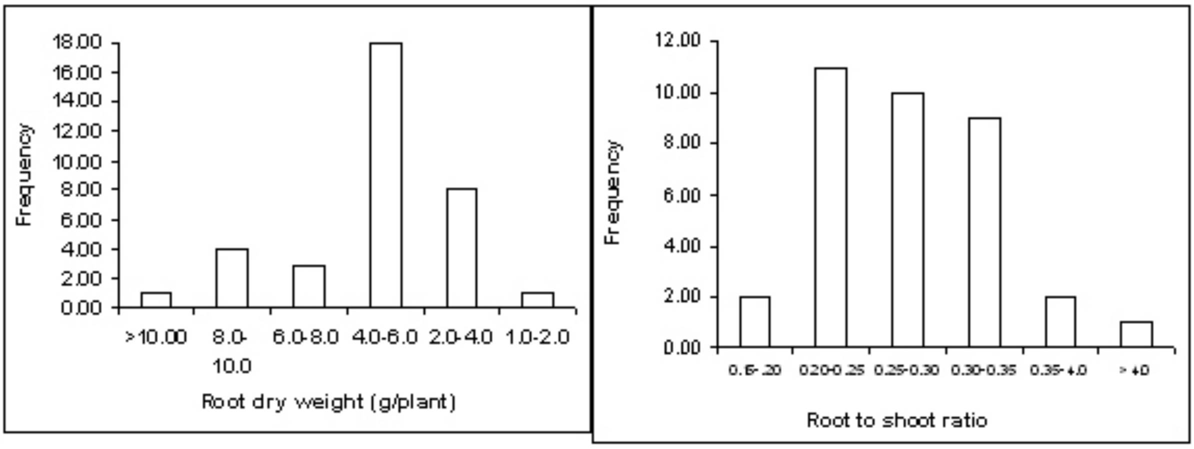

Figure 1. Frequency distribution of root dry weight and root shoot ratio under moderate stress condition.

Table 3. classification of *C. canephora*, accessions on root dry weight basis.

Groups	Root dry weight (g/plant)	Accessions
Group-I	>10	1
Group-II	8-10	2, 3, 6, 31
Group-III	6-8	4, 16, 18
Group-IV	4-6	26, 20, 27, 34, 21, 24, 10, 25, 15, 35, 9, 22, 23, 11, 8, 12, 13, 30
Group-V	2-4	14, 33, 28, 17, 5, 29, 7, 32
Group-VI	1-2	19

A significant positive relationship (r=0.93) was observed between these two parameters, indicating that increase in root biomass resulted in an increase in total dry matter under moderate stress condition (Figure 2a). These results corroborated with earlier in arabica coffee (Bhatt, 2002). There was a positive relationship between TDM and WUE among the accessions (Figure 2b). Since the root dry weight is associated with total dry matter, it is desirable to identify the accession not only with the high root biomass, but also with high TDM and WUE types.

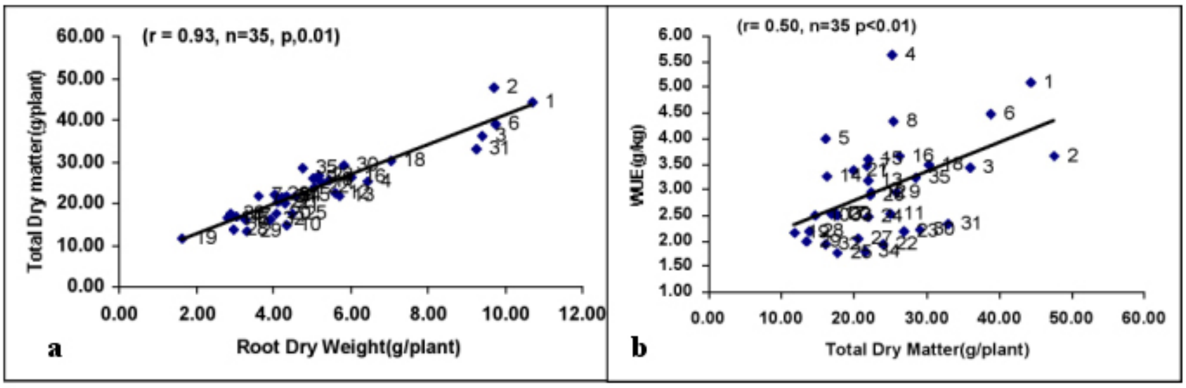

Figure 2. Relationships between root dry weight & TDM and TDM & WUE under 70% FC.

To identify accessions having high root biomass and WUE and also with high total biomass and WUE, the Z-distribution analysis was carried out by transforming the values of root biomass, total biomass and WUE (Figure 3). Based on this analysis, the accessions were classified in to two groups as presented in the Table 4. The difference observed in WUE might be due to variation in stomatal regulation.

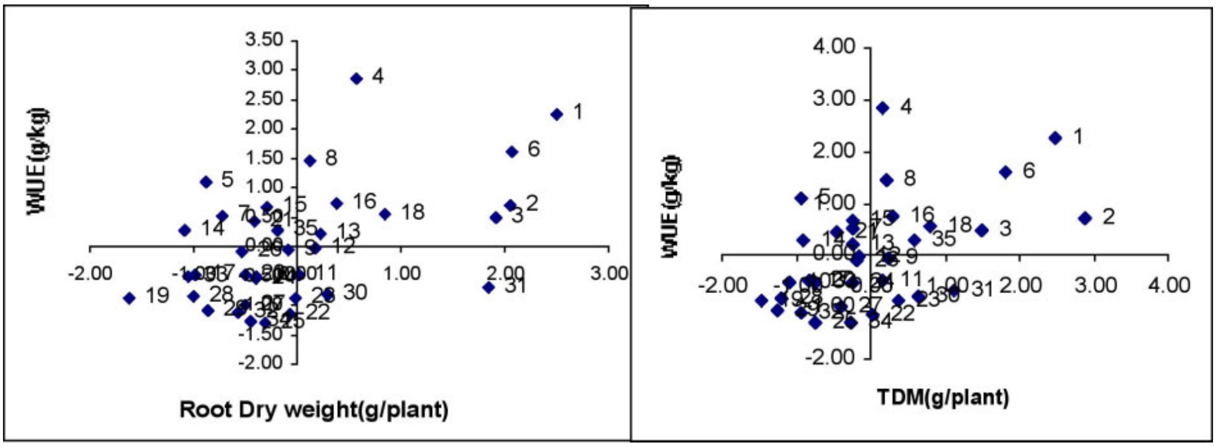

Figure 3. Standard normal Z-distribution plot between root biomass, total biomass and WUE in *C. canephora* accessions grown under 70% FC.

Table 4. Classification of *C. canephora* accessions based on root dry weight, total biomass and WUE under 70% FC.

	No.	Accessions	RDW (g/plant)	TDM (g/plant)	WUE (g/kg)	NAR (mg/gm^2 days)	MTR (ml/dm^2 days)
High Root weight and High WUE	**1**	Java	10.71	44.29	5.08	21.39	4.28
	2	Madagaskar	9.7	47.69	3.65	22.06	6.12
	6	Costarica 3399	9.73	38.77	4.47	18.98	4.27
Low Root weight low WUE	**17**	DR-7	3.04	16.98	2.53	9.55	3.83
	19	DR-9	1.63	11.75	2.17	8.85	4.11
	24	DR-14	4.33	21.88	2.48	11.82	4.78

In the present study considerable genotypic variability in root and total biomass was noticed. This variability provides an option to select the genotypes with better root types for achieving good growth and development under water limiting conditions by utilizing less water. The accessions Java, Madagaskar and Costarica S-3399 showed better root characteristics may be suited for water limited conditions. Hence these accessions could be used as parents in crop improvement programme.

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Diversity in the Ethiopian Coffee (*Coffea arabica* L.) Germplasm

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SUMMARY

Eighty one accessions of the Ethiopian coffee germplasm (*Coffea arabica* L.) were evaluated for fifteen seedling parameters at Jimma Agricultural Research Center during the 2002/2003 cropping season with the objective of clustering the germplasm accessions into genetically diverse classes based on seedling parameters. Cluster analysis grouped the accessions in to six major groups consisting of one to fifty four accessions. No correspondence was observed between the geographic and genetic diversity. Of the eleven principal components involved in explaining the entire variation among the accessions, the first two that had eigen values of more than one explained about 83% of the variation. The first principal component that accounted for about 67% of the total Variance was due chiefly to seedling height (SH), leaf length (LL), leaf width (LW), stem diameter (SD), leaf area (LA), shoot fresh weight (SFW) and root fresh weight. Overall, the study confirmed the presence of trait diversity in the Ethiopian coffee germplasm and this could be exploited in the genetic improvement of the crop through hybridization and selection.

INTRODUCTION

Coffee (*Coffea arabica* L.) is the most important plantation crop and one of the most common beverages enjoyed throughout the world. It generates up to US$ 14 billion annually for the producing countries. More than 80 countries, including Ethiopia cultivate coffee, which is exported as raw, roasted, or soluble product to more than 165 countries worldwide providing a livelihood for some 100 million people around the world (International Coffee Organization, 2001).

The agriculture based Ethiopian economy is highly dependent on arabica coffee. Until recently, it has been contributing more than 60 percent of the country's foreign exchange earnings. It also provides significant employment opportunities in rural areas and is the means of livelihood for over 15 million people in Ethiopia (Coffee and Tea Authority, 1999). Thus, in addition to being an important export crop, coffee plays a vital role in both the cultural and socio-economic life of the country (Workafes and Kassu, 2000).

Ethiopia is considered as the primary center of origin and diversification for arabica coffee (*Coffea arabica* L) and high genetic variability is expected to exist for yield and components of yield, diseases and pest resistance and other traits (Meyer, 1965; Sylvain, 1958; Melaku Worede, 1982; Mesfin Ameha, 1980). However, despite the vast area of cultivation, wealth of tremendous genetic diversity and importance to the national economy, the productivity of coffee per unit area remained very low with the average national yield hardly exceeding 0.5 t/ha clean coffee (Biruk, 2000). The major contributing factors for such low yield include the limited availability and adoption of improved coffee cultivars and lack of well characterized and distinctly variable breeding materials that are readily available for use. Therefore, the present study was carried out with the objective of clustering the germplasm accessions into genetically diverse classes based on seedling parameters.

MATERIALS AND METHODS

The experiment was conducted at Jimma Agricultural Research Center, which has an average annual rainfall of 1500 mm and mean maximum and minimum temperatures of 25.0°C and 11.2°C, respectively.

Experimental Material

Eighty-one coffee accessions collected from coffee growing regions of Kulo, Sidamo, Wollo, Harrar, Maji, Wollega, Illubabour, Kafa and Gambella and established at the research center were used for the study. The experiment was laid in a 9 x 9 Simple Lattice Design. Seedlings were raised following the conventional method of media preparation (Taye Kufa, 1998). All management practices were applied timely and uniformly as per the recommendations of the research center (Tesfaye, 1995).

Methods

Five eight months old seedlings per plot were recorded for root and shoot characters using non-destructive and destructive methods. The characters considered were, Seedling height, Number of true leaves, Mean leaf length, Mean leaf width, Total number of main stem node, Internode length, Stem diameter, Shoot fresh weight, Shoot dry weight, Root fresh weight, Root dry weight, Leaf area, Tap root length, Number of lateral Roots and Lateral root length.

Statistical analysis

All statistical analyses (Mahalanobis's D^2 and cluster analysis) and data processing were performed using SAS (SAS Institute, 2001) version 8.2 Software.

The generalized distance (Mahalanobis, 1936) between any two sets of populations is defined as:

$$D^2_{ij} = (\overline{X}_i - \overline{X}_j)\, S^{-1}\, (\overline{X}_i - \overline{X}_j)$$

Where; D^2ij = the distance between class i and j;$(\overline{X}_i - \overline{X}_j)$ = the difference in the mean vectors of two populations (class i and j); S^{-1}= pooled error variance and covariance matrix. The distances so obtained were tested using tabulated chi-square (χ^2) at 5% and 1% level of probability and 11 degrees of freedom.

RESULTS AND DISCUSSION

Cluster Analysis

The eighty-one coffee accessions considered in the present study were clustered in to six genetically distinct groups using the cluster procedure-Average Linkage Cluster Analysis (Table 1).

Table 1. Summary of cluster number and number of accessions.

Cluster number	Number of accessions
1	54
2	13
3	10
4	2
5	1
6	1

No geographical and altitudinal groupings were detected since accessions collected from the same region or similar altitude were grouped in to different clusters suggesting that there is no close correspondence between geographic and genetic diversity. Therefore, there is no need to go for regional or altitudinal sources to collect genetically diverse plants except when the objective is breeding for disease resistance. However, variations for important traits should be sought for and exploited for further improvement of the crop.

The results of the present study support the previous studies that indicated a very high level of genetic variability for morpho-agronomic traits. The explanation for the genotypes for the same geographical origin falling into different clusters can be found in the wide genetic divergence in the features created within each geographic zone through selection and genetic drift. Earlier observations of (Murthy et al., 1965), in Brassica; (Murthy and Ananda, 1966) in Linseed; (Arunacahlam and Ram, 1967) in sorghum; (Singh and Bains, 1968) in cotton; (Gupta and Singh, 1970) and (Malhota et al., 1974) in Mungbean have also indicated that geographical diversity cannot always be used as an index of genetic diversity. (Murthy, 1979) have also supported this. Similarly, (Bayetta, 2001) reported that morphological variation is more important than variation in geographical origin as an indicator of genetic diversity in coffee.

Inter- and Intra- cluster distance (D2) analysis

In the present study, analyses of distance between and within clusters (Table 2) were carried out using the DISCRIM procedure of Pair wise Generalized Squared Distance Between Groups. The result revealed a highly significant ($p < 0.01$) variation between most of the clusters.

Table 2. Inter (bottom) and Intra- (bold and diagonal) cluster distances among the eighty-one Coffee accessions.

	CL1	CL2	CL3	CL4	CL5	CL6
CL1	**0.81**					
CL2	12.99	**3.51**				
CL3	21.56*	51.17**	**4.39**			
CL4	74.03**	120.19**	23.83*	**7.40**		
CL5	80.92**	63.43**	146.19**	214.48**	**8.79**	
CL6	127.45**	125.37**	200.51**	297.66**	224.06**	**8.79**

**= Significant at $p < 0.05(\chi^2) = 19.67)$*
***= Significant at $p < 0.01((\chi^2=24.72)$*

The genotypes belonging to the significantly distant clusters could be used in hybridization programme for obtaining wide spectrum of variation among the segregants. It has been frequently reported in various crop plants that the magnitude of the resulting hetrosis is largely dependent on the degree of genetic diversity in the parental lines (Arunachalam et al., 1984). Hetrosis studies in crosses among indigenous cultivars repeatedly showed similar results (Bayetta, 2001).

Principal Component Analysis

Of the eleven principal components involved in explaining the entire variation among the accessions, the first two that had eigen values of more than one explained about 83% of the variation (Table 3). The first principal component that accounted for about 67% of the total variance was chiefly due to seedling height (SH), leaf length (LL), leaf width (LW), stem diameter (SD), leaf area (LA), shoot fresh weight (SFW) and root fresh weight (RFW). The study showed that these characters are worth considering in the selection of diverse parents since characters that show more contribution towards the divergence, should be considered during selection of diverse parents (Tikader et al., 1999).

Table 3. Eigen values, total variance, cumulative variance and eigen vectors for the 11 seedling parameters in the eighty-one Coffee accessions.

Seedling parameters	$Prin_1$	$Prin_2$
Seedling height	0.33	0.02
Internode length	0.29	-0.28
Total number of stem nodes	0.17	0.65
Leaf length	0.33	-0.15
Leaf width	0.34	-0.19
Stem diameter	0.30	-0.14
Number of true leaves	0.19	0.61
Leaf area	0.35	-0.16
Shoot fresh weight	0.36	0.07
Root fresh weight	0.32	0.08
Lateral root length	0.27	0.05
Eigen value	7.32	1.78
Total variance	66.57	16.19
Cumulative variance	66.57	82.76

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Effect of Graded Doses of Fertilizers on Biological and Chemical Properties of Coffee Soils Under North-East Monsoon Condition in Tamil Nadu, India

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SUMMARY

Microorganisms are considered fundamentally to be one of the health indicators of agricultural soils, the microbial process depending on seasons, cultural practices, and application of fertilizers and plant protection chemicals. Soil enzymes, microbial populations and basal respiration (microbial activity) are considered to be effective tools to monitor the quality of agricultural soils. A field experiment on the effect of graded doses of fertilizers on biological and chemical properties in coffee soil was taken up at Regional Coffee Research Station, Thandigudi, Tamilnadu, India during 2001-2002 seasons. The trial was conducted in arabica coffee selections Sln.3 (S.795) and Sln.9 (S.2790) planted during 1987, which were receiving graded doses of fertilizer since 1990 with mono shade. CO_2 released microbial activity, soil reaction, moisture, OC and available N from the experimental fields in various depths were estimated at periodic intervals. The microbial activity significantly decreased in the treatments receiving the highest doses of fertilizer (240:120:240 N, P_2O_5, K_2O kg ha^{-1}) and the activities are more in Sln.9 than Sln.3. The details of the study are discussed in the paper.

INTRODUCTION

With increasing emphasis on management practices to enhance productivity of coffee crop, fertilization on soils is inevitable. Positive response of coffee to applied chemical fertilizer was observed at 50-200 kg N ha^{-1} in Kenya (Njoroge, 1985), 336 kg N ha^{-1} in Puerto Rico (Abruna et al., 1959; Chandler et al., 1968), 200-400 kg N ha^{-1} in Brazil (Malavolta, 1970), 180-240 kg N ha^{-1} in Cuba (Ochoa et al., 2000) and in India 112-160 kg N ha^{-1} (Ananth, 1966; Mathew and Krishnamurthy Rao, 1980). While improving the above ground tree biomass, fertilizers could concurrently affect the below ground microbial biomass and microbially mediated nutrient cycling processes. Adverse effects of fertilizers on microbial indices have been detected both under laboratory (Soderstrom et al., 1983; Thirukkumaran and Parkinson, 2000) and field conditions (Nohrstedt et al., 1989; Arnebrant et al., 1996; Thirukkumaran and Parkinson, 2002). As such, more knowledge on the overall effect of graded doses of fertilizers on other biological components of coffee ecosystems is needed.

MATERIALS AND METHODS

Study site

Regional Coffee Research Station, Thandigudi located at 1300m above MSL receives a mean annual rainfall of ca. 125cm. The maximum and minimum temperature ranges from 8^oC to 19^oC and 23^oC to 34^oC respectively. The soil is sandy loam with moderately acidic pH (5.4-

6.1). The phosphorous status was low (< 24.2 mg P_2O_5 kg^{-1} soil) and that of potassium is low (< 140.7 mg K_2O kg^{-1} soil) to medium (140.8-281.1 mg K_2O kg^{-1} soil) in the initial years.

Seedlings of two arabica cultivars Sln.3 and Sln.9 were planted during October 1987 with a spacing of 2m x 2m in three replicated plots. Each plot (56 m x 12 m) having six rows and 28 plants in a row was again subdivided into 4 subplots (6 plants of 7 rows each) to impose fertilizer treatments. During the initial years from October 1987, to March 1990, recommended doses of fertilizers (20: 20: 20 kg ha^{-1} N: P: K) applied to favour the establishment of seedlings. During 1990 flowering season; the flower buds were removed before blossom. The fertilizer treatments viz., unfertilized control, 60: 30: 60 kg ha^{-1} N: P: K, 120: 60: 120 kg ha^{-1}N: P: K and 240: 120: 240 kg ha^{-1}N: P: K in the form of urea, single super phosphate and muriate of potash respectively for N, P and K were imposed annually (in four split doses) from March 1990 onwards. Except fertilizer treatments, all other cultural operations were common for all the treatments. All the trial plots were provided with uniform mono shade of *Erythrina lithosperma***.**

Soil properties

Soil moisture was determined by oven dry method and soil pH was assessed using 1:2.5 ratio of soil to water. Organic carbon content was estimated by wet oxidation titration method (Walkley and Black, 1934) and mineralizable nitrogen by alkaline $KMnO_4$ method (Subbiah and Asija, 1956). Microbial respiration was determined by following titration method (Olinger, 1996). The data were subjected to analysis of variance (Rangaswamy, 1995).

RESULTS

Soil properties

Soil moisture (Table 1), pH (Table 2), and contents of available nitrogen (Table 3), and organic carbon (Table 4) in the treatment plots are the mean values for thirteen monthly observations from January 2001 to January 2002. All the said physical-chemical parameters were comparable between the cultivars Sln.3 and Sln.9 studied.

Graded doses of fertilizer application significantly enhanced soil moisture levels. However, the moisture content showed pronounced decreases with soil depth. In the case of soil pH, no perceptible differences were noted either between treatments or between soil layers. The content of available soil N was not significantly altered at lower doses of fertilizer applications. However, at higher fertilizer doses, there was a pronounced decrease in the N content. In the case of soil organic carbon content, significant variations were observed between the two-arabica cultivars. With Sln.3 cultivar no significant differences in OC content was observed between the treatments. On the other hand, fertilization significantly enhanced OC content in the plots of Sln.9. Among the cultivars, Sln.9 registered higher OC content than Sln.3. In both the cultivars, the OC content showed significant decreases with increasing soil depth.

Soil microbial activity

Soil microbial activity, measured in terms of soil respiration in different plots of arabica cultivars is presented in Table 5. In plots planted with Sln.3, no significant differences in soil respiration were observed between treatments. On the other hand, with Sln.9, significant increases and decreases in respiration were noted respectively with lowest (T_1) and highest (T_3) doses of fertilizer application, while the medium doses of fertilizer application (T_2)

registered no significant changes over control. Soil depth also showed marked impact on soil microbial activity. Sln.3 recorded significant decrease in soil respiration with soil depth. When compare to control, in the case of Sln.9, soil respiration increased up to$T_{2,}$ beyond which it tended to decrease.

Table 1. Soil Moisture (%).

Cultivars	Treatments	Soil Layers (A)			Mean
		A_1	A_2	A_3	
Sln.3	T_0	18.54	17.98	17.01	17.84
	T_1	19.51	19.09	19.78	19.46
	T_2	19.12	18.58	18.61	18.77
	T_3	19.38	18.77	18.86	19.00
	Mean	19.14	18.60	18.56	
Sln.9	T_0	17.48	18.05	17.58	17.71
	T_1	17.16	15.73	16.38	16.42
	T_2	19.71	19.48	19.13	19.44
	T_3	18.74	18.54	17.98	18.42
	Mean	18.27	17.95	17.77	

	Treatments (T)	Soil layers (A)	T X A Plots
CD (5%)	0.8501	0.1120	1.2153

T_o : Control `

T_1 : 60:30:60 (N:P:K kg ha^{-1}) *A_1 : 0 – 10 cm*

T_2 : 120: 60:120 (N:P:K kg ha^{-1}) *A_2 : 11– 20 cm*

T_3 : 240:120:240 (N:P:K kg ha^{-1}) *A_3 : 21– 30 cm*

Table 2. Soil pH.

Cultivars	Treatments	Soil Layers			Mean
		A_1	A_2	A_3	
Sln.3	T_0	5.85	5.84	5.76	5.82
	T_1	5.74	5.65	5.63	5.67
	T_2	5.75	5.80	5.78	5.78
	T_3	5.67	5.55	5.68	5.63
	Mean	5.75	5.71	5.71	
Sln.9	T_0	5.83	5.85	5.82	5.79
	T_1	5.77	5.73	5.87	5.78
	T_2	5.83	5.78	5.73	5.83
	T_3	5.80	5.88	5.82	5.83
	Mean	5.81	5.81	5.81	

	Treatments (T)	Soil layers (A)	T X A Plots
CD (5%)	0.0570	0.0145	0.0839

Table 3. Available Soil N (kg ha^{-1}).

Cultivars	Treatments	Soil Layers (A)			Mean
		A_1	A_2	A_3	
Sln.3	T_0	476.00	376.60	505.40	452.67
	T_1	442.40	436.80	446.60	441.93
	T_2	259.00	365.40	519.40	381.27
	T_3	273.00	351.40	571.20	398.53
	Mean	362.60	382.55	510.65	
Sln.9	T_0	509.60	410.20	491.40	470.40
	T_1	595.00	449.40	385.00	476.47
	T_2	399.00	515.20	443.80	452.67
	T_3	376.20	256.00	338.00	323.40
	Mean	469.95	407.70	414.55	

	Treatments (T)	Soil layers (A)	T X A Plots
CD (5%)	38.2744	26.4417	71.6852

Table 4. Organic Carbon (%).

Cultivars	Treatments	Soil Layers (A)			Mean
		A_1	A_2	A_3	
Sln.3	T_0	4.78	4.11	4.07	4.32
	T_1	4.41	4.24	3.95	4.20
	T_2	4.54	4.16	4.04	4.25
	T_3	4.58	4.49	4.27	4.45
	Mean	4.58	4.25	4.08	
Sln.9	T_0	4.43	4.32	4.01	4.26
	T_1	4.93	4.60	4.32	4.62
	T_2	4.71	4.54	4.38	4.54
	T_3	4.77	4.55	4.24	4.52
	Mean	4.71	4.50	4.24	

	Treatments (T)	Soil layers (A)	T X A Plots
CD (5%)	0.1308	0.0329	0.1922

DISCUSSION

Fertilizer application in crop fields generally alters the physical and chemical properties of the soil (Alexander, 1977). In the coffee fields, the results of the present study revealed that the moisture content of the soil at surface level increased significantly with the increase of the dosage of the fertilizer (Table 1). This may be attributed that the enhanced plant biomass due to fertilizer application increases the litter fall. The accumulation of litter at the floor of the field reduces the evaporation and consequently the water loses. The higher content of OC through higher litter content of soil may also be a reason for the retention of greater moisture at surface level.

The pH of the soil over the period of study was not notably changed (Table 2). This result is corroborated with the findings (Thirukkumaran and Parkinson, 2002), no direct effect of either N or P fertilizer on pH was found.

Table 5. Microbial Respiration (mg CO_2 g^{-1} soil 12 h^{-1}).

Cultivars	Treatments	Soil Layers (A)			Mean
		A_1	A_2	A_3	
Sln.3	T_0	15.60	14.15	14.09	14.61
	T_1	15.41	14.74	13.89	14.68
	T_2	14.78	14.65	14.00	14.48
	T_3	16.10	13.81	14.45	14.79
	Mean	15.47	14.34	14.11	
Sln.9	T_0	15.68	15.05	16.81	15.85
	T_1	18.12	16.65	16.41	17.06
	T_2	16.90	15.68	17.68	16.76
	T_3	15.88	13.25	14.27	14.46
	Mean	18.27	17.95	17.77	

	Treatments (T)	Soil layers (A)	T X A Plots
CD (5%)	0.0570	0.0145	0.0839

The status of N at different layers of soil due to fertilizer application was generally not having any considerable change (Table 3) however in the plot of cultivar Sln.9 the higher doses of fertilizer decreases the N content at A_3 layer the increased anaerobic microbial activity in the lower layer may exhaust the available recourse like N compounds. The organic carbon content in the soil was greater for the cultivar Sln.9 (Table 4). The higher vegetative growth and consequently the greater litter in the cultivar Sln.9 may be accounted to be the reason for this fact. The respiration rate of microorganism in the soil of cultivar Sln.9 was slightly higher than that of the cultivar Sln.3 (Table 5). The specific root exudates or allelopathic chemicals from the respective cultivars may be the possible reason for this fact that the higher dosage of fertilizer application in both cultivars of coffee slightly decreases the soil microbial respiration. The higher concentration of certain elements in the fertilizer may affect the soil microbes, which in turn could convert the soil environment less favorable for the microbial respiration.

The suppressive effect of higher dose of fertilizer on basal respiration was evident in T_3 of Sln.9 cultivar. These results reflect the findings of a laboratory study (Thirukkumaran and Parkinson, 2000), where triple super phosphate added to pine forest floor material caused suppression in basal respiration. The suppression effect of higher doses of fertilizer corroborate the findings of (Thirukkumaran and Parkinson, 2002; Flanagan and Van Cleve, 1983; Kelly and Henderson, 1978; Nommik, 1978), (Kelly and Henderson, 1978) attributed these negative effects to changes in soil acidity and (Nommik, 1978) hypothesized that P caused some toxic effects on soil biota. Decreased soil respiration has also been detected in a P only fertilized agricultural soil in comparison to an N plus P amended soil (Biederbeck et al., 1984). In this study N, P, K proportionally increased not only a single major nutrient.

CONCLUSION

Application of higher doses of fertilizers is not causing any notable beneficial effect in the coffee plantation. The nutrients in the fertilizers are not recycled properly and get leached out which ultimately causes upset in soil ecobalance and wastage of nutrients when applied excessively. The fertilizer level 120: 60: 120 kg N: P: K kg ha^{-1} was found to be optimum in the present study for effective soil health. More data on various characters of soil must be accumulated and processed to confirm this concept.

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Genetic Divergence of Hararge Coffee (*Coffea arabica* L) Germplasm Accessions at Pre-Bearing Stage

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SUMMARY

A field experiment was conducted at Awada Agricultural Research Sub-Center using 100 Hararge coffee germplasm accessions for morphological characterization at pre-bearing stage. These coffee germplasm accessions representing 16 woredas of Hararge coffee growing areas and 4 standard checks from southwest Ethiopia were evaluated for 14 quantitative characters. The germplasm accessions differed significantly for all the characters in the univariate analyses of variances indicating the prevalence of variability among the Hararge coffee germplasm accessions. Further, the first four principal components explained 78.5 per cent of the total variation prevalent within the germplasm accessions out of which 38.5 per cent was explained by the first principal component. Length of the longest primary branch and stem diameter were the two important characters that contributed most to the total variation of the first principal component. Average linkage cluster analysis using Mahalanobis (D^2) distance for the 14 quantitative characters grouped the 100 Hararge coffee germplasm accessions with four standard checks into six clusters. The number of accessions per cluster ranged from 5 in cluster VI to 44 in cluster III. The clustering pattern of the accessions revealed the prevalence of genetic diversity in the Hararge coffee germplasm for the quantitative characters considered. The maximum inter-cluster distance was obtained between clusters II and VI while the minimum was observed between clusters I and III. The study highlighted the possibility of using accessions of the distant clusters as potential candidates for the genetic improvement of Hararge coffee. Nevertheless, the aspects of intensive germplasm exploration in the western Hararge and consideration of additional characters across the bearing stage was suggested in order to confirm the results of characterization of pre-bearing stage.

INTRODUCTION

Ethiopia is well known not only for being the home of arabica coffee, but also for its very fine quality coffee acclaimed for its unique aroma and flavor characteristics. The coffee types that are distinguished for such unique characteristics include Sidamo, Yirgachefe, Hararge, Ghimbi and Limu types (Workafes Woldetsadik and Kassu Kebede, 2000).

Since Ethiopia is the primary center of origin and genetic diversity for *C. arabica*, there is high genetic variability for yield and yield components, disease and pest resistance, and other traits (Sylvain, 1958; Meyer, 1968; Melaku Worede, 1982). The environmental conditions in the coffee producing areas show considerable variations between and within regions. The growth of coffee under such diverse environments is an indication for the presence of genetic variability. This is substantiated by the fact that within Hararge region itself, the most coffee producing areas such as Habro, Chercher, Wobera, Garamuleta, Harar Zuria, and Gursum which are known for production of best quality coffee (Sylvian, 1955; Brown Bridge and Eyassu GebreIgziabher, 1968) are also found to be sources of variation for yield and other characters.

The exploitation of genetic diversity for crop improvement should be the ultimate objective of genetic resources exploration and conservation. Ford-Lloyd and Jackson (1986) opined that the vital stages of evaluation and incorporation of valuable characters such as disease resistance and/or tolerance to environmental stress factors into new varieties appeared to be justifications of genetic resources conservation, characterization and evaluation. In cognizant of this fact, renewed efforts of coffee germplasm collection were undertaken during 1998 from different coffee growing areas of Hararge by JARC and as a result more than 900 accessions were collected and maintained at the center. Pre-breeding studies on land races and wild species, according to them, are highly essential in order to provide breeders with valuable information.

Several workers have estimated the extent of genetic diversity present from the different sources of arabica coffee germplasm collections. For instance, a study by Catter (1992) on second progeny arabica coffee collections of Ethiopian origin indicated the prevalence of high level of variability in morphological, agronomic and biochemical characteristics. The genetic diversity analysis conducted by Lashermes et al. (1996) using RAPD markers on cultivated and sub-spontaneous accessions of arabica coffee confirmed the narrow genetic base of commercial cultivars (3 typica and 3 bourbon types). On the other hand, they reported the existence of large genetic diversity within the sub-spontaneous material, which consisted of 11 samples representing the different coffee growing areas in Ethiopia. Further, they have suggested the prevalence of an east-west differentiation in the Ethiopian coffee germplasm. Similarly, the present study was conducted in order to estimate the genetic divergence among Hararge coffee germplasm collections and to facilitate for use in breeding program.

MATERIALS AND METHODS

The experiment was carried out at Awada Agricultural Research Sub-Center (AARSC) located near Yirgalem town, 45 km south of Awassa at an altitude of 1750 meters above sea level. The sources of test materials were 902 Hararge coffee accessions that were collected from 16 Woredas of eastern and western Hararge zones and maintained in the field at AARSC. These accessions were planted in July 2000. For the present study, 100 accessions were taken at random. Four CBD (coffee berry disease) resistant cultivars well adapted to Sidamo environment were included as standard checks.

Data analysis

Analysis of variance using nested ANOVA was computed for each quantitative character in order to identify the variability among accessions. Further, the data were standardized to a mean of zero and a variance of unity, to avoid differences in scales used for analyses before undertaking principal component and divergence analyses. Genetic divergence between clusters was determined using the generalized Mahalanobis's D^2 statistics. Clustering of the accessions was performed using the proc cluster procedure of SAS version 8.2 software package (SAS Institute, 2001) by employing the method of average linkage cluster analysis of observations. The D^2 values obtained between and within clusters (inter and intra-cluster distances) were tested for significance at the required level of probability against the tabulated values of X^2 for p degrees of freedom (Singh and Chaudhary, 1996).

RESULTS AND DISCUSSION

Analysis of variance (ANOVA)

The ANOVA showed highly significant differences for each of the 14 characters considered suggesting the presence of high genetic variability among the accessions (Table 1). The

Hararge coffee population was stated to be of narrow genetic base (Van der Graaf, 1981). The result of the present study, however, disproved such a statement by clearly indicating the presence of wide variations among Hararge coffee accessions. This finding is in agreement with the work of earlier researchers (Catter, 1992; Leroy et al., 1993). This may be attributed either to the evolutionary tendencies as the species is indigenous to Ethiopia or to the natural mutations occurring to the population of the crop (Avice and Hamric, 1997; Hedric, 2000).

Table 1. Mean squares from the analysis of variance for 14 quantitative characters.

Characters	Mean squares	
	Treatments	Error
Plant height	912.903**	178.046
Inernode length of stem	0.989**	0.297
Internode length of branch	15.478**	0.418
Number of internodes of stem	21.630**	5.855
Number of internodes on the longest primary branch	18.408**	7.986
Total number of internodes per plant	22106.285**	7492.994
Canopy diameter	696.938**	131.200
Stem diameter	0.465**	0.199
Leaf area	177.327**	46.202
Number of primary branches	87.553**	23.878
Angle of primary branches from the main stem	27.262**	10.252
Number of secondary branches	8375.144**	2355.480
Length of the longest primary branch	299.536**	73.424
Average length of primary branches	111.770**	34.231

**Significant at 0.05 probability level, ** Significant at 0.01 probability level*
Note: degrees of freedom for treatments and error for all the 14 characters were the same i.e. 103 and 312, respectively.

Principal component analysis

The first four principal components, with eigenvalues greater than unity, explained 78.5 per cent of the total variation among 104 accessions for the 14 quantitative characters measured (Table 2). Principal component 1 accounted more than one third of the variation. The contribution of a trait can be determined by regarding the absolute value of a trait coefficient (eigenvector) that is greater than half when divided by the square root of the variance of the eigenvalue of the respective principal component (Johnson and Wichern). This criterion was used in the present study to decide the importance of characters in the different principal components. Accordingly, length of the longest primary branch, stem diameter, the average length of primary branches, total number of internodes per plant and total number of primary branches per plant revealed eigenvectors which are greater than 0.50 suggesting that these characters were the most important ones contributing to the total variation of the first principal component.

In light of the results obtained from principal component analysis, it may be possible to deduce that maximum variation (38.5%) accounted by principal component 1 was represented by such quantitative characters as length of the longest primary branch, stem diameter, total number of internodes per plant and total number of primary branches per plant. This perhaps emphasized the significance of these characters to the appraisal of genetic diversity. Similar views were held by earlier researchers (Amsalu Ayana and Endashaw Bekele, 1999; Montagnon and Bouharmont, 1996)

Table 2. Eigenvalues, total variance, cumulative variance and eigenvectors for the 14 quantitative characters in the 100 Hararge coffee germplasm accessions with 4 checks at Yirgalem during 2002-2003.

Characters	PC 1	PC 2	PC 3	PC 4
Plant height	-0.283	0.160	0.483	0.080
Internode length of the stem	-0.086	0.485	0.309	-0.077
Internode length of branches	0.027	-0.281	0.209	-0.633
Number of internodes of stem	-0.288	-0.299	0.364	0.150
Number of internodes on the longest primary branch	-0.264	-0.191	-0.399	0.133
Total number of internodes per plant	-0.343	-0.310	-0.010	0.172
Canopy diameter	-0.310	0.133	-0.160	-0.322
Stem diameter	-0.358	0.097	-0.129	0.023
Leaf area	0.039	0.462	0.143	0.006
Number of primary branches	-0.313	-0.285	0.313	0.050
Angle of primary branches from the main stem	0.083	0.077	0.070	0.626
Number of secondary branches	-0.229	0.136	-0.398	-0.006
Length of the longest primary branch	-0.365	0.213	-0.086	0.019
Average length of primary branches	-0.354	0.217	-0.064	-0.136
Eigenvalues	5.383	2.669	1.8642	1.079
%Total variance	**38.50**	**19.10**	**13.30**	**7.70**
%Cummulative variance	**38.50**	**57.50**	**70.80**	**78.50**

Note: PC1, PC2, PC3 and PC4 are the first four principal components with eigenvalues greater than unity

Cluster analysis

The 104 coffee germplasm accessions were grouped into 6 clusters. The number of accessions per cluster varied from 5 accessions in cluster V to 44 accessions in cluster III. Clusters I, II, and IV contained accessions mainly from the western Hararge woredas whereas clusters III and V had almost equal number of accessions from both east as well as west Hararge woredas. The five accessions in cluster VI were from the two woredas of west Hararge out of which 4 originated from Kuni and only one from Chiro woreda. Three of the CBD resistant cultivars (75227, 74165 and 74140) used as checks were grouped in cluster I, in which middle to high altitude accessions from western Hararge Woredas were most frequent. The fourth check, F-59 was grouped in cluster II, confirming the fact that this cultivar was distinctly different from the rest standard checks in morphology and geographical origin. Lin and Binns (1985) and Lin et al. (1986) also highlighted the advantages of hierarchical cluster analysis in identifying useful germplasm particularly by including reference cultivars.

The overlapping of clustering patterns in respect of the germplasm accessions of majority of the woredas could be explained as lack of differentiation among woredas arising partly due to gene flow (Amsalu Ayana and Endashaw Bekele, 1999). In general, it may be possible to state that germplasm accessions from western Hararge woredas were relatively more variable in their clustering patterns as compared to eastern Hararge woredas. This pointed out that in future endeavors of Hararge coffee germplasm explorations, due emphasis must be given to Girawa, Bedeno, Kuni, Chiro, Mesela and Habro woredas. Such a view is endorsed by earlier researchers (Jagadev and Samal, 1991).

Inter and intra-cluster distance (D^2) analysis

Based on Mahalanobis distance (D^2), no significant genetic dissimilarity was detected within clusters except for clusters I and III that showed highly significant (154.68) and significant (23.93) values of squared Euclidean distances, respectively (Table 3). The significant value of genetic distances within clusters I and III was an indication of heterogeneity of the germplasms present within these clusters. Considering the inter-cluster distances, cluster II showed the maximum and significant genetic distance (102.12) from cluster VI.

Since the magnitude of heterosis largely depends upon the degree of genetic diversity among the parental lines, the germplasm accessions belonging to the pairs of distant clusters could be very useful in hybridization program to obtain a wide spectrum of variation among the segregates and to maximize heterosis. In light of the above finding it is possible to conclude that the germplasm accessions from cluster II and cluster VI could offer potential parental lines for maximizing heterotic value.

Table 3. Inter-(bottom) and intra- (bold & diagonal) cluster distances among 104-coffee genotypes at Yirgalem during 2002-2003.

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	**154.6816****					
Cluster II	14.91634	**15.24226**				
Cluster III	10.78772	16.56251	**23.93316***			
Cluster IV	14.25636	47.83423**	22.36447	**15.37135**		
Cluster V	38.84501**	66.12385**	18.28813	29.39752**	**19.21175**	
Cluster VI	47.52314**	102.12226**	68.19061**	16.35693	59.78586**	**14.17545**

** = Significant at $p < 0.05$ (X^2 =23.685), ** = Significant at $p < 0.01$ (X^2 = 29.141)*

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Morphological Characterization of Hararge Coffee (*Coffea arabica* L.) Germplasm Accessions for Qualitative Characters

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SUMMARY

A field experiment was conducted at Awada Agricultural Research Sub-Center using one hundred Hararge coffee germplasm accessions for morphological characterization. Data on 8 qualitative characters were obtained on those coffee germplasm accessions representing 16 woredas of Hararge coffee growing areas along with 4 standard checks originated from southwest Ethiopia. Based on centroid linkage method of hierarchical cluster analysis for qualitative characters, the germplasm accessions got grouped into 7 clusters at 75 per cent level of similarity. Accordingly, the 100 Hararge coffee accessions fell into the first 5 clusters while the 4 standard checks grouped in the last two clusters. Majority of the Hararge coffee accessions (92) were grouped in cluster I indicating the narrow genetic base of Hararge coffee germplasm for the qualitative characters considered. Characterization of the germlasm accessions was done based on the value of cluster centroids of the respective character.

INTRODUCTION

Ethiopia is the home of the most favored coffee species, arabica coffee (*Coffea arabica* L.). Economically, coffee is the leading export commodity crop of the nation and more than 60 per cent of the annual foreign exchange earnings of the country originates from this single crop. In addition, about 25 per cent of the population directly or indirectly depends on coffee industry through production, processing and marketing (Melaku Jirata and Samuel Assefa, 2000).

The coffee types of Ethiopia that are distinguished for their very fine quality that is acclaimed for its unique aroma and flavor characteristics include Sidamo, Yirgacheffe, Hararge, Ghimbi and Limu types (Workafes Woldetsadik and Kassu Kebede, 2000). The environmental conditions in the coffee producing areas show considerable variations between and within regions. The growth of coffee under such diverse environments is an indication for the presence of genetic variability. This is substantiated by the fact that within Hararge region itself, the most coffee producing areas such as Habro, Chercher, Wobera, Garamuleta, Harar Zuria, and Gursum that are known for production of the best quality coffee (Sylvian, 1955; Brown Bridge and Eyassu GebreIgziabher, 1968) are also highly variable for yield and other characters.

Genetic differentiation between populations is caused by adaptation to environmental factors such as altitude, rainfall and soils, as for the wild species. Briggs and Knowles (1967) expressed that local varieties might have also evolved differently due to differences in cultural practices or in response to farmers' deliberate selections to increase adaptability, yield and quality.

Qualitative genetic variation is characterized by differences in a trait, which are small in number or non-continuous classes or values. These variations are governed by allelic differences at one or few numbers of interacting gene loci and the genotypic differences could be easily identified from the trait's expressions. The expression of these traits appeared less influenced by environment hence, considered important for characterizing plants (Berg et al., 1993). Qualitative genetic variations could be those relating to color, shape, texture, and presence or absence of certain characters. Usually the classification applied for any year, location or environment (Briggs and Knowles, 1967). Multivariate analysis of qualitative characters (using cluster analysis) has been used previously to measure genetic relationships within crop species. Examples include oat (*Avena sativa*) (Souza and Sorrels, 1991); cacao (Frances Bekele and Isaac Bekele, 1996); soybean (Cox et al., 1985) and wheat (*Triticum aestivum* L.) (Wrigley et al., 1982). Similarly, the present study was conducted in order to characterize Hararge coffee germplasm based on qualitative characters.

Table 1. List of the morphological qualitative characters considered for characterization including their codes and descriptions as per IPGRI coffee descriptors list.

Ser.no.	Character	Description and code
1.	Growth habit	Open (1), intermediate (2), compact (3)
2.	Stipule shape	Round (1), ovate (2), triangular (3), deltate (4), trapezium (5)
3.	Stem habit	Stiff (1), flexible (2)
4.	Branching habit	Very few primaries (1), many primaries with few secondary branches (2), many primary and secondary branches (3), many primary, secondary and tertiary branches (4)
5.	Angle of insertion of primary branches from main stem	Drooping (1), horizontal or spreading (2), semi-erect (3)
6.	Young leaf color (leaf tip color)	Greenish (1), green (2), brownish (3), reddish brown (4), bronzy (5)
7.	Leaf shape	Obovate (1), ovate (2), elliptic (3), lanceolate (4)
8.	Leaf apex shape	Round (1), obtuse (2), acute (3), acuminate (4), apiculate (5), spatulate (6)

MATERIALS AND METHODS

The experiment was carried out at the Awada Agricultural Research Sub-Center (AARSC) located near Yirgalem town, 45 km south of Awassa at an altitude of 1750 meters above sea level. Geographically, the site is located at coordinates of 6° 3' N latitude and 38° E longitude. The annual mean minimum and maximum rainfall were 858.1 mm and 1676.3 mm, respectively, and the annual mean minimum and maximum temperatures were 11.0° C and 28.4° C, respectively (AARC, 2000).

For the present study, 100 accessions were taken at random out of the 902 Hararge coffee accessions collected from 16 Woredas of eastern and western Hararge zones and maintained in the field at AARSC. These accessions were planted in July 2000. Four CBD (coffee berry disease) resistant cultivars well adapted to Sidamo environment were included as standard checks. Four random plants per plot (from each accession and each check variety) were taken to measure the qualitative characters considered (Table 2). The descriptors for Coffee (IPGRI, 1996) were adopted to measure the qualitative parameters.

Table 2. Cluster Centroids of the 100 Hararge coffee germplasm accessions with 4 checks for the eight qualitative characters.

Character	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster Cetroid
GH	1.73	1.60	1.00	3.00	2.00	1.00	3.00	1.75
SS	3.47	4.00	3.00	2.00	2.00	2.00	2.00	3.37
SH	1.10	1.00	1.00	1.00	1.00	1.00	2.00	1.11
BH	3.05	2.95	1.25	3.00	4.00	2.50	3.50	3.03
ORPB	2.49	1.40	2.00	2.00	3.00	2.00	3.00	2.40
LC	4.77	2.00	3.00	5.00	1.00	1.50	1.50	4.28
LS	3.23	3.00	3.00	3.00	3.00	4.00	4.00	3.25
LAS	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

GH=growth habit, SS=stipule shape, SH=stem habit, BH=branching habit, ORPB=orientation of primary branches from the stem, LC=leaf tip color, LS=leaf shape, LAS=leaf apex shape

Data analysis

All the qualitative variables were quantified by using appropriate scale (IPGRI, 1996). The plot means data for the qualitative characters was subjected to hierarchical cluster analysis of observations. The associations among the accessions were examined by hierarchical cluster analysis of observations with Euclidean distance and centroid linkage method using Minitab (version 12.21) software package (Minitab Inc, 1998). Clustering of the coffee accessions was performed to group sets of accessions into homogenous groups at 75 percent level of similarity. Then each cluster was characterized for its special feature.

RESULTS AND DISCUSSION

At the 75 per cent level of similarity, the 104 coffee accessions were grouped into seven clusters each containing one or more accessions per cluster (Table 3). Clusters III, IV and V each contained a single accession while clusters VI and VII each had 2 accessions. On the other hand, cluster I contained 92 accessions. The 100 Hararge coffee germplasm accessions (excluding standard checks) were found grouped in the first five clusters. It is of interest to note that cluster I contained accessions from all the 16 woredas of Hararge region. Cluster II had two accessions from Darolobo woreda (western Hararge) and three accessions from Dedder woreda (eastern Hararge). Clusters III, IV and V each contained a single accession from Darolobo, Mesela (western Hararge) and Girawa (eastern Hararge) woredas. Cluster VI was represented by the two standard checks originating from Kaffa region (southwest of Ethiopia) while cluster VII contained the other two standard checks from Illubabor region (southwest of Ethiopia).

In order to analyze the variation between accessions based on the qualitative characters, cluster centroid values (Table 4) were computed. The unique characteristics pertinent to each cluster can be easily determined by comparing the values to the different scales of the respective character. Clusters IV and VII appeared unique for their compact type of growth habit (IPGRI, 1996). Cluster I that comprised majority of the Hararge coffee germplasm accessions (92%), cluster II and cluster V (a single accession from Girawa Woreda) had intermediate type of growth habit while clusters III and VI were open type. Cluster I and II had deltate type of stipule shape and cluster III was the only one with triangular type of stipule shape whereas the remaining clusters had ovate type of stipule shape. Except cluster VII that had flexible type of stem habit, the remaining six clusters had fixed or stiff types of stem habit suggesting that Hararge coffee type are vigorous in vegetative growth. With respect to orientation of primary branches from the main stem, clusters V and VII had semi-erect type of orientation while cluster II had drooping and the remaining four clusters had horizontal type of orientation. Variations among accessions for leaf tip color was also observed, for instance, cluster III was brownish, cluster V greenish, clusters VI and VII had greenish and green leaf tip colors whereas clusters I and IV had bronzy leaf tip color. Regarding leaf shape, except clusters VI and VII (southwest Ethiopian origin) that were lanceolate type, the rest of the clusters had elliptic type of leaf shape. No variation was observed between the accessions for the character leaf apex shape where all the accessions exhibited apiculate type (Table 4).

The four released CBD resistant cultivars that were used as standard checks in the present study got divided dichotomously into two distinct clusters each containing two cultivars per cluster. The two cultivars exhibiting compact type of growth habit (74165 and 74140) fell into cluster VI whereas the other two (F-59 and 75227) with open type of growth habit were grouped into cluster VII (Tables 3 and 4). The CBD resistant cultivars were found to be distinct in their leaf tip color and orientation of primary branches quite different from Hararge coffee germplasm accessions where the former had green leaf tip color and semi-erect orientation of primary branches while the later had mostly bronzy type of leaf tip color and spreading type of orientation of branches. Besides, the CBD resistant cultivars showed complete compact or open type of growth habit whereas majority of the Hararge coffee germplasm accessions showed intermediate growth habit. Such a view is endorsed by the work of earlier researchers (Lashermes et al., 1996; Montagnon and P. Bouharmont, 1996)

Based on the above, it may be possible to state that in general, the variation among Hararge coffee germplasm accessions for qualitative characters appeared to be minimum. This could be seen from the fact that except for Darolobo, Dedder, Girawa and Mesela woredas, the rest twelve woredas (68%) were grouped in the same cluster (cluster I), which showed that no distinctive variation existed in majority of the accessions. The distribution of the accessions from Darolobo into three clusters reflected the presence of relatively little variation. The accessions from Dedder, Girawa and Mesela were found distributed into two clusters each indicating the presence of intra- woreda variations for the characters considered.

In view of the above, the germplasm accessions from Darolobo, Dedder, Girawa and Mesela indicating major variations in respect of qualitative characters, appeared to represent core collections of the Hararge coffee germplasm. Inorder to fully exploit the variations prevailing in Hararge coffee germplasm accessions, it may be worthwhile to carry out intensive exploration, collection and characterization of coffee germplasm accessions from these woredas.

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Water Harvesting and Conservation in Coffee Farms

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SUMMARY

Water is a vital input in coffee production among other life systems and plays a very important role in nutrition uptake and hence the subsequent yields and quality. Its adequate availability and at the right time has to be assured. For this reason, all the relevant measures have to be in place to ensure that any form of water supply system is able to deliver the water into the soil as intended. The soil status must be such that it provides an adequate reservoir for the supplied water for easy release to the coffee later during the crop cycle as required.

However, if recent observations are anything to go by, all is not well. This is particularly evident in rain fed regions where heavy run off water has been seen after only receiving very little rainfall. Consequently, the crops encounter water deficits even after adequate rain has been received. This implies that very little water infiltrates into the soil whenever it rains leading to the loss of the larger component. The necessary physical and cultural measures required to prevent surface water run off are coincidently absent under such circumstances. The water runoff also takes away a lot of soil to waste, thereby aggravating the situation. The lands become barren and can hardly support life with ease. The amounts of rainfall also decline due to dwindling vegetation. Hence life heads towards a stand still.

This presentation revisits the worst situations, which can arise with an intention to stimulate interest and positive action necessary to restore the potential of coffee farms. By so doing our environment will be conserved for better living status devoid of the rampant poverty inflicting some of the regions in world. The available technical, economic and social options necessary for the rehabilitation of our soils are critically exposed.

INTRODUCTION

Coffee, in Kenya is grown on broad gentle or rolling slopes and is usually clean weeded. The topography and the cultivation required for coffee establishment increases the breakdown in soil structure and hence rate of soil erosion. The surface water runoff causes soil erosion, which is responsible for the degradation of soil physical characteristics such as infiltration rate, soil structure and crusting resulting in reduced soil productivity and decreased efficiency in fertilizer use by increasing nutrient losses (Anon., 1994). The main causes of surface water runoff include deforestation, overgrazing and cultivation on slopes without any form of soil conservation. Soil properties such as topography, depth, permeability, texture, structure and fertility influence erodibility of soil and types of conservation practices that can be used successfully.

The goal of water conservation is to essentially reduce soil loss to the level that would occur naturally via increased infiltration rate leading to reduce water runoff on the soil surface. Conservation of soil moisture is therefore closely associated with soil conservation particularly in areas that are prone to drought. The conservation measures are divided into agronomic, mechanical and soil management methods (Odeny and Kimemia, 1999). The choice of which conservation measures to apply involves analysing each situation to determine what problems and potentials exist and what alternatives are available. The best approach in many situations requires a combination of the different methods particularly agronomic and mechanical measures. Effective control of surface water run off is not in place. In this view, various measures are discussed and research options in erosion control suggested.

FACTORS AFFECTING WATER RUNOFF

These included: Slopes - The speed of flowing water is more than on the flat lands; Type of soil - Soil erosion is more if there is loose soil which is easily carried away by flowing water or blown away by strong wind; Bare soil – At a place where land is bare without any protective cover, soil erosion is more; Intensity of rainfall – Heavy rains are harmful as they lead to soil erosion; Human activities – poor cultivation method, overgrazing, burning bush and deforestation damage the structure of the soil and increase the effect of wind and flowing water.

EFFECTS OF SURFACE WATER RUNOFF

Loss of soil leads to loss of soil fertility; the formation of rocky features and deserts; silting and filling up of rivers and; less rainfall and low food production; Soil erosion changes the landscapes as well.

WATER HARVESTING TECHNIQUES

These can be in form of reservoirs made of concrete or simple earth dams, sub-surface dams, reinforced and pre-stressed concrete structures for water storage and treatment (Chana, 1993), channelling water from roof structures to masonry, plastic or GI tanks or other land transformations like furrows, ridges, basin, ditches, contour channels and, open trenches. Water catchments by rooftops and storing it in various types of reservoirs are a common practice. Water can also be harvested from run off on roads and directed to suitable storage or usage in the farms. However, though water harvesting techniques are available, there still prevails a limited status of their usage. As such surface water runoff prevails unabated whenever it rains.

MEASURES USED IN WATER CONSERVATION

Agronomic Measures

Agronomic measures rely on the protective cover provided by the vegetation to alleviate the effect of raindrop splash on bare soil and reduces the erosive effect of runoff across the soil surface. Considering the use of ***cover crops and shade trees*** first, more research is needed to identify suitable species for the various agro ecological zones. However, cover crops are provided either by controlling the natural regeneration of indigenous plants by selective weeding and cutting, or by planting suitable herbaceous or shrubby species mainly legumes. Shade trees maintain soil fertility by: protecting the soil structure against impact of raindrops; reducing soil erosion and leaching of nutrients and alleviating the effects of high soil temperatures, which enhance the breakdown of organic matter (Wiley, 1975).

Spacing between plants influence both yield and erosion. Closer spacing allows crops to cover the soil sooner and protect it better particularly after the canopy is fully established. In ***strip cropping***, the land is divided into long narrow parcels that cross the path of the erosive force of water or wind. Protective crops such as grasses or leguminous crops are planted in rows across the path of the runoff. Erosion is hence limited to the row-crop strips and soil removed from one strip is trapped in the next strip down wind or down slope.

Mulch helps to conserve soil moisture, suppress weed growth, supply nutrients upon decomposition and improve soil structure. Mulch also protects the soil from raindrop impact and reduces the velocity of runoff and wind **(**Tsunoda and Mati**,** 1990). The success of ***contour cultivation*** or planting depends on the slope steepness and slope length. The technique is only effective under conditions of low rainfall intensity. Under high rainfall intensity, contour farming is combined with strip cropping or with bench terracing.

Staggered planting or spacing (triangular planting) of coffee instead of the conventional square planting reduces the rate of runoff by interrupting its flow down hill.

Other measures instruct that: Always cultivate the land across slopes; Do not cut down trees and burn the bush; Avoid overgrazing; Grow trees near rivers/streams, on slopes or in rows at places where wind erosion is common; Build gabions (porous dams) control gully erosion; Do not cultivated the land near rivers; Grow different types of crop in different strips along the contour so that the crops are taken from the soil at different times

Mechanical methods

These involve some modification to the land surface and are used to control the movement of water over the soil surface. They are however, only effective when applied in conjunction with agronomic measures (Morgan, 1980; al, 1981). ***Contour bunds*** for instance are constructed earth or earth and stone embankments, 1.5m to 2.0m wide, placed along the contours and usually at regular intervals (down slope) of 10 to 20m intervals depending on the slope. ***Terraces*** are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity and to shorten the slope length (Lal, 1981). They can be classified into diversion, retention and bench. Diversion terraces are mainly used to intercept runoff and channel it across the slope to a suitable outlet. Retention terraces are used when it is necessary to conserve water by storing it on the hillside.

Soil Management

Soil management measures involve the maintenance and improvement of soil fertility through proper land use and fertilization. The major objective here is thus to maintain and improve the fertility and structure of the soil. The most practical way of achieving and maintaining soil fertility and structure is by application of organic matter, which may be added as green manure, straw, or as well decomposed manure. Well managed soils have a high infiltration, drainage capacity and a stable, usually granular structure, which does not breakdown under cultivation.

CONCLUSION

Water conservation measures should be geared towards reducing soil erosion to tolerable levels and must involve protection of the soil to reduce the volume of run off, protection of the soil from raindrop impact, increasing infiltration capacity of the soil and improving the aggregate stability of the soil. Some practices for conserving soil are expensive while others require only a change in habits, for instance, the application of farmyard manure. Some are permanent while others are temporary. Some methods are restricted in their applicability while others are widely applicable. When deciding on what conservation method to apply, preference should always be given to agronomic measures which can also be easily fitted into existing farming systems. Mechanical measures though useful in supplementing agronomic measures, are expensive and require a lot of attention. Studies therefore should be initiated to provide information necessary for the development of water conservation measures that are cost effective and acceptable. Focus should be on studies on high density planting of improved varieties of arabica coffee to assess their influence on soil erosion; and screening of suitable cover crops for use in coffee: considering other new chemical options which can increase soil water acceptance level.

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Rain Water Harvesting for Water Conservation - Need of the Day and Future for Small Coffee Growers

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SUMMARY

Nearly 90% of coffee growers in India are small growers. Their knowledge on creating water resources, scientific and judicious usage of available water is very poor. During the last three years, majority of coffee growers in coffee tracts faced ever seen drought conditions. The average rainfall of the coffee tracts ranges from 1400 to 3400 mm and nearly 69-80% of this is received only during the monsoon period, which lasts [or three months from mid June to mid September. Most of the rainfall flows out of growers field as runoff after fulfilling the surface retention, infiltration and saturation capacity of the soil. Nearly 50% of rainfall received during the monsoon flows as runoff accounting to 14 to 40 lakh liters of water from one acre in a year. Hence, under the present drought scenario, all coffee growers must get sufficient knowledge about rainwater harvesting and harvest this valuable runoff water for critical operations like blossom and backing irrigation, Bordeaux spraying and lindane swabbing to be carried out during the pre and post monsoon period. Besides this, rainwater harvesting helps not only to increase the water resources but also helps to recharge and improve ground water table.

INTRODUCTION

In India coffee is predominantly grown in the Western Ghat regions of Karnataka, Tamil Nadu, Kerala and Andra Pradesh. The major species of coffee grown in India are *Coffea arabica* and *Coffea canephora* commonly known as arabica and robusta respectively. Robusta is relatively more drought susceptible than arabica and requires irrigation for blossom and fruit set. On the other hand, arabica is more susceptible for rust and attack of white stem borer and requires two rounds of Bordeaux spray and swabbing for control of leaf rust and white stem borer respectively. These operations require a huge quantum of water in plantations especially during the period of February-March, May-June and September-October during which no rains will be there and planters usually struggle hard for water to carry out these operations. The main reasons for shortage of water are either lack of water resources or non-scientific way of using the available water for these operations and lack of knowledge about the possibility of harvesting rainwater and storing the same for critical periods. There is a steady decline of rainfall from 1950s to an extent of 3 to 24% in majority of coffee growing tracts (Radhakrishnan et al., 2004). During the last three years in Karnataka, especially in belts of coffee, planters have suffered a lot of water scarcity due to continuous drought conditions ever seen in the last 2-3 decades. During the year 2003 in Karnataka, the deficit rainfall was 12.42 to 27.25% and 6.43 to 14.26% as compared to the year 2001 and 2002 respectively (Venkararamanan et al., 2004). Under these circumstances, all coffee growers must have sufficient knowledge of rainwater harvesting and scientific way of using available water in their plantations.

RAINWATER HARVESTING

The mean total annual rainfall of three major coffee growing states of India is 1400-3371 mm from 80-127 rainy days. In most of the coffee growing regions, nearly 69-80% of total annual rainfall is received only during the monsoon from mid June to mid September (Radhakrishnan et al., 2004). Remaining period is usually dry with few uncertain winter and summer showers. So, all growers should store sufficient water for critical periods through rainwater harvesting during the monsoon. So, before harvesting rainwater, a grower must have sufficient knowledge on rainwater harvesting and plan properly. As majority of coffee growers in India are small, a typical example is given below which can be used by small growers having around 5 acres of arabica or robusta or mixture of both.

Quantifying the Water Requirement

The quantity of water required for plantations can be worked out with simple mathematical formulae given below which, a farmer should always remember.

One acre = 4000 sq.m.
One cubic meter = 1000 *l*
One inch on one acre = 4000 x 25 mm = 1,00,000 *l* water
Capacity of the tank = Length (m) x Breadth (m) x Depth (m) = LBH (cubic meter)
1 sq.m x 1 mm = 1 *l* .

Case 1. Water requirement of 5 acres of arabica

For Bordeaux spray	= 2 rounds x 8 barrels/acre x 5 acre x 200 *l*/barrel	= 16,000 *l*
For swabbing	= 2 rounds x 4 barrels/acre x 5 acre x 200 *l*/barrel	= 8,000 *l*
For domestic use	= 100 *l*/day x 30 days/month x 8 dry months	= 24,000 *l*
Total		= 48000 *l*
Losses and other wastages 20%		= 9600 *l*
The approximate water requirement of the estate/year		= 60,000 *l*

Case 2. Water requirement of 5 acres of robusta

For blossom 1.5 inch	= 37.5 mm x 5 x 4000 sq.m	= 7,50,000 *l*
For backing 1.0 inch	= 25 mm x 5 x 4000 sq.m	= 5,00,000 *l*
For domestic use	= 100 *l*/day x 30 days/month x 8 dry months	= 24,000 *l*
Total		=12,74,000 *l*
Losses and other wastages 20%		= 2,54,800 *l*
The approximate water requirement of the estate/year		= 16,00,000 *l*

Case 3. Water requirement of 5 acres of mixed crop of arabica and robusta

For arabica

For Bordeaux spray	= 2 rounds x 8 barrels/acre x 2.5 acre x 200 *l*/barrel	= 8,000 *l*
For swabbing	= 2 rounds x 4 barrels/acre x 2.5 acre x 200 *l*/barrel	= 4,000 *l*

For robusta

For blossom 1.5 inch	= 37.5 mm x 2.5 x 4000 sq.m	= 3,75,000 *l*
For backing 1.0 inch	= 25 mm x 2.5 x 4000 sq.m	= 2,50,000 *l*

For domestic use	= 100 *l*/day x 30 days/month x 8 dry months	= 24,000 *l*
Total		= 6,61,000 *l*
Losses and other wastages 20%		= 1,32,200 *l*
The approximate water requirement of the estate/year		= 8,00,000 *l*

Location and Size of the Tank

A tank must be located always at a lower elevation of the field so as to enable diversion of all the water generated from runoff water on estates. As for as possible a natural depression or tank should be selected so as to renovate it to the required dimensions and reduce the excavation costs. Provide water channels along the field and connect them to tank. All water channels must be provided with grass lining or grass barriers with a catch pit at regular intervals to avoid silting of tank and also to prevent soil loss from fields. The dimension of the tank usually calculated as follows.

For convenience the depth of the tank should be always maximum 5 m

Area of the tank (sq.m.) = water requirement (*l*)/1000/depth (m)
Area of the tank = Length (m) x breadth (m)

Tank dimensions of the above mentioned cases can be worked out as follows.

Case 1

Area of the tank = 60000/1000/5 = 12 sq.m.
Length x breadth = 4 m x 3 m

Case 2

Area of the tank = 16,00,000/1000/5 = 320 sq.m.
Length x breadth = 32 m x 10 m

Case 3

Area of the tank = 800,000/1000/5 = 160 sq.m.
Length x breadth = 16 m x 10 m

How Much Water can be Harvested?

Runoff water usually starts flowing out from fields only after fulfilling the surface retention, seepage, infiltration and saturation capacity of the soil body. Nearly 50% of rainwater during monsoon starts flowing out after saturation of the soil. If average rainfall of coffee tracts is considered, nearly 350-1000 mm rainfall flows out as runoff. Each one acre generates 14 lakhs to 40 lakhs liters of water during a year. Once the rainwater is harvested, it is most important to use the same very judiciously and economically on scientific grounds.

Recharging of Water Resources through Rainwater Harvesting

Planters who are depending on bore wells; open wells and natural springs are nowadays facing water scarcity due to reduced water tables. These water resources can be recharged through rainwater harvesting system.

All planters invariably have drying yards and buildings in their plantations. These drying yards and building roofs can be made use for harvesting rainwater. The water so harvested has to be allowed to settle and infiltrate on the upper side of an open well or bore well through a dug out pit filled with alternate layers of pebbles, stones, charcoal and other inert materials. All the water that flows into this pit gets filtered through layers and reaches ground water and increases water table level. Also any water that flows in estates can be diverted into termite mounts, which have a huge underground space. This also helps in more water infiltration into the ground water. Planters having springs can recharge their springs though construction of check dams and storing water on the upstream side of the springs. All slope lands have to be provided with cradle pits across the slope for more retention of water in the field and to improve ground water table.

A B C

Figure 1. A) Blossom failure, B) A tank renovated, C) Roof water.

Rainwater Harvesting from Roof

Wherever, growers can not go for a tank due to lack of space, this can be an alternate method to harvest a small quantity of rainwater for domestic purposes or spraying purposes for arabica coffee. A grower can construct a storehouse at the top most point of his estate and can harvest rainwater from the roof into a constructed cement tank. If not, rainwater can be harvested directly from the roof of residential buildings. A total of 50-100 inch rainfall (average of one year approximately) contributes 12,500-25,000 *l* of water during one year from a roof of 10 sq.m. area.

HOW TO USE WATER JUDICIOUSLY?

Irrigating young coffee plants

Sometimes young coffee establishment is very difficult for lack of sufficient water for irrigation or shortage of water. So, instead of giving sprinkler irrigation for young coffee, planters can adopt/try the following systems of irrigation to save water.

- Drip irrigation, pitcher or micro sprinkler irrigation
- Hose irrigation
- Those who follow hose irrigation can fix one inch pipes with a funnel, near coffee plants upto root zone. These pipes during the winter are able to trap the early morning mist and make it available to young coffee roots. Where as, these pipes can be used to fill water during hose irrigation. This method not only helps to reduce water requirement but also helps to control weed growth in young plantations of coffee.

Irrigation of Old Coffee

Most of the planters in India usually irrigate coffee nearly for 5-6 hours using sprinkler system without considering the actual discharge rate. Actual discharge of sprinkler jets varies depending on the distance of water source from the field, number of jets used, spacing of the jets etc. So, it is very important to know the following hints for deciding the irrigation time and quantity of irrigation required.

Hints for irrigation

- Blossom irrigation - The quantity required is 1.5 inch i.e. approximately 40 mm per unit area which accounts to one and half lakh liter per acre
- Backing irrigation - The quantity required is 1.0 inch i.e. approximately 25 mm per unit area which accounts to one lakh liter per acre
- Arrange sprinkler jets always in a rectangular or square shape so as to get exact area of irrigation and irrigation quantity.
- Always maintain distance between sprinkler jets to ensure at least 50 % overlapping of spread but not 100 % over lapping

Water requirement (*l*) = area (sq.m.) x Irrigation requirement (mm)

- Measure discharge of jets in liter per minute from different points so as to ensure average discharge
- Then calculate irrigation time using the following formula

Duration of Irrigation (hours) = Water required (l)/(Discharge in l/min x 60 x No. of jets used)

Besides this, planters having small area can adopt micro sprinkler irrigation for inducing blossom in robusta through a savings of 50-60 % water as compared to sprinkler irrigation.

Economizing the Bordeaux Mixture Spray

Normally, planters use spray pumps or guttar sprayers for spraying Bordeaux mixture. Usually, 8 barrels approximately 1600 liters of water is consumed for each acre. The solution requirement can be reduced by adopting following hints.

- Spray only lower surface of leaves
- Get the spray pump/nozzles/lances repaired well before the commencement of spray to ensure no leakage
- Keep the lances off while changing over from plant to plant and block to block
- Use as much as possible shorter pipes
- For small areas and young coffees use backpack or knapsack sprayers

Economizing the Swabbing

Swabbing is the operation in which a solution of lindane is spread on to main stem and thick primary branches to kill white stem borers. This operation also consumes a large quantity of water. Instead of swabbing, planter can go for spraying lindane with backpack sprayers. Avoid pouring the solution on to top the plant and don't allow it to run along the main stem during swabbing.

Water Saving During the Wet Processing of Coffee

Processing is the other operation, which consumes a good quantity of water. For the very purpose, fruits have to be harvested at right stage and water for pulping and washing can be reduced by 50% through fermenting of fruits overnight before pulping.

CONCLUSIONS

Majority of coffee growing tracts receive nearly 69-80% of total annual rainfall during the monsoon period, which lasts for three months. Major portion of this rainfall flows out as waste runoff. There is a large scope to harvest and retain this water in fields to increase the water availability and to increase ground water table. Also, knowledge on scientific and judicious usage of available water helps the planters to overcome water shortage for irrigation, spraying and swabbing etc during critical periods.

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Coffee Based Agroforestry: Overview of the CIRAD and ICRAF Research Alliance

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SUMMARY

Coffee grown under shade is the most commonly used coffee cultivation system in the tropics. It represents more than 7 millions ha of planted areas and 60% to 80% of the total world production. The practice involves more than 20 millions people, most of them being small farmers. In view of the current global coffee crisis and the increasing focus on poverty alleviation across the tropics, the Centre International pour la Recherche en Agronomie pour le Développement (CIRAD) and the World Agroforestry Centre (ICRAF) have launched a partnership initiative on coffee agroforestry systems. The initiative is expected to benefit small holders coffee farmers by enhancing improved income opportunities in a more sustainable production system.

As a core element of the research framework, coffee based agroforestry is seen as a multidimensional system with biologic, economic and social components. The research agenda will therefore test the following assumptions:

- that shade favors the quality of both Arabica and Robusta coffee. An appropriate, well organized local production chain could then help the farmer to match the International Coffee Organization (ICO) standards and to address the growing market of coffee specialty;
- that trade-offs of the shade coffee system are globally beneficial for biodiversity, watershed, and soil preservation, as well as amelioration of pest and diseases;
- that coffee agroforestry systems offer multiple, viable, options of diversified sources of income through associated crops and shade tree species with various uses (e.g. medicinal, fruit, timber);
- that such systems would then offer more opportunities for sustainability in terms of economic viability and landscape management.

For the farmers to achieve those goals, "good agroforestry practices" will be defined, to develop modern skills in tree management, adapted to the various areas in Africa, Asia and America where the ICRAF-CIRAD initiative should apply.

Impact of Diversification in Indian Coffee Plantations – A Sustainable Approach

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SUMMARY

Diversification has been the main characteristic feature of Indian coffee plantations because of the fact that coffee in India is shade grown and the conditions are ideal for cultivation of many fruit, spice and cash crops. The cultivation of black pepper, orange, banana, cardamom and areca in coffee plantations gained popularity in different regions in addition to the other minor crops. Thus, cultivation of intercrops could help the growers when coffee is not economical especially during drought years or when coffee prices plummets. In this study, it was possible to evaluate and study the economics and adoptability of different coffee based cropping systems in various coffee growing regions of India.

A field survey was carried out covering 132 arabica and 88 robusta coffee plantations of different coffee growing regions. The results revealed that in arabica coffee plantations the income from inter crops represented 12% in Karnataka and 37% in Tamil Nadu regions. While in robusta plantations the income from inter crops constituted around 40% in Karnataka and 26% in Kerala regions. The major intercrops in Chikmagalur region of Karnataka represented pepper, areca, while in Coorg, pepper, cardamom, areca and orange. In Kerala where robusta coffee is more, pepper as a major intercrop followed by areca. The arabica dominated Tamil Nadu region diversified their coffee plantations with varied crops in recent years which comprised of orange, pepper, banana, cardamom, lemon, avacado and vegetable crops. Thus, the results revealed that robusta plantations of all the regions and arabica plantations of Tamil Nadu region have varying coffee based cropping systems which generate an additional revenue to sustain in adverse coffee market scenario.

INTRODUCTION

‘Sustainable Agriculture’ is a wide umbrella that includes numerous agricultural systems. Cohen et al. (1991) identified it as being, ‘A management system for renewable natural resources that uses such resources to provide food, income and livelihood for current and future generations and that maintains and improves the economic productivity and ecosystem services of these resources’. This definition and even the term sustainable suggest the necessity of sustainable agriculture using sound agronomic principles. Soil erosion control, weed management, maximum efficiency of on-farm and purchased inputs, minimal leaching of pollutants through the root zone, maintenance of soil fertility by proper addition of plant nutrients and utilization of appropriate biological principles throughout the farming operation should be included among the sound agronomic principles which may result in sustainability (Keeney, 1989 and Kirschenmann, 1989). Multiple cropping, the growing of two or more crops on the same field in one year, fits under the umbrella of sustainable agriculture. Multiple cropping systems result in efficient use of land resources. Perhaps the most attractive aspect of multiple cropping to producers is that these systems can boost yields and increase profits.

Coffee provides a particularly important share of the export earnings of developing countries and the large number of growers who depend on coffee for most of their income have been hard hit by the sharp fall in prices in recent years. The situation at present is quite alarming with coffee prices plummeting to all time low with no signs of immediate recovery due to global surplus. Coffee in India is grown under well-established mixed shade canopy comprising of evergreen, leguminous trees. Major coffee growing regions are situated in the ecologically sensitive forest hill tracts of the Western Ghats. In these areas, coffee is often cultivated with inter-crops like pepper, cardamom, orange, Banana etc. In India it is an age-old practice to train pepper vines on shade trees in coffee (Reddy and Rao, 1999). A long term study in India on coffee intercropping systems with bananas, orange and pepper indicates that the income realized from coffee alone was not significantly different from the intercropping systems (Korikanthimath, 1999) and the intercrop could also cushion farmers when coffee is not economical especially during drought years or when coffee price plummets. Nayer (1976) noted that, ginger, yam in young robusta coffee was a source of higher return per unit area/time, food and employment. Thus, diversification has been the main characteristic feature of Indian coffee plantations as the conditions are ideal for cultivation of many fruit, spice and cash crops. India is a major contributor of both arabica and robusta coffees, because of its suitable growing conditions. In India, Karnataka produces both arabica and robusta in almost an equal proportion, while Kerala specialized in robusta and Tamilnadu in arabica coffee. It is known fact that arabica is grown comparatively high elevated areas than robusta. Further arabica is comparatively more drought tolerant than robusta. Robusta is more sensitive to moisture stress and responds well to timely irrigation therefore, majority of the growers are going for irrigating the crop. Hence, robusta plantations can have comparatively better multi-cropping systems than arabica.

In this context, an attempt was made to evaluate and study the economics and adoptability of different coffee based cropping systems for sustainable production in various coffee growing regions of India.

METHODOLOGY

A field survey was carried out covering 220 estates of which 132 are arabica and 88 are robusta coffee plantations of different coffee growing regions as indicated in Table 1. The study covered small, medium and large holdings by adopting multistage random sampling method. The information was collected for the year 2000-01 for robusta and 2001-02 for arabica by personal interview using structured questionnaire. The data was generated on expenditure incurred and income from coffee and inter/associate crops. The data was tabulated and analysed by calculating net returns, B:C ratio etc. The returns are calculated with a price Rs. 60/kg for arabica coffee and Rs. 30/kg for robusta coffee.

Table 1. Distribution of coffee estates surveyed.

Particulars	Arabica	Robusta	**Total No. of estates**
Chikmagalur	63	31	94
Coorg	31	20	51
Waynad	0	37	37
Pulneys	38	0	38
Total	**132**	**88**	**220**

RESULTS

The results on comparative economics of intercrops are discussed for arabica and robusta estates separately.

ARABICA COFFEE FARMS

The results revealed that in arabica coffee plantations, the income from inter crops to the total returns represented 12% in Karnataka and 37% in Tamil Nadu regions. The major intercrops in Chikmagalur region of Karnataka represented pepper, areca, while in Coorg, pepper dominated as a major intercrop. It is interesting to note that Tamil Nadu growers have diversified their coffee plantations with varied crops in recent years comprise of orange, pepper, banana, cardamom, lemon, avacado and vegetable crops.

Figure 1.

When we compare the cost of cultivation of the major crop (arabica) and the intercrops, intercrops required lesser costs out of the returns realized by that crop compared to the major crop i.e. coffee. The arabica coffee incurred 74% of the returns towards its cost of cultivation vis-à-vis 68% of the returns towards cost of cultivation along with intercrops in Chikmagalur region. In Coorg, 62% of the returns had gone towards its cost of cultivation of arabica coffee compared to 57% with intercrops. While in Tamilnadu, 65% of the returns had gone towards cost of cultivation of arabica coffee compared to 49% with intercrops indicating that the returns from intercrops was more in Tamilnadu. This resulted a substantial increase in B:C ratio from mono cropping of arabica coffee to arabica with intercrops from 1.35 to 1.47 in Chikmagalur, 1.62 to 1.75 in Coorg and 1.53 to 2.03 in Tamilnadu. The average income realized from intercrops in arabica coffee plantations was higher in Tamilnadu (Rs. 26,888/ha) followed by Rs. 9645/ha in Coorg and Rs.8350/ha in Chikmagalur (Table 2).

Figure 2.

Table 2. Comparative economics of intercrops of Arabica coffee farms.

Amount in Rs./ha

Particulars	**Chikmagalur**				**Coorg**				**Tamilnadu**			
	Gross returns	Costs	Net returns	% to the total income	Gross returns	Costs	Net returns	% to the total income	Gross returns	Costs	Net returns	% to the total income
Arabica	62400	46380	16020	88	75000	46425	28575	89	46200	30125	16075	63
Pepper	4000	700	3300	6	8700	1700	7000	10	6000	1200	4800	8
Arecanut	3500	1000	2500	5		0	0	0		0	0	0
Orange		0	0	0	160	50	110	0	14075	3000	11075	19
Cardamom	400	100	300	1	85	25	60	0	1983	400	1583	3
Lemon		0	0	0		0	0	0	1700	350	1350	2
Banana		0	0	0		0	0	0	2500	750	1750	3
Avacado		0	0	0		0	0	0	600	150	450	1
Other crops	450	100	350	1	700	150	550	1	30	10	20	0
Total	70750	48280	22470	100	84645	48350	36295	100	73088	35985	37103	100
Average size of coffee farm (ha)	20.34				15.93				7.52			
B:C Ratio mono cropping of arabica	1.35				1.62				1.53			
B:C Ratio arabica with intercrops	1.47				1.75				2.03			

Table 3. Comparative economics of intercrops of robusta coffee farms.

Amount in Rs./ha

Particulars	**Chikmagalur**				**Coorg**				**Kerala**			
	Gross returns	Costs	Net returns	% to the total income	Gross returns	Costs	Net returns	% to the total income	Gross returns	Costs	Net returns	% to the total income
Robusta coffee	43050	30195	12855	60.48	57660	31626	26034	64.48	36090	29864	6226	74.77
Pepper	10075	2000	8075	14.15	25505	4000	21505	28.52	8850	1750	7100	18.34
Arecanut	17300	7000	10300	24.31	2482	1000	1482	2.77	2100	800	1300	4.35
Orange				0	2575	1250	1325	2.88				
Cardamom	350	100	250	0.49	750	200	550	0.84	125	50	75	0.26
Other crops	400	150	250	0.56	450	150	300	0.50	1100	500	600	2.28
Total	71175	39445	31730	100	89422	38226	51196	100	48265	32964	15301	100
Average size of coffee farm (ha)	15.7				7.31				21.92			
B:C Ratio mono cropping of robusta	1.43				1.82				1.21			
B:C Ratio robusta with intercrops	1.80				2.34				1.46			

ROBUSTA COFFEE FARMS

Compared to arabica plantations, the income from intercrops in robusta plantations is higher which constitutes around 40% of the total returns in Karnataka and 26% in Kerala regions. The major intercrops in Chikmagalur region of Karnataka represented pepper, areca, while in Coorg, pepper, cardamom, areca and orange are the major intercrops. In Kerala pepper as a major intercrop followed by areca.

Figure 3.

The comparison of cost of cultivation of major crop i.e. robusta and the intercrops indicated that the intercrops required lesser costs out of the returns realized by that crop compared to the major crop. The robusta coffee crop incurred 70% of the returns towards its cost of production while the total costs along with intercrops represented around 55% of the returns in Chikmagalur region. In Coorg, 55% of the returns had gone towards its cost of cultivation of robusta coffee vis-à-vis 43% with intercrops indicating a higher net return realization compared to other regions. While in Kerala, 83% of the returns had gone towards cost of cultivation of robusta coffee compared to 68% with intercrops. This resulted in substantial increase in B:C ratio from mono cropping of robusta coffee to robusta with intercrops from 1.43 to 1.80 in Chikmagalur, 1.82 to 2.34 in Coorg and 1.21 to 1.46 in Kerala. The average income realized from intercrops in robusta coffee plantations was higher in Coorg with Rs. 31762/ha followed by Rs. 28125/ha in Chikmagalur and Rs.12175/ha in Kerala (Table 3).

CONCLUSION

The study revealed that the robusta plantations have realized higher income from intercrops compared to arabica plantations in Karnataka indicating that the dependence on coffee was more by the arabica growers. While the robusta plantations have intensive multiple cropping systems resulted in higher net income from a unit area. However, the arabica growers of Tamilnadu region have made a dent towards setting a good example for diversified crops in coffee plantations. Thus, in order to achieve higher net income from an unit area, there is a felt need to adopt mixed cropping system selecting suitable inter crops in various agro-climatic regions and also there is a need to assess the suitability of other high value crops like vanilla, flori-tech crops, aromatic and medicinal plants etc., in different coffee tracts to develop a more profitable coffee based cropping system (Anonymous, 2001). This will result to sustain in adverse economic and market scenario.

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Relative Performance of Decomposing Micro-organisms for Composting of Coffee Farm Wastes

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SUMMARY

The trial on relative performance of decomposing micro-organisms for composting of coffee farm wastes was conducted during 2002-03 at Central Coffee Research Institute in Randomized Block Design with three replications and six composting treatments. The result of the experiment on composting revealed that C:N ratio was considerably narrowed in all the treatments receiving decomposing microbial cultures compared to un-inoculated heaps indicating role of micro-organisms in reducing composting duration. Among the inoculated treatments, faster reduction of C:N ratio in all the stages of composting was noticed in treatment receiving multimedia culture containing *Phanerocheate chrysosporium, Trichoderma viride Pleurotus sajarcaju* and *Aspergillus awamori* (from initial 31.2:1 to 11.8:1 at 90 DAI) followed by treatment receiving *Phanerocheate chrysosporium* ((from initial 31.2:1 to 12.2:1 at 90 DAI). Out turn ratio was also higher in inoculated treatments (65.2 to 66.8%) compared to control (61.5%). Further, enhanced decomposition in inoculated heaps resulted in significantly higher nitrogen, phosphorus and potassium content compared to un-inoculated control heaps. Total N,P,K content among the inoculated treatments ranged from 1.7 to 1.9%, 0.15 to 0.19%, 2.8 to 3.05% respectively at 90 days after initiation (DAI). Addition of enriching microbial cultures viz., Azatobacter, Phosphorus solubilizers after 90 DAI have further improved the nitrogen and phosphorus status of compost. The population of beneficial bacteria, fungi and actinomycetes in the compost were improved due to inoculation of decomposing microbial cultures.

INTRODUCTION

The awareness about environment concern and food safety in major coffee importers and consumers insisting to adopt sanitary and phytosanitory measures contemplated by the World Trade Organisation. Thus in future, all the coffee producing countries may have to adopt ecofriendly farming approaches and produce coffee in the form acceptable to the global consumers. Indiscriminate use and over reliance on synthetic fertilizers and pesticides has resulted in environmental problems in the form of eutropication of surface water, nitrate pollution in ground water, heavy metal pollution and atmospheric pollution due to carbon monoxide, nitrous oxide, acid rain etc. The intensive agriculture and improved varieties and hybrids left the soil fatigue due to depletion of soil organic carbon stock. Under such condition, Sustainable farming or organic farming which rely on natural principles are only the alternative farming systems to restore soil productivity and environmental health.

The soil organic matter is the key to soil nutrient transformation, soil structure and fertility so as to keep the soil biologically active. In order to maintain threshold of organic matter in localized soil, the effective orgnic manures needs to be added periodically so as to support the soil microorganisms, maintain chelation and buffering of soil and better crop growth. Composting could also be used in the remediation of soils contaminated with a number of organic compounds, including PAHs, but use of composting as a bioremediation technology has been given very little attention (Potter et al., 1999).

About 30 to 35% of applied N and p and 70 to 80% of applied K are retained in the crop residue, making them potential source of plant nutrients. The coffee plantation could be converted to organic farming as it contributes around 10 tonnes/ha of leaf litter by shade trees every year. Additional requirements of plant nutrients could be met by effectively recycling coffee pulp/husk which can contribute about half the nitrogen and potash and 25 percent of phosphorous requirement. Thus cost of inorganic fertilizers can be reduced.

MATERIALS AND METHOD

The experiment was conducted during 2002-03 at Central Coffee Research Institute in Randomized Block Design with 4 replications and 6 decomposing microbial treatments. Coffee pulp produced during wet processing of coffee, stored for two weeks was used for present study (one tons per treatment. About one ton of following raw material/farm wastes were composted using 2 kg of following microbial decomposing cultures (treatments)

1. Mixed culture (*Tricoderma viridae*, *Aspergillus awamori*, *Phaenerocheate chrysosporium* and *Pleurotus sajarcaju*)
2. *Tricoderma viridae*
3. Aspergillus awamori
4. *Phaenerocheate chrysosporium*
5. *Pleurotus sajarcaju*
6. Control

Preparation of heap

Dry weed bio-moss and dry leaf litter were spread as base layers for better aeration of heap during composting and preventing water stagnation. Above the base layer, coffee pulp/cherry husk was spread to the height of 15 cm followed by FYM and green leaves and rock phosphate. Microbial culture was spread over the FYM.

About 100 liters of water was sprayed to moisten the pulp at start of composting and later 80, 60 and 60 liters of water was applied at first, second and third turning in order to maintain 70 per cent moisture level. During the period of composting temperature of heaps was maintained between 60°C to 70°C. The temperature and pH control in composting of coffee and agricultural wastes is very important (Nogueira et al., 1999). The samples of composting treatments were collected at 30, 60 and 90 days of composting for analysis of organic carbon, nitrogen, phosphorous, potassium following standard procedures (Jackson, 1960). Microbiological analyses are more effective to describe the qualitative composition of microflora but scarcely for quantitative determination. Total fungi, bacteria, actinomycetes and yeast was enumerated following standard dilution technique (Waksman, 1927). Monthly turning and watering of compost heaps was carried out for proper distribution of moisture, air and microflora. After 90 day of composting, Azotobacteria, and ‘P’ solubilizer, and VAM were added @2 kg to each heap.

RESULTS AND DISCUSSION

Maturation of compost

Application of fresh pulp or under composted pulp may cause root injury and some time withering of plant due to heat liberated during fermentation. Digested or composted pulp is always preferred over the fresh pulp (Adams & Dougan, 1981). Therefore, compost, product of composting process under controlled condition has to be applied to crops after its maturation. The maturity of compost could be decided based on C:N ratio, PH, EC and nutrient content. The result of the composting trial revealed that C:N ratio was considerably narrowed in all heaps which received decomposing microbial cultures compared to uninoculated heaps indicating role of microbes in reducing composting duration (Table 5). The faster reduction of C:N ratio in all the stages of composting was noticed in treatment receiving multimedia culture *(Phanerocheate chrysosporium, Trichoderma viride, Aspergillus awamori* (11.8:1 from initial 31.2:1) followed by treatment receiving *Phanerocheate chrysosporium* (13.6:1 from initial 31.2:1). The relevance of addition of nitrogen to composting heaps to reduce the C:N ratio faster was noticed by Nagaraj et al. (2000). The PH and EC did not differ significantly among the treatments at 90 days and vary from 6.6 to 6.8 and 0.35 to 0.39 dS m^{-1} respectively.

Table 1. Carban and Nitrogen ratio at different days after initiation of composting process and out turn at 90 days of composting.

	C:N ratio			Out turn
Treatment	30 DAI	60 DAI	90 DAI	90 DAI
Mixed culture	25.1:1	18.1:1	11.8:1	66.8
Trichoderma viridae	26.2:1	20.1:1	13.4:1	65.5
Aspergillus awamori	26.7:1	20.5:1	13.6:1	65.5
Phaenerocheate chrysosporium	25.3:1	19.1:1	12.2:1	66.0
Pleurotus sajarcaju	26.8:1	20.2:1	13.9:1	65.2
Control	27.7:1	23.7:1	18.1:1	61.5
CD (5%)	0.92	1.08	1.63	-

Table 2. Total Nitrogen content (per cent), at different days after initiation of composting process.

	Nitrogen			
Treatment	30 DAI	60 DAI	90 DAI	After enrichment
Mixed culture	1.6	1.8	1.9	2.15
Trichoderma viridae	1.5	1.7	1.8	1.90
Aspergillus awamori	1.5	1.6	1.8	1.90
Phaenerocheate chrysosporium	1.5	1.7	1.8	2.20
Pleurotus sajarcaju	1.4	1.6	1.7	2.25
Control	1.3	1.4	1.5	1.55
CD (5%)	0.04	0.04	0.10	0.19

Table 3. Phosphorus content (per cent), at different days after initiation of composting process.

	Phosphorus			
Treatment	30 DAI	60 DAI	90 DAI	After enrichment
Mixed culture	0.14	0.18	0.19	0.28
Trichoderma viridae	0.13	0.16	0.18	0.31
Aspergillus awamori	0.14	0.16	0.18	0.29
Phaenerocheate chrysosporium	0.13	0.17	0.19	0.29
Pleurotus sajarcaju	0.13	0.15	0.15	0.30
Control	0.13	0.140	0.15	0.17
CD (5%)	NS	NS	0.03	0.062

Table 4. potassium content (per cent), at different days after initiation of composting process.

	Potassium			
Treatment	30 DAI	60 DAI	90 DAI	After enrichment
Mixed culture	2.90	2.90	3.05	2.90
Trichoderma viridae	2.80	2.80	2.95	2.85
Aspergillus awamori	2.80	2.80	2.90	2.85
Phaenerocheate chrysosporium	2.75	2.75	2.85	2.90
Pleurotus sajarcaju	2.70	2.70	2.80	2.78
Control	2.60	2.60	2.70	2.75
CD (5%)	NS	NS	NS	NS

Table 5. Beneficial microbial population in the compost as influenced by composting treatments.

Treatment	Bacteria 10^6/g (DAI)		Fungi 10^4/g (DAI)		Actinomycetes 10^5/g (DAI)		Yeast 10^4/g (DAI)	
Days after initiation (DAI)	60	90	60	90	60	90	60	90
Mixed culture	7.8	8.4	9.1	12.6	4.5	6.3	11.4	7.8
Trichoderma viridae	7.2	7.9	8.5	10.4	4.0	5.3	8.5	8.1
Aspergillus awamori	6.9	8.1	8.4	10.7	2.8	5.1	7.9	8.0
Phaenerocheate chrysosporium	7.6	8.7	8.9	10.9	5.1	4.8	10.7	9.1
Pleurotus sajarcaju	6.1	7.5	7.4	11.5	3.0	3.9	9.1	8.0
Control	6.5	6.9	8.0	9.4	3.6	4.1	8.0	8.4
CD(5%)	0.13	0.12	NS	0.98	NS	0.65	0.47	NS

Manurial value of compost

Due to faster decomposition in inoculated heaps, the total nitrogen, phosphorus and potassium content were higher compared to control heaps where microbial decomposers were not added. Total N, P, K content among the inoculated treatments ranged from 1.7 to 1.9%, 0.15 to 0.19%, 2.8 to 3.05% respectively at 90 days after initiation (DAI). Whereas, un-inoculated control recorded 1.5% 0.15% and 2.7% N, P and K respectively (Table 2, 3 and 4; Figure 1 and 2). Nutrients content of one ton of vermicompost produced with use of areca nut waste was 18.0, 2.0 and 1.5 kg N, P and K respectively (Kavitha et al., 2003). The compost could not be assessed only by means of mere nutrients content. The organic matter of compost has millions of beneficial symbiotic and free-living nitrogen fixers, p solubilisers, bacteria, fungi, actinomycetes, and invertebrates which could well established into the local ecological niche. The treatments receiving decomposing microbes recorded higher population bacteria, fungi and actinomycetes compared to un-inoculated treatments (Table 5). It has been shown that the microbes present in composts are capable of mineralizing pentachlorophenol and other organic pollutants (Valo and Slakinoja-Salonen, 1986). And also compost teas (compost extracts) have the potential to suppress plant diseases, particularly fungal infections (Sarah Kelley, 2004).

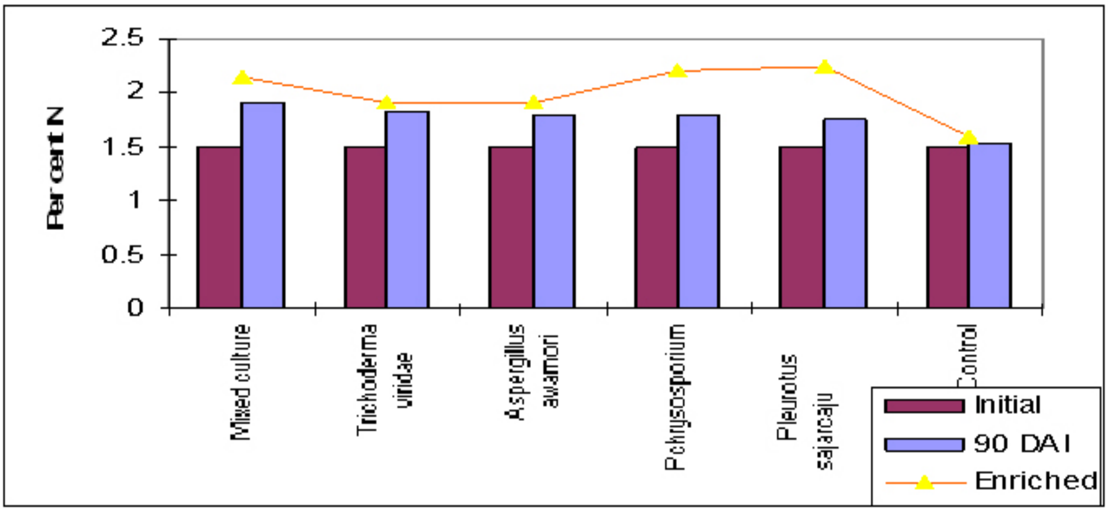

Figure 1. Total Nitrogen in pulp, compost and enriched compost.

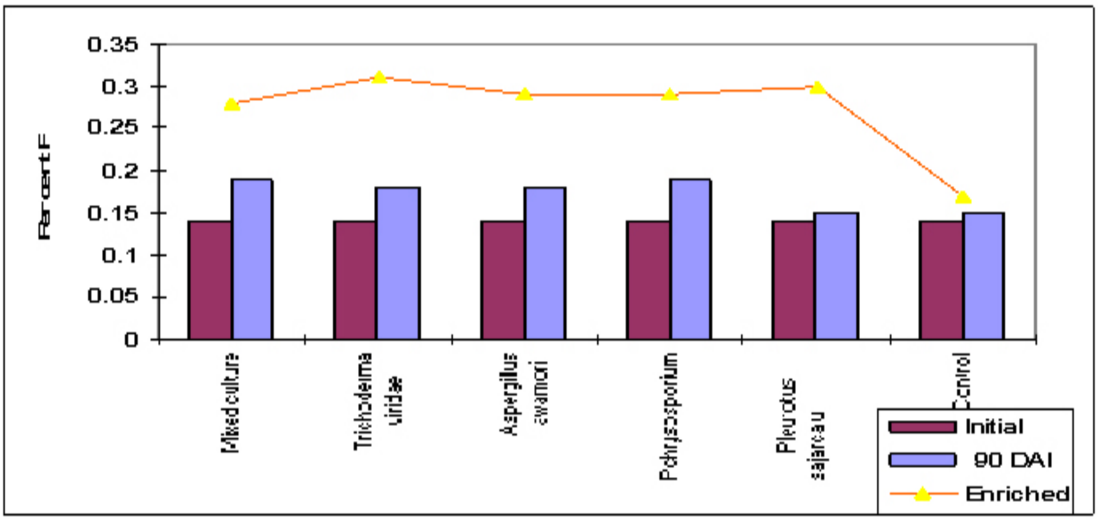

Figure 2. Phophorarus in pulp, compost and enriche compost.

Addition of enriching microbial cultures viz., Azatobacter, Phosphorus solubilizers after 90 DAI have further significantly improved the nitrogen and phosphorus status of compost. The increase in nitrogen content of compost at 20 days after addition of enriching microbial cultures was 5 to 32 per cent among the inoculated treatments over nitrogen at 90 DAI. Whereas, phosphorus content among the inoculated treatments increased from 47 to 100 per cent at 20 days after addition of enriching microbial cultures. The potassium content did not vary significantly due to addition of enriching microbial cultures. Manurial value of pulp compost can be rated higher than cattle manure in western ghats where scope for cattle rearing is not all that bright due to heavy rains (Korikanthimath and Hosamani, 2000). Cost of cattle manure was more than one and half thousand per ton. The nutrients content of compost prepared with and without use of microbial cultures could be rated more than farm yard manure.

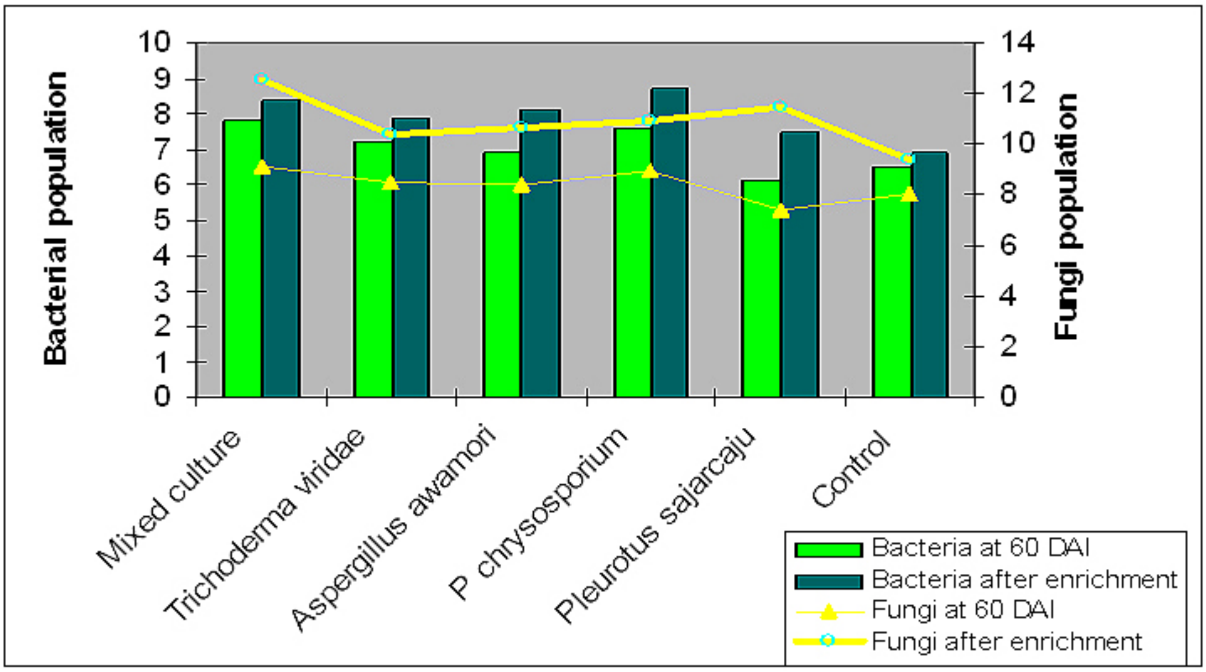

Figure 3. Beneficial microbial population in enriched compost visa-vis heaps under composting.

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Growth and Physiological Processes in *Coffea Canephora* Clones in Response to Water Deficit Stress

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SUMMARY

Leaf water potential (LWP), stomatal conductance (g_s), rate of net photosynthesis (P_N) and leaf fall in response to imposed water deficit stress and rate of recovery in growth, LWP and g_s after rewatering were studied using 12-month-old seedlings of six Coffea canephora clones (IC-2, IC-3, IC-4, IC-6, IC-8 and R-4). The seedlings were subjected to soil drying by withholding water in a rain shelter for about two weeks. The plants were rewatered when severe water stress developed (as shown by the degree of wilting and leaf fall) and the rate of recovery was measured. In all the clones, LWP, P_N and g_s significantly declined as the period of soil drying was prolonged. The decrease in the former two parameters was more obvious and greater after a week, while the rate of decline in g_s was faster at the early stages of stress development (until day six). The difference between the clones was significant for leaf fall and rate of recovery from drought up on rewatering. The rate of leaf fall was higher for IC-2, IC-4, IC-8 and R-4, which also exhibited lower rate of recovery after rewatering. On the other hand, IC-3 and IC-6 had lower rate of leaf fall but showed higher rate of recovery in LWP and g_s. These observations suggest that it is possible to detect the level of drought tolerance in Robusta coffee clones based on such growth and physiological parameters.

INTRODUCTION

Among the species in the genus *Coffea*, Robusta coffee (*C. canephora* Pierre ex Froehner) is the most important crop next to Arabica coffee (*C. arabica* L.) in the world market. In spite of its economic importance and contribution (20%) in the world coffee trade (Cambrony, 1992), its production in some areas is limited due primarily to unfavorable climate. It has long been recognized that seasonal drought may significantly reduce both yield and quality of the crop especially in areas where the annual rainfall is less than the minimum amount required for normal growth and development and supplemental irrigation is impossible or expensive (Kumar, 1982; Meinzer et al., 1992).

Reductions in crop growth and productivity because of limited soil moisture supply have been associated with decline in rate of photosynthesis (P_N), which is, in turn, attributed to the decline in leaf growth (Adam and Barakbah, 1990) and stomatal conductance (g_s) as a result of reduced leaf water potential (LWP) (Ismail et al., 1994; Ismail and Dalia, 1995). Nevertheless, as it has been reported for other crops (Ismail et al., 1994; Volkmar and Woodbury, 1995; Loewenstein and Pallardy, 1998), sensitivity of coffee to water stress may vary with species or genotype, growth condition and severity of the stress (Meinzer et al., 1992; Lima et al., 2002).

This study was, therefore, conducted with the objective of identifying drought tolerant Robusta coffee clones for drier areas based on their LWP, g_s, and P_N rate in response to soil drying and rate of recovery after re-watering at seedling stage.

MATERIALS AND METHODS

Grafted seedlings of six clones of Robusta coffee (*C. canephora* Pierre ex Froehner) (clone IC-2; IC-3; IC-4; IC-6; IC-8 and R-4) were grown in 8.60 liter pots filled with a standard nursery medium (mixture of top soil, manure and sand in 3:2:2 ratio) and managed in a conventional way. When the plants were 12 months old, water deficit stress was imposed by withholding irrigation until severe wilting and partial leaf drying symptoms were observed, while plants in the control plot were watered daily or every other day. Then the stressed plants were re-watered to evaluate variations among clones for rate of recovery. The experiment was carried out in a randomized complete block design with three replicates of twelve factorial treatment combinations (two watering regimes x six clones) in a rain shelter at the Hydroponics Unit of Universiti Putra Malaysia (3°02' N; 101° 42' E and 31 m a. s. l.).

Leaf water potential (*LWP*), stomatal conductance (g_s) and rate of photosynthesis (P_N) were measured on fully expanded leaves of the seedlings. Measurements were taken every three days at noon hours (between 11:00 and 13:00). All the plants in water-stressed plots were considered to determine extent of leaf fall at the end of the stress cycle and rate of recovery (initiation of new flushes) after re-watering. Rate of net photosynthesis was measured using a portable infrared gas analyzer (Port. Photosynthesis system, Li-6200 and CO_2 Analyzer, Li-6250, Li-Cor, U.S.A). Leaf water potential and g_s were determined with a pressure chamber (PMS, soil moisture Equipment, Santa Barbara, USA) and diffusive porometer (AP-4, Delta T Devices Ltd., Cambridge UK), respectively.

RESULTS AND DISCUSSION

Leaf Water Potential

Leaf Water Potential (LWP) progressively decreased from less than –1.0 to –3.4 MPa with time of exposure of coffee plants to soil drying. The rate of decline in LWP was significant (P = 0.05) and faster at later stages (after six days) than at the early stages of stress development. The difference between coffee clones was also significant (P=0.05) for LWP (Table 1), which was higher in IC-2, IC-6 and IC-8 but lower in IC-3, IC-4 and R-4 for the measurements taken until day six. On day nine, LWP values were still higher for IC-2 and IC-8, while R-4 had the lowest values both on day nine and day 12 after the commencement of the water stress treatment. However, all the clones had similar and lowest values of LWP (< –3.20 MPa) at the end of the drying cycle on day 12.

After re-watering, LWP of clone IC-4, IC-6, IC-3 and IC-2 rapidly increased within three days and, on day six, it reached a level equivalent to that measured in well-watered plants (< –1.0 MPa) specially for IC-3 and IC-6. In general, IC-3 and IC-6 showed significantly faster rate of recovery than did other clones upon re-watering at the end of the drying cycle. On the other hand, IC-8 and R-4 exhibited a slower rate of recovery and significantly lower values of LWP after re-watering.

Stomata Conductance

Stomatal conductance (g_s) in all the coffee clones significantly (P = 0.05) decreased as the intensity of water deficit stress increased with time of soul drying. Clonal differences for g_s were also significant (P = 0.05) at the initial stage (under well-watered condition) (Table 1), and on the 3rd and 6th day after the plants were subjected to soil drying. But variations between clones were not significant on day nine and 12, where the stomata were nearly closed.

The decline in g_s was faster at early stages of stress development (within the first three days in IC-4 and R-4, and within six days in IC-3 and IC-8), then it decreased at a slower rate and reached the lowest level for all the clones on day 12. On the other hand, IC-3 and IC-8 had lower g_s values on day six, while g_s gradually decreased at a relatively constant rate until day nine for IC-6 and IC-2, and was generally higher in IC-6 and IC-3, compared to its mean value in other clones (Table 1). Clone IC-2 exhibited lowest g_s all the time during the stress period, except on day six.

There was a significant (P = 0.05) difference between the coffee clones for g_s after re-watering at the end of the drying cycle. It was observed that IC-3 maintained significantly higher level of g_s at a faster rate (on day three) than IC-2, IC-4 and IC-6, which showed a gradual recovery in g_s after re-watering. On the other hand, g_s in IC-8 and R-4 was not much improved by re-watering.

Rate of Photosynthesis

Differences between the coffee clones were not significant for net photosynthesis (P_N) especially at the beginning and at the end of the drying cycle. But the rate of net $P_{N\ was}$ significantly (P = 0.05) higher in clone IC-6 and lower in IC-4 on day six after exposure of plants to soil drying. In general, water deficit stress significantly (P = 0.05) reduced the rate of net P_N (by 75% compared to the well-watered or unstressed plants) (Table 1).

The rate of P_N declined by more than 60% in IC-2, IC-4 and IC-3 on day six after the stress treatment, but it decreased by only 6% and 12% in IC-6 and IC-8, respectively. The decline in P_N was relatively lower in IC-8 (55%) and IC-6 (60%) even on day 12, whereas IC-2, IC-3, IC-4 and R-4 showed 81% to 88% reduction. On the other hand, all the clones except IC-8, showed a negative carbon balance, with more negative value for R-4 as the period of stress was prolonged by a week.

Leaf fall and Rate of Recovery

The difference between coffee varieties was significant (P = 0.05) for leaf fall induced by water deficit stress. Loss of photosynthetically active leaf area due to wilting or drying and leaf fall was significantly higher (81 to 97%) for IC-8, R-4, IC-4 and IC-2. On the other hand, the rate of leaf fall, as recorded at the end of the drying cycle, was lower (63 to 71%) for IC-3 and IC-6 (Table 2). Rate of recovery of coffee plants from induced drought stress significantly (P = 0.05) varied with clone. Some of the clones, particularly IC-3 and IC-6, produced new leaves and flowers more rapidly than did R-4 following re-watering at the end of the drying cycle. Initiation of new flashes in plants of R-4 and IC-8 was significantly lower (< 52.00%), and it was between 62 and 72% for IC-2 and IC-4, while IC-3 and IC-6 showed as high as 86.67% just three to six days after re-watering (Table 2).

In general, clone IC-6 had higher values of LWP, g_s and $P_{N\ rate}$, while higher g_s in IC-4 was associated with lower LWP and net P_N during the stress cycle. In IC-2, despite higher LWP, g_s and rate of P_N were lower during the water stress period. In contrast, higher g_s was related to lower LWP but higher net P_N in R-4 especially until the 6th day of soil drying.

Higher rates of decline in $g_{s\ of}$ leaves (> 50% on day three and > 75% on day six) with considerable reduction in LWP (27-52% on day three and 65-80% on day six) of clones IC-4, R-4, and IC-3 could be regarded as desiccation-avoidance mechanism at early stages of water stress development. As it has been discussed by Rhizopoulou et al. (1991), Ismail et al. (1994) and Loewenstein and Pollardy (1998), stomatal closure or a decrease in $g_{s\ is}$ one of the most important physiological mechanisms that assist plants in avoiding the adverse effects of drought. It has also been reported that water stress causes substantial reduction in LWP, which is associated with inhibition of $P_{N\ and}$ stomatal closure in drought-tolerant species (Loewenstein and Pallardy, 1998), possessing morphological hydration even under limited water supply (Rhizopoulou et al., 1991). However, these clones exhibited considerably higher rate of decline in $P_{N,}$ compared to IC-6 and IC-8, and maintenance of such a lower rate of net P_N (negative carbon balance) and lower LWP has been associated with greater sensitivity to drought (Adam and Barakbah, 1990; Ismail et al., 1994).

In clone IC-8, interestingly, higher rate of decline in g_s was related to lower rate of decreases in LWP and net $P_{N\ during}$ this period. In line with this, it has been suggested that stomatal regulation of plant water status may be important for the prevention of xylem cavitation and for the maintenance of tissue turgor and cell volume by minimizing unnecessary water loss (excess transpiration) from plants and favoring photosynthetic gain (Adam and Barakbah, 1990; Rhizopoulou et al., 1991; Volkmar and Woodbury, 1995). On the other hand, it has been reported that g_s considerably declines with soil moisture depletion and $P_{N\ reduces}$ with a small reduction in leaf water status in drought-sensitive species (Loewenstein and Pallardy, 1998).

However, maintenance of higher values with lower rates of decline in LWP, g_s and net $P_{N\ in}$ clone IC-6 during soil drying may agree with the findings of Ismail et al. (1994), who suggested that plant water status, expressed as LWP or RWC, is important in controlling stomatal aperture and $P_{N\ rate}$, which will contribute to the difference between genotypes for drought tolerance. Similarly, higher rate of recovery in vegetative growth, LWP and g_s in IC-3 could be regarded as a drought tolerance character in Robusta coffee.

Table 1. Mean leaf water potential (LWP), stomatal conductance (SC) and rate of net photosynthesis (PN) in seedlings of Robusta coffee clones as influenced by water deficit stress (A = well-watered, control and B = water-stressed).

Clone	LWP (MPa)			SR (m molm^{-2}s^{-1})			PN (μmolm^{-2}s^{-1})		
	A	B	Mean	A	B	mean	A	B	mean
IC-2	-0.86 b	-1.62 a	-1.24 a	130.75 d	51.25 c	91.00 c	4.60	2.06	3.33
IC-3	-0.87 b	-1.74 b	-1.30 ab	158.18 b	76.16 a	117.17 a	5.26	2.04	3.65
IC-4	-0.88 b	-1.76 b	-1.31 ab	167.31 a	64.23 b	115.77 a	6.40	1.74	4.07
IC-6	-0.86 b	-1.68 ab	-1.27 ab	151.53 bc	78.47 a	115.00 a	7.29	3.73	5.51
IC-8	-0.77 a	-1.93 c	-1.35 b	147.45 c	39.97 d	93.71 bc	6.71	3.31	5.01
R-4	-0.87 b	-2.03 d	-1.45 c	157.57 b	39.65 d	98.61 b	9.28	2.40	5.84
Mean	A		-0.85 a			152.13 a			6.59 a
	B		-1.79 b			58.29 b			2.55 b

Figures followed by same letters within a column are not significantly different (P = 0.05).

Table 2. Mean rate of leaf fall (RLF) in seedlings of Robusta coffee clones at the end a drought cycle and rate of plant recovery (RR) after re-watering.

Variable	Clone					
	IC-2	IC-3	IC-4	IC-6	IC-8	R-4
RLF (%)	84.92 ab	63.50 b	81.50 ab	71.35 ab	97.16 a	94.59 a
RR (%)	62.50 ab	86.67 a	71.67 ab	86.67 a	51.67 ab	36.67 b

Figures followed by same letter or letters are not significantly different (P = 0.05).

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Effect of Native Vesicular Arbuscular Mycorrhizal (VAM) Fungi on the Growth of Coffee Seedlings in the Nursery

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SUMMARY

In order to study the response of coffee seedlings to VA mycorrhiza, different strains were isolated from the rhizosphere of various agro climatic zones of Karnataka state, India where coffee is grown. Selected areas of the cities viz., Hassan, Chikmagalur, Mudigere, Koppa were taken for the studies. Among 56 isolates collected, six isolates were found predominant and they were maintained using Rhodes grass as the host plant in 1:1 sterile sand soil mixture and were screened on coffee seedlings of arabica coffee. Native VAM cultures were inoculated at the rate of 12,500 IP/plant while transplanting the seedlings into the poly bags. All the 6 isolates were found to be better symbionts for coffee. However among these native isolates *Glomus radiata* and *Acaulospora myriocarpa* have resulted in augmenting the plant growth. The growth parameters recorded are plant height; number of leaves; leaf area; total biomass; 'P' uptake; acid phosphatase enzyme activity and percent root colonization. The observations indicated that *Glomus radiata* has shown the significant difference in increasing the biomass and also enhanced the vigor of coffee seedlings as compared to un-inoculated control plants. However all the isolates have performed better than the un-inoculated control plants.

INTRODUCTION

Mycorrhiza, a mutualistic symbiont between plants and fungi is one of the most important biological associations. There has been a great progress in understanding of the VAM fungi in the last few years. These specialized groups of fungi i.e. vesicular arbuscular mycorrhizae occur in the nature in most of the vascular plant families. The symbiotic nature of the interactions is a critical character that differentiates a mycorrhiza from other plant fungus association. The fungus extends both into the host and into the surrounding substrate. Role of VAM fungi in improving crop growth and reducing phosphorus fertilizer application is well documented. It is also observed that there is increase uptake of other nutrient elements like Zn, Fe, and Cu etc. Vesicular arbuscular mycorrhiza also said to improve the beneficial rhizosphere microbial activity and suppress plant pathogenic microbes. Bagyaraj (1992), in his study demonstrated the beneficial role of mycorrhizal fungi in many horticultural crops. Improved plant growth due to inoculation of soil with vesicular arbuscular mycorrhiza has been demonstrated especially under 'P' deficient condition (Mosse, 1973).

Coffee occupies a place of pride among plantation crops grown in India. Coffee is second most important commodity in the world trade next to petroleum products (Anonymous 1998). Cultivation of this stimulating beverage crop is mainly confined to the southern states of Karnataka, Kerala, Tamil Nadu and Andra Pradesh. Coffee belongs to the family Rubiaceae. The genus *Coffea* is reported to comprise over 60-70 species and only *Coffea arabica* L. and *Coffea canephora* (Pierre ex Frochner) are commercially cultivated in India and elsewhere.

Coffee is a perennial crop depends primarily on plant vigor, disease free seedlings in the field. Research findings in the last three decades have shown that VA mycorrhizal inoculation is very useful in transplanted crops as it results in healthy vigorously growing seedlings with a profuse sturdy root system. (Linderman and Hendrix 1982, Fogher et al., 1986, Vidal et al., 1992). Since coffee is transplanted crop, inoculation of efficient VAM fungi in the nursery will play an important role in getting healthy and vigorous seedling. The present investigation was undertaken to select the efficient indigenous VAM for inoculating *Coffea arabica* to enhance the growth of the seedlings in the nursery.

MATERIALS AND METHODS

Intensive survey was conducted across the geographical areas of coffee growing regions like Hassan, Mudigere and Chikmagalur districts. Root zone soil samples with feeder roots were collected from 0-15cm depths after removing the topsoil. Fifty-nine soil samples replicated thrice were collected in poly bags and the VAM spores were isolated by adopting wet sieving and decantation method (Gerdeman and Nicolson, 1963). Identification of the isolates was made using the Manual for the identification of VA mycorrhizal fungi by Schenck and Perez (1987). Staining of root segments was carried out as per the procedure proposed by Phillips and Hayman (1970). The percent root colonization was determined by adopting the gridline intersect method proposed by Giovannetti and Mosse (1980). Acid phosphatase activity was estimated as per the procedure given by Eivazi and Tabatabai, 1977. ‘P’ estimation was carried out following vanadomolybdate yellow colour method as described by Jackson (1973).

Vesicular arbuscular mycorrhizal inoculation studies on coffee were carried out in the glasshouse. Polythene bags were filled with a mixture of soil: sand in the ratio of 6:2:1. Coffee seedlings at button stage are transplanted from the seedbed to the poly bags and the selected six isolates were incorporated. The inoculum to the plants was carried out at a standard level and the inoculum consisted of fractions of roots together with organisms that could colonize. The selected isolates were identified as *Glomus fasciculatum, Glomus aggregatum, Glomus etunicatum, Glomus radiata, Acaulospora myriocarpa* and isolate –1 could not be identified (Figure 1). Seven treatments with ten replication per treatment were arranged in completely randomized design and the position of the poly bags were changed once in a month to reduce experimental error due to positional effects. Observations were recorded regularly after 30, 60, 90, 120, 150 and 180 days after planting (DAP) and the observations were taken on the shoot length, number of pairs of leaves, leaf area and total plant biomass. Plant height and number of leaves were recorded once in 30 days up to 180 days at 30 days interval and the other growth parameters like leaf area and plant biomass, acid phosphates activity ‘P’ uptake were recorded and analyzed after harvest i.e. 180 DAP.

RESULTS AND DISCUSSION

Marked difference in growth was noticed among plants in the treatments as compared to un-inoculated control. There was significant enhancement in plant height due to inoculation of native VAM fungi at different intervals of plant growth. Maximum plant height was observed in *Glomus radiata* (42.4 cm) followed by isolate -1 (34.5cm), *Glomus aggregatum* (32.1 cm) and *Acaulospora myriocarpa* (32.5 cm) over the un-inoculated control plants at 180 DAP. However least plant height was noticed in *Glomus fasciculatum* (23.7 cm) inoculated plants compared to the un-inoculated (29.8 cm) control plants (Figure 2). Among the different native isolates tested, *Glomus radiata* was found to show a more consistent effect on plant growth on arabica coffee at all intervals.

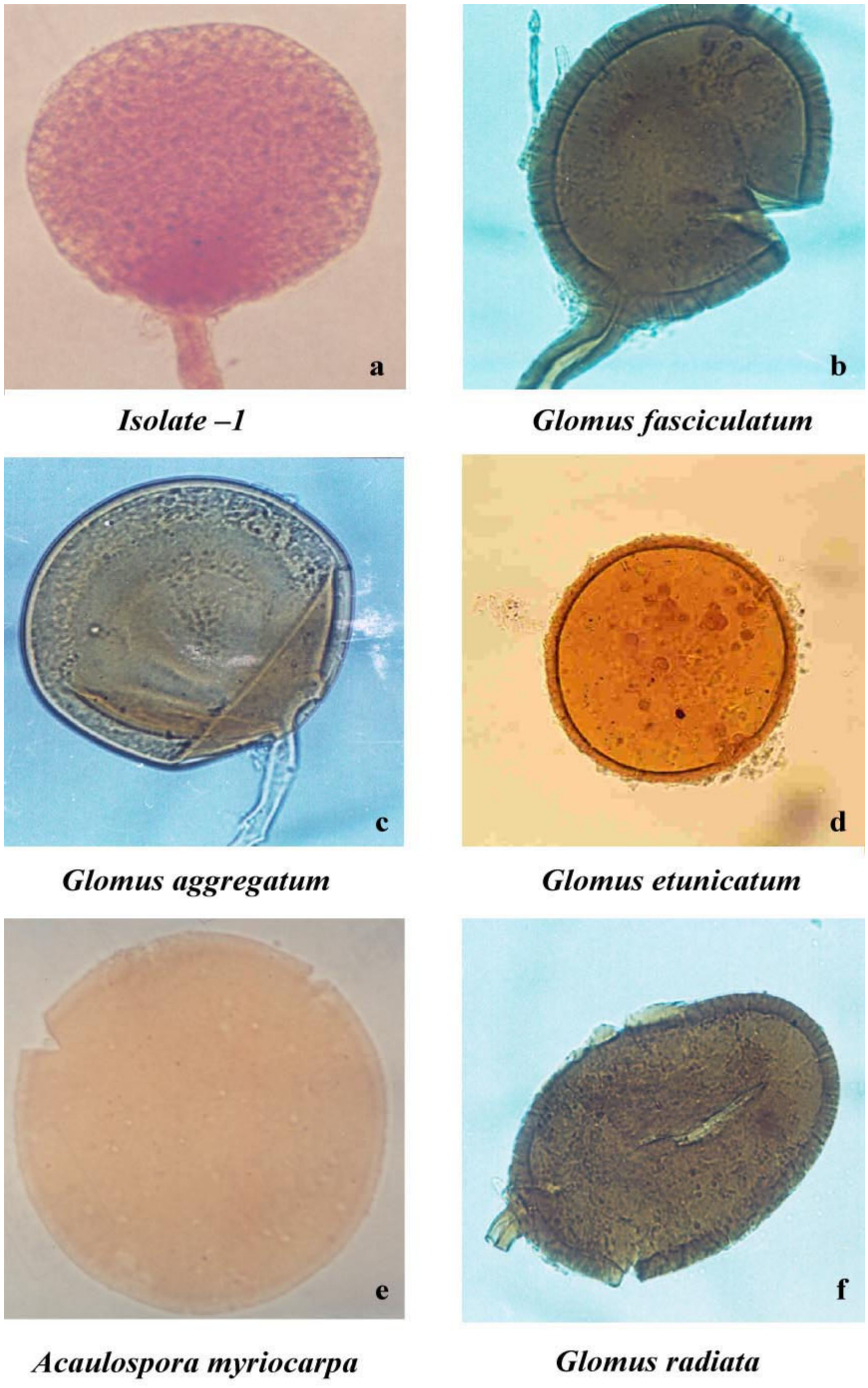

Figure 1. Native Vesicular Arbuscular Mycorrhizal spores.

The effect of inoculation of native VA mycorrhizal fungi on the number of leaves was observed that the number of leaves was significantly increased in plants inoculated. Highest leaf number was seen in case of plants treated with *Glomus radiata* (15.0) followed by *Acaulospra myriocarpa* (12.7), isolate –1 (12.3) and *Glomus aggregatum* (12.3). The least number of leaves was observed in plants inoculated with *Glomus etunicatum* (10.9), which is lesser than the un-inoculated (11.3) control plants. Isolate –1 and *Glomus aggregatum* did not differ significantly compared to the un-inoculated control plants.

Figure 2. Effect of native Vesicular Arbuscular Mycorrhiza on arabica coffee seedlings.

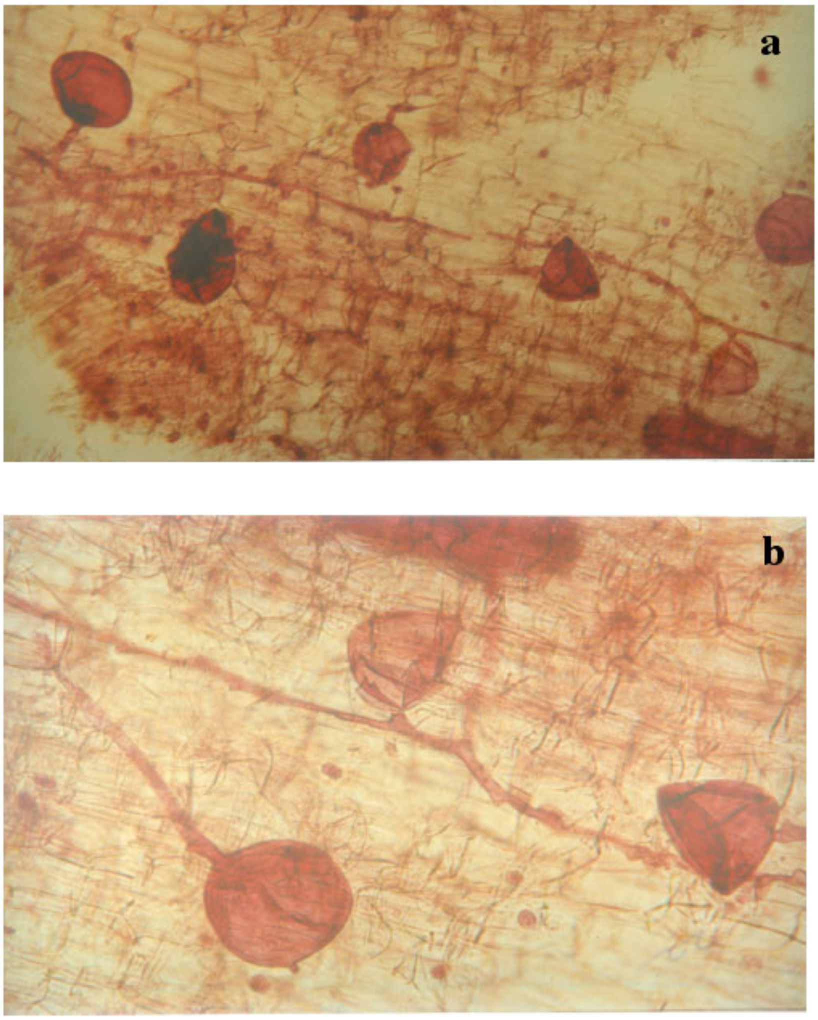

Figure 3. Vesicular Arbuscular colonization in coffee roots.

Effect of native VA mycorrhizal fungi on leaf area in arabica coffee indicated that significant differences in leaf area could be seen in arabica coffee plants at harvest. Higher total leaf area per seedling was recorded in the arabica plants inoculated with *Acaulospora myriocarpa* (4381.7c m^2) followed by *Glomus fasciculatum* (3904.2 cm^2), *Glomus radiata* (3790.8cm^2) and *Glomus etunicatum* (2617.4 cm^2). Least leaf area was recorded in isolate-1 (1755.8cm^2) and un-inoculated (1730.2 cm^2) control plants.

There were significant differences in total biomass production of plants. Maximum total biomass is recorded in plants inoculated with *Acaulospora myriocarpa* (36.67 g/plant) followed by *Glomus radiata* (35.67g/plant), *Glomus aggregatum* (23.67 g/plant) and isolate -1 (19.08 g/plant). Lowest total plant biomass was noticed in *Glomus fasciculatum* inoculated plants (7.24 g/plant) when compared with the un-inoculated control plants (13.50 g/plant)

There were significant differences in total 'P' uptake due to inoculation of native VAM fungi in arabica coffee plants except in plants inoculated with *Glomus fasciculatum* (321.05mg/plant). Maximum total 'P' uptake was seen in the plants inoculated with *Acaulospora myriocarpa* (103.31mg/plant) followed by *Glomus radiata* (107.37 mg/plant, *Glomus aggregatum* (91.87 mg/plant) and isolate –1 (65.18 mg/plant). *Glomus etunicatum* (36.50 mg/plant) and un-inoculated (38.22 mg/plant) control plants did not differ significantly and were statistically on par with each other. Least total 'P' uptake was seen in the plants treated with *Glomus fasciculatum*.

The results on acid phosphatase activity in the root zone soil of arabica coffee inoculated with native VAM fungi indicated that, the maximum acid phosphatase activity is recorded in root zone soils of *Acaulospora myriocarpa* (108.55 µgPNP g^{-1}soil hr^{-1}) followed by *Glomus etunicatum* (132.86 µgPNP g^{-1}soil hr^{-1}), *Glomus aggregatum)* 127.25 µgPNP g^{-1}soil hr^{-1}) and *Glomus radiata* (123.24 µgPNP g^{-1}soil hr^{-1}) and isolate –1 (112.78 µgPNP g^{-1}soil hr^{-1}). *Glomus radiata* and isolate –1 were statistically on par with each other. Least acid phosphatase activity was observed in the un-inoculated control plants (112.79 µgPNP g^{-1}soil hr^{-1}).

There were differences in percent VAM root colonization as influenced by native VA mycorrhizal fungi. Highest VA mycorrhizal colonization was observed in plants inoculated with *Glomus radiata* (69.46%) followed by *Glomus etunicatum* (68.04%), *Glomus aggregatum* (60.47%) and isolate –1 (55.92%). Least colonization was observed in the un-inoculated control plants.

In the present study, screening studies of these native endophytes, in arabica have shown varied response to inoculation. Thus there is a need for selecting efficient strains of AM fungi for inoculation where these crops are grown. The present study was attempted at selecting an efficient AM fungus for inoculating seedlings of arabica coffee in the nursery, so that healthy and vigorously grown seedlings are produced. In general, the plants inoculated with native VAM fungi grew taller than the control plants. Maximum increase in the plant height was observed in plants inoculated with *Glomus radiata*.

It is well-known fact that, VA mycorrhizae improve plant growth mainly through the increased uptake of nutrients especially, phosphorus uptake. The present study revealed that in variety arabica plants inoculated with *Acaulospora myriocarpa* have resulted in a maximum 'P' uptake followed by *Glomus radiata* and *Glomus aggregatum*. Similar trend was observed regarding the dry matter production i.e. total biomass. An increased total plant biomass by 2.7 times more followed by *Glomus radiata* and *Glomus aggregatum* compared to the un-inoculated control plants.

Pessoa A.C dos. S et al evaluated the effects of native VAM fungi, *Glomus clarum* and *Glomus etunicatum* on ‘P’ uptake and dry matter production, as well as the compatibility of the introduced and native VAM species at different levels of ‘P’. At intermediate P levels of 15 ppm and at pH 4.5 the introduced fungi did not differ from the control as well as the native VAM with regards to dry matter production. At pH 5.5 and intermediate ‘P’ levels, the introduced fungi were superior to the un-inoculated control and native fungi with regard to dry matter production. Higher percentage of root colonization was correlated with greatest yields. This suggests that, native VAM fungi that have acclimatized to such soil pH conditions and when introduced in large numbers must have performed better compared to other VAM fungi, which have been introduced, but originally isolated from elsewhere. In the present study also the native VAM fungi when inoculated to coffee have resulted in enhanced plant growth.

The present study also revealed that significantly higher amounts of acid phosphatase activity were recorded in the root zone soils of arabica plants inoculated with *Acaulospora myriocarpa.* It is well known that lower amounts of P favors higher mycorrhial colonization. The available ‘P’ of these soils is very low. The mycorrhizal colonization in these treatments was significantly higher and mycorrhizal infection has been shown to influence phosphatase activity. The fact that higher amounts of acid phosphatase are recorded in these treatments could be due to mycorrhizal stimulation of the root phosphatase activity in the presence of P_o to hydrolytic cleavage. Tarafdar and Clarren (1988) have also made similar observations. VA mycorrhizal root colonization and number of spores signifies the establishment of that particular VAM fungus with the host plant and this aid in drawing more nutrients from the rhizosphere resulting in enhanced growth of the plant. In the present study, mycorrhizae inoculated plants had higher percentage of root colonization compared to the un-inoculated control plants. However the extent of colonization varied with the endophyte. The maximum root colonization was observed in plants treated with *Glomus radiata* followed by *Glomus etunicatum* and *Glomus aggregatum*.

Several workers have observed such variations in root colonization by different VAM fungi. For example variation in the response of six cultivated species of mint (*Mentha arvensis* sub sp. *Haplocalyx*, *M. citrata, M. spicata, M. cardiata* (*M. gracilis*) and *M. virdis* to colonization by VA mycorrhizal fungi were recorded. All the species of mint had abundant VAM associations. Root colonization varied from 37.2 to 56.0%. The highest level of VAM colonization (56.0%) was observed on the roots of *M. spicata* and *M. citrata*. Rhizosphere soil of these plants had a VAM spore population ranging from 416 to 707/100 g soils. The result of this study revealed that cultivated species of mint had significant variation in their responses to native VAM fungi.

CONCLUSIONS

Mycorrhizal plants help in the uptake of major and micronutrients from soil. Because of enhanced production of plant hormones and improved physiological conditions, crops inoculated with VAM fungi show better growth and produce more yields. The results of many research studies indicated that the quantity of inoculum required for directly sown crops is quite high. Hence inoculations of VAM fungi to nursery beds of transplanted crops to pre-colonize the seedlings help in the economic use of inoculum. Pot culture trials were conducted to harness the mycorrhizal benefit in coffee plants, which is one of the predominant transplanted crops.

In general, the result of the present study has clearly brought out that, coffee plants responded well to VA mycorrhizal inoculation. Based on the results of the screening trials, taking into consideration the various plant parameters, it is concluded that among the native VAM fungi isolated, *Glomus radiata* and *Acaulospora myriocarpa* are found to be the most efficient VAM fungi for inoculating arabica coffee seedlings in the nursery.

Since coffee is a transplanted crop, the growers can easily follow inoculation of efficient VAM fungi in coffee nursery. This simple low cost agricultural technology will play an important role in getting healthy vigorous coffee seedlings.

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Activities of Women in a Coffee Growing Area of Nigeria

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SUMMARY

Contributions of women in agriculture cannot be over-emphasised. They perform several roles in farm family welfare and farming activities. 100 women were randomly interviewed on coffee growing Mambilla Plateau of Nigeria. 64% of the women performed multiple chores on the farm. The task commonly performed by the women was weeding either singly or together with other farm work. All of the respondents held land acquired by inheritance (34%), purchase (52%) or by both means (14%). 38% used their land mainly for farming while 2% used land for farming and construction (of buildings). 13% believed that there was no constraint facing women while 74% believed that farm specific as well as economic/financial and infrastructure problems were the major constraints of women. It was suggested that gender sensitive programmes and policies be put in place to achieve a sustainable women empowerment.

INTRODUCTION

Women do participate in productive, economic, activities in many societies. Rural women in most parts of the developing world bear a major responsibility in producing food for their families. Women produce between 60 and 80 percent of the food in most developing countries (ESCAP, 1995; Shirin, 1995; UNDP, 1997). However, their key role as food producers and providers and their critical contribution to household food security is recently becoming recognised. FAO studies confirm that women are the mainstay of small-scale agriculture in terms of farm labour force and day-to-day family subsistence. However, women’s access to resources e.g. land and productivity enhancing inputs/services is more difficulty compared to men.

The rapid modernization of agriculture through technology had a differential impact on both class and gender of the rural populace. A dramatic consequence of modernisation in agriculture has been the loss of opportunities of wage labour by poor rural women due to the introduction of technology that mechanises tasks traditionally performed by women. For instance, the introduction of a subsidized scheme for motorized rice hullers in Java, Indonesia, is estimated to have thrown out of work 1.2 million landless women, who were employed in the hand pounding of rice (FAO, 1980; Jiggins, 1986). Neglecting women as agricultural producers and resource managers inhibits attaining the goals of food security. Women's limited access to resources and their insufficient purchasing power are products of interrelated social, economic and cultural factors that forcefully subordinate their role, to the detriment of their own development and that of society as a whole. Therefore, this study was carried out to: identify and describe the roles of women in a coffee growing area, assess to land and properties, and constraints been faced by women.

METHODOLOGY

A multi-stage sampling technique was employed in randomly selecting 8 villages from 2 local government areas on the arabica coffee (*C. liberica*) growing Mambilla Plateau of Nigeria. 100 respondents were interviewed with the aid of well-structured questionnaire. Analytical methods include frequencies, percentages and chi-square statistics.

RESULTS AND DISCUSSIONS

52%, 34% and 14 % of the women held land acquired through purchase, inheritance and by both (purchase and inheritance) respectively (Table 1). Also, 87.1% of total land hectarage held by women was purchased (Table 1). This showed lack of discrimination against the women in land acquisition.

Table 1. Type of land holding by respondent.

Holding	Frequency	Percentage	Hectarage	Percentage
Purchase	52	52	907.00	81.7
Inheritance	34	34	181.67	16.4
Both	14	14	21.33	1.9
Total	100	100	1110.00	100

Source: Field Survey, 2001.

2% of the women did not own properties and 98% of the women owned properties in the study area. However, 52% held land as a property while 38% held crop farms. 33% held coffee farms solely or in mixed farms as properties. Only 2% and 6% had buildings and household items respectively as properties (Table 2). This indicates that coffee is an important commodity to the women in the study area.

Table 2. Land holding and property ownership by respondent.

Holding	C	C & O	L & C*	L & F	Land	Building	N	T & V	Total
Purchase	5	5	5	5	32	0	0	0	52
Inheritance	3	2	2	0	17	2	2	6	34
Both	8	0	3	0	3	0	0	0	14
Total	16	7	10	5	52	2	2	6	100

NB:- C – Coffee farm; C & O – Coffee & other crops farm; L & C – Livestock & crop (including coffee) farm; L & F – Livestock & Food Crop farm; N – No property; T & V – Television & Video. Source: Field Survey, 2001.*

13% of the respondents performed weeding as a sole activity on the farm while 64% performed multiple chores inclusive of which is weeding (Table 3). Only 7% did not perform any farm chore at all (Table 3). This shows that weeding is a key activity for women on the farm and that women are actively involved in coffee farming.

Table 3. Farm activities performed by respondent.

Chore	Frequency	Percentage
None	7	7
Planting	3	3
Weeding	13	13
Harvesting	3	3
Soil improvement	10	10
*Multiple Chore	64	64
Total	100	100

*NB:- *Multiple chores – Weeding plus one or more farm chores. Source: Field Survey, 2001.*

31%, 30%, 10% and 7% of the women identified economic (e.g. lack of credit), farm specific problems (such as farm inputs, diseases, inadequate/unavailable farmland, input adequacy, etc) social services (including extension) and social problems (including male chauvinism), and lack of extension services respectively as constraints being faced by women while 13% did not identify any constraint on women in the study area (Tables 4). Also, from Table 4, 29% and 58% of those who had contact and did not have contact with extension services identified constraints facing women in the study area. Hence, access to extension services significantly constrains women in the study area (Table 4).

Table 4. Constraint and contact with extension service by respondent.

Farm	EC	NEC	Total	%
None	3	10	13	13
Economic	0	31	31	31
Financial and Infrastructure	0	3	3	3
Farm Specific	23	7	30	30
Social Services and Social Problems	0	10	10	10
Absolute Poverty	3	0	3	3
Fund and Social Problems	3	0	3	3
Lack of Extension Services	0	7	7	7
Total	32	68	100	100

NB:- EC – Extension contact; NEC – No Extension contact. Source: Field Survey, 2001.

51% of the respondents opined that the government should put in place a sustainable legislation that will promote and enhance the establishment or operation of programmes by government agencies and Non Governmental Organisations (NGOs) such as adult education; provision of extension services, loans, infrastructure e.g. irrigation facilities amongst others. 17% believed that Cocoa Research Institute of Nigeria should assist the women (especially through well designed extension programmes) by facilitating adult education, helping them to source for loans, inputs, etc. 32% did not suggest any solution. The table reveals that the respondents still had faith in government agencies and other institutional bodies.

Finally, chi-square statistical tests revealed that in the study area, extension contact had significant effect on constraints facing women ($P > 0.5$); land holding had significant effect on women's land use ($P > 0.5$); also, land holding had significant effect on ownership of property by women ($P > 0.5$).

CONCLUSION

Demand-led research and extension systems need be developed to identify women's and men's needs and constraints, priorities and opportunities, to ensure that technological package meet their requirements. Also, guidelines for gender-responsive policy, implementation and monitoring of research and extension functions are highly essential. This will make possible the achievement of a sustainable women empowerment programme through adult education, provision of inputs, etc.

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Performance Evaluation of Interspecific Hybrids of *Coffea Racemosa* X SLN.3 R (*Coffea Congensis* X *Coffea Canephora*) under Indian Conditions

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SUMMARY

In India, both arabica (*Coffea arabica*) and robusta (*C. canephora*) are commercially cultivated taking into account their suitability to high and low altitudes respectively. The diploid species of *Coffea* are characterized by considerable genetic variability compared to the only tetraploid species *C. arabica*. The objectives of robusta breeding in India have been directed mainly towards evolving high yielding, widely adaptable varieties with improved bean and quality traits. In this direction, inter-specific hybrids of *C. racemosa* x Sln.3R (*C. congensis* x *C. canephora*) were evolved in view of developing varieties with low caffeine content and early ripening behaviour. These hybrids were evaluated for growth parameters. Hybrid plants exhibited intermediate nature with regard to characters like leaf size and internode length. The hybrids recorded less fruit size and fruit weight compared to both the parents. Percentage of floats also was found to be high. With regard to maturity of fruits, the hybrids resembled the female parent viz. *C. racemosa*. The potential of these hybrids as reflected by the initial growth behaviour are detailed and discussed.

INTRODUCTION

Coffee occupies an important position in Indian agriculture. *Coffea arabica* and *Coffea canephora* are the two economically important species of *Coffea*. *Coffea arabica* is a highland coffee suitable for cultivation at an elevation of 1000 to 1500 meters above MSL. Quality of *Coffea arabica* is well accepted due to its lower caffeine content and fine aroma. Robusta coffee is a low land species, suitable for cultivation at elevation ranging from 500-1000 meters. It is inferior in quality compared to arabica and it also characterized with high caffeine content. Due to the perceived ill effects of caffeine on human system the market of decaffeinated coffee is expanding in Western countries. Most of the people still prefer natural coffee with low caffeine content coupled with superior quality. As lower caffeine content is considered a desirable character in coffee breeding for improved quality and less caffeine content is an endeavor of robusta coffee breeders. Varieties with improved quality and low caffeine content need to be developed to create demand for robusta coffee. This could be achieved by interspecific hybridization utilizing *Coffea* species like *Coffea racemosa*, which is having lower caffeine content. Interspecific hybridization between *Coffea racemosa* and coffee selection Sln.3 R (*Coffea congensis* x *Coffea canephora*) offers tremendous scope for the improvement of genetic base of coffee.

MATERIALS AND METHODS

During the year 1989, interspecific hybridization was effected between *Coffea racemosa* and Sln.3R (*Coffea congensis* x *Coffea canephora*) with an objective of evolving varieties with low caffeine content and improved quality. *Coffea racemosa* was used as female parent and Sln.3R was used as male parent. Two plants of *Coffea racemosa* and three plants of Sln.3R were utilised and totally 17 hybrid plants in F_1 progenies are established in RCRS farm.

Characteristically *Coffea racemosa* is a diploid coffee species having low caffeine content and high drought tolerance (Clarke and Macrae, 1988). But yield is observed to be very poor. Sln.3R (CxR) is an interspecific hybrid between *Coffea congensis* x *Coffea canephora* sub var. robusta cv. S.274 released by Central Coffee Research Institute of India for commercial cultivation. This is a compact variety possessing high yielding ability and better beverage quality compared to robusta varieties.

Data on vegetative and fruit characters were recorded. Caffeine content also was estimated by UV spectrophotometric method.

RESULTS AND DISCUSSION

The data on vegetative, fruit and seed characters of interspecific hybrid and both the parents recorded are presented in table 1. Length of internode was intermediate (3.73cm) compared to both the parents. Length, breadth and area of the leaves of hybrid and parents also were recorded. It was found that all these parameters were intermediate in hybrids compared to both the parents. Length of the fruit was slightly higher in the hybrid compared to its parents. But breadth and thickness of fruits were less in hybrids. Hence hybrids recorded lesser fruit volume. Weight of fruits was very less in hybrids. This may be due to the high percent of floats recorded in fruits of F_1 hybrids.

The main objective of breeding Sln.3R (CxR) with *Coffea racemosa* was to evolve varieties with reduced caffeine content and improved quality. In this cross, hybrid recorded less caffeine (1.03%) as compared to Sln.3R (Table 1).

Besides, in hybrids the fruits recorded early maturity compared to the normal robustas. Fruits in the hybrid plants matured within 5-7 months after flowering.

Studies on similar lines conducted earlier in Central Coffee Research Institute utilizing *C. racemosa* and *C. canephora* cv. S.274 have also recorded intermediate nature of F_1 hybrid (Anonymous, 1974). Many studies on these hybrids were conducted and scientists have observed sterility and poor fruit set in these hybrids (Santharam, 1998; Reddy et al., 1991).

CONCLUSION

Though the hybrid recorded less fruit volume and high percentage of floats in fruits it is having desirable characters like early maturity of fruits and low caffeine content. This hybrid can be improved by effecting further back crossing with Sln.3R. Interspecific hybridization may widen the gene pool and thus provide an opportunity to tailor the coffee plant in the desired direction.

Table 1. Data on vegetative fruit and seed characters in *C. racemosa,* Sln.3R and its hybrid.

Characters	Sln.3R (CxR)	C.racemosa	C.racemosa x CxR
Internode length (cm)	7.14	1.64	3.73
Length of the leaf (cm)	21.27	4.78	8.18
Breadth of the leaf (cm)	9.23	1.75	2.55
Leaf area (cm^2)	134.57	5.90	14.51
Fruit length (mm)	16.17	12.69	13.88
Fruit breadth (mm)	13.99	12.43	10.96
Fruit thickness (mm)	11.96	10.98	9.90
Fruit volume (mm^3)	1410.07	900.61	783.14
Weight of 100 fruits (gm)	202	102.95	68.99
Floats (%)	2.22	9.00	42.18
Specific gravity of fruits	1.01	0.94	0.91
Percentage of PB (fruits)	14.80	13.33	0.91
Seed length (mm)	10.37	7.19	7.23
Seed breadth (mm)	7.86	4.55	5.55
Seed thickness (mm)	5.09	2.94	3.99
Caffeine content (%)	1.76	0.38	1.03

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Efficacy of Different Sources of Biofertilizers and N-PGPR on Growth and Vigour of Coffee Seedlings

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SUMMARY

A study was conducted at Coffee Research Sub Station, Chettalli, for a two seasons in randomized block design with three replications to asses the efficacy of different sources of bio-fertilizers and N-PGPR on growth, vigour and development of coffee seedlings and nutrient availability. Results revealed that the combined inoculation of Azospirillum + VAM + PSP + N-PGPR increased the plant height, tap root length, stem girth and dry matter weight of seedlings significantly at all the stages of growth as compared to un inoculated control. Results also revealed that when VAM, PSP, N-PGPR were inoculated with Azospirillum there was significantly increase in plant height, tap root length and dry weight of seedlings at all the stages of crop growth when compared to individual inoculations and un inoculated control. All the bio-fertilizers were found superior individually or in consortia than control with respect to seedlings growth and availability of N, P and K in the nursery mixture after experimentation.

INTRODUCTION

The viable and successful new planting in coffee mainly depends on raising the vigorous and disease free seedlings in nursery. The recommended nursery mixture for coffee in India consists of Jungle soil, FYM and sand in 6:2:1 proportion (Anon, 1996). Nutrition of seedlings plays important role for improving the vigour and disease free seedlings.

In recent years a number of commercial organic manures have come into the market that help in increasing germination, boosting growth of seedlings but adverse effect of seedling growth due to increased susceptibility to pest and diseases. Viable option is biofertilizers and beneficial microorganisms. Combined inoculation of VAM + Azospirillum brasilense to coffee seedlings (Cauvery) has been reported to significantly increasing the shoot length, root length, total dry weight and total P uptake (Glori Swaroopa, 1997). Inoculation of Azotobacter on S. 795 arabica coffee indicated positive improvement in the shoot dry weight, root spread and girth of seedlings (Mir Azizuddin and W.K. Rao, 1984).

In this context biofertilizers and PGPRs were tried as a source of nutrient and plant growth hormones with the following objectives.

1. To evaluate effects of different biofertilizers and their combinations on coffee seedlings growth and vigour.
2. To assess the nutrients availability/contribution with the use of biofertilizers and PGPRs to coffee seedlings.

MATERIAL AND METHODS

The experiment was conducted during the year 2002-03 and 2003-04 at CRSS, Chettalli nursery site in RBD with three replications. Following biofertilizers and their combinations were tried.

T1- Azospirillum
T2- Phosphate Solubalizer (PSB)
T3-VesicularArbescicular Mycorrhiza (VAM)
T4- N-PGPR(Native Plant Growth Promoting Rhizobacter)
T5- Azospirillum + P-Solubalizer
T6- Azospirillum + VAM
T7- VAM + P-Solubalizer
T8- Azospirillum +VAM + P-Solubalizer + N-PGPR
T9-N-PGPR + Azospirillum + VAM
T10- Control (Un Inoculated)

The poly bags were filled with nursery mixture consisting of jungle soil, FYM and sand in 6:2:1 proportion. Bio-fertilizers were brought from UAS Dharwad and N PGPR taken from Pathology Division, CRSS, Chettalli were analyzed for effective microbial counts before applying to nursery mixture. About 5 grams of microbial culture was mixed with moistened nursery mixture filled in polybags. The seedlings were transplanted from primary bed at button stage after dipping the roots in respective microbial cultures (100 g in one liter of water). Total number of seedlings per treatment were 50. The following observations were made

1. Plant height , tap root length, stem girth and total dry weight of seedlings at monthly intervals.
2. Nutrient content (N, P and K) of nursery mixture before and after experimentation were analyzed.

RESULTS AND DISCUSSION

The combined inoculation of Azospirillum + VAM + PSB + N PGPR (T8) recorded significantly higher plant height, tap root length, stem girth and total dry matter weight of seedlings at all the stages of crop growth as compared to un inoculated control and was on par with inoculation of either Azospirillum, PSB, VAM, N- PGPR in their various combinations with respect to seedling growth parameters at 150 days after transplanting.

The dry matter production in microbial inoculated treatments at initial stages of growth was on par with each other. But later stages, significant increase in dry matter production was noticed in combination of Azospirillum + VAM + PSB + N PGPR (T8) over other inoculations and was on par with other combined inoculations. Balanced nutrition of seedlings in combined inoculation enhanced the growth of seedlings compared to individual inoculation. The results also reveled that when endophytic fungi (Galmmous fasiculatum) were inoculated with other microbial cultures, the significant increase in the shoot length, root length, dry matter production of coffee seedlings were obtained compared to individual inoculations.

Such increase in growth parameters, dry weight reported previously with inoculation of two biofertilizers by Marina Prem Kumari and Balasubramanian, (1993). Enhanced production and subsequent release of IAA, IBA, NAA, GA 1, 2, 3 phytohormones, vitamins, antibiotics and other PGPRs in growth media by Azospirillum and VAM fungi in combined inoculation boosted the growth, dry matter production of coffee seedlings at all the stages. Further, consortia of these microbes in increasing nutrients availability helps the seedlings to attain maximum growth as compared to individual inoculation. Production of PGPs by biofertilizers was also reported by Mishra, 1993 (Table 1).

Table 1. Efficacy of different sources of bio-fertilizers and N-PGPR on growth and vigor in coffee seedlings.

Treatments	Plant height (cm)		Tap root length (cm)		Stem girth (mm)		Dry weight (g)	
	60 DAS	150 DAS	60 DAS	150 DAS	60 DAS	150 DAS	60 DAS	150 DAS
T1	9.86	26.8	13.50	27.50	1.90	3.20	1.23	14.83
T2	9.96	25.46	8.23	24.76	1.46	2.60	1.2	13.16
T3	9.36	26.40	9.50	24.16	1.70	2.93	1.23	14.66
T4	9.46	26.16	8.83	25.50	1.60	2.80	1.23	13.6
T5	10.00	27.13	10.96	27.90	1.93	3.63	1.33	15.8
T6	10.76	28.66	11.76	28.76	2.20	3.90	1.56	16.50
T7	10.50	27.86	11.26	28.16	2.06	3.76	1.4	16.13
T8	12.76	29.86	12.70	30.80	2.4	4.33	1.8	17.16
T9	11.43	29.30	12.60	29.50	2.26	4.20	1.7	16.70
T10	8.30	24.43	5.40	13.66	1.33	2.46	1.33	8.40
C D At 5%	1.18	4.20	2.20	4.30	0.19	1.30	0.17	1.30

Available N content was increase in all the treatments inoculated with Azospirillum alone or with PSP and VAM. Maximum available N,P and K in nursery mixture was recorded in combined inoculation of Azospirillum + VAM + PSB + N PGPR (T8) because of synergistic interaction between the growth and nutrient uptake of arabica coffee seedlings (Table 2).

Table 2. Nutrient status of nursery mixture before and after experimentation.

	Initial Nutrient content (mg/Kg mixture)			Final Nutrient content (mg/Kg mixture)		
	N	P	K	N	P	K
T1	358	73	381	360	70	409
T2	350	71	381	356	67	401
T3	356	72	382	369	69	407
T4	351	72	380	359	68	403
T5	359	74	388	363	71	412
T6	362	75	390	370	75	422
T7	361	75	391	365	72	415
T8	365	78	395	375	80	430
T9	364	76	390	372	79	428
T10	350	72	380	350	62	400
C D At 5%	NS	NS	NS	13.00	7.20	22.00

CONCLUSIONS

The study revealed that growth vigour and disease resistance of coffee seedlings will be enhanced by inoculation of bio fertilizers in coffee nursery at seedling stage and nutrient availability can be improved through bio fertilizers and PGPRs application either individual or in consortia.

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A Comparative Study of Biometrical Characters Related to Yield and Quality in New Coffee Genotypes

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SUMMARY

Seven genotypes of arabica coffee (*Coffea. arabica* L*)* were studied biometrically with respect to variation for six vegetative and three reproductive characters including yield. Variation for all characters (stem girth, number of primaries, length of longest primary, bush diameter, number of fruiting nodes on primary, number of fruits per node and yield) was significant except for number of secondaries. Phenotypic and genotypic co-efficient of variation was high (> 20%) for total nodes, number of fruiting nodes and yield. Heritability estimates were high for stem girth (84.6%), and total nodes (74.4%) and low for rest of the characters.

A total score method for evaluating the over all performance of the genotypes showed that S.4643 (Brazilian Catimor) is the most promising composite genotype. S.4643 recorded the highest out-turn (16%), 'A' grade beans (68.8%) and low fruit float % (2.5%). The highest average projected yield of 1190 kg / ha clean coffee with a cup quality of FAQ + standard was also recorded by this genotype.

INTRODUCTION

Genetic diversity is the basis for the continued improvement of crop plants whether through natural selection or human selection. Coffee (*Coffea arabica* L*)* plant improvement through breeding has been in progress at Central Coffee Research Institute (CCRI) for the past several decades with the objective of improving yield, leaf rust resistance (*Hemileia vastatrix*), quality and resistance to biotic and abiotic factors limiting productivity. To develop newer genotypes of arabica with the above criteria, zonal trials are in progress at CCRI and Regional Research Stations of the Board.

Arabica coffee (*Coffea arabica* L) is considered as polymorphic species due to its wide variability in growth and yield (Dharmaraj and Gopal, 1989). Carvalho et al. (1969) and Srinivasan et al. (1979), stressed the need of testing coffee in the different ecoclimatic conditions for selecting progenies suitable for particular regions as well as for wide adaptability. The biometrical studies indicated that selection of a particular arabica type with higher yield could be done efficiently by taking into account of various growth parameters and yield characters (Singh, 1968; Srinivasan and Vishveshwara, 1973, 1981; Walyaro and Van-der-Vossen, 1979; Srinivasan, 1980; Van der Vossen, 1985).

A set of seven new genotypes of arabica planted at Coffee Research Sub-station, Chettalli in Coorg, which is a major coffee growing district of India, formed the basis for the present study.

MATERIALS AND METHODS

Plant Materials

The materials used for the study comprised of seven new genotypes viz.,S.4643,(Brazilian catimor), S.4640 (advanced generation of Selection 10), S.4638 (Cauvery x Ethiopian wild arabica), S.4635 (Ethiopian wild arabica x cauvery), S.4622 (Cauvery x Sln.9), S.4621 (Sln.9 x cauvery) and S.4596 (Sln.11 x F_2 of Wallamo x HDT) established during 1996 at Technology Evaluation Centre, Coffee Research Sub-Station, Chettalli. All are semi-dwarf genotypes except S.4596, which is tall (Table 4).

Methodology

The study of genotypes was conducted in a compact block of 0.5 ha at a spacing of 1.8 x 1.8 m. Plants were topped single stem under mixed shade canopy and timely standard cultural operations were adopted. Four replications and five competitive plants per replication were chosen for the study making a total of 140 plants for all the parameters. Plot yields were recorded for five years (1999-2000 to 2003-04) and converted to projected yield of clean coffee per ha.

Six morphological characters (stem girth, number of primary branches, number of secondary branches on primary, length of longest primary, total nodes and bush diameter) and two reproductive characters (no. of fruiting nodes on primary and no. of fruits/node) were recorded during 2002-03 when the plants were 7 years old. Stem girth was recorded using vernier calipers at 15 cms above the collar region (Awatramani and Subramanya, 1973) and bush diameter was measured from north to south and east to west direction in the form of '+' sign.

Number of primaries was counted on the main stem from base to tip of the plant. The longest primary was chosen and measured from base to the tip and on the same branch, number of fruiting nodes, number of fruits / node and number of secondaries present on it were counted. (Amaravenmathy and Srinivasan, 2004).

Progeny yield was recorded for 5 years from 1999 to 2004. Six kg. of ripe cherry was pooled from marked plants of each genotype and processed by 'wet' method. The clean coffee obtained was asssessed for outturn, grade percentage and sent to Cup Tasting Unit, Coffee Board, Bangalore for evaluation of quality. Means were calculated for each of the growth and yield parameters.

Analysis of variance was carried out for each character and wherever progeny mean square was significant, critical difference was calculated. In order to arrive at an index to represent the overall performance of a genotype, across the characters and yield, the mean value of each genotype in respect of each character was expressed as a proportion of the grand mean and summed across all the characters and yield to get a total score. The genotype getting the highest score was considered as the best and the genotypes were ranked in that order (Amaravenmathy and Srinivasan, 2004).

RESULTS AND DISCUSSION

Results are presented in Tables 1, 2, and 3. S.4596 [Sln.11 x (Wollamo x HDT)] showed the highest summative index of 10.48 considering all the characters taken for the study followed by S.4643 (Brazilian Catimor) (Table 3). However for important characters like stem girth, number of primaries and yield, S.4643 showed higher index values compared to S. 4695.It has further recorded 68.8% 'A' grade beans and FAQ+ cup quality. Hence this genotype can be considered as the best performing among the genotypes taken for the study. Some enterprising coffee planters have already taken up the cultivation of this genotype, based on its encouraging performance.

Table 1. Variation for Morphological characters.

Sl. No.	Progeny	Stem girth	No. of primary	No. of secondaries	Length of longest primary	Total nodes	Bush diameter
1	S.4643	5.0	23.6	10.3	120.9	215.9	206.1
2	S.4640	3.8	18.1	9.5	114.1	210.2	202.4
3	S.4638	4.0	20.1	8.4	114.2	185.6	214.6
4	S.4635	3.8	21.4	9.6	116.6	116.6	222.5
5	S.4622	4.4	21.8	7.6	117.9	166.4	214.0
6	S.4621	3.9	21.2	7.5	111.1	134.2	199.9
7	S.4596	4.6	17.7	11.4	146.5	271.4	246.1
	Mean	4.21	20.56	9.19	120.19	185.76	215.09
	F Test	* *	* *	N.S.	* *	* *	*
	CD 5%	0.30	2.17	-----	12.52	44.02	17.43
	CD 1%	0.41	2.98	-----	17.17	60.36	-------
	PCV %	12.2	11.9	21.9	11.7	31.6	9.2
	GCV %	11.2	9.6	13.2	9.4	27.2	7.2
	H^2	84.6	64.4	36.0	64.0	74.4	60.9

***Significant @ 1 %*
**Significant @ 5 %*
N.S.= Not Significant

Table 2. Variation for reproductive characters and yield.

Sl. No.	Progeny	No. of fruiting nodes	No. of fruits/node	Mean yield of 5 years Kg/ha
1	S.4643	32.3	13.3	1190
2	S.4640	49.8	10.6	558
3	S.4638	48.1	10.0	479
4	S.4635	49.1	11.3	515
5	S.4622	48.3	11.3	790
6	S.4621	42.2	15.0	609
7	S.4596	79.3	14.4	464
	Mean	49.87	12.27	657.57
	F Test	**	**	*
	CD 5%	13.14	2.18	405
	CD 1%	18.03	3.00	----
	PCV %	32.69	19. 1	54.8
	GCV %	27.44	14.8	34.6
	H^2	70.47	60.2	39.7

***Significant @ 1 %*
**Significant @ 5 %*
N.S.= Not Significant

Table 3. Index of vegetative and reproductive parameters.

Sl. No.	Progeny	Stem girth	No. of primary	No. of secondaries	Length of longest primary	Total nodes	Bush diameter	No. of fruiting nodes	No. of fruits/ node	Yield	Total Score
1	S.4643	1.19	1.15	1.12	1.01	1.16	0.96	0.65	1.08	1.81	**10.13**
2	S.4640	0.90	0.88	1.03	0.95	1.13	0.94	0.99	0.86	0.85	**8.53**
3	S.4638	0.95	0.98	0.91	0.95	1.00	1.00	0.96	0.81	0.73	**8.29**
4	S.4635	0.90	1.04	1.44	0.97	0.63	1.03	0.98	0.92	0.78	**8.69**
5	S.4622	1.05	1.06	0.83	0.98	0.90	1.00	0.96	0.92	1.20	**8.90**
6	S.4621	0.93	1.03	0.82	0.92	0.72	0.93	0.85	1.22	0.93	**8.35**
7	S.4596	1.09	0.86	1.24	1.22	1.46	1.14	1.59	1.17	0.71	**10.48**

Table 4. 1996 Planted arabica genotypes TEC, Chettalli.

Sl. No.	Genotypes	Parentage	No. of plants	Projected average yield in kg / ha (5 yrs)	Out turn %	Fruit Float %	'A' grade %	Cup quality	Leaf rust incidence (%)
1	S.4643	Brazilian Catimor	126	1190	16.0	2.5	68.8	FAQ +	14.58 medium
2	S.4640	Adv.gen. of S.3826	105	558	12.5	5.0	60.0	FAQ	20.80 medium
3	S.4638	Cauvery x Ethiopian Arabica	105	479	14.5	12.5	48.3	FAQ	52.27 severe
4	S.4635	Ethiopian Arabica x Cauvery	105	513	13.5	10.0	55.6	FAQ	35.61 severe
5	S.4622	Cauvery x Sln.9	126	790	14.5	11.5	58.6	FAQ	19.22 severe
6	S.4621	Sln.9 x Cauvery	125	609	14.5	5.5	51.7	FAQ	38.55 severe
7	S.4596	Sln.11 x Wallamo x HDT	125	464	15.0	11.5	42.4	FAQ	43.16 severe

For the six morphological characters studied, the genotypes showed significant variation as indicated by the significance of 'F' test in the case of 5 characters except number of secondaries (Table 1). The semi-dwarf genotype S.4643 recorded significantly higher stem girth and number of primaries compared to rest of the genotypes. S.4596, a normal tall arabica genotype, recorded greater length of primary, total nodes and bush diameter, which is expected. Phenotypic and genotypic coefficient of variation (PCV and GCV) was highest (>20%) for total nodes per plant and lower for rest of the characters. Heritability estimates were high (>70%) for stem girth and total nodes.

For the two reproductive characters and yield, the genotypes recorded significant variation (Table 2). Number of fruiting nodes per plant and number of fruits per node was high in S.4596, but these advantages were not reflected in projected yield per hectare, which could be due to smaller size of the berries, and poor out-turn (fruit to clean coffee) in this genotype. PCV and GCV were high but heritability was low for yield, which indicates that yield *per se* is not a dependable parameter for selection. Conversely no. of fruiting nodes indicated high PCV, GCV(>20%) and heritability (70%) which can therefore be taken as a reliable character under genetic control and of selection value.

The present study has given an insight regarding the performance of new arabica genotypes under the agro climatic conditions of Chettalli. A similar study conducted in respect of eight tall and one semi-dwarf genotypes grown at Chettalli has shown high PCV and GCV (>20 %) for number of primary branches and moderate heritability 55%) for length of primary and number of primary branches (Amaravenmathy and Srinivasan, 2004). This shows that estimates of the genetic parameters and relative importance of characters could vary according to the composition of the genotypes under study. However considering the results of both the studies, the importance of number of primaries, length of primary and total nodes per plant is borne out .The importance of these characters in breeding was stressed previously by Srinivasan 1980) and the same author also developed a selection index based on these characters Srinivasan, 1982).

Based on this study, the genotype S.4643 (Brazilian Catimor) could be recommended for large scale trials.

Figure 1. S.4643 (Brazilian Catimor) distant view.

Figure 2. S.4643 (Brazilian Catimor) closer view.

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Multiplication of Selected Clones of *Coffea canephora* through Grafting

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SUMMARY

Vegetative propagation through grafting is a means of maintaining genetic constituents in plants. One hundred scions each of five improved clones (M10, C111, C36, C90 and T1049) of three varieties (Niaolli (M10), Quillou (C111, C36, C90) and Java (T1049) of *Coffea canephora* were grafted using top-cleft method. Seedling rootstocks of 6months of age were used. Initial success-take at 3weeks after set (WAS) were highly significant ($p \leq 0.01$) been highest (21.25) in M10 and lowest (12.75) in C90. A reduction in success-take was observed with time until 18WAS when stability was obtained. Success-take at 18WAS was still highest (15.75) in M10 but lowest (1.25) in T1049 while C90 ranked fourth position with 8.25 mean value. Ranking in success grafting from varietal perspective follows the order: Niaolli (M10) > Quillou (C111, C36, C90) > Java (T1049) success-take for M10 and C111 were however not different ($p \leq 0.05$) at 3 and 18 WAS.

INTRODUCTION

Grafting as a method of vegetative propagation is usually practiced to induce vigour into a desirable seedling scion and to multiply a promising mother clone (Quarcoo, 1973). Mossu, (1912) regarded it as a method that does not require large investment hence it is favoured in several countries in America and South East Asia. Grafting is used in central America in controlling nematodes, where a nematode-susceptible variety of arabica is grafted into canephora coffee plants, having resistant or tolerant root systems. This method is second to rooting of stem cuttings in vegetative propagation of coffee (Cambrony, 1992). According to Soderholm and Shaw (1965) cited by Wood and Lass (1975) grafting is used in cocoa to detect virus infection in budwood. Extensive work has been done on the rooting of coffee stem cuttings in Nigeria (Adeyemi et al., 2002; Obatolu and Omolaja, 1999). There is however dearth of information on propagation through grafting, hence the justification of this study. The objectives of the study are to determine success-take in grafting of coffee and to access clonal and varietal effects on grafting of coffee.

MATERIAL AND METHODS

Five improved clones of *C canephora* belonging to three varieties were selected from *Coffea* germplasm plot at CRIN in October, 2003. The clones and varieties were: C111, C36, C90, (Quillou) T1049 (Java) and M10 (Niaolli). Orthotropic branches of these clones were obtained from the plot using secateur and wrapped in polythene sheet to reduce rate of evapotranspiration. The branches were conveyed to the nursery that was 3km away. One hundred scion each of the five clones were prepared from the orthotropic branches and grafted on 6 months old seedling root stock using top-cleft method as described by Mossu (1992). Twenty-five grafts per clone were laid out in Randomized Complete Block Design (RCBD) replicatedfour times. Leaves of the scion were detached and covered with a white cello-phane bag and insect attach respectively. Watering of pots was done as necessary. Examination for initial success-take was done 3 weeks after setting (WAS) and monitored until 18WAS when stability was attained.

RESULT AND DISCUSSION

Initial success-take at 3WAS was highly significant (P<0.01) been highest (21.25) in M10 and lowest (12.75) in C90. A reduction in success-take was observed with time until 18 WAS when stability was attained. Success-take at 18WAS was still highest (15.75) in M10 but lowest (1.25) in T1049 while C90 ranked fourth position with 8.25 mean value (Table 1). Ranking in grafting success from varietal perspective follow the order: Niaolli (M10) > Quillou (C111, C36, C90) > Java (1049). Success take for M10 and C111 were however not different (P, 0.05) at 3 and 18WAS.

Table 1. Grafting success-take at 3 and 18 WAS.

	Means success-take	
	3WAS	18WAS
M10	21.25	15.75
C111	20.50	15.25
C36	13.00	8.50
C90	12.75	8.25
T1049	13.25	1.25
LSD (0.05)	2.72	1.90

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Dynamics of Mixed Farming in Coffee: Implications of Globalization on Small Estate Holders

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INTRODUCTION

Coffee prices reached their lowest levels in 30 years, and have risen only slightly with the ICO composite indicator price at 52.89 US cents/lb. According to the International Coffee Organization (ICO), in almost all coffee-producing counties, such prices are unable to cover production costs and have led to serious social and economic problems, including increased poverty, indebtedness and abandonment of coffee farms. The crisis facing the coffee industry has been symptomised by massive over production, collapsing prices, deteriorating coffee quality, disease and above all the growing inequality in the coffee value-chain. At the farmer level price volatility has affected livelihoods of the farmers to the extent that they no longer have reliable source income, purchasing power and sustain their livelihoods. The overall negative effect is food insecurity leading to economic and social disorder in the various coffee households. The ICO and the World Bank ended a round table to share the burden of the present coffee crisis while also urging the industry representatives to discuss alternatives such as diversification, quality, added value and market development. The principal outcome of the meeting is to recommend potential diversification in coffee-producing countries.

DIVERSIFICATION

Regions with a high concentration of “marginal” coffee producers are in-crisis and must diversify their economies with help of mixed farming. Diversification effort is not a matter of switching individual farmers or farmer groups from one crop to another. Rather, it involves introducing new “high-value” enterprises in-crisis regions or helping existing farming system to work towards alternative sources of employment and income. Possible examples of high-potential enterprises are: fruits & vegetables; ornamental plants, vanilla, cattle, medicinal & aromatic plants, eco-tourism, etc. It appears that few diversification efforts exist in coffee system because there is a concern that diversification products will be abandoned if coffee prices rise and there is a preconception that there are no viable diversification alternatives.

According to the United Nation’s Food and Agricultural Organization (FAO, 1996), food security is achieved “when all people, at all times, have physical and economical access to enough safe and nutritive food to fulfill their dietary needs and alimentary preferences to lead an active and healthy life”. To provide food security, food availability, an access must be guaranteed. Food security program empowered small farmers by helping them discover the potential production to feed their families and generate income. The definition of sustainability as the UN commission on Environment and Development defined it as: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

METHODOLOGY

This study was descriptive, exploratory and analytical in nature and relayed on qualitative and quantitative data. A number of researchers have commitment on the advantages of combining quantitative and qualitative methods (triangulations) in mixed farming. Both qualitative and quantitative data were used because in using the grounded theory approach "there is no fundamental clash between the purposes and capacities of qualitative or quantitative methods of data". An exploratory approach was considered necessary because of the scant literature on overall assessment of MFS.

Dindigul district in Tamil Nadu was selected for the study and datas were collected during the year 2003-04. The agripreneurs of coffee, coconut, chili based mixed farming from thirty villages were selected for the study. From the villages selected, seventy-five agripreneurs each for coconut, chili, coffee were represented with a total population of 225. In the study, commission agents, contractors, village leaders and traders were represented. The study focussed on the strategic policy orientation on a broad holistic dimensions of decision making process, MFS institutional support, group effectiveness, market orientation, quality of decision, WTO led extension, gender domain, supply chain management, risk management in agri-business, diversification in competitiveness, optimization of natural resources and leadership. However, this paper focuses only on the analytical aspect of the mixed farming in coffee and its diversification with reference to crisis management.

RESULTS AND DISCUSSIONS

The important issue in mixed farming is selection of appropriate technology or crop combination suited to coffee based MFS. In the first instance, technology or mixed farming pattern choice must be in a manner, which will maximize the net income that farmers perceive. In other words, the technology chosen must allow the farmers to make as much as money as possible. Sustainable coffee is more than a series of techniques, which balance among agronomic, management, environment, economic and social optimums.

The study result illustrated in Table 1 indicates the operational cost and net return on coffee based mixed farming under crisis situation. It indicates that farmers obtained a least net profit of Rs.5590/ac from coffee as compared with the income of lab lab at the rate of Rs. 32,500/season. Under the crisis scenario as indicated above, diversification in coffee in favour of more competitive and high value commodities is reckoned and important strategy to overcome emerging challenges. If carried out apparently in coffee system, diversification can be used as a tool to assignment farm income, generating employment, resolve food insecurity, etc.

Table 2 further elaborates the potential of coffee based MFS in generating employment opportunity within the family and at the village level. For example, a quantum of labour usage in coffee system reveals that introduction of sixth component of mixed farming fetched an annual higher labour requirement of 1520 mandays as compared with other combination. Data suggest that higher the combination of mixed farming, better in generation of employment opportunities.

Table 1. Operational cost and net return of coffee based mixed farming.

Sl. No.	Crop combinations	Operational cost (Rs)	Gross Return (Rs)	Net Return (Rs)
1.	Coffee	18110	23700	5590
2.	Orange	15200	34000	18800
3.	Banana	17700	52000	34300
4.	Pepper	16500	80000	63500
5.	Beans	12050	18000	5950
6.	Lab Lab	20000	52500	32500

Table 2. Employment potential under different crop combination.

Sl. No.	Coffee based Mixed Farming	Annual labour requirements (Number of mandays)
1.	Coffee + Orange	218
2.	Coffee + Orange + Chow Chow	395
3.	Coffee + Orange + Banana	273
4.	Coffee + Orange + Pepper + Chow Chow	485
5.	Coffee + Orange + Banana + Pepper + Beans	531
6.	**Coffee + Orange + Cardamom + Pepper + Beans + Lab Lab**	**1520**
7.	Coffee + Orange + Banana + Cardamom	605
8.	Coffee + Orange + Banana + Beans	464
9.	Coffee + Orange + Banana + Lab Lab	1217

Note: Perennial and annual crops are standardized at an annual (or) for year, other than annual crop like seasonal crops are standardized at per season.

If coffee based MFS capitalize on profitable growth opportunities in its present situation, there is no urgency to pursue diversification. But, when growth opportunities in coffee sector diminishing, diversification is usually the most viable option for reviving the coffee business.

As part of the decision to diversify, farmer can diversify plantation into closely related crops or into totally unrelated crops within the acceptable quantum of diversification. It can expand into agribusiness and leverage existing competencies and capabilities where same resource strands are key success factors and valuable competitive assets. It can pursue opportunities to get into other product markets where its present technological know how can be applied and possible in competitive advantage. It can diversify towards small extent or to a large extent. It can move into one or two large new mixed cropping or a greater number of crops in smaller areas.

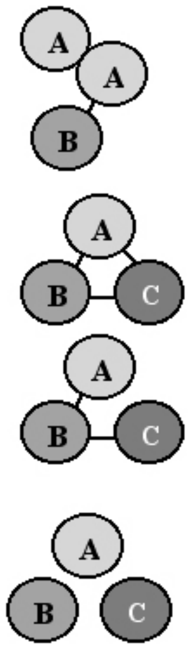
LEVELS OF DIVERSIFICATION

Diversified firms vary accordingly to their level of diversification and the connections between and among their businesses. Figure 1 lists and defines five categories of businesses according to increased level of diversification and availability of resources. Highly diversified firms, which have no relationships, are called unrelated diversified firms. Related diversification is a strategy through which the firm intents to build upon or extend its existing resources capabilities, and core competencies in the pursue of strategic competitiveness.

Low Levels of Diversification	
Single business :	More than 95% of revenue comes from a single business
Double business :	Between 70% and 95% of revenue comes from a single business

Moderate to High Levels of Diversification	
Related constrained :	Less than 70% of revenue comes from the dominant business, and all businesses share product, technological, and distribution linkages.
Related linked (mixed related and unrelated) :	Less than 70% of revenue comes from the dominant business, and there are only limited links between businesses

Very High Levels of Diversification	
Unrelated :	Less then 70% of revenue comes from the dominant business, and there no common links between businesses.



Source: Adapted from R.P.Rumelt, 1974, Strategy, structure and Economic Performance (Boston: Harvard Business School)

Figure 1. Levels and types of diversification.

A sound understanding of the pattern of coffee based diversification and the constraints it faces would help in crafting appropriate policies regarding institutional arrangements and creation of adequate infrastructure, which could benefit a large mass of small and marginal holder in MFS. The proposed study is an attempt to identify the optimum percentage of diversification in coffee sector. Within MFS, however, diversification is considered as a shift of resources from one crop (or livestock) to a target mix of crops and livestock. Keeping in view the varying nature of risks and expected returns from each crop/livestock leads to optimum portfolio of income in MFS.

Diversification in coffee sector is gradually picking momentum in favour of high value crops and livestock activities to assign incomes rather than a coping strategy to many risk and uncertainty. However, the nature of diversification differs across regions due to wide heterogeneity in agro ecological factor and socio-economic condition. Therefore, it would be interesting to delineate key areas where diversification is profitable. The following section is an attempt to unfold the above features and diagnose the diversification in study area.

Table 3 illustrates nine different components of mixed farming structure, out of which item number nine exemplify the combination. The above combination had shown a definite improvement in income. The cost benefit ratio of 1:2.61 indicates a profit of 260 percent. The primary reason for taking up the combinations were due to significant income from banana and short duration bean.

The finding of the study also reveals that mixed farming sector should gradually diversify its farming with short duration high value commodities, vegetables, livestock, non-farming entrepreneurs activities, value addition, process based unit, etc to minimize the risk. Production of vegetables and livestock products has increased remarkably high income due to awareness & prediction skill on market demand. According to the finding, diversification in favour of varied enterprises was more pronounced as a successful parameter, than very high diversification in single enterprises under crisis situation.

Table 3. Coffee based MFS structure and cost benefit ratios.

Sl. No.	Combinations	B:C Ratio
1.	Coffee + Orange + Chow Chow	1:1.27
2.	Coffee + Orange	1:1.58
3.	Coffee + Orange + Banana + Lab Lab	1:1.80
4.	Coffee + Orange + Banana + Cardamom	1:1.88
5.	Coffee + Orange + Cardamom + Pepper + Beans + Lab Lab	1:1.98
6.	Coffee + Orange + Banana + Beans	1:2.09
7.	Coffee + Orange + Banana	1:2.28
8.	Coffee + Orange + Pepper + Chow Chow	1:2.55
9.	**Coffee + Orange + Banana + Pepper + Beans**	**1:2.61**

An analysis of linear programming was taken to predict optimum income opportunities in coffee MFS. The study also brought out findings related to possibility of optimum income within the available resources. Linear programming is a more systematic and accurate method of determining mathematically the optimum combination of enterprises or inputs so as to maximize the income or minimize the cost with in the limit of available resources. LP results for Coffee based MFS comprises of three group of farmers viz., marginal (3.14 acres), small (7.3 acres) and medium (23.9 acres) which are classified based on land holdings as indicated in the parenthesis. The data reveals that existing and proposed optimum number of plants per unit area to optimize overall profitability in MFS varied from Rs.66,665 to Rs.1,40,177 for the category of marginal and small farmers respectively.

According to Table 4 optimal recommended plant population for marginal farmers to optimize income are given below based on number of plants per unit area. It suggests that the optimum plant population for marginal farmers (3.14 acres) could be 1020 coffee plants in 1.08 acre, 190 banana plants in 0.87 ac, 50 orange plants in 0.80 ac, 43 pepper plants in 0.29 ac, and 3 cardamom plants in 0.10 ac. On an average 13% income (Rs.7606) could be increased due to proposed optimal planting (e.g., Rs.66,665 per unit area).

Table 4. Normative plan for coffee based marginal farmer.

(No. of plants/unit area)

Sl. No.	Crops	Area (acre)	Existing number of plants	Optimal number of plants
1.	Coffee (Arabica)	1.08	972	1020
2.	Banana	0.87	130	190
3.	Orange	0.80	120	50
4.	Pepper	0.29	23	43
5.	Cardamom	0.10	60	3
	Net income in Rs.	3.14	59,062.00	66,665.80

Similar results are presented to optimum population for medium and small growers with and without vegetables and illustrated from Table 5 to 8 in the Annexure.

To sum up, coffee based MFAs are classified into five different categories for optimization through LP consolidated results are given in Table 9.

In case of marginal MFA category, LP predicts that increase in number of coffee plants, banana suckers and pepper vines are of good option for optimization. Further, the optimal solution suggests that number of orange and cardamom plants to be reduced.

The optimal solution for small MFAs growing vegetables along with coffee will have to increase marginally number of jack trees, with reduction of appreciable number of banana suckers and cultivation of beans are recommended to fetch Rs.1.40 lakhs/unit area (Refer Table 5 & 6). Under the category of small MFAs, those not cultivating vegetables, it is recommended that the optimal plan of marginal increases in number of jack trees and decreases in number of banana and lemon plants. In a nutshell, the optimization revealed that small farmers are recommended to include beans in their farming system.

Table 5. Normative plan for coffee based small farmers without vegetables.

(No. of plants/unit area)

Sl. No.	Crops	Area (acre)	Existing number of plants	Optimal number of plants
1.	Coffee (Arabica)	3.49	3141	3185
2.	Banana	1.79	152	110
3.	Orange	1.07	203	204
4.	Pepper	0.74	59	50
5.	Cardamom	0.01	6	6
6.	Lemon	0.18	12	5
7.	Jack fruit	0.02	4	11
	Net income in Rs.	7.30	94,990.50	1,38,689

Table 6. Normative Plan for coffee based small farmers with vegetables.

(No. of plants/unit area)

Sl. No.	Crops	Area (acre)	Existing number of plants	Optimal number of plants
1.	Coffee (Arabica)	3.49	3141	3185
2.	Banana	1.79	152	110
3.	Orange	1.07	203	204
4.	Pepper	0.74	59	50
5.	Cardamom	0.01	6	6
6.	Lemon	0.18	12	5
7.	Jack fruit	0.02	4	11
8.	Chow Chow	0.06	-	0
9.	Beans	0.16	-	0.25
	Net income in Rs.	7.52	1,01,940	1,40,177

The optimum plan for medium farmers growing vegetables indicates that there should be two fold increase in number of pepper vines and area under beans. The optimization also suggested that 40% of cardamom plants are to be decreased. The medium farmer without vegetable cultivation in their fields are recommended to increase the number of pepper vines two fold and the number of cardamom plants reduced drastically (Refer Table 7 & 8). The subtle observation of the optimization reveals that increase in number of pepper vines, decrease in number of cardamom plants and additional inclusion of beans would form an optimal plan for medium farmers.

Table 7. Normative plan for coffee based medium farmer without vegetables.

(No. of plants/unit area)

Sl. No.	Crops	Area (acre)	Existing number of plants	Optimal number of plants
1.	Coffee (Arabica)	7.17	6453	6453
2.	Orange	5.07	761	760
3.	Banana	4.64	882	875
4.	Pepper	3.10	248	629
5.	Lemon	2.50	162	187
6.	Cardamom	1.50	900	500
7.	Chow Chow	-	-	-
8.	Beans	-	-	-
	Net income in Rs.	23.98	4,29,877	6,70,954

Table 8. Normative plan for coffee based medium farmer with vegetables.

(No. of plants/unit area)

Sl. No.	Crops	Area (acre)	Existing number of plants	Optimal number of plants
1.	Coffee (Arabica)	7.17	6453	6453
2.	Orange	5.07	761	760
3.	Banana	4.64	882	875
4.	Pepper	3.10	248	630
5.	Lemon	2.50	162	187
6.	Cardamom	1.50	900	500
7.	Chow Chow	1.50	-	-
8.	Beans	2.00	-	3.50
	Net income in Rs	27.48	4,93,285.50	7,22,169

The optimal solution indicates that medium farmers are expected to get more optimal income (Rs.6.7 to 7.2 lakhs) than marginal (Rs.60,000 to 66,665) and small farmers (Rs.1.3 to Rs. 1.4 lakhs) due additional income gained from vegetables.

The complexity of coffee based MFS system and intensified competition has been forced the coffee growers to predict crisis management in coffee. The result on hierarchical regression coefficient strongly suggests that risk bearing ability of coffee growers contributes on the only significant variable for the diversification of coffee based MFS. Furthermore, in order to assess strategic risk management in coffee, the concept of break even analysis has chosen to predict risk related to coffee based diversification. The major factors such as effects of price and sensitivity of yield per acre contributed as a risk management tool in coffee based farming. The study also suggest that productivity of plant per acre is a crucial tool to manage risk in the current price fall scenario of coffee based system.

Table 9. Optimization of coffee based MFA.

Categories	Existing Income	Optimal Income	Optimal Allocation
Marginal farmer without vegetables	59,062	66,665.80	**Increase-** no. of coffee, banana, pepper plants **Decrease-** no. of orange and cardamom plants
Small farmer with vegetables	1,01,940	1,40,177	**Increase-** marginal increase of jack **Decrease-** no. of banana plants **Additional inclusion-** beans
Small farmer without vegetables	94,990.50	1,38,689	**Increase-** no. of jack tress **Decrease-** no. of banana and lemon
Medium farmer with vegetables	4,93,285.50	7,22,169	**Increase**-two fold of pepper **Nil**-Chow chow **Decrease**-two fold of cardamom **Additional inclusion**-bean
Medium farmer without vegetables	4,29,877	6,70,954	**Increase-**two fold the no. of pepper vines **Decrease**- no. of cardamom plants

CONCLUSION

Sustainable mixed farming in coffee requires the balancing of variety of goals. This means that often no single goal can be maximized, since such optimization might totally preclude the achievement of one of the other goals of sustainability. For this reason, trans-disciplinary team containing advocates of various goals, with ability to negotiate, prioritize, provide an important input into Sustainable Mixed Farming Business and Management (SMFB/M) is warranted. Further, coffee growers participation on these team is particularly crucial, because sustainable coffee means that the farmer shifts from a user of technology to producer of technology and monitor of its impact.

To compliment and improve upon early gains in coffee system, agronomic research for small farmers should focus on optimization with respect to different types (Refer Figure no.1) of diversification under the crisis situation. Enhancing growth of small farmers in achieving more equitable income among coffee growers are paramount objectives of sustainable mixed farming business and management. Most agronomist agree that sustainable mixed farming business and management (SMFB/M) is interdisciplinary and farmer oriented, with the system approach to agronomic research.

SMFB/M presents a systematic methodology for changing mixed farming systems, including changing the actions of farmers, researchers and extension personnel. It has a tradition of involving interdisciplinary teams in its implementation. Key changes in team formulation and dynamics would be needed for SMFB/M to function as a major mechanism for generating and implementing more sustainable coffee systems. Broadening the composition and mandate of the trans-disciplinary teams would be one mechanism for such change.

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Creating Learning Experiences for Smallholder Producers in Sustainability Initiatives

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SUMMARY

Several initiatives are being developed to improve sustainability of coffee production throughout the chain from farmer to roaster. Initiatives such as the Common Code for the Coffee Community (4C) and Sustainable Agriculture Initiative (SAI) are partnerships between major roasters, NGO's, Unions and coffee federations. Presently, both codes are in the design phase and initial testing and adaptation of the codes takes place in pilot projects.

The project 'improvement of coffee quality and sustainability of production in Vietnam', financed by SaraLee-DE and Kraft Foods, serves as one of these pilots. Working with Tan Lam Company (Talaco), a local processor and exporter, the project is active in an area of small-scale but intensive Arabica production. Farmers in the area are positive of the codes but don't see any immediate benefits and therefore might be hesitant in its application, especially because both codes are rather demanding. From early 2003, the pilot explored several ways of integrating sustainability codes in training of farmers. In this way it is expected to increase the immediate usefulness of codes for farmers leading to better uptake on field-level. By benchmarking values, e.g. on fertilizer use, farmers can learn of improvements that not only benefit the environment but also have an immediate economic kickback in terms of cost reduction and/or product quality.

INTRODUCTION

As a result of the coffee price deterioration of the late nineties, millions of smallholders came into severe problems. These problems are still of such severity that the term "coffee crisis" was coined. After adjustment for inflation, the price for green coffee reached its lowest level in 100 years (Lewin et al., 2004). The Worldbank estimates that 20 to 25 million smallholders directly depend on coffee, while a total of 100 million people are involved in production and other coffee related enterprises (Lewin et al., 2004). Smallholders are the group that has been most severely affected by the "coffee crisis", but also larger plantations, processors, traders and exporters have noticed its effects.

To reduce the impact of the "coffee crisis" several initiatives have started, such as raising awareness in consumer countries, development of certified coffees, and coffee targeted development projects. Two ambitious initiatives that stand out are the Common Code for Coffee Community (4C) and the Sustainable Agriculture Initiative Platform (SAI). These initiatives are partnerships between major roasters, NGO's, Unions and coffee federations. Both follow a business-based approach and target mainstream producers (Common Code Secretariat, 2004; SAI Platform,, 2004). Presently, both codes are in the design phase and initial testing and adaptation of the codes takes place in pilot projects around the world. This paper argues how to improve the effectiveness of such codes in the field by:

1. Generating quantitative data on the state of sustainability in coffee growing areas;
2. Linking these data to existing or future farmer training structures in these areas;
3. Increasing credibility through better traceability; and
4. Making suggestions for simplified assessment procedures.

CONTEXT

Organisationally, the smallest entity in the 4C structure is the 4C unit. 4C is intended as an open system, which means that any group of producers can attempt to join. With traceability from mill to cup in mind the only principle criterion for a 4C unit is that it has to produce minimally one container of green beans. The 4C prerequisites for application are a self-assessment, the exclusion of unacceptable practices and a commitment to continuous improvement (Common Code Secretariat, 2004). The code allows for a transition period wherein all stakeholders of the 4C unit combine to continuously improve practices in coffee production and/or processing. Improvement is monitored by a National 4C Body using a traffic light system where red indicates practices that have to change within 2 years time, yellow practices that should change in a transitional period and green suitable practices. 4C units that are average yellow can sell 4C coffee.

The project serves as one of the pilots for both 4C and SAI (Nguyen et al., 2004). Working together with Talaco, the project is active in an area of smallholder managed but investment intensive Arabica production. Farmers, processors and authorities in the area are positive of the goals of the codes but see it largely as a complex thing to implement where immediate benefits seem unsure. Therefore they seem hesitant in its application, especially because both codes are rather demanding (Kuit et al., 2004). From March 2002 onwards, Talaco and the project explored several ways of generating quantitative data to reflect the state of sustainability in the area and for use in farmer trainings at 4C unit level. These trainings provide farmers accurate feedback on the extend to which their present practices are in line with sustainability codes. Applying this approach could integrate sustainability codes in existing and newly developed training structures to a far greater extend than a traffic light system where a farmer is only shown that he does not comply with the code, but is not given clear suggestions on how to improve.

Sustainability codes have often a broad scope, aiming to address all three dimensions of which sustainability is commonly understood to be composed of: a) environment; b) economy; and c) society. However, several farmer consultations revealed that the perception of sustainability between (western) consumers and producers often differs. Whereas consumers tend to put a lot of emphasis on social and environmental standards, a typical ethnic Vietnamese producer is primarily concerned with economical returns on investments (Nguyen et al., 2004), just as an entrepreneur in any other field. This is exemplified by decreasing productivity levels in times of lower coffee prices.

DESIGNING QUANTIFIABLE SUSTAINABILITY INDICATORS

Sustainability indicators that reflect present management practices and potentials for improvement in a quantitative manner can be designed, but should include the effect of local conditions that may vary among coffee regions because of soil-types, altitude, latitude and climate. A quantitative approach will initially result in a substantial amount of data collection work for each of the dimensions. The amount of research will vary by coffee region and depends on what is known already. Combined with data provided by producers in their Fieldbook (see below), the basic data allows the development of a benchmarking system. Although not applicable for each indicator, benchmarking is a vital component in a sustainability code. It will allow the National 4C Body to set clear and objective limits in their decision on what is to be considered sustainable and what is not. Furthermore, producers exceeding benchmark values will know clearly which criteria should be improved and in which direction[1].

IMPLEMENTATION

Success of any sustainability code in improving sustainability of coffee production depends to a large extend on the uptake at field level. The latter requires producers to see an immediate benefit for themselves, for else they will not, or only reluctantly, be willing to implement a code. This immediate benefit can come along in two ways:

1. Higher coffee prices at the farm-gate; and
2. Higher relative income due to more efficient input use

Option 1 is the responsibility of all coffee chain stakeholders. In effect it requires the price of coffee as paid by buyers to producers to reflect also the qualities of the production process in addition to the sensorial qualities of the product. This means that roasters and traders should have a buying policy that accepts sustainability of the production methods as part of product quality, and reflect this in a pricing policy to reward the product accordingly. Especially in situations where traders are working independently from roasters, the result of these policies may not reach farmers, or only in a delayed and watered down version. Unpublished farmer consultations by the project suggest that this leads farmers to be reluctant in taking up the code. Therefore option 2 seems a more viable and direct approach to successful implementation in that the sustainability code can potentially give the producer the immediate means and benefits of improving management. Management improvements via a traffic light or other qualitative system can be achieved but offer little incentives for the farmer to strive for continuous improvement because attaining green status is all that is required. Facilitating continuous improvement is more easily brought about in a quantitative indicator system, which expresses the actual performance of farmer's management.

Several generic approaches that allow users to collect and analyse quantitative data are readily available in the market, some more suitable then others. The approach developed by the project however is one of the few specifically targeted at coffee (Jansen et al., 2004). The Fieldbook package consists of a software tool for swift input and analyses of data and an approach for effective data collection. The Fieldbook does not only record physical inputs but also (child) labour allocating it to a range of 11 different activities as well as farmer specific information such as education level, number of children, total area under coffee. Additionally, site-specific parameters can be set, e.g. nutrient removal (N, P & K) per kg fresh cherry, prices for hired labour and all inputs, cherry price (with daily differentiation), characteristics of biocides, and nutrient content of fertilisers and organic manures. A similar approach could easily be developed and applied for processing facilities using ISO 14001 style environmental monitoring systems which would leave a few, mainly social, indicator categories to be covered by other means of data collection.

[1] Take the example of fertilization. The Fieldbook shows that the farmer applied 250 kg of nitrogen during a crop year, with a yield of 15 ton of fresh Arabica cherry per ha. Nutrient removal data indicates that a removal of 150kg nitrogen from the field via harvested cherries. Based on the regional soil-type and climate (rainfall) he is allowed to exceed the removed amount of nitrogen by 30%. Maximum application for the crop year is therefore: 150kg*130% = 195 kg. The producer exceeded the maximum amount by 55 kg. He would be marked "yellow", because he does keep a record of his fertilization but exceeds the threshold value of 30%. Similarly underscoring the threshold would also lead to "yellow".

Three primary issues are vital for this approach:

1. A given number of 4C unit members should record their field activities, inputs used and products produced on a daily basis (a so-called Farmer's Fieldbook).
2. At 4C unit level collection and processing of this data should take place with the purpose of:
   a. Forwarding it to the National 4C body which decides on admittance of a 4C unit into the system; and
   b. Feeding it back to the farmers through meetings and/or trainings thus allowing them access to accurate management information

PRECONDITIONS FOR QUANTIFIABLE ASSESSMENTS

Implementation of quantifiable assessments on field-level is by no means an easy feat. Several preconditions at different levels have to be met and the approach will not be suitable for every situation. For example an African Robusta producer with 20 coffee trees in his home-garden can hardly be expected to keep a Fieldbook, whereas for a Vietnamese farmer with 2 ha Robusta monoculture it makes a lot of sense. This leads to an overriding pre-condition, that of regional adaptation of the assessment approach. Adaptations will have to be made in a consensual process among stakeholders, in which care should be taken that the meaning, credibility and relevance of the 4C code do not suffer. Other pre-conditions for successful implementing a quantifiable approach can be split according to three levels:

1. Producers should
   a. be able to read and write
   b. have a notion of abstract concepts (to be able to read graphics and tables)
   c. preferably be investment oriented
2. 4C unit should
   a. have at least one staff member that is responsible for collecting, analysing and disseminating results
   b. have a producer training strategy
   c. have access to means of processing data
3. A national body should
   a. have a coffee development strategy supporting 4C
   b. provide (access to) assistance to potential 4C units. This can be in combination with (inter)national donors.

DISCUSSION

Integration of a tool as described above into a sustainability code is expected to lead to:

1. Increased credibility of the Code with consumers;
2. Quicker eradication of red criteria; and (if taken up globally);
3. Increased predictability in development of quantities and qualities of coffee; and
4. A better uptake of the code at field level.

It may cover a large part of the information requirements of the Code in an objective way, setting clear limits for indicator values. The tools allows retrieval of most of the indicators relevant for producers related to use of fertilisers, biocides, organic manures and water, of the value distribution, working hours and Good Agricultural Practices.

Advantages of the approach at 4C unit level are:

1. Higher usefulness of information for improvement of management than in normal audits as producers benefit directly and over a long period of time (long term data collection);
2. Reduction of costs for inputting and analysis of data through the use of software; and
3. Reduction of costs for auditing: in the project area initial set-up costs are higher than a normal audit from a certified national auditor, but after three years, implementation of the Fieldbook tool becomes cheaper.

However, not all potential 4C units fit the preconditions for successful implementation of a quantifiable approach. Experience in the project area clearly shows that only investment-oriented farmers with a minimum of primary education are interested in, and take full advantage of this approach. 4C units, which do not fit this profile, will require a different approach, perhaps in the shape of "normal" audits. Not all information requirements of the Code at 4C unit level can be derived from the Fieldbook, necessitating a supplementary audit. This will effect the cost-effectiveness of the system, but since the audit itself can be reduced in size this is expected to level out against implementation costs of the Fieldbook.

Although the pilot work has been carried out in a small area in Vietnam, national adaptability looks feasible as the majority of producers in Vietnam fit the profile of educated entrepreneur.

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Improved Arabica Varieties for the Benefit of Tanzania Coffee Growers

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SUMMARY

The traditional Arabica coffee varieties in Tanzania – Bourbons and Kents – are of exceptionally good beverage quality appreciated by roasters and consumers, but are highly susceptible to coffee berry disease (CBD) and coffee leaf rust (CLR) and come from a very narrow genetic base. Costs of controlling CBD and CLR through fungicide sprays – as many as 10 sprays per season – are high, making coffee production uncompetitive and unprofitable in the current scenario of historically lowest coffee prices. The Tanzania Coffee Research Institute (TaCRI) has unidentified hybrid varieties that are better than the traditional varieties. The new varieties possess hybrid vigour, and combine high yields and resistance to CBD and CLR with exceptionally good beverage quality.

INTRODUCTION

Nyange et al. (1999) have made a comprehensive review of the coffee improvement programme in Tanzania over the last 70 years. The commercial Bourbon and Kent coffee varieties in Tanzania, N 39, KP 423, KP 162 and H 66 were selected, multiplied and distributed to growers by 1960. These varieties have exceptionally good beverage quality appreciated throughout the world, but come from a narrow genetic base and are highly susceptible to coffee berry disease (CBD) incited by *Colletotricum kahawae* Waller & Bridge and coffee leaf rust (CLR) incited by *Hemileia vastatrix* Berk et Br. These two diseases not only reduce yields, by as much as 20-60%, but also are also expensive to manage. The cost of controlling these two diseases through fungicide sprays, as many as 10 sprays per season depending on location and weather, are high, amounting to 30-50% of the cost of producing coffee in Tanzania. CBD and CLR constitute a real threat to the profitability and sustainability of the Tanzanian coffee industry. Hence, the most important priority unanimously identified by stakeholders is the continued development and distribution to growers of new high yielding, good beverage quality Arabica varieties with high and durable resistance to these two fungal diseases. Nyange et al. (1999) reported the achievements of the programme where 16 hybrid progenies were selected and were being evaluated in 25 multilocational trials and for ability to be multiplied vegetatively by somatic embryogenesis. We report on the multilocational and on-farm trials using the 16 hybrid progenies and tissue culture derivatives of eight of these progenies. We have put strong emphasis in re-confirming the beverage quality of the improved hybrids since 2001 with impressive results.

MATERIALS AND METHODS

Hybrid progenies

Sixteen hybrid progenies (Table 1) were selected on basis of performance (yield, hybrid vigour, resistance to CBD & CLR and beverage quality) and multiplied vegetatively from mother trees (Nzallawahe et al., 2004) to get seedlings from rooted cuttings in polythene bags. The potted seedlings were transplanted when they were nine months old for multilocational and on-farm trials.

Table 1. Performance of Arabica coffee hybrid progenies in Tanzania.

Selection	Cross	Mean Yield (kg/ha)	% Yield increase over N 39	Disease Reaction Class: North CBD	North CLR	South CBD	South CLR	Vigour [1]	Bean size % (AA + A) [2]	Beverage quality (10 years average) [3]
SC 1	Rume Sudan x HDT	2091	63	R	R	R	R	1	84	5+
SC 2	Kaffa x KP 423	2638	106	R	R	R	R	1	61	5+
SC 3	(N 39 x HDT) x Rume Sudan	2633	105	R	R	R	R	2	68	5+
SC 4	Kaffa x (N 39 x OP 729) x HDT	2939	129	R	R	R	R	2	74	6
SC 5	(N 39 x OP 729) x HDT) x Illubabor	2969	131	R	R	R	R	2	70	6+
SC 6	Rume Sudan x HDT	3485	172	MR	R	R	R	1	59	6+
SC 7	(N 39 x kaffa) x Rume Sudan x HDT) x HDT	2874	124	R	R	R	R	2	64	6+
SC 8	(N 39 x OP729) x HDT)x Illubabor	2891	125	R	R	R	R	1	76	6+
SC 9	(N 39 x OP 729) x HDT) x N 39	2891	125	R	R	R	R	1	70	5+
SC 10	(N 39 x OP729) x HDT) x Kent	2885	125	R	R	R	R	1	67	6+
SC 11	N 39 x HDT	1487	16	R	R	R	R	2	74	6
SC 12	HDT x (N 39 x Geisha) x HDT	1060	14	R	R	R	R	1	75	5
SC 13	KP 423 Hb x HDT	1457	14	R	R	R	R	1	86	5
SC 14	KP 423 x HDT	1126	-7	R	R	R	R	2	66	6
SC 15	Rume Sudan x HDT	1091	-15	R	R	R	R	2	74	6
SC 16	N 39 x Rume Sudan	1040	-19	R	R	R	MR	2	74	6
SC 17	N 39 (Control)	1283		S	S	S	S	3	59	5+

[1] *Hybrid vigour: 1 = very high; 2 = high; 3 = average; 4 = low.*
[2] *Bean size: > 50% (AA + A) = high quality beans.*
[3] *Beverage quality: 2 = Good; 3 = Fair to Good; 4 = Fully Fair; 5 = Fair Average Quality (FAQ); 6 = About Fair; 7 = Poor to Fair; 8 = Poor.*

Tissue culture materials

The best eight of the 16 hybrid progenies (SC 4, SC 5, SC 8, SC 10, SC 10.1, SC 11, SC 12 & SC 13) were selected for evaluation for ability for vegetative multiplication by somatic embryogenesis at CIRAD, France (Bertouly et al., 2001; Etienne-Barry et al., 1999). Lyamungu received plantlets that were nursed in an acclimatization room, potted in polythene bags and raised into seedlings ready for establishment of on-farm trials.

Multilocational trials

Twenty four sites for multilocational trials with the 16 hybrid progenies were selected in high CBD and CLR pressure areas in the major coffee growing zones: Northern Zone, 14 sites, Southern Highlands Zone, 9 sites and Lake Zone 1, site, in altitudes ranging from < 1,200 to >1,400 m a.s.l. On-farm trials with eight tissue culture (TC) plants were established in the Northern (19 sites) and Southern Highlands (6 sites) Zones.

Experimental Design and Management

The experimental design was RCBD with two replicates with entry of 16 hybrid progenies and N 39 (the commercial variety) as a control, planting five trees per progeny per block in a spacing of 2.74 m x 2.74 m. Multiple pruning system was adopted. Other management practices were as recommended for coffee growing in each of the zones. There were no fungicide application to control CBD and CLR.

On-Farm Trials

TC materials were established in 25 selected sites in major coffee growing areas between 2001 and 2002. The plants were established in a block of 50 plants per progeny, with N 39 and/or KP 423 in farmers' fields as checks.

Data collection

CBD and CLR assessment started from 1995 to 1999 in multilocational sites and continued in on-farm trials from 2001 to 2003. A scale of 1-6 was applied (1 = no disease and 6 = severe infection) to classify the reaction of the progenies into resistance (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S) & highly susceptible (HS) categories. Hybrid vigour was assessed using a scale of 1-4, (1 = high vigour and 4 = low vigour. Cherries for yield assessment were harvested and processed as recommended and weighed at 12% moisture content based on 10 trees per progeny per plot. Samples for liquoring were harvested and prepared as described by Robinson (1964) and sent for cupping internally and externally. Bean size percentage was determined by selecting beans in sizes AA, A, B, and PB per sample of 100 g, weighed separately and then calculating percentage of each size per sample.

Growers' assessment

Participating growers (smallholders and estates) jointly evaluated the improved hybrids along with the commercial varieties in February 2004 in a travelling workshop facilitated by the Ministry of Agriculture and Food Security. Tools for analysis were absolute evaluation, matrix ranking and pair-wise comparison. Criteria for selection included disease resistance, quality, vigour and yield.

RESULTS AND DISCUSSION

Multilocational trials and on-farm trials

Table 1 summarizes the performance of the selected 16 hybrid progenies under different coffee ecological areas. CBD and CLR severity was high in the control commercial control varieties (N 39 and/or KP 423). All the tested hybrid progenies were resistant to moderately resistant to both CBD and CLR with vigour that was superior to the control varieties. The performance of TC lines was similar to their parents with no apparent somaclonal variation.

Quality of the hybrid progenies was equal to or better than that of traditional varieties (Table 2; Figure 1).

Farmers' assessment

Application of matrix rating revealed that cup taste followed by big bean size, tolerance to drought, high yields, leafiness (resistance to CLR) and resistance to CBD were the most preferred criteria for the selection of the new hybrid varieties by farmers. Pair wise ranking of the coffee lines indicated the order of preference for the "best bet" hybrid progenies as follows: SC 10, SC 5, SC 12, SC 8 and SC 4 out of the 16 hybrid progenies.

Table 2. Beverage quality of pre-released hybrid progenies.

Selection	New variety name	Quality description
SC 4	N 39-1	Cup is good balanced in both body and acidity with pleasant aroma
SC 5	N 39-2	Cup is balanced in body and acidity with pleasant aroma
SC 8	N 39-3	Cup is fair with pleasant aroma
SC 10	KP 423-1	Coffee is fully fair, clean, sweet and full flavours pleasant aroma
SC 12	N 39-4	Cup is fair with pleasant aroma
N 39 (Control)	Commercial variety	Cup is fair, sweet with pleasant aroma

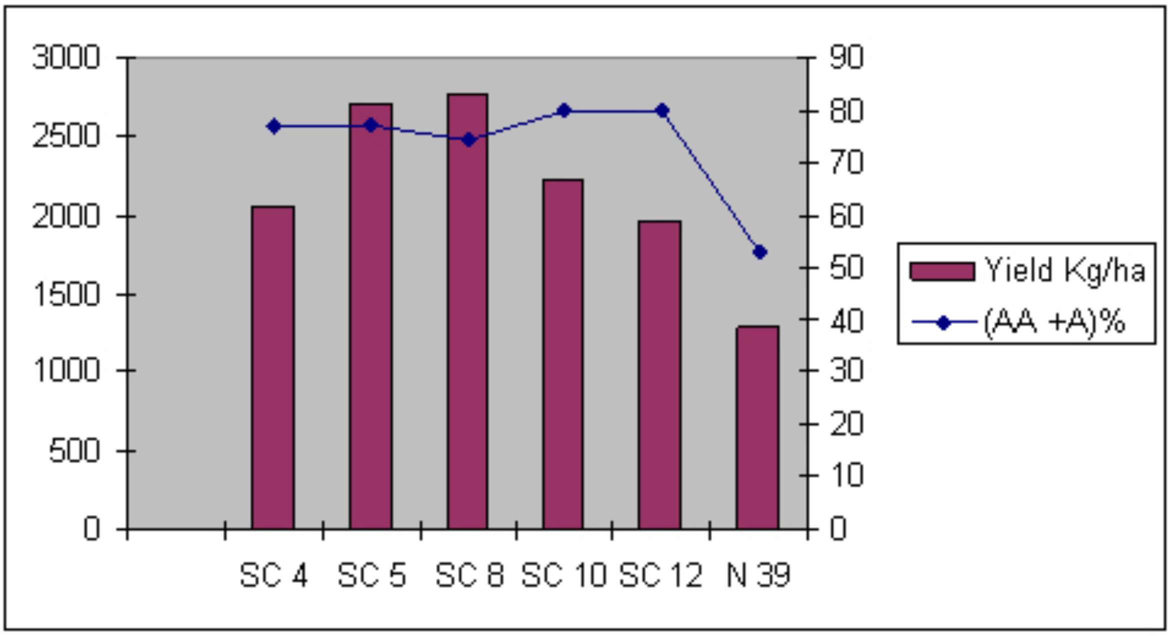

Figure 1. Yield and bean size of selected hybrid progenies in Tanzania compared with commercial variety N 39.

CONCLUSION

The results reported here confirm the conclusion by Bertrand, et al. (2003) that it is possible to select hybrid progenies that combine good beverage quality with resistance to CLR from HDT. The "best bet" Tanzania hybrid progenies have high yield potential (productivity 63-

172% higher than N 39), have bigger bean size (mean AA+A is 78% compared to 53% for N 39), beverage quality equal to or better than N 39, and combine resistance to CBD and CLR. Five of these hybrid progenies have been officially pre-released (Table 2). The impact of these new hybrid varieties will be significant in reducing costs of producing coffee in Tanzania by 30-50% thus increasing cash returns to demoralized growers (Fernie, 1962; van der Vossen, 2001). Reducing fungicide sprays from 10 per season to zero will also have positive health and environmental impacts.

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Association of Diverse Groups of Bacteria with 'Panchagavya' and their Effect on Growth Promotion of Coffee Seedlings

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SUMMARY

Thirty-seven diverse groups of bacteria were cultured from three formulations of 'Panchagavya'. The formulation PG-III harbored the highest number of bacteria followed by PG-II & PG-I. *Pseudomonas fluorescens, Pseudomonas aeruginosa, Ochrabactrum anthropi* and species of *Bacillus, Deinococcus, Aeromicrobium, Acetobacterium, Caryophanon, Terrabacter, Kurthia, Flavobacterium, propionibacterium, Brachybacterium, Cupriavidus, Curtobacterium, Actinomyces, Methylobacterium, Bifidobacterium* and *Microbacterium* were identified. All the 37 bacterial isolates of 'Panchagavya' were screened for *in vitro* antagonism in dual cu/ture against coffee pathogens viz., *Poria hypolateritia, Colletotrichum gleosporoides, Ceratocystis fimbriata, Rhizoctonia solani* and *Ambrosiella xylebori*. *Aeromicrobium* sp (P5), *Flavobacterium* sp (MPK7), *Pseudomonas fluorescens* (MPK 13), *Methylobacterium* sp (MPK II-2), *Bacillus* sp (OPK 2), MPK3 and MPK16 were identified as potential antagonists against all the five pathogens. Of the 37 bacteria screened for growth promotion on coffee seedlings under green house conditions, *Aeromicrobium* sp (P5), *Caryophanon sp* (P9), MPK6, MPK12, *Pseudomonas fluorescens* (MPK 13), MPK II-1 & MPK II-6 treated coffee seedlings recorded higher biomass and vigour index when compared to untreated control and other bacterial isolates.

INTRODUCTION

"Panchagavya" is a fermented mixture of cow's urine, dung, milk, curd and ghee. Its use in the traditional medicine and agriculture has been referred in Vrkshayurveda, Ayurveda text, Dharmashastra and Agamas of ancient Sanskrit literature (Subhasini et al., 2001)

However in recent years there have been number of reports about the preparation of 'Modified Panchagavya' either by adding one or more ingredients such as sugar cane juice, tender coconut water, toddy, banana and gobar gas slurry or by changing the proportion of the ingredients (Nataraj, 2003). Panchagavya formulations are extensively used on various crops either as soil drench or foliar spray to maintain vigour, suppression of pests and diseases and increase overall yield. Effect of 'Panchagavya' as organic nutrient in various crops is attributed to the presence of growth regulatory substances such as IAA, GA and cytokinins, essential plant nutrients and naturally occurring effective microorganisms (Somasundaram et al., 2004). Association of four *Bacillus* spp, *Ochrobactrum anthropi* and *Pseudomonas aeruginosa* in PG-II formulation of Panchagavya and their effect to promote the growth of the coffee seedlings and inhibit the growth of coffee pathogens was reported (Sudhakar et al., 2003).

In the present investigation, association of diverse group of bacteria in three formulations of Panchagavya and the effect of individual bacterium on promoting the growth of coffee seedlings and suppressing five major coffee pathogens is reported.

Figure 1. Growth inhibition of coffee pathogens by MPK 13.

MATERIALS AND METHODS

The three formulations of Panchagavya prepared for the study had the following composition.

PG-I: Cow's milk, curd, ghee, freshly collected cow dung & cow's urine in equal proportions.
PG-II: Cow's milk (1 *l*), curd (1 *l*), ghee (250g), fresh cow dung (1 Kg), cow's urine (1 *l*) and palm jaggery (250g).
PG-III: Cow's milk (2 *l*), curd (2 *l*), ghee (1 Kg), fresh cow dung (1 Kg), cow's urine (3 *l*), gobar gas slurry (4 *l*), sugar cane juice (3 *l*), tender coconut water (3 *l*), toddy (2 *l*) and banana (12 no).

Ingredients for each formulation were separately mixed in a wide mouth plastic container and kept under shade. The mixture was stirred twice a day and allowed to ferment for 21 days.

Isolation and characterization of bacteria

After 21 days of fermentation, each Panchagavya formulation was serially diluted and plated separately on Nutrient agar, King's B agar and Tryptone Soya Agar and incubated for 48 h at 37^{o}C. Based on the colony morphology under the stereomicroscope, individual bacterium was cultured and maintained in pure form. Bacteria were identified based on the colony morphology and biochemical tests (Bergey's manual, 1994).

Screening Bacteria for growth promotion

After removing the parchment cover, coffee seeds were surface sterilized and placed for early germination. Coffee seeds with just emerged radical were soaked in bacterial suspension @ 10^7 cfu/ml for 30 minutes. Bacterium treated seeds were sown in earthen pots containing nursery mixture (Sudhakar et al., 2003) and bacterial suspension @ 1 ml/seed was also supplemented immediately after sowing. Growth parameters viz., root & shoot length, number of leaves and biomass were recorded after 120 days of treatment. Vigour index was calculated as per the procedure adapted by Rangeswaran & Prasad, 2000.

In vitro screening for antagonism

All the 37 bacterial isolates were screened for *in vitro* antagonism by dual culture method on PDA against five fungal pathogens viz., *Poria hypolateritia, Colletotrichum gleosporoides, Ceratocystis fimbriata, Rhizoctonia solani* and *Ambrosiella xylebori*. Pathogens were cultured two days prior to streaking of bacteria on PDA. Individual bacterium was streaked as a 4 cm line in triangular fashion at least five centimeter away from the pathogen. Inoculated plates were incubated at room temperature (26 $\pm$ 2°C) until growth of the pathogen in control attains 90 mm diameter. Percent mycelial inhibition was calculated by using the formula

Inhibition % = 100 x (Control -Treated)/Control (Joseph et al., 2003).

RESULTS AND DISCUSSION

Bacteria isolated from the three formulations of Panchagavya are listed in Table 1.

Table 1. Bacterial identified from Panchagavya formulations.

PG-I	PG-II	PG-III
MPK 1 *	MPK2 (*Propionibacterium*)	MPK 5 (*Aeromicrobium sp*)
MPK 7 (*Flavobacterium sp*)	MPK 3 *	MPK 6 *
MPK 13 (*Pseudomonas Fluorescens*)	MPK 4 *	MPK 8 (*Aerobacterium sp*)
MPK II-1 *	MPK II-3 (*Bacillus sp*)	MPK 9 (*Microbacterium sp*)
MPK II-2 (Methylobacterium sp)	MPK II-4 (*Bacillus sp*)	MPK 10 (*Brachybacterium sp*)
	P 1 (*Bifidobacterium sp*)	MPK 12 *
	P 3 (*Actinomyces sp*)	MPK 14 (*Cupriavidus sp*)
	P 5 (*Aeromicrobium sp*)	MPK 15 (*Curtobacterium sp*)
	P 7 (*Acetobacterium sp*)	MPK 16 *
	P 11 (*Kurthia sp*)	MPK 17 *
	OPK 1 (*Bacillus sp*)	P 6 (Deinococcus sp)
	OPK 6 *	P 9 (*Caryophanon sp*)
	OPK 7 (*Pseudomonas aeruginosa*)	P 10 (*Terrabacter sp*)
		OPK 3 (*Bacillus sp*)
		OPK 4 (*Bacillus sp*)
		OPK 5 (*Ochrobactrum anthropi)*

Table 2. Growth promotion of coffee seedlings by bacterial isolates.

Treatment	Vigour index	Biomass /plant (g)	Treatment	Vigour index	Biomass /plant (gms)	Treatment	Vigour index	Biomass /plant (gms)	Treatment	Vigour index	Biomass /plant (gms)
P1	1229.14	0.08	OPK 1	1336.80	0.13	MPK II 1 *	1410.00	0.11	MPK 1 *	975.52	0.01
P3	1057.28	0.08	OPK 2	1412.98	0.06	MPK II 2	1186.54	0.08	MPK 2	1021.08	0.11
P5	1822.00	0.10	OPK 3	1453.76	0.12	MPK II 3	1109.08	0.08	MPK 3 *	1810.00	0.12
P6	1189.62	0.04	OPK 5	995.00	0.11	MPK II 4	974.72	0.10	MPK 4 *	851.46	0.05
P7	1077.44	0.06	OPK6 *	752.80	0.09	MPK II 5	996.48	0.09	MPK 5	1553.16	0.11
P9	1701.04	0.10	OPK 7	1066.04	0.10	MPK II 6 *	1682.00	0.11	MPK 6 *	2043.56	0.14
P10	276.00	0.03	Mixture of the above	1349.00	0.12	MPK II 8	1153.66	0.08	MPK 7	1139.76	0.09
P11	1507.44	0.07	control	1704.76	0.13	Mixture of the above	1231.92	0.10	MPK 8	1755.60	0.11
Mixture of the above	0.00	0.00	Mean	1258.89	0.11	control	1528.00	0.09	MPK9	1364.00	0.10
control	650.00	0.07	Std. Dev.	301.82	0.02	Mean	1252.49	0.09	MPK10	1590.80	0.12
Mean	1050.96	0.06				Std. Dev.	240.57	0.01	MPK12 *	2184.42	0.13
Std Dev.	590.95	0.03							MPK 13	2030.40	0.12
									MPK 14	1471.36	0.11
									MPK 16 *	886.00	0.02
									MPK 17 *	1372.80	0.10
									Mixture of the above	394.00	0.05
									Mean	1305.76	0.09
									Std. Dev	521.93	0.04

Table 3. Inhibition of fungal pathogen under dual culture by bacterial antagonist.

ISOLATE	*P. hypolateritia*	*C. fimbriata*	*C, gloeo-sporioides*	*R, solani*	*A.xylebori*
P1	0.0	0.0	30.9	0.0	0.0
P3	0.0	0.0	0.0	0.0	0.0
P5	35.5	45.6	45.5	33.7	34.2
P6	39.3	0.0	0.0	0.0	0.0
P7	0.0	0.0	0.0	0.0	0.0
P9	0.0	0.0	34.2	0.0	0.0
P10	0.0	0.0	37.3	0.0	0.0
P11	43.3	31.3	34.9	0.0	34.6
MPK 1 *	0.0	0.0	0.0	0.0	0.0
MPK 2	0.0	0.0	0.0	0.0	0.0
MPK 3 *	46.3	48.7	28.3	38.0	41.8
MPK 4 *	0.0	0.0	0.0	0.0	0.0
MPK 5	38.7	0.0	0.0	0.0	0.0
MPK 6 *	38.1	34.1	38.8	28.3	0.0
MPK 7	30.8	39.1	34.4	19.6	30.2
MPK 8	0.0	0.0	0.0	0.0	0.0
MPK9	0.0	0.0	0.0	0.0	0.0
MPK10	35.3	0.0	35.9	30.0	0.0
MPK12 *	39.2	35.8	38.9	32.3	0.0
MPK 13	50.7	51.8	43.9	33.8	50.5
MPK 14	35.8	33.0	37.7	0.0	0.0
MPK 15	0.0	35.0	0.0	0.0	0.0
MPK 16 *	44.1	42.1	34.8	30.4	43.0
MPK 17 *	0.0	37.2	0.0	0.0	0.0
MPK II 1 *	0.0	0.0	0.0	30.8	0.0
MPK II 2	36.4	49.9	39.0	31.9	35.7
MPK II 3	0.0	0.0	0.0	0.0	0.0
MPK II 4	0.0	0.0	0.0	0.0	0.0
MPK II 5	0.0	0.0	0.0	0.0	0.0
MPK II 6 *	30.7	0.0	0.0	0.0	0.0
MPK II 8	0.0	0.0	0.0	30.7	0.0
OPK 1	30.1	0.0	0.0	0.0	0.0
OPK 2	49.1	51.6	42.8	32.9	36.0
OPK 3	31.8	32.6	37.3	0.0	29.5
OPK 5	31.0	32.7	32.7	28.8	0.0
OPK6 *	34.2	36.2	0.0	30.2	0.0
OPK 7	29.8	0.0	0.0	0.0	0.0
F test	**	**	**	**	**
CD 1%	3.359	2.738	2.451	1.081	2.025

Thirty-seven different bacteria were isolated from three formulations of Panchagavya. Among the formulations, PG-III harbored more bacterial groups followed by PG-II & PG-I. *Pseudomonas fluorescens, Pseudomonas aeruginosa, Ochrabactrum anthropi* and species of *Bacillus, Deinococcus, Aeromicrobium, Acetobacterium, Caryophanon, Terrabacter, Kurthia,* *Flavobacterium, propionibacterium, Brachybacterium, Cupriavidus, Curtobacterium, Actinomyces, Methylobacterium, Bifidobacterium* and *Microbacterium* were identified and remaining isolates are yet to be identified.

Vigour index and biomass of coffee seedlings treated with bacteria are presented in Table 2. Among the 37 bacteria isolates screened for growth promotion, higher growth index and biomass of seedlings was found with the application of *Aeromicrobium* sp (P5), *Caryophanon* sp (P9), MPK 6, MPK 12, *Pseudomonas fluorescens* (MPK 13), MPK II-1 & MPK II-6 as compared to control seedlings.

Percent growth inhibition of five coffee pathogen with individual bacterium is presented in Table 3. *Aeromicrobium* sp (P5), *Flavobacterium* sp (MPK 7), *Pseudomonas fluorescens* (MPK 13), *Methylobacterium* sp (MPK II-2), *Bacillus* sp (OPK 2), MPK3 and MPK 16 inhibited the growth of tested coffee pathogens.

The present study revealed that the Panchagavya formulations facilitated the growth of diverse groups of beneficial bacteria. Plant growth promoting bacteria identified so far were either from the rhizosphere or internal tissues of various crop plants. **Hence, an alternative source, Panchagavya formulations can be utilized for culturing Plant Growth Promoting Bacteria.**

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Converting Old Coffee Trees to New Hybrids in Tanzania by Grafting

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SUMMARY

Coffee Berry Disease (CBD) and Coffee Leaf Rust (CLR) are economically important diseases of coffee in Tanzania. The only control measure available to growers is fungicide applications, as many as 10 applications per season. This is expensive, amounting to 30-50% of the cost of producing Arabica coffee in Tanzania. The Tanzania Coffee Research Institute (TaCRI) has identified Arabica coffee hybrids that have resistance to the two diseases and yield better than the traditional varieties while retaining the exceptionally good beverage quality renown for the traditional varieties. Replacing old trees to replant with the new hybrids by uprooting and replanting is wearisome. TaCRI is experimenting with grafting of scions of the new hybrids on shoots of old trees as a cheaper alternative of converting old plantations to the new hybrids.

INTRODUCTION

Arabica coffee grown commercially in Tanzania is mainly the Bourbon (N 39) and Kent (KP 423) types. However, the varieties are highly susceptible to coffee berry disease (CBD); caused by *Colletrichum kahawae* Waller and Bridge, and coffee leaf rust (CLR) caused by *Hamileia vastatrix* Berk et. Br. These two diseases not only reduce yields, by as much as 20-60%, but are expensive to manage. The cost of controlling these two diseases per season amounts to 30-50% of the costs of producing coffee in Tanzania. The Tanzania Coffee Research Institute (TaCRI) has identified Arabica coffee hybrids that have resistance to the two diseases and yield better than the traditional varieties while retaining the exceptionally good beverage quality renown for the traditional varieties(Teri et al., 2004). There is high demand from coffee growers to replant or replace CBD and CLR susceptible varieties the improved coffee hybrids. There are three possible methods of vegetative multiplication of coffee hybrids. This includes: (i) Clonal multiplication (Nzallawahe, et al., 2004), (ii) Somatic embryogenesis (Bertoully et al., 1999) and (iii) Grafting (van der Vossen et al., 1977; Wamatu and King'oro, 1993). Each of method has its pros and cons. For example grafting requires minimal cost of establishment (van der Vossen et al., 1977) and take off is much quicker when compared to clonal multiplication and somatic embryogenesis. In countries like India and Kenya grafting has been successfully used to change the traditional coffee varieties by grafting with improved varieties (Kumar and Sriniravasan, 1999; van der Vossen et al., 1977). Grafting has not been applied in Tanzania on a commercial scale (Fernie, 1962). This is a preliminary report on the possibilities of grafting scions of improved coffee hybrids, on root stocks of old varieties on a commercial scale.

MATERIALS AND METHODS

These preliminary studies were carried out at Lyamungu, Moshi starting from March 2004 to September 2004. Lyamungu is located at coordinates of 3º 14' S. latitudes 37º 15' E.

longitude, on the slope of Mt. Kilimanjaro at 1268 m a.s.l. Grafting was carried out July 2003 to 13 April 2004 on new pencil-thick suckers on old stumps commercial variety N 39 trees stumped and nursed to rejuvenate. The pencil-thick suckers were topped at about 30 cm above soil level. A 2.5 cm vertical slit was made on the topped sucker and a one node cutting, with two leaves trimmed by half, from hybrid variety KP 423-1 of same thickness made into a wedge inserted in the slit and then tied firmly with a clear polythene strip ensuring cambial contact. This was covered by a clear polythene bag tied firmly to the plant using the same polythene strips. Water was added to the polythene bags filled to a level just below the union, and made air tight to maintain a saturated humidity for about a month (Figure 1) after which the polythene bag was removed (van der Vossen, 1977). The graft union was painted with permanent red paint to identify the union during subsequent cycle changes. A casual worker was trained in grafting and his performance assessed in terms of number of grafts made in a day and success rate.

Figure 1. New grafts covered with clear polythene bag with water to maintain saturated humidity.

RESULTS AND DISCUSSION

Results have been impressive. Take off has ranged between 67 and 85% with one casual worker being able to perform more than 60 grafts in a day. Some grafts made in July 2003 will start flowering with the October/November 2004 short rains. These results confirm results from Kenya (van der Vossen et al., 1977; Wamatu and King'oro, 1993) and India (Kumar and Sriniravasan, 1999) that topworking by cleft grafting can be successfully applied to Arabica coffee in Tanzania as an alternative cheaper means of converting old trees to the new disease resistant hybrid varieties (van der Vossen et al., 1977). Future studies will focus on the eeffect of root stock type and age on performance of scion: take off and growth rate, yield and beverage quality.

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Clonal Multiplication of Arabica Coffee Hybrids in Tanzania

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SUMMARY

The Tanzania Coffee Research Institute (TaCRI) has unidentified Arabica coffee hybrid varieties that are better than the traditional varieties. The new varieties possess hybrid vigour, and combine high yields and resistance to coffee berry disease (CBD) and coffee leaf rust (CLR) with exceptionally good beverage quality that is equal to or better than that of traditional varieties.

Accelerated multiplication and distribution of the new hybrids to growers pose considerable challenge. The improved hybrids have to be multiplied vegetatively in order for the progenies to remain true to type. TaCRI has improved and perfected the Lyamungu system of clonal propagation with a rooting success exceeding 90%. We are training growers to use this technique to accelerate the multiplication of the new hybrids.

INTRODUCTION

The Tanzania Coffee Research Institute has identified and released to growers improved coffee hybrids that possess hybrid vigour and combine high yields and resistance to coffee berry disease (CBD) and coffee leaf rust (CLR) with good bean size and exceptionally good beverage quality that is equal to or better than that of traditional coffee varieties. These hybrids have been selected from complex multiple crosses and backcrosses as described by Nyange et al (1999) and Teri et al. (2004). Multiplying these hybrid progenies by seed results in considerable heterogeneity and loss of genetic uniformity of the hybrid progenies (Etienne, undated). Fernie (1962) described the Lyamungu system of mist propagation of hybrid cuttings on a commercial scale in Tanzania and recommended it as the only known method then by which immediate use of the new hybrid material can be made. All plants produced vegetatively by cuttings will be identical to the parent from which the cuttings were obtained. However, there are some reservations that the technique is not applicable to Arabica coffee trees on a large scale (Etienne, undated). We report here progress made in perfecting the Lyamungu system of mist propagation and its use for accelerated multiplication and distribution of the new improved coffee hybrids on a commercial scale in Tanzania.

MATERIALS AND METHODS

Establishment of mother-trees garden

A one-hectare mother-trees garden of 11 improved hybrids was established at Lyamungu during 2002/03 containing 12,000 mother trees. Planting holes were dug 60 cm x 60 cm and 60 cm deep at 1.0 m x 1.0 m spacing. Each hole was filled with about 20 kilograms of well rotten farmyard manure, mixed with top soil and 100 g of Triple Super Phosphate 46%.

Potted rooted cuttings prepared as described below were planted one per filled hole and pegged to lie at 45 degrees angle in east-west direction. The planted garden was covered with thick grass mulch and watered daily to encourage rapid establishment of the mother trees. Twenty grams of CAN 23% and NPK (20:10:10) fertilizers were applied alternatively at monthly intervals. Primary branches were removed three months later except for the apical growing points that were left as a lung to encourage proliferation of orthotropic shoots.

Lyamungu Mist Propagators

Concrete propagating boxes were constructed as described by Gibbins (1936). The boxes were put 60 cm in the ground to help to retain the moist atmosphere needed. The underground was filled with stones that were followed with a layer of aggregates. The sizes of the boxes were 90cm by 105cm, the top of the boxes sloping outwards at an angle of one in nine. Hinged lids were fixed and glass inserted. Three meters iron posts were erected to support shading of the boxes using cheesecloth and canvas blinds on angle iron 3 m above the top of the boxes.

New Lyamungu Mist Propagators

Slight modifications were made in the Lyamungu mist propagators to make them cheaper and affordable experimenting with timber instead of concrete boxes and replacing glass with transparent polythene sheets and black shade net with easily available local materials like dry grass and banana leaves supported by bamboo frames instead of angle iron. This modification was ideal for smallholder groups. Additional on-station modification was concrete propagating boxes 3 m x 1.2 m and 60 cm deep. The top was covered with transparent polythene sheet held in place by bent iron bars covered with black shade net supported by iron posts as described above.

Rooting media

Rooting media used in the propagation boxes were a mixture of two parts forest soil (rich in humus) or sawdust or rice husks and one part fine sand to improve drainage. This was steam sterilized, allowed to cool and then put on a layer of stone aggregates to a depth of 15 cm and watered ready for inserting cuttings. This rooting mixture was used for rooting twice and then recycled for use after decomposition for at least 12 months.

Preparation of cuttings and planting

Cuttings were taken from orthotropic shoots (upright suckers) from mother-trees about 30 cm and pencil-thick. Shoots were harvested early in the morning and cuttings prepared by removing all the primaries and trimming remaining leaves to half and the lower more mature portion cut into one-node cuttings while the less mature top portion was cut into 3-node cuttings using a sharp knife, the portion to be placed in the rooting mixture being trimmed to have sharp smooth end as described by Gibbins (1936). Cuttings were then planted at 4 cm x 4 cm in the mist propagators, sprayed with Dithane M45 at the rate of 4 g/l of water that was repeated as necessary to control Cercospora leaf spot. The boxes were then covered with either glass or transparent polythene sheets and saturated atmosphere and even temperatures maintained as described by Gibbins (1936).

Potting and Hardening of Rooted Cuttings

Cuttings formed adventitious roots and were ready for transplanting into polythene bags in about 2-3 months after planting in propagators. Potted rooted cuttings were hardened off in hardening boxes constructed as described above for mist propagators except that they were bigger in size to in order to hold large quantities of potted cuttings. Humidity and temperatures were maintained in the hardening boxes similar to the propagators but gradually reduced by gradual opening for two months and then transferred to an open light shaded area for final hardening. Frequent applications of fungicides (Dithane M45 or copper oxychloride) were made to control opportunistic pathogens in the mist propagators.

Participatory Accelerated Multiplication of Hybrid Clones

Smallholder growers were organized into groups of 20-40, trained on the establishment and management of mother-trees garden and mist propagators using readily available local materials. Each group was then provided with at least 500 potted cuttings of the improved hybrid varieties produced as described above to establish their own mother-trees gardens to advance the accelerated multiplication programme. Managers from coffee estates were similarly trained in clonal multiplication and supplied with mother trees to establish mother gardens. Thereafter, TaCRI continued with backstopping activities for both farmer groups and estates until they completed the whole cycle from mother-trees garden establishment to final hardening of clonal cuttings.

RESULTS AND DISCUSSION

We have established a healthy one-hectare primary mother-trees garden with 12,000 trees each capable of producing 30 orthotropic suckers per annum (15 suckers per harvest) at Lyamungu starting with only one tree per clone in 2001. This gives a potential of producing 360,000 orthotropic suckers per annum each giving 3-4 cuttings for rooting, making a potential total of 1,080,000-1,440,000 cuttings per annum. The Lyamungu mist propagation system has been expanded and improved giving a rooting success >90%. This is a potential capacity of producing 972,000-1,296,000 rooted cuttings per annum. We are establishing similar capacity primary mother-trees gardens at the Mbimba and Ugano sub-stations in the Southern Highlands Arabica producing zone. This will give a potential capacity of producing approximately 3-4 million rooted cuttings at the three stations by 2007.

Rooting and hardening of rooted cuttings has also been improved and 35 farmer groups and 10 estates successfully trained to establish secondary nurseries and producing rooted cuttings for potting and raising seedlings using low cost technology. The seedlings will form the back borne of the massive replanting effort with the new improved hybrids. The target is to produce a minimum of 15 million seedlings for replanting per annum by 2007. Individual farmers may also establish their own tertiary nurseries to produce own seedlings further accelerating the multiplication process. We envisage that secondary and tertiary nurseries may produce seedlings for sale after satisfying their own needs, thus increasing the sustainability of the programme. This effort will be supplemented with grafting (Magina, et al., 2004) to accelerate the replacement of old commercial varieties with the improved hybrids resistant to CBD and CLR. Enthusiasm is high as growers see the new improved hybrids as their last hope of remaining in business as coffee growers.

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Improving Smallholder Coffee Quality and Incomes : Experience from Mbinga District, Tanzania

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SUMMARY

Mbinga District in the Southern Highlands of Tanzania produces some of the finest mild Arabica coffee that accounts for 20-25% of the total Tanzania Arabica coffee production. This entire production is by 42,000 smallholders on 32,000 ha of land. Germany is the major market of the Mbinga coffee.

One of the major objectives of the new Tanzania Coffee Research Institute (TaCRI) is to improve smallholder incomes by improving coffee productivity and quality, and marketing. TaCRI has put emphasis in organizing these smallholder coffee growers into farmer groups, each group consisting of 25-30 members, since 2002. We have organized the groups around production and primary processing to improve productivity and quality and eventually assist each group to auction its coffee directly at the coffee exchange. Results have been very encouraging. Productivity and quality have improved; auctioning directly at the coffee exchange has reduced charges by intermediaries. These two interventions have increased growers incomes by 57-188%. This has acted as a catalyst for the formation of more farmer groups and as an incentive for greater attention to quality benefiting both producers and consumers.

INTRODUCTION

Mbinga district, Ruvuma in the Southern highlands of Tanzania, with fertile soils formed from igneous rocks, is one of the major 12 coffee producing districts in Tanzania producing some of the finest mild Arabica coffee that accounts for 20-25% of the total Arabica coffee production in Tanzania. This entire production is from 42,000 smallholders on 32,000 ha of land that accounts for about 70% of the districts economy. Germany is the major market of the Mbinga coffee. The district, with rainfall ranging from 1,000 to 2,000 mm per annum, has the potential of producing more than 25,000 tonnes of clean Arabica coffee per year.

However, coffee production in Mbinga has been in a state of steady decline from 13,000 tonnes in 1995 to 7,500 tonnes in 1999. This is attributed to demoralised growers in the current scenario of lowest coffee prices ever who are unable to invest in ever-expensive inputs. Coffee trees are in a state of neglect because of poor crop husbandry. Quality has suffered, further eroding incomes. The declining coffee production and quality in Mbinga has increased poverty among coffee growers and has affected the economy of the district considerably apart from denying the world with some of the finest coffees. It is a vicious circle.

The Tanzania Coffee Research Institute (TaCRI) has embarked in a programme financed by the coffee growers through cess contribution and EU/STABEX funds to rejuvenate coffee production in Mbinga and improve quality, working from its research sub-station situated in the heart of the coffee producing district at Ugano, using an integrated participatory approach.

TACRI'S TECHNOLOGY TRANSFER AND TRAINING STRATEGY

One of the core activities of TaCRI is to communicate outputs from research to the industry in formats and ways that are appropriate to different stakeholders with the following key functions (TaCRI, 2002):

- Support the rejuvenation of the Tanzania coffee industry by promoting and disseminating appropriate and financially viable, proven technologies to coffee growers
- Facilitate two-way linkages between researchers, district extension staff and farmers
- Develop and deliver training courses to coffee growers through training of trainers and formation of farmer groups
- Create market awareness, and appreciation of beverage quality, amongst coffee growers.
- Support establishment of grower-managed nurseries for the accelerated clonal multiplication and re-planting with improved hybrid varieties.

Mbinga district was chosen as a pilot district for implementing this strategy because of the history and the importance of coffee in the livelihoods and income security of smallholders in this district starting in 2002. Working from Ugano sub-station, with backstopping from TaCRI Head Office in Lyamungu, Moshi, the Extension Agronomist embarked in a massive organization of smallholder coffee growers in the district in collaboration with other partners (district and village extension and NGO staff).

The dissemination of proven, financially viable technologies is done through organized farmer groups using participatory approach. TaCRI has put emphasis in organizing these smallholder coffee growers into farmer groups, each group consisting of 25-30 members, since 2002. Participatory approach is used is group- based, with in-built flexibility that empowers the groups to make appropriate decisions and take actions to improve coffee productivity and quality for the benefit of each group member (Manion, 1991). The group is able to diagnose problems related to coffee production and quality and suggest the possible solution using their experience. It enhances farmer-to-farmer dissemination of technologies and information. Participatory approach is a discovery learning process where farmer participation is enhanced.

A CASE OF SUCCESSFUL SHARED VALUES AND CONFIDENCE BUILDING

Voluntary farmer groups in Mbinga district have jumped from nine in 2002 to 85 groups in 2004. TaCRI initially offered training in group formation and group dynamics and how to enhance group learning followed by dissemination of technologies. The factors influencing good yield and quality were summarised in one page for each member to make easy follow up and take action. Groups have been visiting one or two farms managed by their fellow members per week in rotation to diagnose coffee production and primary processing problems and best practices in each member's farm, advising solutions to problems with periods set for solving identified problems or enhancing best practices. Group members monitor one another to ensure implementation of group recommendations on members units. Smallholder coffee units are now in outstanding condition. The Mbinga Coffee Curing Company owned by growers has stepped in to assist with provision of inputs to groups on credit and offering liquoring services to the groups so that groups become aware of the quality of their coffee and the progress they are making in improving quality. Productivity has increased from 200 g/tree to 800 g/tree with a target of reaching 2 kg/tree. Quality has also improved with some groups aiming at achieving Classes 1-4 this season. TaCRI assisted 35 farmer groups to sell 480 tonnes of quality coffee (7% of Mbinga coffee) directly through the Moshi Coffee Exchange during 2003/04 season further reducing charges by intermediaries. These interventions have increased growers incomes by 57-188%. This has acted as a catalyst for the formation of more farmer groups and as an incentive for greater attention to quality benefiting both producers and consumers.

A PROMISING START AND AN OPTIMISTIC FUTURE

TaCRI's target is to have at least 20% of the Mbinga coffee produced by farmer groups as high quality coffee by 2008 and sold directly in the Moshi Coffee Exchange or through the second window of direct export to enhance growers' incomes. TaCRI is also training these groups to establish mother-trees nurseries for the accelerated clonal multiplication of the improved hybrids which will further increase growers' incomes by reducing costs of production associated with the control of coffee berry disease (CBD) and coffee leaf rust (CLR) (Nzallawahe et al., 2004; van der Vossen, 2001).

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The Biology and Feeding Behavior of the Coffee Berry Borer, *Hypothenemus hampei* (Ferrari) (*Coleoptera: Scolytidae*) and its Economic Importance in Southwestern Ethiopia

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SUMMARY

The biology and feeding behavior of the coffee berry borer, *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) and its economic importance in southwestern Ethiopia was studied on coffee (*Coffea arabica* L.) in the field and laboratory. The results showed that egg to adult development period took 24 to 43 days with mean of 31.7 $\pm$ 0.8 days. Oviposition started on 7-12 days after emergence of female borer. Female borer significantly preferred laying inside the parchment of berry (44% of eggs) ($P < 0.05$). Highly significant and positive correlation was found between age of berry and number of eggs laid ($r = 0.87$, $P < 0.01$). There was no significant difference in percent egg mass between dry leftover and fallen berries ($\chi^2 = 0.22$, $P > 0.05$). Most of the borers used the apex to enter the berry. Under field observations, 1-6 entrance holes per damaged berry were observed and 1-55 adult borers were recorded per damaged berry. On the average, a female borer spends 5.8 hr to enter the berry. Mean percent damaged berries in the surveyed areas ranged from 8-60%.

INTRODUCTION

Coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae) is a major pest of coffee worldwide (Le Pelley, 1968). Originating from Africa it has spread to nearly all the major coffee producing countries of the world (Mansingh, 1991; Baker, 2000). Crop losses caused by the pest can be severe, ranging from 50-100% if no control measures are applied (Le Pelley, 1968). Earlier workers made several searches for coffee berry borer and concluded that it was absent from Ethiopia; however, its incidence was reported for the first time by Davidson (1968) from Mizan Teferi area, in the then Keffa administrative region. Until recently, this insect was considered as a minor pest, causing relatively little damage on dry left over berries (Crowe and Tadesse, 1984: Million, 1987) as a result it deserved little attention. However, recent survey works revealed its wide spread occurrence in the country especially in low altitude grown large-scale coffee plantations that are becoming hot spot areas of the borer (EARO, 2000; Esayas et al., 2003).

The life history of this pest has been reviewed by various workers such as Evans (1965), Le Pelley (1968) and Wrigley (1988). In order to plan a strategy for control measures, it is necessary to understand the biology and other related characteristics of the insect. Therefore, this study is initiated to study the biology and feeding behavior of the borer and determine its importance on Arabica coffee.

MATERIAL AND METHODS

Description of the study area

The research was conducted from 2000 to 2001 in a laboratory at Jimma Agricultural Research Center (JARC) with temperature at 25°C and 60% relative humidity. JARC is located around 7^{o} 46' N latitude and 36^{o} E longitude, and at an elevation of 1750 m.a.s.l.

Life history

Coffee berry borer infested berries were collected from *Coffea arabica* trees at JARC and dissected with surgical blade in the laboratory to obtain adult borers. The adult borers were then maintained on freshly picked dry coffee berries. From the above culture, ten newly emerged borers were allowed to feed inside a petridish containing twenty freshly picked berries.Each petridish was considered as one experimental unit and replicated five times. After a week, each of the infested coffee berries were dissected with surgical blade and observed for oviposition using stereo dissecting microscope. When eggs were found, site of oviposition were observed, date of oviposition was recorded and number of eggs were counted. The eggs were carefully collected using camel hairbrush and kept in petridish lined with filter paper until hatching. Then incubation periods were recorded. Newly emerged larvae, which were obtained from the above egg mass were kept separately in petridish. Each larva was provided with freshly picked dry coffee berries until they developed to adult. When adults emerged, they were sexed based on their morphological characteristics as described by Booth et al. (1990) cited in Baker (1999).

Feeding behavior study

As part of determining colonization process of *H. hampei*, a study was conducted on feeding behavior of the borer. For this study, one thousand naturally infested coffee berries were collected from *Coffea arabica* trees at JARC. In the laboratory, each damaged berry was observed for the nature of damage inflicted by the borer. All berries were also carefully examined for position of entrance hole. Then number of entrance hole was recorded and mean percentage was calculated for each position on the berry. The number of entrance holes recorded from each position of berry was used to determine total number of entrance hole per damaged berry. In addition, based on preliminary observation, 350 damaged berries were separately dissected with surgical blade and the number of adult borers per damaged berry was recorded. In order to investigate the time required to bore a single berry, forty healthy and freshly picked green, ripe and dry coffee berries were kept in petridish separately. Then one adult female borer was released on each berry in the petridish. The time required to bore each berry was observed and recorded. Moreover, number of borer that successfully penetrated, abandoned and dead on the three stages of berries were carefully observed and recorded. The collected data on site of oviposition, position of entrance hole and penetration time of female borer were subjected to one-way analysis of variance using MSTAT-C microcomputer program (MSTU, 1985).

Importance of coffee berry borer

To study the distribution and importance of the borer, surveys were conducted at 22 sites in the major coffee growing areas of southwestern Ethiopia. Sampling was done following the method of Rémond and Cilas (1997).

RESULTS AND DISCUSSION

Oviposition and fecundity

Oviposition started at about 7-12 days after the emergence of female borer (Table 1). Four sites of oviposition were identified inside the berry. Analysis of data on choice of site for oviposition inside the berry indicated that the female borer significantly preferred laying inside the pulp of the berry followed by inside the bean and on the surface of the pulp of the berry with mean percent egg mass of 43.7 ± 2.9, 26.6 ± 3.1 and 22.3 ± 3.2, respectively ($P < 0.05$). On the other hand, minimum egg mass were deposited at the tip of entrance hole of the berry borer (Table 2). The preference of the borer to oviposit inside the pulp of the berry may be to ensure the safe development of the larva i.e. upon hatching the larva can have easy access to feed on the bean and is less vulnerable to natural enemies. In addition, eggs inside the pulp could be protected from desiccation.

Egg laying continued up to 10-25 days. The number of eggs laid per female per day ranged from 2 to 3 eggs with a mean of 2 ± 0.1. Total number of eggs laid per female ranged from 20 to 40 with a mean of 32 ± 0.3. Egg viability ranged from 88 to 96 percent with an average of 95% (Table 1). Coffee berry borer showed a marked preference of oviposition among the different developmental stages of coffee berry. Highly significant and positive correlation was found between age of berry and the number of eggs deposited ($r = 0.87$, $P < 0.01$). The borer consistently preferred to oviposit on dry coffee berries. There was no significant difference in percent egg mass between dry left- over and fallen berries ($P > 0.05$, $\chi^2 = 0.22$).

Table 1. Pre oviposition, oviposition period and fecundity of coffee berry borer.

Events	Range (Days)	Mean ± SE (Days)
Pre oviposition period	7 – 12	10 ± 0.1
Oviposition period	10 – 25	18 ± 0.2
Number of eggs laid per female per day	2 – 3	**2 ± 0.1**
Total number of eggs per female	20 – 40	32 ± 0.3
Egg viability (%)	88 – 96	95

Table 2. Percent egg mass of coffee berry borer on four sites of oviposition.

Site of oviposition	Range	Mean ± SE
Tip of entrance hole	0 – 20	6 ± 1 c
On surface of the pulp	1 – 46	22 ± 3 b
Inside pulp	24 – 66	44 ± 3 a
Inside the bean	3 – 45	27 ± 3 b

Means within columns followed by the same letters are not significantly different from each other; P <0.05, DMRT.

Development period and sex ratio

Results of developmental period and sex ratio of coffee berry borer are shown in Table 3. The incubation period of egg ranged from 5 to 10 days with mean of 6.5 ± 0.3 days. There are two larval instars for the female and one for the male with the average larval period of 17 ± 0.5 days. There was a resting period of 2 to 3 (2 ± 0.1) days before pupation. The pupal stage for the female lasted 6 to 9 with mean of 6 ± 0.3 days and that of male 5 to 7 with mean of 5 ± 0.1 days. The average pupal period ranged from 5 to 9 with mean of 6.2 ± 0.3 days. Complete development period (egg to adult) took 24 to 43 with mean of 31.7 ± 0.8 days. Le Pelley (1968) also reported 25 to 35 days with an average of 27.5. Similarly, Murphy and Rangi (1991) found an average development period of 28 days. Abraham and Moore (1990) also reported 25-27 days. In this study, female borers were found to be more numerous than males with an average female to male sex ratio of 10: 1. This is in agreement with the finding of Morallo-Rejesus and Baldos (1980). Such variation in the development period of the borer can largely be attributed to the different temperature and humidity regimes in which the experiments were carried out (Le Pelley, 1968; Abraham. and Moore, 1990; Murphy and Rangi, 1991). In addition, Abraham and Moore (1990) elucidated that developmental period of the borer varies with the stage of the coffee berry in which green and ripe berries retarded while dry berries hasten the development of the borer.

Table 3. Developmental period and sex ratio of coffee berry borer.

Stage	Range (Days)	Mean ± SE (Days)
Egg	5 – 10	6.5 ± 0.3
Larva	12 – 21	17 ± 0.5
Pre pupa	2 – 3	2 ± 0.1.0
Pupa	5 – 9	6.2 ± 0.3
Total development period (egg – adult)	24 – 43	31.7 ± 0.8
Sex ratio (female: male)	20: 1 – 30: 1	10:1

Feeding behavior

Nature of damage on dry berries

During feeding and tunneling activities, the borer makes a small perforation of about 1 mm diameter, which is often clearly visible at point of entrance. This entry hole is distinctive and can signify attack of coffee berry borer. The larvae, on hatching, feed on the tissue of the berry, making a small gallery of the main tunnel. It then causes further destruction of the berry. Damage due to the borer may vary according to the level of infestation and incidence. Sometimes small perforation may be observed with out significant damage of the berry. On the other hand, during high infestation the whole of the bean may be totally damaged making it worthless. The borer seldom moves to other berry before it totally consumes the first berry. Another type of damage due to the borer is berry fall and rotting

Position of entrance hole

The borer enters the berry, for feeding and oviposition, at three positions of the berry. The borer significantly ($P < 0.01$) preferred to enter through the apex. Rarely, does the borer use the stalk to enter the berry.

Number of entrance hole per berry

Under natural infestation, one to six entrance holes per damaged berry were observed. Most of the damaged berries contained 2 to 3 while a few of them had 5 and 6 entrance holes per damaged berry (Figure 1). This is in agreement with the report of Wrigley (1988) who stated that during the period of intense infestation, more than one female might bore into a single berry, each female with its own entrance. The occurrence of more than one borer within a single berry can be an indication of the level of infestation or severity of damage.

Number of adult borer per damaged berry

Under field observation, number of adult borers per damaged berry ranged from 1-55. Most of the damaged berries harbored 1-20 adult borers per damaged berries. However under severe infestation up to 55 borers were recorded in a single berry (Figure 2). The existence of such difference in infestation may be due to the presence of the different stages of borer in a single berry, often experiencing interbreeding among borers of the same brood. It was also noted that before exhausting the

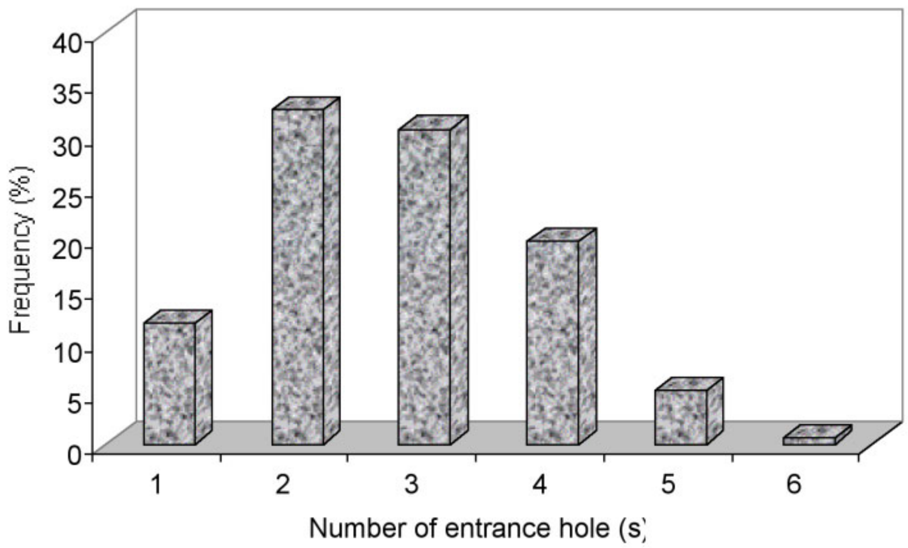

Figure 1. Percentage frequency of coffee berry borer entrance hole (s) against damaged berries.

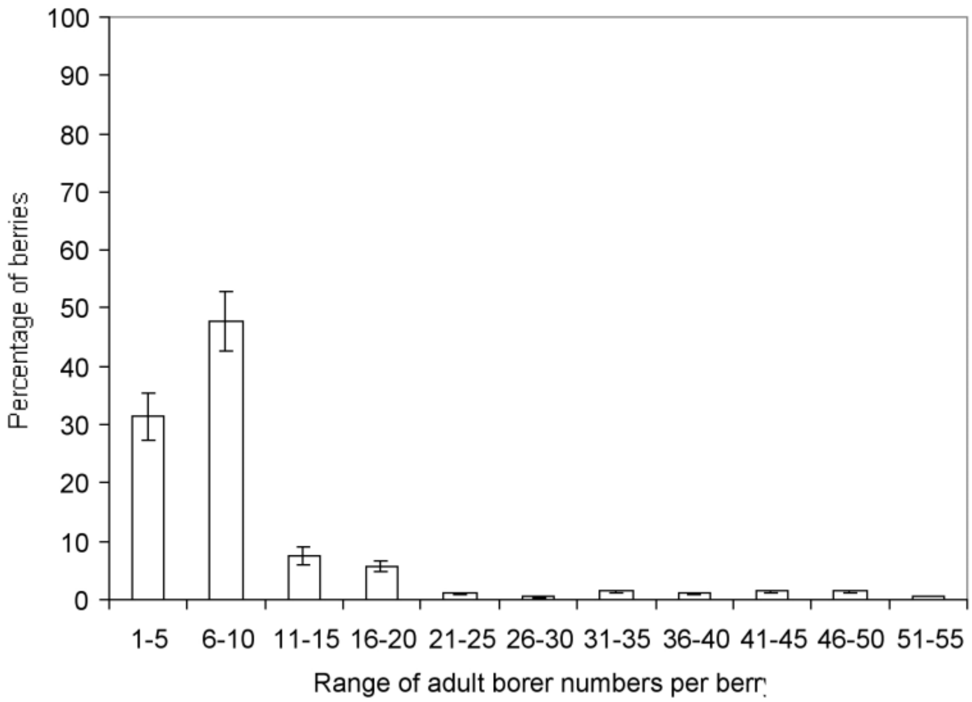

Figure 2. Proportion of berries (± SE) containing variable number of coffee berry borer. Infested berry the borers seldom move in search of another berry, which indicates their feeding efficiency on the available host.

Penetration time

Under laboratory condition female borers spent on the average 7.97, 5.55 and 3.91 hours to penetrate in to green, ripe and dry berries, respectively (Table 4). It significantly ($P < 0.05$) spent less time to enter dry coffee berries. Mean percent borers penetrated in to dry berries were considerably higher than ripe and green berries. Similarly, percentage of borers abandoned and dead while penetrating, was higher on green berries followed by ripe and dry berries. The time required by female borer to penetrate into the berry varies according to the stage of coffee berry. In addition, thickness (hardness) of the skin of the berry appeared to determine penetration time of the borer. Smooth and soft skinned berry can easily be penetrated as compared to thick and hard skinned berry. Generally, boring activity is an important colonization process of the borer. The success of feeding and oviposition of the borer is highly dependent on its boring efficiency.

Table 4. Time spent by female borer to penetrate green, ripe and dry coffee berries.

Stage	Range (hr)	Mean ± SE (hr)
Green	3.83 – 8.3	7.97 ± 0.47 a
Ripe	2.50 – 8.10	5.55 ± 0.96 b
Dry	0.66 – 8.00	3.91 ± 0.42 b
Mean		5.81
SE (±)		0.61
CV (%)		22.89

Means within columns followed by the same letters are not significantly different from ach other; P <0.05, DMRT.

Importance and distribution

Coffee berry borer existed under a wide range of altitudes from 1200 at Tepi to 1900 m.a.s.l. at Gera though the level of damage was often very low at the latter. In the surveyed areas, mean percent damaged berry ranged from 8-60%. The borer consistently attacks overripe and dry leftover coffee berries in the presence of green and ripe berries. Nevertheless, under laboratory condition the borer fee on green, and ripe coffee berries (Esayas et al., 2003) which indicated the potential danger of the pest to attack green and ripe berries as it does elsewhere. Therefore, it is important that the pest be monitored following the crop phenology to detect any deviation in its feeding behavior and also find out whether or not it is the same species as elsewhere.

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Field Expression of Resistance to Coffee Berry Disease (CBD) as Affected by Environmental and Host-pathogen Factors

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SUMMARY

Field resistance to Coffee Berry Disease (*Colletotrichum kahawae*) can be pre-determined with a high measure of accuracy by screening six weeks old seedlings in the laboratory. However, mature plant resistance is still prone to variation due to wide environmental fluctuations including encounters with pathogen strains that were hitherto not used in the pre-selection tests.

In this study, host x pathogen interaction experiments were conducted alongside comparative evaluation of field and laboratory resistance to determine the causes of variation in mature plant resistance. It was established that variation may be attributed to environmental factors which influence disease epidemics in the field and differences in levels of resistance in the host plant population. Specifically, resistance appeared to be dependent on the duration of the wet season and the dosage effect of genes. This paper discusses means of attaining stability of resistance under different environmental and host-pathogen factors.

INTRODUCTION

Coffee production in Kenya is still constrained to a large extent by the ability of the growers to control Coffee Berry Disease (CBD). The disease is caused by the fungus *Colletotrichum kahawae,* which attacks all stages of the developing crop from pinhead to ripe fruits (Mulinge, 1970). The most susceptible stage occurs during the fruit expansion period provided suitable weather conditions for the disease prevail.

The traditional Arabica coffee varieties commercially grown in Kenya are all susceptible. The varieties including SL 28, SL 34, K7 and Blue Mountain among others occupy over 80% of the total Kenyan coffee acreage. They are protected by an intensive fungicide spray programme that accounts for up to 30% of the total cost of production (Nyoro and Sprey, 1986). The fungicides are not only uneconomical but are also environmentally unsafe. It is for this reason that selection for resistant coffee types was initiated in Kenya in 1971. A method of pre-determining mature plant resistance on six weeks old seedlings was developed (Van der Vossen et al., 1976). A high correlation (r = 0.73-0.80) was observed between mature plant resistance and the pre-selection test. The method has been used in the Kenyan coffee breeding programme that culminated in the release of a population of hybrids. Other promising true breeding lines are currently being tested in readiness for release. In addition to the pre-selection test, screening methods based on molecular markers have been tested to accelerate the process of breeding and selection for CBD resistance (Agwanda et al., 1997). The demand for resistant varieties has been steadily rising since the first hybrids were released in 1985. New coffee plantations have been established in areas of the country that are currently having adequate potential land for expansion but were hitherto non-coffee growing areas. Some of the pathogen strains encountered in these regions were not used in the pre-selection tests during the development of the resistant varieties. The climatic conditions also differ from those found in the main coffee growing regions where the varieties were tested. In these regions, the CBD fungus has occasionally been isolated from the resistant coffee types. The objective of this study was therefore to determine the possible causes of variation in mature plant resistance as observed in different coffee growing regions.

MATERIALS AND METHODS

Host resistance

The incidence and severity of CBD was assessed on two commercial fields planted with resistant hybrids at Ruiru (1603 m asl) and Kitale (1890 m asl). Ruiru is located in the main coffee growing zone while Kitale has recently emerged as a coffee growing area due to availability of potential land for expansion. Disease incidence was assessed as the number of infected trees as a proportion of the total number of trees in the field. Disease severity was assessed as the mean number of infected berries as a proportion of the total number of berries on three most infected branches. Ripe cherries were harvested from two infected and two non-infected (standard) trees, processed and germinated for screening under controlled laboratory conditions. Susceptible SL 28 variety was included as a control. An isolate coded KW 33 obtained from the hybrid plants at Kitale was used to inoculate 200 six-week old pre-germinated seedlings per tree in two replications. The distribution of seedlings from infected hybrids on the 12-class disease scale was compared to the non-infected standard and the SL 28 control. This was to determine if the infected hybrids carry resistance genes by observing the proportion of seedlings segregating for resistance.

Table 1. A list of *C. kahawae* isolates including the sampling locations and the phenotype of the host variety of origin.

Isolate code	Location of origin	Phenotype of the host variety of origin
KC 4	CRF, Thika District, Central Province	Susceptible
KC 10	Nyeri District, Central Province	Susceptible
KE 15	Meru Central, Eastern Province	Susceptible
KM 13	CRF Collection, Benlate Resistant	Anonymous
KM 19	CRF, Thika District, Central Province	Excelsa (Not known)
KM 29	CRF, Thika District, Central Province	Susceptible
KM 30	CRF, Thika District, Central Province	Java (Not Known)
KP 1	Taita Taveta District, Coast Province	Resistant
KW 3	Kakamega District, Western Province	Resistant
KW 33	Kitale, Trans Nzoia District, Rift Valley Province	Resistant
KW 39	Bungoma District, Western Province	Partially resistant
KW 41	West Pokot District, Rift Valley Province	Susceptible

Host x Pathogen Interaction

Seeds from six varieties with known reaction to CBD were harvested, sown and inoculated with 12 monoconidial isolates from different coffee growing regions in Kenya. A brief description of the isolates and the varieties are presented in Tables 1 and 2. For each of the 12 isolates, two replications of 100 seeds of each variety were sown in moist sterilized sand in plastic boxes. Twenty seedlings of the susceptible SL 28 control were sown alongside the test seedlings in each box. Inoculation and incubation procedures described by Van der Vossen et al. (1976) were followed. At the end of the incubation period which lasted about three weeks and determined by full expression of disease on the susceptible SL 28 variety, the seedlings were individually scored for disease symptoms developed on the hypocotyls stem using the scale of Van der Vossen et al. (1976). A mean grade was computed for each box and the results were subjected to an analysis of variance using the MSTAT statistical programme.

Table 2. Some characteristics of Coffea arabica varieties used for host-pathogen interaction analysis.

Variety	Characteristics
Rume Sudan	Introduced into Kenya from Boma Plateau in Sudan. Resistant to CBD at the R-, and k- loci.
Pretoria	Ex-Guatemala variety introduced to Kenya from Lyamungu, Tanzania. Resistant to CBD at the R- and k-loci.
Hibrido de Timor	Introduced to Kenya from the Rust Research Center (CIFC) at Oeiras, Portugal in 1960. It is a spontaneous hybrid combining CBD resistance at the T- locus with rust resistance that is effective against most races.
K7	A selection from the French the French Mission coffee used as a commercial cultivar in Kenya. It has partial resistance to CBD at the k-locus and the most prevelant race II of Hemileia vastatrix.
Padang	Introduced from Gautamela and shows partial resistance to CBD.
Catimor	Introduced from Colombia and combines CBD resistance at the T-locus with rust resistance

Weather parameters

Average monthly rainfall and temperature (minimum and maximum values) were recorded for two years at Ruiru and Kitale to determine the correlation between CBD incidence and the prevailing weather conditions.

RESULTS AND DISCUSSION

Host Resistance

CBD was observed on five trees in a block of 4631 trees at Kitale. Similar hybrids at Ruiru had no CBD symptoms. Infected trees at Kitale had disease levels ranging from 7–70%. Laboratory screening data indicated that the proportion of seedlings in the resistant classes was low among the infected trees but high in the infected hybrids (Figure 1). The pattern of seedling distribution of susceptible SL 28 variety was clearly distinct from the hybrids with all seedlings falling in the susceptible classes of 11 and 12. This observation is consistent with the theory of dosage effect of genes. The hybrid populations tested is a mixture of plants with one or two genes of resistance. Resistance at two loci appears to confer better resistance at Kitale. Narrow based resistance is not stable across locations.

Host x Pathogen Interaction

Results of the analysis of variance on the host x pathogen interaction data indicate that the only significant effect ($p < 0.05$) was due to varieties (Table 3). The main effect of isolates and the interaction effects of varieties x isolates were both non-significant. It can be concluded that there is no genetic variability among isolates of the fungus causing CBD. Therefore, the observed variation in field resistance of mature coffee trees is not due to variations in the pathogen population. Similar results were been reported by Omondi et al. (2001).

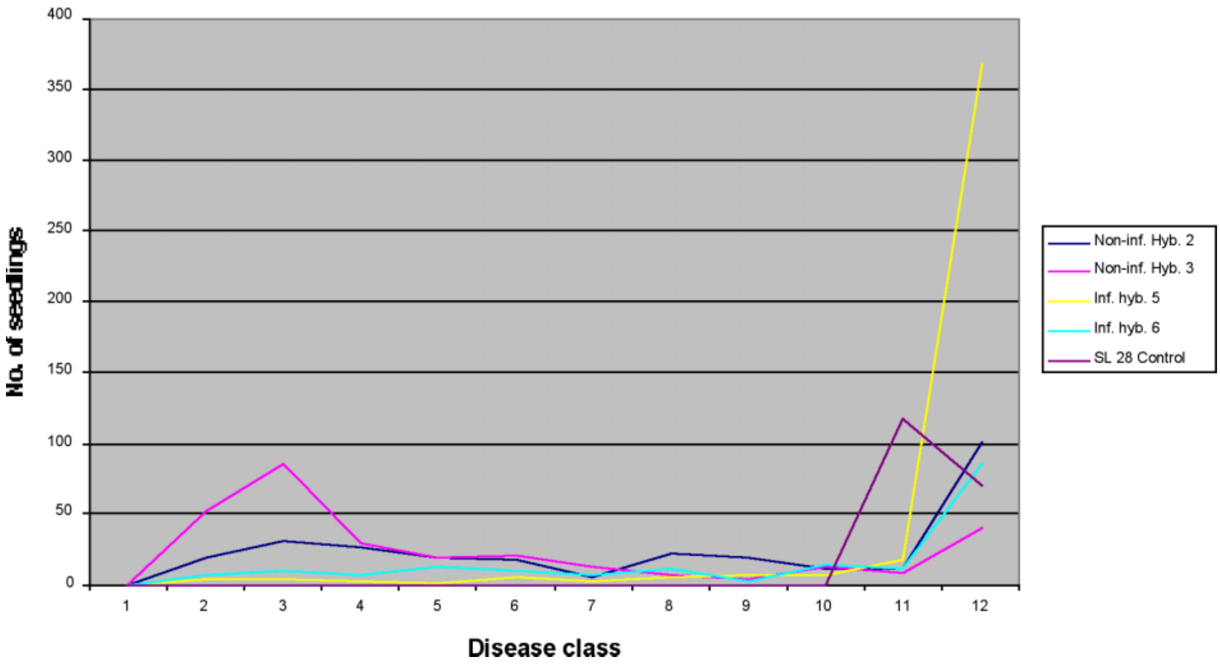

Figure 1. Distribution of screened seedlings from infected/non-infected trees and SL 28 control over a 12-class disease scale.

Table 3. Reaction of six coffee varieties varying in resistance/susceptibility tested with 12 isolates of C. kahawae.

Isolates	Varieties						Mean*
	Rume Sudan	Catimor	Pretoria	Hibrido de Timor	K 7	Padang	
KM 30	6.36	7.18	8.59	8.73	10.61	10.10	8.59A
KM 13	7.37	5.17	8.85	9.55	9.51	9.93	8.39A
KW 33	5.84	8.01	9.32	6.77	9.11	8.97	8.00A
KC 10	6.81	7.96	11.79	9.85	9.56	11.82	9.63A
KC 4	6.30	6.71	7.63	8.58	8.20	6.39	7.30A
KW 3	9.43	7.34	9.93	8.21	9.76	10.82	9.25A
KW 41	9.58	7.71	9.99	11.13	9.06	10.21	9.61A
KE 15	7.40	7.30	9.99	8.71	9.98	11.05	9.07A
KW 39	6.60	7.80	9.48	9.15	7.12	10.12	8.41A
KM 29	8.18	5.89	10.64	10.03	9.84	10.71	9.38A
KP 1	8.80	11.28	10.24	10.37	7.73	10.39	9.80A
KM 19	8.12	6.74	9.92	10.44	9.10	10.41	9.12A
Mean*	7.56B	7.44B	9.70A	9.37A	9.13A	10.08A	8.88

**Means followed by the same letter along the rows or columns are not significantly different according to Duncan's Multiple Range Test (P<0.05).*

Weather Parameters

Weather data recorded during the two years of the experiment are presented in Table 4. The data indicate that:

1. the average maximum and minimum temperatures did not show much variation at both sites

2. the months of May to August which coincided with peak CBD season in both sites were wetter in Kitale than in Ruiru.

It is therefore evident that wet weather conditions at Kitale were favourable for disease expression on hybrids with narrow resistance base. The incidence and severity of CBD on resistant hybrids will continue to be assessed at Kitale site with the ultimate goal of identifying trees which show no CBD symptoms. Selected trees with specific adaptation will be cloned using tissue culture and released for cultivation.

Table 4. Mean monthly rainfall and temperature records for the years 1999 and 2000 at Kitale and Ruiru.

Kitale							Ruiru					
Month	Year 1			Year 2			Year 1			Year 2		
	Rainfall (mm)	Temperature (°C)		Rainfall (mm)	Temperature (°C)		Rainfall (mm)	Temperature (°C)		Rainfall (mm)	Temperature (°C)	
		Max	Min		Max	Min		Max	Min		Max	Min
Jan	7.1	27.8	11.2	19.3	28.2	10.1	3.3	28.0	11.7	5.9	26.2	10.3
Feb	3.3	29.7	10.5	0.0	28.4	10.2	0.0	29.2	10.8	0.0	28.6	8.5
March	86.2	26.9	13.4	13.6	29.2	12.1	185.5	29.1	13.5	52.8	28.5	12.5
April	180.9	26.7	13.5	126.9	27.6	13.7	163.1	25.8	13.9	105.9	26.7	13.6
May	92.7	25.3	12.9	144.1	25.7	13.4	26.2	25.3	13.1	32.3	25.9	12.1
June	171.3	24.1	12.0	73.9	25.1	12.0	0.4	24.2	11.5	15.4	23.9	11.5
July	121.6	23.3	11.5	145.2	24.1	12.5	10.4	22.8	11.1	31.1	22.6	10.2
Aug	103.9	24.2	11.5	184.6	24.1	11.5	22.4	22.9	11.3	5.9	25.1	10.7
Sept	74.2	25.3	11.4	57.9	25.3	11.1	5.5	25.8	11.0	22.7	25.8	10.8
Oct	275.3	25.7	13.0	-	-	-	32.9	26.5	12.2	2.7	27.9	12.6
Nov	63.6	24.9	11.7	-	-	-	285.7	24.6	12.9	186.1	26.1	13.2
Dec	15.9	25.7	11.1	-	-	-	208.0	24.1	12.8	69.1	26.0	12.7
Total/ Mean	1196.0	25.8	12.0	765.5	26.4	11.8	943.4	25.6	12.2	529.9	26.1	11.6

CONCLUSION

Expression of resistance to CBD can be observed on varieties carrying single or multiple genes. Broad based resistance appears to be more stable across locations with varying environmental conditions. There was no indication of genetic variability in the pathogen population in this study.

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Genetic Diversity in the Coffee Wilt Pathogen (*Gibberella Xylarioides*) Populations: Differentiation by Host Specialization and RAPD Analysis

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SUMMARY

Gibberella xylarioides (*Fusarium xylarioides*) causes vascular wilt disease, tracheomycosis, in almost all coffee species in Africa. Coffee wilt disease is endemic with certain outbreaks on Arabica coffee (*Coffea arabica* L.) in Ethiopia and re-emerged as a mjor threat to Robusta coffee (*C. canephora*) in Congo (Zaire), Uganda and Tanzania. The population structure of the pathogen was studied in recent and historic strain collections employing pathogenicity and RAPD-PCR analysis. In the pathogenicity test that consisted of 11 isolates and 9 cultivars from Arabica and Robusta coffee, the Arabica isolates were pathogenic only to seedlings of *C. arabica* with significantly varying degrees of aggressiveness across cultivars, but incompatible with seedlings of *C. canephora*. In contrast, the Robusta strain was specifically compatible with seedlings of *C. canephora* without showing any infection symptom in all *C. arabica* cultivars. This result is the first cross-inoculation evidence proving host specialization of *G. xylarioides* populations to the two economically important coffee species. There existed also highly significant differences among cultivars, isolates and cultivars-isolates interactions. In the RAPD-PCR analysis of 22 *G. xylarioides* strains of the recent and historic collections from Arabica, Robusta and Excelsa coffee, the Ethiopian Arabica isolates clustered into a single homogeneous population although distinctly polymorphic to the recent and old strains from *C. canephora* and *C. excelsa*. The recent Robusta isolate from Uganda showed close genetic relatedness to the historic strain collected from *C. excelsa* in Central African Republic (CAR) suggesting that the current tracheomycosis outbreaks might have been caused by the fungus inculum originated from *C. excelsa* in CAR spread to Uganda via Congo. The historic Arabica isolate (1971) was slightly different from the recent (2001) collections in Ethiopia illustrating little genetic change in the population structure over the last 3 decades. This in turn implies that the sexual (teleomorphic) state of the fungus has little contribution to the population genetics rather serving for survival and dissemination mechanisms. The findings of both host-pathogen interactions and RAPD-PCR markers corroborated existence of host specialization into at least two pathogenic forms within *G. xylarioides* populations. Thus two *formae speciales*, namely; *G. xylarioides* f.sp. *abyssiniae* (anamorph: *F. xylarioides* f.sp. *abyssiniae*) for the fungus strains attacking only *C. arabica*; and *G. xylarioides* f.sp. *canephorae* (anamorph: *F. xylarioides* f.sp. *canephorae*) pathogenic to *C. canephora* and *C. excelsa* are proposed. This subdivision enables to design effective coffee wilt management strategies, develop resistant cultivars/lines and formulate further breeding programs towards each population group in Africa.

INTRODUCTION

Gibberella xylarioides Heim & Saccas (anamorph: *Fusarium xylarioides* Steyaert) causes a vascular wilt disease referred to as tracheomycosis. It was perhaps historically the first renowned coffee disease causing large-scale damages to plantations of various *Coffea* spp. in Africa in the early 1950s (Wellman, 1961; Kranz, 1962; Muller, 1997). In Ethiopia, the earliest unequivocal record of tracheomycosis and its causal pathogen on *C. arabica* as a new host was reported by Kranz and Mogk (1973). Subsequent surveys accompanied by isolation works verified occurrence of the disease in most coffee growing areas of the country. During the past years, the incidence and distribution of coffee wilt disease (CWD) has been remarkably increasing throughout the major coffee producing districts in the south and south-west of Ethiopia (Girma et al., 2001; Girma and Hindorf, 2001).

Tracheomycosis re-emerged as a serious disease of coffee in Africa and certain factors, acting either independently or in concert, have been postulated about its reappearance and becoming a major constraint to coffee production in this continent (Flood and Brayford, 1997; Girma and Hindorf, 2001; Girma 2004). *G. xylarioides* is a heterothallic ascomycete producing perithecia on dead coffee plants (van der Graaff and Pieters 1978, Flood and Brayford 1997, Girma et al., 2001). *In vitro* mating tests of the fungus isolates confirmed formation of fertile perithecia with oozing ascospores in culture (Girma, 2004). Genetic diversity is most likely expected in such heterothallic organisms where recombination by meiosis would generate a large number of various unique genotypes (Chen and McDonald, 1996). By analyzing the structure of the pathogen populations it is possible to understand the change in populations, and that provides the basis for disease management strategies including development and use of resistant hosts (Leung et al., 1993). The determination of the virulence spectrum with a set of differential varieties and variety of neutral markers distributed randomly in the genome have been used extensively to define fungal populations at species, infraspecific and strain levels including *Fusarium* spp. (Leung et al., 1993; Bentley et al., 1995; Migheli et al., 1998). The objectives of this study were to determine host specialization and pathogenic variation of *G. xylarioides* strains on *C. arabica* and *C. canephora* and to assess genetic diversity in the fungal populations of recently isolated and historic strains collected from different *Coffea* spp. in various geographic regions in Africa employing RAPD-PCR analysis.

MATERIALS AND METHODS

Pathogenicity test

Ten *G. xylarioides* isolates: Gx1-Gx9 and Gx11 were selected from large collections grouped basically on cultural differences and geographic origin ranging in altitudes (1000 to 2000 m) from 10 major Arabica coffee growing districts under semiforests, gardens and plantations conditions in the south and south-west of Ethiopia. A Robusta isolate (Gx12) obtained from Uganda was also included for host specificity analysis. A total of 5 *C. arabica* cultivars, namely 2485, 7440, F-59, Catimor-J19 and Caturra Rojo; representing indigenous and exotic coffee collections, and one *C. canephora* line were considered in the experiment. Seedlings of each coffee cultivar were raised in heat sterilized sandy soil in plastic boxes, and inoculated at cotyledon stage with conidia of each isolate cultured on sterile coffee twigs. The suspensions were adjusted to 2.2×10^6 conidia/ml and then inoculated by a stem nicking technique (Pieters and van der Graaff, 1980; Girma and Mengistu, 2000). The experiment was laid out in a randomized complete block design with 3 replications in factorial treatment combinations of 11 isolates and 6 cultivars (20 seedlings/treatment). Seedlings treated in the same way with sterile water were included as control. The number of seedlings showing wilting symptoms were recorded and the date, on which symptoms first appeared on the seedlings were noted to determine incubation periods. The percentage of dead seedlings was computed and then transformed to arcsine-square root (angular) values to normalize the data. The analysis of variance (ANOVA) and means comparisons of the two parameters (% wilt and incubation periods) were performed by general linear model procedure of SAS program (SAS 8.1, SAS Institute Inc.).

Random amplified polymorphic DNA (RAPD-PCR) analysis

Twenty two *G. xylarioides* isolates, comprising 17 recently isolated strains (1999-2001) from Arabica coffee (Ethiopia), 1 strain from Robusta coffee (Uganda) and 4 historic collections (1963-1971) from Arabica (in Ethiopia), Robusta (in Guinea) and Excelsa (in Centeral African Republic) coffee; were subjected to RAPD-PCR analysis. The isolates were grown in 30 ml malt yeast peptone (Merck) liquid media for DNA extraction after 3-4 days. DNA extraction was effected employing DNeasy Plant Mini Kit (Qiagen, Germany) according to the procedures outlined in the manufacturer's handbook.

Twelve 10-16 (mer-) oligonucleotide primers (Carl Roth, Karlsruhe), that indicated inter- and intra-species variation in the genus *Fusarium* (Hering, 1997) were selected and used. The PCR reaction mixtures setup and amplification conditions were independently optimized and standardized for each 10-mer and 15- or 16- mer primers group. Accordingly, the reaction protocol for decamer primers were made to the final concentration of 1x reaction buffer of 10x PCR buffer with $(NH_4)_2SO_4$, 0.2 mM of 2 mM dNTP mix (each dATP, dCTP, dTTP and dGTP), 3.5 mM of 25 mM $MgCl_2$, 1.0 µM of primer (10 µM) and 1U (0.18 µl) *Taq* DNA polymerase (5U/µl) (MBI, Fermentase). The reaction protocol for the 15- /16- mer primer group was the same except the final concentration of $MgCl_2$ was reduced to 3.0 mM. Amplification was performed in a Minicycler or PT-100 Thermal Cycler (MJ Research) programmed to initial denaturation temperature of 94°C for 2 min, followed by 35 cycles of denaturation at 94°C for 1 min, annealing at 37°C for decamer (50°C for 15-/16- mer) primers for 1 min and elongation at 72°C for 2 min followed by final extension at 72°C for 5 min.

The PCR products were electrophoresed in 1.5% agarose gel (Sigma) prepared in 1x Tris-acetate-EDTA (TAE) buffer and stained with 1% Ethidium bromide (10 mg/ml). The resolved bands were viewed over UV-light and visually scored as present (1) or absent (0). Genetic distance matrix between all pairs of the isolates were computed to construct a phylogenetic tree according to the unweighted pair-group method with arithmetic average (UPGMA) NEI (1987) using PAUP software (Swofford, 1998).

RESULTS

Host specialization and pathogenic diversity in *G. xylarioides* populations

C. canephora appeared to be very susceptible and was severely attacked (84.1%) with its own isolate (Gx12) within a short period of 44 days (Table 1 and 2). However, seedlings of that coffee species were incompatible with all the Arabica isolates (Gx1-Gx9 and Gx11) and no infection symptom was observed even after terminating the experiment 12 months later. The Robusta strain was non-pathogenic to Arabica coffee while Arabica isolates were non-pathogenic to Robusta coffee, thus proving host specificity or specialization of *G. xylarioides* populations to each *Coffea* spp.. There existed also highly significant ($P < 0.001$) differences among Arabica cultivars, the isolates and cultivar x isolate interactions both in percent wilt of seedlings and incubation periods. Among the cultivars, Catimor-J19 showed significantly ($P < 0.05$) low mean percentage of dead seedlings of 22.2%, followed by cultivar 7440 with 47.4% (Table 1). Incubation periods for these cultivars were about 70 and 83 days, respectively

(Table 2) and they turned out to be highly and moderately resistant to the coffee wilt agent. The highest mean incidences were observed on cultivar F-59 (71.4%) and Caturra Rojo (67.4%) with significantly ($P < 0.05$) short incubation periods. F-59 exhibited unexpectedly more susceptibility than the susceptible check (2485).

There were significant ranges of variation in aggressiveness among isolates of Arabica coffee. Isolate Gx3, Gx5 and Gx8 caused significantly ($P < 0.05$) low seedling infections of 38.0, 33.2 and 35.6%, respectively, with long incubation periods. On the other hand, significantly ($P < 0.05$) high mean death rates of 58.1, 57.3, and 67.8% were induced with isolates Gx1, Gx4 and Gx11, respectively (Table 1 and 2). Thus Gx1, Gx4 and Gx11 isolates were most aggressive while Gx3, Gx5 and Gx8 proved to be less aggressive strains. In comparing cultivar *vs*. isolate interactions (differential effects), there were low levels of infections on cultivar 7440 with Gx3, Gx5, and Gx8 with respective wilt incidences of 30.8, 30.5 and 27.1%, while severe seedling deaths of 66.2, 65.8, 62.7 and 86.0% were induced on the same cultivar with isolate Gx1, Gx4, Gx7 and Gx11, respectively. Cultivar 2485 and Caturra Rojo were susceptible but moderately tolerant to Gx3, Gx5 and Gx8 isolates (Table 1 and 2).

Table 1. Percent wilt of *Coffea arabica* and *Coffea canephora* seedlings inoculated with 11 *Gibberella xylarioides* isolates collecetd from various geographic origins[1]

Isolate[2]	*Coffea arabica* cultivars					*Coffea*	Mean[3]
	Catimor-J19	7440	F-59	Caturra Rojo	2485	*canephora*	
Gx 1	30.6 p–r	66.2 f-j	90.0 a	83.5 a-c	78.2 a-f	0.0 v	58.1 B
Gx 2	19.9 r-u	52.5 j-n	78.2 a-f	81.7 a-d	69.6 c-i	0.0 v	50.3 C
Gx 3	17.4 r-u	30.8 p-r	64.6 f-j	64.9 f-j	50.3 k-o	0.0 v	38.0 E
Gx 4	27.9 q-s	65.8 f-j	83.9 ab	85.7 ab	80.3 a-e	0.0 v	57.3 B
Gx 5	8.8 uv	30.5 p-r	67.3 e-i	47.6 l-o	44.6 m-o	0.0 v	33.2 E
Gx 6	8.3 uv	42.3 n-p	77.4 a-f	65.2 f-j	68.4 d-i	0.0 v	43.6 D
Gx 7	24.3 r-t	62.7 g-k	81.7 a-d	81.8 a-d	68.9 d-i	0.0 v	53.2 BC
Gx 8	14.4 tu	27.1 q-t	75.0 b-g	58.7 h-l	38.0 o-q	0.0 v	35.5 E
Gx 9	15.0 s-u	57.5 i-m	85.7 ab	81.6 a-d	62.5 g-k	0.0 v	50.4 C
Gx 11	77.2 a-f	86.0 ab	81.5 a-d	90.0 a	72.2 b-h	0.0 v	67.8 A
Gx 12	0.0 v	0.0 v	0.0 v	0.0 v	0.0 v	84.1 ab	14.0 F
Mean	22.2 T	47.4 S	71.4 P	67.4 Q	57.6 R	7.6 U	

[1]Percent wilt was calculated from cumulative number of dead over total number of seedlings (20 per treatment) 6 months after inoculation, and the actual wilt values were arcsine-square root transformed to normalize the data. [2]Gx1, Gx2, Gx3, Gx4, Gx5, Gx6, Gx7, Gx8, Gx9, Gx11 and Gx12 designate Gibberella xylarioides isolates collected from Jimma, Gera, Chira, Gechi, Yayo, Mettu, Tepi, Bebeka, Ayraguliso, Yirgacheffe and Uganda (Robusta strain), respectively. [3]Means followed with the same letter(s) are not significantly different from each other and least significant difference (LSD) values (P = 0.05) for the cultivars, the isolates and the interactions comparisons are 3.5, 4.7, and 11.6, respectively. CV = 15.8%.

RAPD–PCR analysis

Out of 12 oligonucleotide primers used in the RAPD analysis, 5 primers produced informative and reproduceable polymorphic DNA banding patterns. The analysis showed that all the recent Arabica isolates including those isolates derived from the same ascus had monomorphic RAPD amplifications. There were, however, clear DNA polymorphism among *G. xylarioides* strains from *Coffea arabica*, *C. canephora* and *C. excelsa* with varying fragment lengths (Figure 1). The dendrogram grouped these isolates into three clusters with reliable bootstrap values ranging between 73 and 96% (Figure 2). The Arabica isolates of Ethiopia clustered into one major group with two subgroups of the recent and historic collections indicating that there is no genetic variation within the pathogen populations in the diverse sampling locations. The subgroupings, however, suggested slight differences between recent and historic isolates. The two historic strains collected from Robusta coffee in Guinea formed the second cluster with high bootstrap value of 96% confidence. The recent Robusta isolate from Uganda clustered with the old Excelsa strain of the Central African Republic (CAR) with a robust bootstrap value of 73% (Figure 2) implying close genetic relatedness between the two strains originated from the different host species in geographically separated but neighbouring countries. The result of RAPD-PCR analysis revealed certain genetic diversity within the fungal populations across *Coffea* spp. and geographic origins. The Arabica strains of Ethiopia are genetically homogeneous but different from both the Robusta strains in Uganda and Guinea as well as the Excelsa strain in CAR.

Table 2. Incubation periods (days) after inoculating seedlings of *Coffea arabica* and *Coffea canephora* cultivars with 11 *Gibberella xylarioides* isolates collecetd from various geographic origins[1]

Isolates[2]	*Coffea arabica* cultivars					Mean[3]	*Coffea*
	Catimor-J19	7440	F-59	Caturra Rojo	2485		*canephora*
Gx 1	62.0 h-p	72.3 f-n	60.7 i-p	52.0 m-p	66.7 g-p	62.7 D	NIP
Gx 2	70.0 f-p	80.3 e-j	66.0 g-p	56.0 k-p	69.7 f-p	68.4 CD	NIP
Gx 3	65.3 g-p	92.3 c-f	80.7 e-j	65.3 g-p	70.0 f-p	74.7 BC	NIP
Gx 4	57.3 j-p	79.0 e-k	59.7 i-p	58.0 i-p	65.3 g-p	63.9 D	NIP
Gx 5	127.3 ab	112.3 bc	75.7 f-l	86.7 d-g	74.3 f-m	95.3 A	NIP
Gx 6	104.7 bcd	101.3 c-e	73.0 f-n	68.3 g-p	58.7 i-p	81.2 B	NIP
Gx 7	68.0 g-p	80.3 e-j	60.0 i-p	46.7 p	64.0 g-p	63.8 D	NIP
Gx 8	70.0 f-p	140.0 a	70.7 f-o	47.0 p	61.7 i-p	77.9 BC	NIP
Gx 9	85.3 d-h	77.3 f-k	60.3 i-p	52.7 l-p	81.0 e-i	71.3 BCD	NIP
Gx 11	56.0 k-p	79.3 e-k	72.7 f-n	50.3 n-p	48.7 op	61.4 D	NIP
Gx 12	NIP	NIP	NIP	NIP	NIP		43.7
Mean [3]	76.6 Q	91.5 P	67.9 R	58.3 S	66.0 R		

[1]*Incubation periods indicate the number of days between inoculation and the first date of symptom appearance; and NIP refers to no incubation period, i.e. there appeared no infection symptom on seedlings of Coffea arabica cultivars inoculated with the Robusta strain (Gx12) and on seedlings of C. canephora inoculated with the isolates from Arabica coffee until termination of the experiment.* [2]*Gx1, Gx2, Gx3, Gx4, Gx5, Gx6, Gx7, Gx8, Gx9, Gx11 and Gx12 designate Gibberella xylarioides isolates collected from Jimma, Gera, Chira, Gechi, Yayo, Mettu, Tepi, Bebeka, Ayraguliso, Yirgacheffe and Uganda (Robusta strain), respectively.* [3]*Means followed with the same letter(s) are not significantly different from each other, and LSD values (P = 0.05) for cultivars, isolates and interactions comparisons are 7.5, 10.6, and 23.6, respectively. CV = 20.2%.*

DISCUSSION

All *G. xylarioides* isolates from *C. arabica* were pathogenic to seedlings of the host cultivars with varying levels of aggressiveness but non-pathogenic to *C. canephora*. Conversely, the strain from *C. canephora* was highly pathogenic to seedlings of its host but not to the *C. arabica* cultivars and thus indicating incompatible host-pathogen interactions. This is, to our knowledge, the first cross inoculation experiment that clearly evidenced host specialization of *G. xylarioides* populations to the two commercial coffee species. There were similar observations in the field (Girma et al. 2001, Flood 1997).

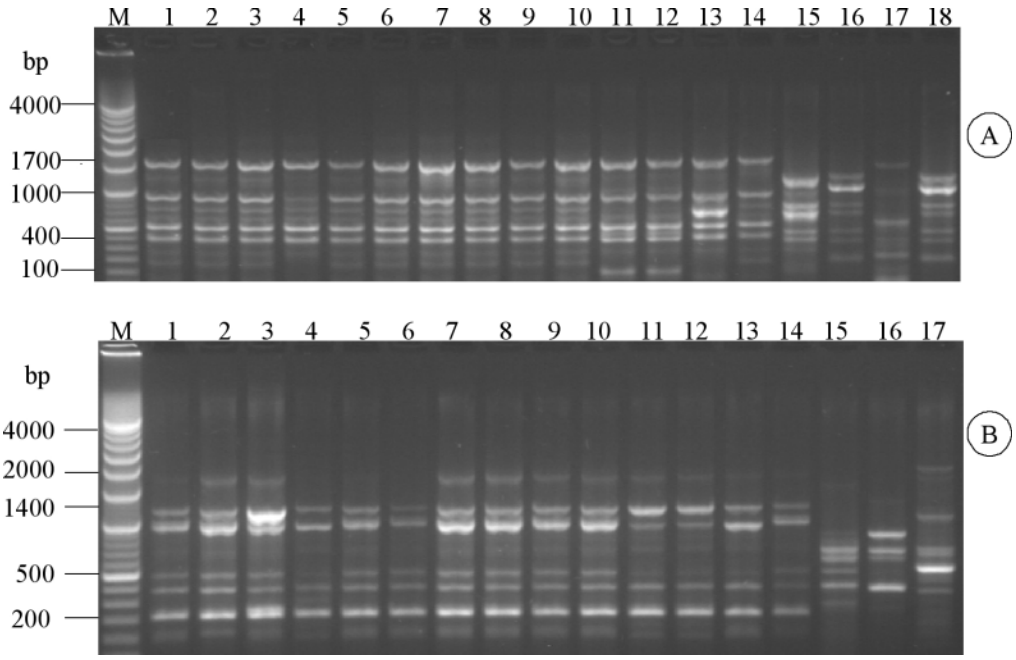

Figure 1. RAPD patterns of selected *Gibberella xylarioides* isolates and other *Fusarium* spp. generated by primer P5 (5´- GAG GGT GGC GGT TCT– 3´) (A) and P63 (5´-CAG CAG GTC GAT GCG– 3´) (B). Lane M is a molecular size marker (500 and 100 bp), lanes 1-3 and 5-10 are recent Arabica isolates (lanes 8-10 derived from an ascus), lane 4 recent Robusta isolate, lanes 11 and 12 old Robusta isolates, lane 13 historic Excelsa isolate, lane 14 historic Arabica isolate; and lanes 15, 16, 17 and 18 are *Fusarium stilboides, F.* cf. *eumartii, F. lateritium* var. *longum*, and *F. solani,* respectively.

There occurred highly significant differences among Arabica cultivars, *G. xylarioides* isolates and cultivar-isolate interactions, suggesting horizontal resistance in the host, aggressiveness in the pathogen and vertical resistance/virulence combinations, respectively. This result, which is consistent with the previous findings of Girma and Mengistu (2000) is not congruent with the work of Pieters and van der Graaff (1980). Catimor-J19 showed horizontal resistance although it was highly infected by an isolate from Yirgacheffe (Gx11). Cultivar 7440 became moderately resistant while Caturra Rojo and 2485 were susceptible to the Arabica isolates. Catmor-J19 also showed dramatically low incidence in the field where the other cultivars succumbed to wilt. Lines of *C. arabica* derived from the Timor hybrid are resistant to almost all races of coffee leaf rust (CLR), *Hemileia vastatrix*, and to root-knot nematode, *Meloidogyne exigua* (Walyaro 1997, Bertrand et al. 2001). The Timor hybrids have been crossed with several commercial varieties such as Caturra through recurrent breeding and released for large-scaled production in Brazil, Colombia and other Latin American countries (Fazuoli et al. 1999, Bertrand et al. 2001). Similarly Catimor-J19 was among the introduced F-5 Timor hybrids released for large-scale production in low altitude areas of Ethiopia as it was found to be resistant to CLR races although very susceptible to coffee berry disease (CBD) caused by *Colletotrichum kahawae* under conditions favouring the disease (Bayetta et al., 1998).

RAPD-PCR analysis with 5 oligonucleotide primers produced clear DNA polymorphism among *G. xylarioides* isolates of *C. arabica*, *C. canephora* and *C. excelsa*. All isolates collected from *C. arabica* in Ethiopia in 2001 revealed monomorhpic DNA banding patterns and clustered into a single group indicating homogeneity of the population. Eventhough they originated from diverse environments like host cultivar, agroecological zones as well as production systems and varied significantly in aggressiveness in the pathogenicity test. The historic Arabica strain of 1971, however, seems to be slightly different from the recent Arabica collections that may implicate little genetic changes in the pathogen populations over the last 30 years (1971-2001). This in turn shows that the sexual state of the fungus has little contribution to determine the population structure rather serving as survival and dissemination mechanisms.

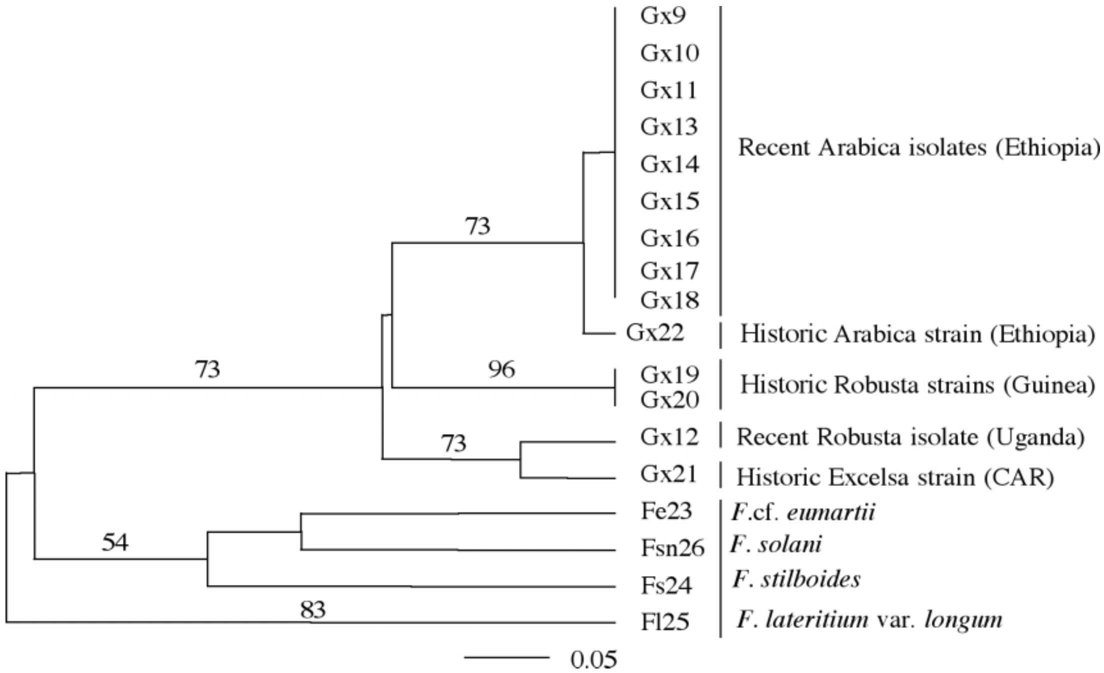

Figure 2. Clustering of *Gibberella xylarioides* strains from *Coffea arabica*, *Coffea canephora* and *Coffea excelsa* and other *Fusarium* spp. on the basis of genetic similarity coefficients or distance matrix of RAPD profiles produced with 5 primers generated by UPGMA. (Numbers on the branches indicate the confidence intervals obtained by bootstraping with 500 replications).

The two historic collections (Gx19 and Gx20) from *C. canephora* in Guinea clustered to a separate sub-population specific to West Africa and might have been introduced with planting material from the neighbouring Ivory Coast as speculated by Kranz (1962). The recent Robusta strain (Gx12) obtained from Uganda, however, showed close genetic relatedness to the historic Excelsa isolate (Gx21) collected in the Centeral African Republic (CAR) most probably during the earliest tracheomycosis outbreaks in the 1950s. CWD was originally recorded destroying *C. excelsa* in the CAR and seriously attackimg lines of *C. canephora* in Congo (Muller, 1997). It re-appeared in the mid 1980s and devastated Robusta coffee in eastern Congo, and some years later became a serious coffee disease in Uganda. Thus far it was highly believed that CWD was introduced to Uganda from Congo (Flood, 1997; Lukwago and Birkunzira, 1997). The results of RAPD-PCR analysis backed up with the historical background of the disease show that the strains attacking *C. canephora* both in Congo and Uganda most probably belong to the same population that might have originated from *C. excelsa* in CAR spread to Uganda via Congo. Similar work by Janzac et al. 2004 (this proceedings), employing microsatellite markers, indicated that large samples of *G. xylarioides* isolates collected from *C. canephora* in Congo, Uganda and Tanzania were homogeneous population.

The pathogenicity test combined with molecular markers evidenced host specialization of at least two pathogenic forms within *G. xylarioides* populations that might have attained pathogenic fitness through coevolution. Thus we propose two *formae speciales* namely

Gibberella xylarioides f.sp. *abyssiniae* (anamorph: *Fusarium xylarioides* f.sp. *abyssiniae*) for the fungus strains attacking only *Coffea arabica* and confined to Ethiopia; and *Gibberella xylarioides* f.sp. *canephorae* (anamorph: *Fusarium xylarioides* f.sp. *canephorae*) pathogenic to *C. canephora* and *C. excelsa* in West and Central African coffee growing countries.

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Mode of Penetration and Symptom Expression in Robusta Coffee Seedlings, Inoculated with *Gibberella xylarioides*, the Cause of Coffee Wilt Disease in Uganda.

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SUMMARY

Coffee wilt disease caused by *Gibberella xylarioides* (*F. xylarioides*) is the most destructive disease of robusta coffee (*Coffea canephora* Pierre) in Uganda. Robusta is a major export crop and foreign exchange earner for Uganda. Control of the disease has been hampered by lack of information on the etiology of the pathogen, its epidemiology and cultural practices that influence spread of the disease. The goal of this study was to determine how the fungus infects the host plant and subsequent symptom development. Inoculation experiments were conducted using susceptible robusta coffee seedlings of 6-8 months old, under screen house conditions from 2002-2003 to establish mode of penetration of the host by the pathogen. Wounded and unwounded stems, leaves and roots were inoculated with a spore suspension containing 1.3 x 10^6 spores/ml. Stems were inoculated at 3 points/positions along the stem (stem base, half way and just below the growing point). Roots were inoculated by dipping bare roots of seedlings in similar spore suspension and by drenching. Unwounded inoculated seedlings remained assymptomatic. Seedlings inoculated after wounding at the stem bases and those inoculated by root dip developed systemic infection of CWD and attained highest wilt incidence and mortality. In seedlings where inoculations were done just below the growing points, these original growing points wilted and dried up. However, one or two new shoots were produced just below the inoculation points and no mortality occurred. No infection or symptoms occurred in leaf inoculations. In general, inoculations on the aerial plant parts in the absence of wounds resulted in no infection. Wounding in the lower half of plants in the presence of inoculum and favourable environmental conditions resulted in development of wilt symptoms on more seedlings than those inoculated on the upper plant parts. These experiments confirm that infection by *G. xylarioides* largely occurs through wounds on the roots and lower parts of stems. Wounding of plants under field conditions normally occur during field operations such as weeding by hoeing, slashing and pruning, which are likely avenues for infection by the wilt pathogen.

INTRODUCTION

Coffee wilt disease is the most widespread and damaging disease of robusta coffee in Uganda since its appearance in the early 1900's (Hakiza, 1995; Hakiza and Mwebesa, 1997; UCDA, 2000). The causal agent is a vascular wilt fungus, *Fusarium xylarioides* Steyaert (teleomorph *Gibberella xylarioides* Heim and Sacc.). The disease also occurs in other African countries such as the Democratic Republic of Congo (DRC), Tanzania and Ethiopia. It remains a threat to the other nations bordering those already invaded. The fungus attacks all species of coffee causing a vascular wilt, commonly known as tracheomycosis, which lead to death of the plant.

The effect on the smallholder coffee farmers has been devastating. In the absence of effective control, poverty at farm level will continue to increase. Worse still, there is scanty information on the epidemiology of the disease. This has frustrated the development of effective disease management strategies. Although it is believed that infection occurs through wounds on all above ground parts of the plant, this has not been fully demonstrated. The objective of the current study is to identify the main mode of entry of the pathogen into the host tissue with a view of using this information for formulation of control strategies.

MATERIALS AND METHODS

Source of plant materials

Robusta coffee seeds for raising seedlings for inoculations were obtained from the seed garden at the Coffee Research Institute, Kituza, Uganda. These comprised the clonal varieties 1s/2, 1s/3, 1s/6, 257/53 and 258/24(0). Parchment was removed from the seeds prior to planting in sand beds 5-7 cm deep, spaced at about 2.5 x 2.5 cm and covered with about 1cm of sand. A thin layer of grass mulch was then applied to maintain moisture and reduce temperature fluctuation. The grass mulch was removed as soon as germination occurred which was 4-6 weeks from planting. Transplanting of seedlings in polypots was done when the two cotyledons leaves started unfolding.

Suitable media commonly used at CORI are black organic forest soil or a mixture of two parts of garden topsoil and 2 parts of compost or manure. The mixture was wetted and sterilised by heat to destroy disease organisms and weed seeds e.g. Oxalis spp. When cool, polypots (of 15 cm x 22 cm laid flat, gauge 250) were filled with the sterile soil mix. Each pot had two rows of perforations at the lower end to facilitate drainage. The transplanted seedlings were maintained in the nursery.

Inoculum preparation

Inoculum was obtained from naturally infected plants in the field. Wilt infected stems or branches were collected from farmers' field. Isolation of the pathogen from infected plant parts was done within 1-7 days from collection. In the laboratory, suitable pieces of wood, about 20mm were trimmed off from the margins of the infected tissues and surface sterilized in 2% (v/v) of Jik (Sodium hypochlorite 3.5%, Reckitt Benckiser East Africa Limited, Nairobi, Kenya) for 3 minutes, then rinsed in three rounds of sterile distilled water. Excess moisture was removed with sterile tissue paper and aseptically placed onto agar plates (Petri dishes 9cm diameter containing 2% Tap Water Agar (TWA) and incubated at room temperature (23-25°C) under fluorescent light. Three to four days later, the fungal colonies were examined and identified, and single spore isolates of *F. xylarioides* made. Conidia required for inoculations were produced on Synthetic Nutrient Agar (SNA), from 10-14 day old single spore cultures.

Conidial suspension for inoculations was prepared by adding sterile distilled water, rubbing the culture surface gently with a sterile wire loop, and filtering through three layers of cheesecloth. The suspensions were adjusted with sterile distilled water to the desired concentrations using a haemocytometer.

Mode of infection

This was investigated by application of a standard inoculum (1.3×10^6 spores/ml) of *Fusarium xylarioides* to various plant parts, prior to and after wounding as indicated below. All the seedlings used in these studies were 6-7 months old.

Infection through roots

Intact root system

Uniform seedlings were selected and watered in the evening before inoculation. The next day each seedling received a drench of 20ml of the standard inoculum poured directly on the soil surface.

Wounded roots

The selected plants were first watered well, and then gently removed from their bags/pots. Soil attached to the root system was gently removed under running water. The root tips were cut once using a pair of scissors, prior to placing plants in the inoculum suspension for 2 hours. The treated plants were replanted in sterile soil, watered and placed under polythene cover for 24 hours after which they were placed randomly in the green house.

Stem wounding

A cut was made on the stem just below the second internode and a drop of the standard inoculum placed in the wound. The inoculated plants were carefully kept under polythene cover as for root dip.

Leaf inoculation

This was done in two ways. A set of 3 plants/clone had 4 of the fully opened leaves wounded on the under surfaces and inoculum was applied by spraying with an atomizer prior to placing them under cover as before. The leaves of the second set of plants were left intact and sprayed with inoculum as indicated earlier.

Root wounding

A sharp knife was used to cut the roots without uprooting the plants after which 20 ml of the spore suspension was poured/pot as in the case with drenching.

RESULTS

Symptoms on inoculated plants included wilting of leaves followed by defoliation, dieback from the apices and eventually death of plants. Wilted leaves remained green and abscission occurred very rapidly, so that recording was more frequent (once every 4 days) until death of plants or until 90 days after inoculation. In a few cases, leaves wilted, turned brown but remained attached to plants for at least up to 7 days. Latent period varied with inoculation methods. Re-isolation from the infected plants revealed Fusarium xylarioides.

No infection occurred on plants inoculated by through the leaves with or without wounding. The highest wilt incidence occurred in case of plants inoculated by rooting dipping (wounded), followed by stem wounding.

Plants inoculated by stem wounding at the base developed systemic wilt symptoms; unlike in plants wounded at the shoot tip. Most of those plants developed symptoms above the inoculation points and below inoculation point there were no symptoms.

Only the shoot tips developed symptoms and died 60 days from inoculation, while new shoots developed from just below the inoculation points.

The experiments imply that the pathogen is transported upwards from lower down the plant than downwards from point of inoculation. It also implies wounds on the roots or close to stem bases are more likely to cause fatal infection than from upper parts of the plants. Wounds appear to be essential for entrance of pathogen.

Under normal management practices, farmers are likely to wound plants on the root system or lower stem parts of stems or in normal pruning. These sites could provide avenues for infection. Grazing animals are normally tethered to the middle or lower parts of the coffee trees and these too can provide avenues for infection. Recommendations for farmers to avoid wounding any parts of plants could reduce entrance points for the pathogen.

Developing Mass Rearing Procedures for the Parasitoid *H. coffeicola* Schmeid for Control of the Coffee Berry Borer *Hypothenemus hampei* Ferrari

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SUMMARY

The coffee berry borer (*Hypothenemus hampei* Ferrari) undoubtedly is one of the most damaging pests of coffee worldwide (Moore et al., 1990; Guadalupe-Rojas et al., 1998). Use of pesticides for control of the pest is widely discouraged because of problems of pesticide residues in coffee beans, and effect of the pesticides on natural enemies of the borer and other beneficial insects. Biological control programmes based on use of the parasitoids *Prorop nasuta* (Waterston), *Cephalonomia stephanoderis* (Betrem) and *Phymasticus coffeae* (La Salle) have been successful in many countries including Colombia. However, attempts at use of the Braconid *Heterospilus coffeicola* (Schmeid), considered the most efficient at suppressing borer populations in its native Africa, have been largely unsuccessful owing to its inability to reproduce in captivity.

Studies were conducted in Uganda during 1999-2000 into aspects of the biology and ecology of *H. coffeicola* in order to develop procedures for its mass rearing. The study investigated the effect of temperature, light intensity, space and feeding on sexual behaviour, egg development, oviposition and fecundity. Results show temperature was not a critical factor in egg development but affected incubation period and proportion of the initial eggs developing into the larval, pupal and adult stages of the wasp. Conditions of illumination far stronger or weaker than normal daylight did not favour oviposition. The rate of oviposition in sleeve cages was also found to increase with size of the cages. Mating and feeding led to better and more viable eggs being oviposited.

The findings of the study were incorporated into the strategy for mass rearing of *H. coffeicola* for use in coffee berry borer biological control programmes in Africa and South America.

INTRODUCTION

The coffee berry borer (*Hypothenemus hampei* Ferrari) undoubtedly is one of the most damaging pests of coffee worldwide (Moore et al., 1990; Guadalupe-Rojas et al., 1998). The pest is endemic to Central and East Africa from where it has spread to Asia, and more recently to the Americas (Allard and Moore, 1989).

Up to 90% of coffee berries can be attacked with yield losses of up to 40% (Le Pelley, 1968). In Kenya, infestation levels of 80% during the peak season with similar magnitude of crop losses with reduction in quality of the remaining yield have been reported (Masaba et al., 1985). Severe infestation may result in up to 80% of berries being attacked in Uganda, Ivory

Coast and Brazil, 90% in Malaysia, 96% in Congo and Tanzania (Waterhouse and Norris, 1989). 21% of the export quality of coffee in Jamaica is estimated to be lost as a result of damage caused by *H. hampei* (Reid and Mansingh, 1985).

Although the pesticide endosulfan is known to be effective for control of *H. hampei* (Ingram, 1964; Baker, 1999), its use for control of the pest is widely discouraged because of problems of pesticide residues in coffee beans, and effect of the pesticides on natural enemies of the borer and other beneficial insects (Musoli et al., 2000), and pesticide resistance (Brun and Ruiz, 1987).

Cultural control practices such as frequent and careful harvesting to prevent infested berries falling to the ground, total removal of all berries from the bushes and the ground after the main harvest, open pruning of bushes to create positive environs for borer parasitoids have had limited success because the labour requirements render them unsuitable for large plantations, while the small scale farmers are less anxious to adopt such elaborate procedures (Moore et al., 1990).

The focus to-date is to develop classical biological control programmes that are cheap, safe and effective. Considerable progress has been achieved in the use of the entomopathogens *Beauveria bassiana* (Bustillo, 1998; Murillo, 1998) and *Metarhizium anisopliae* (Metsch.) (Lecuona et al., 1986; Bustillo, 1998) while the entomopathogenic nematode *Heterorhabditis sp*. has yielded promising results under optimum laboratory conditions (Allard and Moore, 1989).

Biological control programmes based on the use of the parasitoids *Prorop nasuta* (Waterston), *Cephalonomia stephanoderis* (Betrem) and *Phymasticus coffeae* (La Salle) have been adopted in many countries including Brasil, Ecuador, Colombia and Mexico (Klein Koch, 1989; Moore et. al., 1990; Mora et. al., 1998).

Despite the advances made in the use of *P. nasuta* and *C. stephanoderis*, it is contended that biological control of the borer solely based on the two parasitoids may be inadequate (Moore et. al., 1990). Hargreaves (1923) considered that together with *P. nasuta,* the parasitoid *Heterospilus coffeicola* (Schmied.) kept *H. hampei* infestation under control in Uganda. In a more recent study, Orozco-Hoyos and Kucel (2000) considered *H. coffeicola* the most efficient parasitoid suppressing borer populations in its native Africa.

Integration of the use of *H. coffeicola* in biological control programmes therefore offers the best prospects for enhancing the effectiveness of the programmes in controlling the coffee berry borer menace. However, attempts at use of the *H. coffeicola* have been largely unsuccessful owing to its inability to reproduce in captivity (De Toledo and Da Fonseca, 1935; Baker, 1999).

This study therefore broadly aimed at elucidating the biology and ecology of *H. coffeicola* essential for developing rearing techniques for the wasp, to open way for its successful utilization in biological control programmes of the coffee berry borer. Specifically, the study aimed to, amongst others, determine the ambient temperature for maximum mating, oviposition and fecundity, establish the influence of light intensity on mating behaviour and oviposition, establish the effect of space on mating and oviposition behaviour of *H. coffeicola*, and to determine the effect of feeding on sexual behaviour, oviposition, egg development and fecundity.

METHODOLOGY

The studies were conducted at the Coffee Research Institute, Uganda (0°15′N, 32°46′E) during 1999-2000. Investigations were made into aspects of the biology and ecology of *H. coffeicola* in order to develop procedures for its mass rearing. The study investigated, amongst others, the effect of temperature, light intensity, space and feeding on sexual behaviour, egg development, oviposition and fecundity.

Effect of temperature on egg development in adult female *H. coffeicola*

This study aimed at establishing the influence of temperature on egg development in adult female *H. coffeicola* in order to identify the optimum temperature range for egg development in the laboratory. A review workshop on *H. coffeicola* held during 7-8 November, 2000 in Mukono, Uganda, suggested that unfavourable temperature regimes in the laboratory is probably one of the factors responsible for poor egg development in adult females relative to that in their free living field counterparts.

Three groups of wasps, each consisting of several pairs of male and female *H. coffeicola,* were each placed in three well-ventilated plastic boxes complete with cotton bungs soaked in diluted honey to cater for the nutritional requirements of the wasps. Two of the boxes were separately placed in two incubators, one at a temperature of 19 $\pm$ 1°C and the other at 30 $\pm$°C. The third box was incubated at room temperature that averaged 27 to 28°C. Egg development in the females was assessed through daily dissections of samples drawn from each box.

Effect of space on oviposition by H. coffeicola

In a preceding trial, oviposition by *H. coffeicola* of up to 30% was realized in the laboratory using sleeve cages. Previous attempts to induce oviposition using much smaller cages were futile, hence it was suspected that differences in space could have been responsible for the observed differences. This study was therefore conducted to determine the influence of space on in-vitro oviposition by *H. Coffeicola*.

This trial was first conducted during March, 2001 and repeated during June, 2001.

2 sets of sleeve cages of different sizes were used in the experiment. The first set of 3 cubical sleeve cages each measured 45cm x 45cm x 60cm, while the second set consisted of 3 smaller but cylindrical sleeve cages 40cm long and 20cm in diameter. These were all fitted with cotton bungs soaked in diluted honey and placed side by side outside the laboratory under the same but improved conditions of temperature and illumination. A primary branch with coffee berries carrying 4 days hold CBB infestation were placed into each sleeve cage. Finally, 2 male and 3 female *H. coffeicola* were placed in each cage.

Effect of light on oviposition by *H. coffeicola*

Three sleeve cages, each measuring 45cm x 45cm x 60cm, had plastic trays containing an assortment of weeds placed in them. Primary branches with coffee cherries carrying 4 days old CBB infestation and cotton bungs soaked in diluted honey were placed in each of them. 3 males and 4 female *H. coffeicola* were introduced into each of the cages. The cages were then placed under different conditions of illumination as follows:- Cage 1 was exposed to light from a florescent tube representing a situation of continuous near double normal daylight; Cage 2 was exposed to normal daylight in the veranda of the laboratory, representing a situation of alternate normal daylight and night; Cage 3 was placed in a dark corner of the room representing a situation of continues near darkness. Oviposition in the cages was assessed after a period of 4 days.

Effect of mating and feeding by H. coffeicola on oviposition, fecundity and egg viability

The study was envisaged against the background that many parasitic wasp species neither require to feed nor mate in order to oviposit viable eggs. In other cases, viable eggs are laid but may fail to develop into the mature adult if the female was not well fed.

Four experimental treatments, each replicated three times, and consisting of mated females fed with honey, mated females which were not given any nutrients, unmated females fed with diluted honey, and unmated females not given any nutrients, all in sleeve cages, were established during May and June, 2001.

The ovipositon rate, egg development in the females, viability of eggs laid, and duration of the various developmental stages were separately assessed.

RESULTS AND DISCUSSIONS

Effect of temperature on egg development in adult female *H. coffeicola*

The findings of the experiment ate summarized in Table 1 below.

Table 1. Effect of temperature on egg development in adult female *H. coffeicola.*

Ambient Temperature	Dominant egg shape	Dominant egg colour	Dominant egg size	Remarks
19±1°C	Elliptical	Whitish	Small	Fair egg development
(Room temperature) 27-28°C	Irregular	Translucent	Small	Fair egg development
30±1°C	Irregular and shriveled	Translucent	Small	Fair egg development
Free living wasps	Elliptical	Whitish	Large	Standard

Egg development in the females based on shape and size of the eggs was largely similar under the three temperature regimes, although the temperature conditions below room temperature showed slightly better egg shape and size. Again, the free living *H. coffeicola* exhibited better egg development than those kept in the laboratory.
From the foregoing, temperature may not be a critical factor for egg development in *H. coffeicola,* but further investigations much higher and lower temperature regimes need to be carried out in order to fully understand its influence on egg development.

Effect of space on oviposition by *H. coffeicola*

Table 2 below summarises the findings of the study of effects of space on oviposition by *H. coffeicola.*

In the first trial, oviposition in the larger cages averaged 11.3% and that in the smaller cages averaged 5.6%. In the repeat trial, the larger cages recorded an average 2.5% oviposition while no oviposition was achieved in the smaller cages. It should be noted that the results of the second trial was to some extent affected by ants which invaded the honey soaked cotton bungs and uncontrolled sunshine in the veranda.

Table 2. Effect of space on oviposition by *H. coffeicola*.

Trial	Cage shape	Cage dimension	Mena ovipostion rate%
1st Trial	Cubical	45cm x 45cm x60cm	11.3
	Cubical	45cm x 45cm x60cm	2.5
2nd Trial	Cylindrical	20cm long x 20cm diameter	5.6
	Cylindrical	20cm long x 20cm diameter	0

The result of the above two studies appear to suggest that the rate of oviposition in the sleeve cages increase, albeit nominally, with size of the cages. In a preceding trial, oviposition by *H. coffeicola* of up to 30% was realized in the laboratory using sleeve cages. Attempts to induce oviposition using much smaller cages were futile, suggesting that cage size influences oviposition.

Effect of light on oviposition by *H. coffeicola*

Results of the study to investigate the influence of light on oviposition show that in the first trial, 2.5%, 22.9% and 2.5% of oviposition was obtained under electric tube lighting, normal daylight and dim light respectively, while in the second trial, 5.3% oviposition was obtained under normal daylight but no oviposition was recorded under the electric tube light and dim light.

From the above results, conditions of illumination far stronger or weaker than normal daylight do not favour oviposition.

Effect of mating and feeding by *H. coffeicola* on oviposition, fecundity and egg viability

The results of the study on the effect of mating and feeding by *H. coffeicola* on oviposition, egg viability and fecundity are presented in Tables 3 and 4 below:

Table 3. Effect of mating and feeding on oviposition by *H. coffeicola.*

Treatment	No of Females	No. of Males	No. of Berries	No. of eggs in cherries	No. of larvae in cherries	Oviposition rate (%)
Mated and fed	**4**	**2**	**119**	**12**	**4**	**12.8**
Mated but unfed	**4**	**2**	**104**	**8**	**6**	**15.2**
Unmated but fed	**4**	**-**	**177**	**18**	**33**	**27.6**
Unmated and Unfed	**4**	**-**	**153**	**5**	**0**	**3.2**

Results show higher rate of oviposition by the females that were unmated but fed with diluted honey, followed by the mated but unfed females. The results therefore appear to suggest that mating may not be a crucial factor for ovipostion, but that feeding of the wasps enhances oviposition.

Table 4. Effect of mating and feeding on egg development in adult female *H. coffeicola.*

Treatment	Egg Shape	Egg Development			Remarks
		Number of Eggs	Egg Colour	Egg Size	
Mated and fed females	Elyptical and shrivelled	2.0	Generally whitish	Medium	Fair egg development
	Irregular				
	Elyptical				
Mated but unfed females	Irregular	1.0	Generally translucent	Small	Poor egg development
	Irregular				
	Elyptical				
Unmated but fed females	Elyptical and shriveled	1.3	"	Medium	Fair egg development
	Elyptical				
	Elyptical				
Unmated and unfed females	Elyptical	1.3	"	Small	Poor egg development
	Elyptical				
	Elyptical				

The most surprising finding here is that the eggs oviposited by the unmated females were able to hatch into the larva in the berries (see Table 1), when incubated in the laboratory. Their development into the pupa and adult wasps is being followed to determine if the resultant adult wasps are viable. The sex ratio, aspects of behaviour and other characteristics of the resultant wasps will also be determined.

Development of the eggs was also found to vary with the treatments (Table 2). The shape of the eggs was generally elliptical irrespective of whether the female wasps were fed or mated or not. The mated and fed females generally had more eggs that appeared to be better developed than that laid by the other categories.

CONCLUSION AND RECOMMENDATIONS

The study showed that ambient temperatures and conditions of illumination, in the ranges considered in the study, do not influence the rate of oviposition by *H. coffeicola* in-vitro. However, oviposition was influenced by space as evidenced by the increase, albeit nominally, of the rate of oviposition with increase in size of cages, and seemingly by feeding and mating of the wasps as evidenced by the high oviposition rates of mated and fed compared to wasps that were neither mated nor fed.

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Validation of Coffee Berry Borer (CBB) Trapping with the Brocap® Trap

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SUMMARY

The purpose of this two years' work was to validate CBB trapping, after a long development and industrial manufacturing phase to produce a commercial trap model patented and registered under the BROCAP® brand. The main aims were to evaluate the capture potential of the BROCAP® trap in the field, demonstrate its effectiveness during actual trapping campaigns and determine its impact on coffee production. In this context, the objective was to identify any weaknesses of the trap, assess how future users would accept this new tool and estimate costs.

On the fifteen coffee farms selected during the first year, which were located in the main three coffee areas in El Salvador, two 4.2 ha plots were marked out per farm, one with trapping the other without. The total number of traps per farm was 12 per 0.7 ha, i.e. a total of 72. They were installed for the start of CBB migration from residual fruits remaining after the harvest and were only removed once migration was complete. Prior to trapping, infected berries were sampled in all the plots to determine live CBB population levels. CBB catches were measured by a volumetric method. Population levels were then assessed after trapping, or more precisely after the colonization of new fruits, and then at the beginning of the harvest. The same procedure was followed in the second year on a sample of four farms only.

The results showed that the BROCAP® trap was able to catch large numbers of CBB. On one farm, 7 million females were caught, with an average of 76 000 per trap in 20 days. In the first year, on the 8 plots where the protocol was strictly applied, the infestation level fell visibly when compared to the control plots, with a reduction of 84.6% in one plot. In the second year, the greatest reduction reached 87.1%. The plots with trapping also displayed higher green coffee yields than the control plots, with a weight gain varying from 2.9% to 16.3%. With the experience of this CBB control programme, some suggestions were made to improve the BROCAP® trap, adjust it to true field conditions and ensure its commercial success.

INTRODUCTION

The first work on coffee berry borer (*Hypothenemus hampei* Ferr.) trapping in El Salvador in 1997 followed on from specific studies on this subject by Gutiérrez-Martinez et al. (1995), Mathieu et al. (1997) and Mendoza Mora (1991). At the outset, excellent capture results were obtained with a home-made trap and an attractant with methanol as the main active ingredient (Dufour et al., 1999). Several experimental and commercial trap models were then tested, leading to the production of two prototypes combining the most suitable architectonic characteristics for trapping (Dufour et al., 2001). A final model based on these prototypes was created, then manufactured industrially, patented and registered under the BROCAP® brand. The trap underwent validation in 2000 and 2001, with a view to assessing its trapping ability, its efficiency in controlling CBB, and its effects on yields. The cost of trapping and of the improvements made to the trap and technique were also determined. Farmers were asked for their views on trapping.

MATERIAL AND METHODS

In the first year, validation was carried out in the main three coffee producing areas of El Salvador on fifteen CBB-infested farms that had one characteristic in common, the existence of permanent shade. On each of the selected farms, two 6-mz plots (i.e. 4.2 ha) were marked out in a paired-plots design, one for trapping, the other as the control. Thirty-six coffee trees per plot were systematically marked in order to take samples of fruits attacked by CBB. Trapping was carried out for two and a half months with 12 BROCAP® traps per mz. The year after, validation was continued following the same rules, on four farms only and for four months.

Infestation levels were assessed prior to trap installation by sampling all the residual fruits on the marked coffee trees, along with random sampling of 200 pest-damaged fruits per plot, followed by their dissection to determine the structure of the CBB populations. CBB captured during the trapping period were counted. Infestation levels were then assessed by further exhaustive sampling of new-generation fruits, and by studying the CBB population structure on 200 fruits per plot. Lastly, at harvest time, cherries were taken directly from the bags to determine infestation levels again and calculate yields.

RESULTS

Of the fifteen coffee farms selected in the first year, seven did not respect the stipulations of the protocol, notably by carrying out sanitation harvests or uncontrolled harvesting of early fruits. Their sampling data were therefore discarded. In the end, the number of sites used was reduced to eight.

The best trapping results were obtained on the "Lutecia" and "Carbonera" farms, where 4.9 and 6.9 million females were caught respectively in 34 days during the first year of validation, with an average of 76 000 per trap obtained in 20 days' trapping at "Carbonera" (Figure 1).

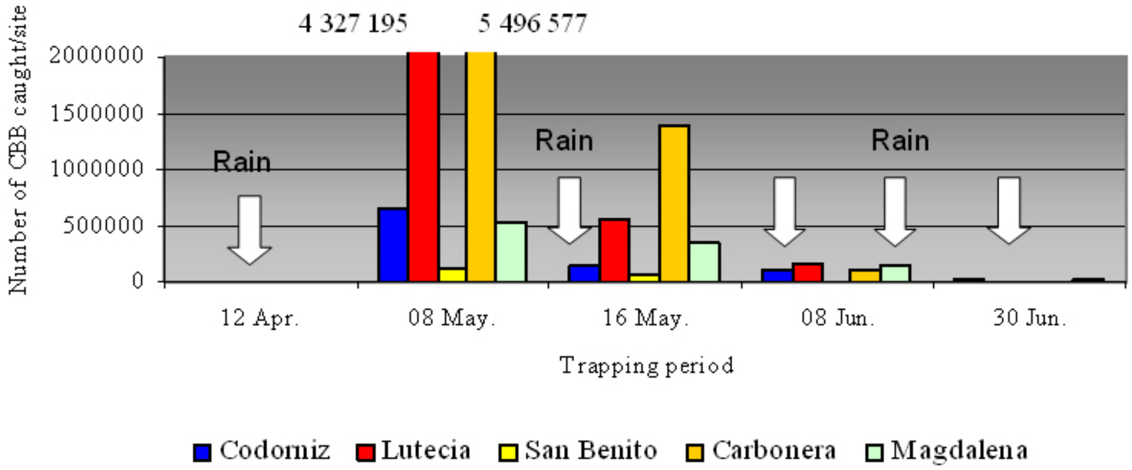

Figure 1. CBB capture trends in the Central Region (first year).

The infestation levels observed at the outset merely provided an indicative value for this study. Only the infestation data for new fruits were taken into account (Table 1). The

Wilcoxon non-parametric paired data classification test applied to these data (8 pairs) indicated that trapping with the BROCAP® trap had a real effect in controlling colonizing CBB populations ($P < 0.01$). The trapping efficiency results are shown in Table 1. Efficiency was defined as being the "rate of reduction in CBB populations affecting new fruits in the plots with trapping, compared to their respective controls without trapping".

Table 1. Infestation levels, capture, attack rates and yield increases.

Validation site	Treatment	Initial infestation of residual fruits (number of CBB female stages per tree)	Quantity of CBB captured during the trapping period	Infestation of young fruits (number of CBB female stages per tree)	Trapping efficiency (% reduction in infestation)	Attack rate at start of infestation (% damaged fruits)	Attack rate at harvest time (% damaged fruits)	Harvest increase (% of green coffee weight)
Year 1								
San Pablo	Trapping	529.0	216 868	38.1	**12.2**	3.30	6.20	**5.2**
	Control	419.9		43.4		4.01	32.60*	
Atocha	Trapping	1045.0	244 733	11.8	**81.1**	1.01	4.60	**16.3**
	Control	899.8		62.3		4.46	13.20	
El Zapote	Trapping	916.1	1 098 751	16.6	**80.4**	5.56	11.70	**8.4**
	Control	574.0		84.7		9.15	18.10	
Santa Laura	Trapping	414.0	134 507	22.3	**41.3**	4.63	5.70	**10.6**
	Control	231.2		38.0		5.69	9.40	
Las Lajas	Trapping	166.8	183 888	12.0	**84.6**	0.48	4.90	**2.9**
	Control	170.9		77.7		5.27	12.20	
Codorniz	Trapping	170.3	903 386	8.5	**30.9**	1.87	4.80	**4.5**
	Control	14.3		12.3		1.56*	1.10*	
Lutecia	Trapping	1452.4	5 047 616	24.5	**42.4**	6.65	10.40	**11.7**
	Control	305.5		42.5		5.84*	18.60	
Los Humos	Trapping	138.9	675 150	12.6	**31.2**	3.52	15.60	**8.4**
	Control	108.8		18.3		7.18	32.60	
Year 2								
Atocha	Trapping	400.8	382 268	2.0	**87.1**	0.17	0.80	**3.3**
	Control	306.0		15.8		2.32	5.30	
El Zapote	Trapping	106.6	1 146 657	11.1	**70.6**	0.83	2.30	**6.9**
	Control	197.5		37.9		2.03	4.20	
Lutecia	Trapping	557.2	956 729	18.1*	**-**	2.45*	1.20	**3.4**
	Control	659.1		11.8		1.45	3.00	
Carbonera	Trapping	577.4	611 491	27.7*	**-**	2.36*	1.30	**10.3**
	Control	2028.4		25.3		2.22	5.30	

**Abnormal values caused by sampling errors.*

Attack rates were assessed in August and November (Table 1). These rates were calculated using the following formula: [(number of pest-damaged fruits/number of healthy and pest-damaged fruits) x 100]. Cherry coffee conversion to green coffee resulted from the processing of 30 pounds of cherries into green coffee with a 12% moisture content, expressed in grams. The harvest increase corresponded to the difference in weight of green coffee produced with the same amount of cherries in the plots with and without trapping.

It is difficult to quote an precise cost for trapping, since the price of the trap varies depending on the quantities purchased and the export costs. However, based on 3.10 dollars/trap, with a life span of 4 years, and 0.58 dollars/additional dispenser, the annual cost of trapping/mz amounts to 19.74 dollars. Endosulfan application costs 20.31dollars if the price of the insecticide per mz is 9.14 dollars and if labour costs and amortization of the treatment equipment are taken into account.

DISCUSSION AND CONCLUSION

Of the fifteen validation sites where trials effectively took place, eight really fulfilled the requirements of the experimental protocol. It was in the Western Region that the protocol was most effectively applied, but it is also in that region that coffee growing is the most developed and best managed.

In accordance with the results of earlier trials (Dufour et al., 1999), the capture peaks were associated with the first significant rainfall marking the end of the dry season in El Salvador (Figure 1).

After a long development phase, the resulting BROCAP® trap offers substantial capture ability, verified during periods of mass migration, notably at the "Lutecia" and "Carbonera" sites, where CBB is not usually controlled (Figure 1). However, catches were very different from one site to the next, primarily depending on the abundance of the populations able to migrate, and a combination of the main two factors that trigger migration: heat and humidity (Baker et al., 1992; Dufour et al., 1999).

The efficiency results were also very different, since they varied from 12.2% to 84.6% in the first year (Table 1). The best results were found at "Atocha", "El Zapote" and "Las Lajas", where upkeep was good. The results were confirmed the following year at "Atocha" and "El Zapote", with efficiency values of 87.1% and 70.6% respectively. During the second validation operation, contradictory infestation results were found at "Lutecia" and "Carbonera". These data were the result of sampling errors.

The attack rates assessed at the beginning of infestation, in August and at harvesting time, were good indicators of the effects of trapping, as was the estimation of yield increases. Generally speaking, all the plots with trapping produced more coffee than the control plots without trapping (Table 1).

The cost of trapping was more or less the same as for chemical treatment, hence economically barely competitive. However, trapping needs to be seen in a context of IPM, where non-chemical alternative control methods are a priority, since they do not endanger human and animal health and are environment-friendly.

Among the improvements to be made to the trap, a protective cover should be installed over the capture funnel, to prevent it becoming clogged up with plant waste, and an antiseptic should be added to the capture liquid to slow down insect decomposition and thereby reduce inspection frequency. In irregularly shaped plots, the number of traps should be increased to ensure coverage of all the areas to be treated.

All the farmers who took part in the validation trials acknowledged that this method is an excellent control alternative since it is easy to implement and only requires moderate monitoring. In addition, the visual checking of catches encourages users to manage CBB control more effectively in post-harvest periods.

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The Coffee Gene *Mex*-1 of Resistance to Root-knot Nematode *Meloidogyne exigua* Induces a Hypersensitive-like Reaction

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SUMMARY

Meloidogyne exigua is widely distributed in Central and South America. Attacks cause general weakening of coffee (*Coffea arabica*) trees associated with a drop in yield. All traditional cultivars are susceptible to *M. exigua*. The recent identification of the coffee gene *Mex-1* conferring resistance to *M. exigua* led us to investigate the phenotype of resistance with the objective to characterise histologically the coffee response to infection in both resistant and susceptible cultivars. Nematode penetration and development in resistant plants were reduced in comparison with susceptible plants. Resistance conferred by *Mex*-1 gene was strongly associated with a hypersensitive reaction-like phenotype.

RÉSUMÉ

Meloidogyne exigua est largement distribué en Amérique centrale et du Sud. Ses attaques provoquent un affaiblissement des caféiers (*Coffea arabica*), associé à une baisse de production. Tous les cultivars traditionnels sont sensibles à *M. exigua*. La récente identification du gène *Mex*-1, responsable de la résistance à *M. exigua* chez le caféier, nous a permis d'étudier le phénotype de la résistance avec l'objectif de caractériser histologiquement la réponse à une infection chez des cultivars résistants et sensibles. La pénétration et le développement des nématodes dans les plantes résistantes furent réduits en comparaison avec des plantes sensibles. La résistance conférée par le gène *Mex*-1 fut fortement associée au phénotype de réaction hypersensible.

INTRODUCTION

The root-knot nematode *Meloidogyne exigua* is widespread in South America; it is the most common species in Central America. In Costa Rica, attacks cause general weakening of the coffee trees (*Coffea arabica*) with an estimated drop in yields ranging from 10 to 20% (Bertrand et al., 1997). All traditional cultivars (i.e. Caturra, Catuai, Mundo Novo) are susceptible to *M. exigua*. No resistance was found in the species *C. arabica*, including the wild gene pool from Ethiopia, except in some accessions of *C. canephora* and *C. racemosa* (Anthony et al., 2003). A major gene (*Mex*-1) conferring resistance to *M. exigua* was recently identified in introgressed lines derived from the Timor Hybrid (*C. arabica* x *C. canephora*) (Noir et al., 2003). A localized genetic map of the chromosome carrying *Mex*-1 was constructed (Noir et al., 2003), along with physical mapping of the *Mex*-1 region (Noir et al., 2004). Here we report the results of the histological characterisation of the coffee response to *M. exigua* infection in both susceptible and resistant plants (Anthony et al., 2004).

MATERIAL AND METHODS

Two well-characterised coffee cultivars were used in this study: the commercial cv. Caturra, which is susceptible to *M. exigua* (Bertrand et al., 1997), and the introgressed line (F8) cv. Iapar 59, which has inherited the resistance gene *Mex*-1 from *C. canephora* through the Timor Hybrid (Bertrand et al., 2001). The seedlings of both cultivars were provided by the coffee research centre of Costa Rica (CICAFE). The source of nematode inoculum was a culture of *M. exigua*, which derived from one egg mass collected in an infected field at CICAFE and multiplied on the susceptible cultivar cv. Caturra at CATIE (Costa Rica). Infected root tips (3 mm) of resistant and susceptible cultivars were sampled at 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 17 and 19 days after infection (DAI), and prepared for histological observation as previously described (Anthony et al., 2004).

RESULTS AND DISCUSSION

Nematode multiplication in susceptible plants

Penetration of roots and development of nematodes in the susceptible cultivar confirmed previous observations of *Meloidogyne* species in their hosts (von Mende, 1997). Numbers of juveniles penetrate the sub-apical region (Figure 1A). Après penetration (4-6 DAI), nematodes migrate intercellularly inside the susceptible roots. At 10 DAI, cells begin to increase in size, predicting their differentiation in giant cells (Figure 1B). Eight to 12 cells constitute the feeding sites induced by nematodes. Some nematodes increase in size and differentiate in females. Egg-masses laid by females form galls on the roots.

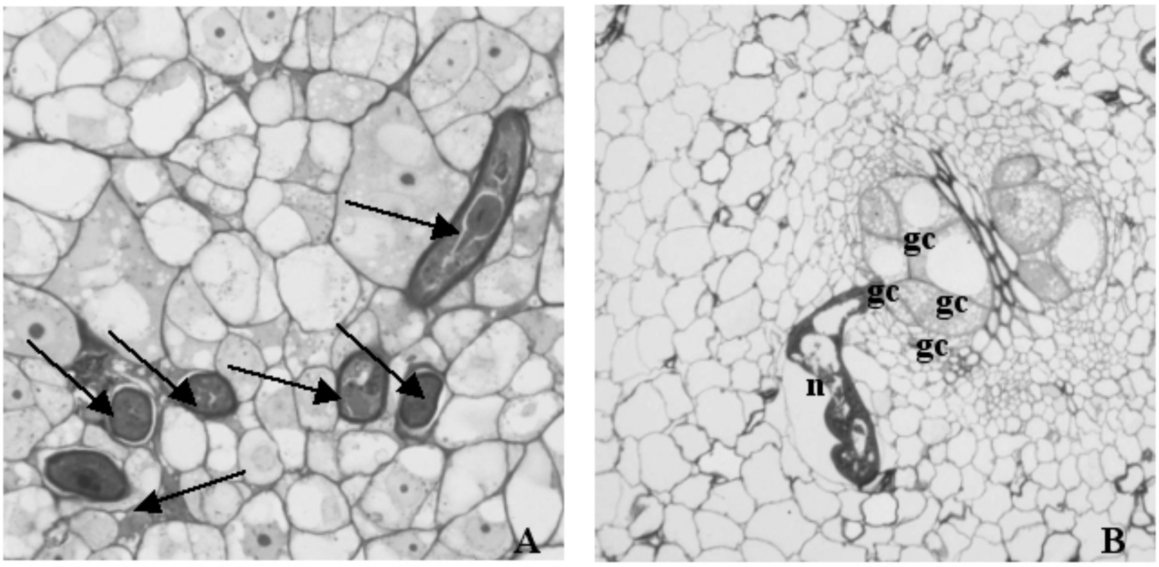

Figure 1. Observation of susceptible coffee roots after inoculation with *M. exigua*. A) Numerous second-stage juveniles (arrows) in the sub-apical area of infected roots, 10 DAI. B) Head of nematode (n) in a feeding site between giant cells (gc), 13 DAI.

Hypersensitive-like reaction in resistant plants

The response of resistant plants to *M. exigua* infection limits penetration and further development of nematodes. Few nematodes are able to invade roots of the resistant cultivar as compared to the susceptible one. Nematodes are generally surrounded by collapsed cells (4-6 DAI), suggesting a hypersensitive-like (HR) reaction (Figure 2A). Other features of HR cells are frequently observed (10-14 DAI). Few cells show features of giant cells (10-14 DAI), but most of them present an altered cytoplasm, highly vacuolated, with thin and irregular cell wall (Figure 2B). The seldom feeding sites are frequently associated with nematodes reduced in size or rarely in a normal shape. A same infected root sometimes contains both necrotic-like areas in the root tip and giant cells in differentiated portions (Figure 2C).

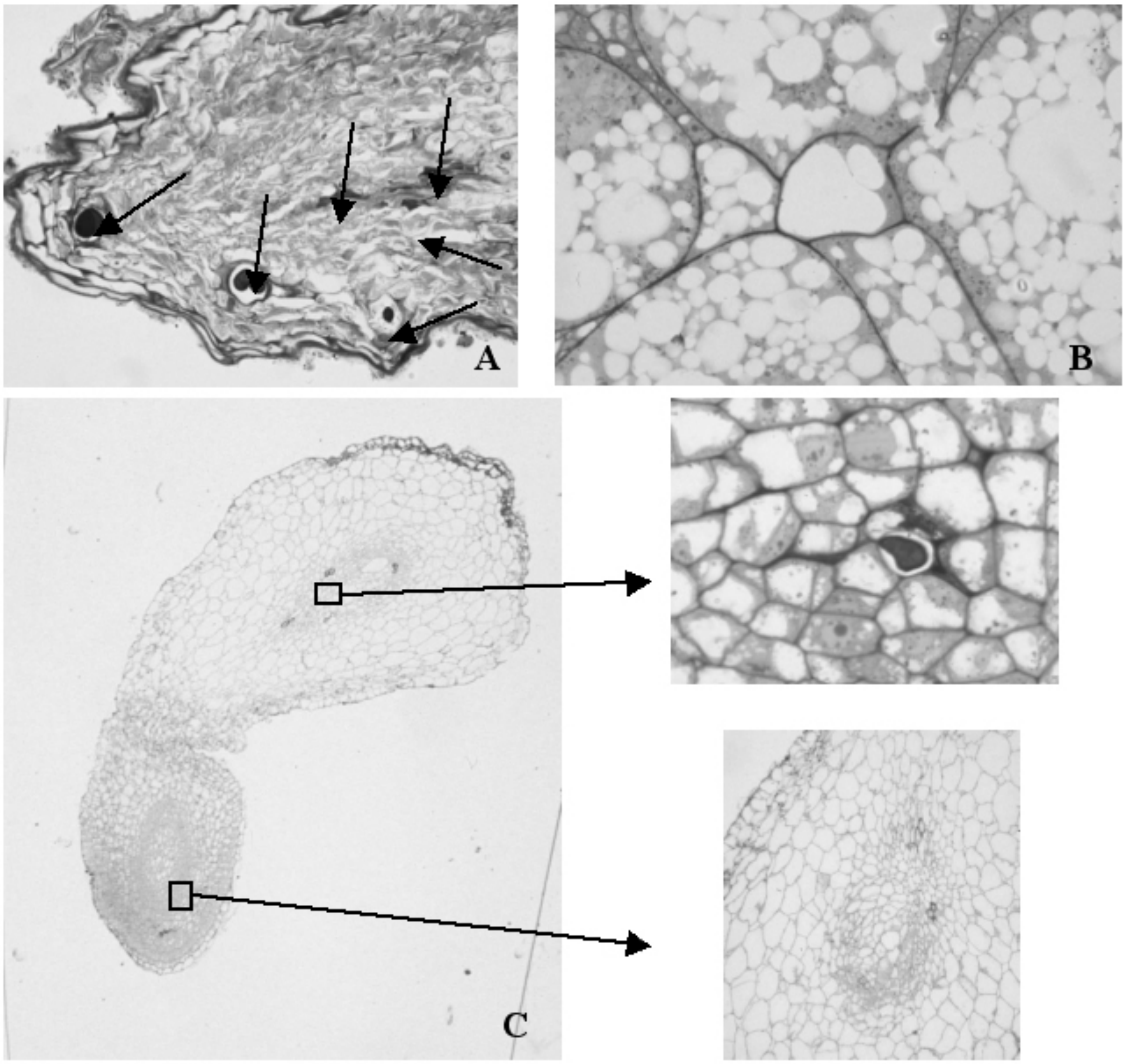

Figure 2. Observation of resistant coffee roots after inoculation with *M. exigua*. A) Several HR sites (arrows) observed within a same root tip. B) Giant cells in a feeding site displaying altered cytoplasm highly vacuolated. C) General view of an infected root showing both a HR-like (top) and giant cells (bottom).

CONCLUSION

Resistance conferred by *Mex*-1 gene is strongly associated with a HR-like phenotype which may respond to the gene-for-gene interaction. Nematodes that escaped the coffee defence may eventually reach maturity, which allows maintaining a residual population in the resistant roots (data not shown). *Mex*-1 transfer into susceptible cultivars can be monitored using the molecular markers tightly linked to the gene that were identified (von Mende, 1997).

ACKNOWLEDGEMENTS

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Surveys to Establish the Spread of Coffee Wilt Disease, *Fusarium* (*Gibberella*) *Xylarioides*, in Africa

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SUMMARY

Coffee wilt disease (CWD), also called Tracheomycosis, is caused by the fungus *Fusarium (Gibberella) xylarioides*. It was first observed in 1927 on Excelsa coffee (C*offee excelsa*) in Central Africa Republic and subsequently spread to Robusta coffee (*C. canephora*) in Democratic Republic of Congo (DRC) and Cote d'Ivoire in the 1950s. This disease is a major threat to the coffee industry in Africa as infected trees wilt and inevitably die.

As an essential prerequisite in the effective management of coffee wilt disease, there was a need to ascertain the current incidence and spread of this disease in East, Central and West Africa. To this end, extensive biological surveys were carried out between March 2002 and January 2003 in the coffee growing regions of Uganda, DRC, Rwanda, Tanzania, Ethiopia, Cameroon and Cote d'Ivoire. These surveys, done partly under the auspices of Coffee Research Network (CORNET) of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), were carried out by scientists from the respective National Programmes and coordinated by CAB International – Africa Regional Centre.

Over 7,000 coffee farms were visited during the surveys. The highest incidence was in Uganda, where 90.3% of farms had CWD, with an average severity (% trees infected) of 44.5%. The disease was observed in all of the coffee growing districts surveyed. In Tanzania, the disease was only found in Kagera Region, which borders Uganda, so the overall incidence and severity was much lower, 2.2% and 0.7%, respectively. The disease was observed only in North Kivu and Oriental Provinces and occurred at a National average incidence of 26.5% and severity of 17.8% in DRC. Incidence and severity of CWD in Ethiopia were 27.9% and 3.0%, respectively, and again the disease was found in all regions surveyed. CWD was not observed in Rwanda, Cameroon or Cote d'Ivoire. This disease was observed only on *C. canephora* in Uganda, Tanzania and DRC, and only on Arabica coffee (*C. arabica*) in Ethiopia. This finding suggests that the diseases found in the two coffee types, which are also separated geographically, are genetically distinct.

INTRODUCTION

Coffee (*Coffea* spp.) (Rubiaceae) is a major foreign exchange earner in many countries in Africa. Both *Coffea arabica* L. (Arabica) and *C. canephora* Pierre ex Froehner (Robusta) are grown. However production of this beverage is constrained by several factors including pests. One of the major diseases threatening coffee in Africa is Coffee wilt disease (CWD), also called Tracheomycosis, which is caused by the fungus *Fusarium (Gibberella) xylarioides* (Oduor et al., 2003). It was first observed in 1927 but was managed in the 1950s through massive uprooting of infected trees and use of resistant varieties. However, this CWD was reported to be devastating coffee in DRC in 1970s and spread to Uganda in 1997.

As a first step to develop an effective strategy to manage this disease, a regional survey was undertaken to establish how far this disease had spread in East, Central and West Africa.

MATERIALS AND METHODS

The surveys were conducted in 2002 and 2003 by staff from CAB International and the Ministries of Agriculture in the collaborating countries, i.e. Uganda, Tanzania, DRC, Rwanda, Ethiopia, Cameroon and Cote d'Ivoire. These surveys were done partly under the auspices of Coffee Research Network (CORNET) of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA).

With the assistance of the local Ministry of Agriculture staff, each country was divided into administrative units and a pre-determined number of farms visited in each. The numbers of farms visited in each unit was determined using coffee production, coffee variety, agro-ecological zone and accessibility as the main criteria.

A clustered sampling procedure was carried out, whereby 3-4 coffee farms were sampled at every stop. At each farm, 30 randomly selected trees on a diagonal transect across the farm were assessed for the incidence and severity of CWD, together with the presence of other diseases and insect pests. Penknives were used to confirm whether observed dieback/symptoms were due to CWD or other causes. A diagnostic symptom of CWD is the presence of characteristic blue/black staining when the bark is scraped (Figure 1).

Figure 1. Coffee stem showing the characteristic blue/black colouration typical of infection by coffee wilt disease.

As the disease is systemic and results in the death of the tree, a simple scoring system for the presence or absence of CWD per tree is a robust and appropriate means of quantifying the disease. Thus, data for two disease variables were collected:

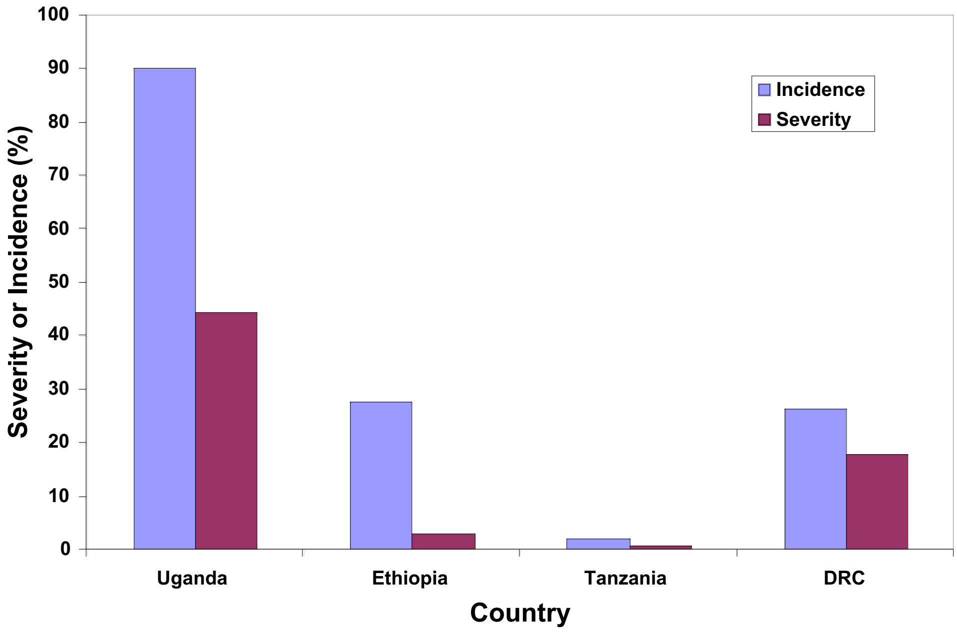
- Disease Incidence - presence or absence of CWD per farm
- Disease Severity - % coffee trees infected with CWD per farm

A total of 8505 coffee farms were sampled (i.e. 1374, 964, 1000, 1560, 1607, 1000, and 1000 in Uganda, Tanzania, DRC, Rwanda, Ethiopia, Cameroon and Cote d'Ivoire, respectively).

RESULTS AND DISCUSSIONS

Coffee wilt disease was observed in four of the seven countries surveyed. The distribution between the countries was uneven. Despite the intensive surveys, the disease was not observed in Rwanda, Cameroon or Cote d'Ivoire. The coffee varieties introduced into Cameroon and Cote d'Ivoire in the 1950s seems to be still effective at managing the disease. However, the absence of CWD in Rwanda was interesting since it is surrounded by counties in which the disease was observed. The cultivation of predominantly Arabica coffee may explain the absence of this disease in Rwanda, even though Robust farms were also uninfected.

The highest incidence of CWD was observed in Uganda, where 90.3% of farms were infected (incidence), with an average severity (% trees infected) of 44.5% (Figure 2). The disease was observed in all of the coffee growing districts surveyed. Coffee Arabica trees examined were found to be free on the disease. In Tanzania, the disease was only found in Kagera Region, so the overall incidence and severity was much lower, 2.2% and 0.7%, respectively (Figure 2). Kagera Region is planted with Robusta coffee, and is an extension of the Robusta belt from the neighbouring Uganda. The disease was observed only in North Kivu and Orientale Provinces and occurred at a National average incidence of 26.5% and severity of 17.8% in DRC. Incidence and severity of CWD in Ethiopia were 27.9% and 3.0%, respectively, and again the disease was found in all regions surveyed.



Figue 2. Incidence (% of farms infected) and severity (% of trees infected at each farm) of coffee wilt disease during a survey conducted in 2003 in different countries. The disease was not observed in Rwanda, Cameroon and Cote d'Ivoire.

This disease was observed only on Robusta coffee (*C. canephora)* in Uganda, Tanzania and DRC, and only on Arabica coffee (*C. arabica)* in Ethiopia. This finding suggests that the diseases found in the two coffee types, which are also separated geographically, are genetically distinct

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Preliminary Studies on the Epidemiology of Coffee Wilt Disease (*Gibberella xylarioides*) in Uganda

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SUMMARY

Coffee Wilt disease (CWD) caused by *Gibberella xylarioides* (Heim and Saccas) = *Fusarium xylarioides* Steyaert is the most destructive disease of robusta coffee in Uganda. To understand the dynamics of the disease, disease progress on naturally infected coffee fields were monitored at 5 sites from 1997 to 2000 and on research station from 2002. Spatial distribution of naturally infected plants in the field showed aggregation of diseased plants around infected trees or stumps. Infected plants also randomly appeared some distance from infected clusters. These revealed that epidemics are initiated from diseased plants within the field and from distant sources conveyed by wind or human beings. Human activities appeared to have accelerated spread of the disease. Integrated disease management would probably be most effective.

INTRODUCTION

Robusta coffee (*Coffea canephora* Pierre) is an important source of foreign exchange, local revenue, and employment to Uganda. Over 2.5 million people are involved in its cultivation, processing, trading, roasting and retailing. An estimated 240,000 ha of Uganda's farmland were dedicated to robusta coffee production prior to emergence of CWD in the early 1990's.

Coffee Wilt Disease (CWD) caused by *Gibberella xylarioides* (Heim and Saccas) = *Fusarium xylarioides* Steyaert is the most destructive disease of robusta coffee in Uganda. The highest economic losses are caused by loss of trees and the costs of replanting. Over 14 million trees are estimated killed by the disease, which is found in all robusta growing areas.

The disease symptoms include wilting, leaf drop, chlorosis and eventually death of plants. Frequently, the external symptoms are apparent on a single branch or a single side of an affected branch. Examination of the stems at the collar from the wilted side of the diseased bush reveals darkening of the vascular tissue just under the bark. Plate 1 shows wilt symptoms on robusta.

Disease management recommendation practices are mainly through sanitary measures, which do not adequately suppress the disease, e.g. use of clean planting materials, uprooting and burning infected plants and good crop husbandry practices among others. Lack of information on epidemiology of the disease hinders the development of rational guidelines for disease management (Jeger, 1983; Campbell and Madden, 1989). Detailed studies on the epidemiology of the disease and host-pathogen interactions could lead to the development of concepts for effective disease suppression, the objective of the present study.

MATERIALS AND METHODS

Trial sites

Five sites were selected for observation of natural epidemics in farmers' fields. Trees under observation were marked out 8 trees x 16 trees giving a total of 128 trees, at each site for observation. At the start of the recording, all fields were already infected and some trees had died and/or cut to stumps by the farmers. The health status of each plant with respect to CWD was recorded. Subsequent recording was planned at 4 weekly intervals.

Disease assessment

Diseased trees were identified by symptoms, which were later confirmed through laboratory isolations. Wilt incidence and severity were assessed at 4 weekly intervals. There were no weather recording devices at all sites except at the research station.

RESULTS

Field management practices

The coffee trees varied in age from 15 to over 30 years. All the coffee plots were established from farmers' own seeds planted at variable spacing. Recommended spacing is 3 x 3 m. All the coffee was interplanted with bananas except at one site where the crop was under shade of *Ficus* trees.

Age of coffee trees

CWD attacked plants of all ages from seedlings to mature plants. Diseased seedlings were often found sprouting from under diseased and dead trees. Most of the seedlings planted next to diseased/dead stumps developed symptoms and died within a few months (2-3 months).

Disease progress

During the rainy season, rapid defoliation was the first indication of disease, which resulted in death of plants within 2-4 weeks from the first symptoms. At one site disease progress was so rapid, that plant with no external symptoms at the last recording date were dead and dry one month later. Leaf drooping was more pronounced followed by leaf curling and wilting under drier conditions.

Effects of shade on CWD

Farmers favoured *Ficus* trees as the shade provider. Normally only a few trees are planted irregularly in the field. The mature trees provide shade of 20-40 m in diameter. Coffee trees were attacked by CWD irrespective of whether they were under shade or not. However, in some instances plants under shade were attacked first and in other cases plants under shade were attacked after all trees in the open have died of wilt.

Slope of the field

Two districts were on sloppy land. In both cases the first affected plants were in the valley or low-lying parts of the fields. The other 3 farms were more or less on level grounds where the disease appeared at random. Plants were attacked on level ground, valleys and hills.

Alternate hosts for CWD

Specimens of roots, bark and stems were examined for presence of the wilt pathogen from perennial crops in farmers' fields. The wilt pathogen was not recovered from any of the plant species examined.

Sexual form of *F. xylarioides*

Formation of perithecia on barks of trees dying from CWD was common. These were observed as the trees were beginning to dry up.

Spatial distribution

Observation of the spatial distribution of coffee wilt disease in naturally infected fields revealed aggregation of diseased plants around infected stumps or diseased trees. Random distribution of diseased plants, not all located next to the original cluster of diseased trees/stumps were also observed. From these points, the disease spread to neighbouring plants. Rate of spread varied from 8-12 trees/month depending on site.

From our observations, disease spread from these points was enhanced by human activities. The dry diseased stems and branches were cut for firewood and dragged along the field to the homesteads. More diseased plants appeared along the path where infected plants were dragged and at the homestead around the heap of infected firewood, coffee bushes previously healthy were infected.

DISCUSSION

The present culture of robusta coffee in Uganda is susceptible to wilt. Coincidentally with prevalence of environmental conditions that are conducive to the pathogen. Wilt incidence varied with site. Aggregation of diseased plants indicated sources of infection from a group of plants close to each other. The original infection could have come from distant sources. Similarly, random infection foci observed could have originated from infection brought in from elsewhere by wind or from infected materials or both. Presence of CWD in forest coffee could be an important source of inoculum to nearby coffee farms. Movement of infected plants as firewood was observed to be a major mode of inoculum dissemination.

Farmers attributed more rapid disease spread to increased population of bees visiting flowers. Other insects whose roles could not be defined were berry borers, stem borers and termites.

Muller (1997) reported that Jacques Felix (1964) considered that conidia and ascospores were spread by wind, rain and most importantly human activities as has also been observed in Uganda. Wounding of trees is reported to favour infection (Kranz and Mogk, 1993). In the course of this study, increased wilt incidence was observed on a farm animals (cattle, goats and sheep) were tethered or allowed to graze in coffee plots. Wounds and damage to trees under such situations were obvious. Insects mainly termites that cause wounding, were common, but their role in disease transmission could be established.

Perithecia were abundantly produced at all sites. Ascospores could be alternative to chlamydospores, for survival and contribute to soil inoculum and probably spread by rain splash and run-off.

This initial study has been able to identify areas for in-depth studies which include the effects of effects of shade, gradient, soil fertility and other physical soil characters, as well as the influence of weather factors particularly rainfall. There has been speculation that heavier rainfall than usual in affected areas could have contributed to the epidemic.

ACKNOWLEDGEMENTS

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Complete and Partial Resistance to *M. exigua* in *C. arabica* Modified Pre-existing Field Nematode Populations

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SUMMARY

Nematodes represent a major threat in all major coffee-growing (*Coffea arabica* L.) areas throughout the world. Chemical control by nematicides is only effective in the short term, expensive to use and hazardous to the environment and human health. Growing nematode-resistant coffee trees constitutes so far the most promising option to control the pest. In most coffee regions of Costa Rica, commercial cultivars are infested by two damaging nematode species, *Meloidogyne exigua* and *Pratylenchus* sp. In this study we evaluated if the introduction of new genotypes with complete or partial resistance to *M. exigua*, could modify the competition pre-existing in the roots between the two nematode populations. *M. exigua* and *Pratylenchus* sp. populations were recorded every month during one year on roots of susceptible, partial and complete resistant *C. arabica* genotypes to *M. exigua*. High number of both eggs and juveniles of *M. exigua* with few *Pratylenchus* sp. were present in roots of the susceptible genotype. In contrast, a high number of *Pratylenchus* sp. with none *M. exigua* was observed in complete resistant genotype. Interestingly, a low density of both nematode populations was recorded within intermediate resistant genotype. The results obtained confirm that the introduction of partial or complete resistance to *M. exigua* modified the pre-existing competition between the two populations in field conditions. Since mixed populations nematodes are highly frequent in most coffee fields in Latin America, it seem necessary to make previous studies before doing massive commercial diffusion of nematode resistant genotypes.

INTRODUCTION

The nematode *Meloidogyne exigua* is a very common parasite in the roots of the coffee trees in Latin America. Yield losses caused by this root-knot nematode infection are estimated between 10 to 15% (Bertrand et al., 1997). Nematicide treatments are expensive, hazardous for environment and human health (Campos et al., 1990). Genetic resistance seem the best way to fight against root-knot nematode (Luc and Reversat, 1985). In a first work (Bertrand et al., 2001), observed several Arabica lines derived from the interspecific Timor hybrid (wild *C. arabica* x *C. canephora*), that exhibited resistance to the nematode and we had confirmed that *M. exigua* resistance came from *C. canephora*.

Noir et al. (2003) had identified molecular markers associated with the *M. exigua* resistance. Segregation data analysis of F2 progeny derived from the cross between the resistant introgression line T-5296 and the susceptible accession ET-6 had showed that the resistance (R) to *M. exigua* is controlled by a simply inherited major gene, designated as *Mex*-1 locus. However this major gene could have an incomplete dominant expression because most of the resistant showed a gall index higher than the mean value of the resistant parent T-5296.

MATERIAL AND METHODS

Plant material

Three cultivars were employed in the study, one susceptible (cv. CR-95); one resistant (cv. IAPAR-59) and one F1 hybrid clone derived from the cross between the *M. exigua* resistant T-5296 and the susceptible accession ET-6.

The cv. IAPAR-59 and cv. T-5296 are derived from the same F3 accession named C1669 (from Instituto Agronomico de Campinas, Brazil) that originated from the cross between 'Timor Hybrid CIFC 832/2 x cv. Villa-Sarchi'. The cv. IAPAR-59 is highly homozygous with progenies that were all resistant, while the cv. T-5296 presented some level of heterozygous and presented resistant and susceptible plants (Bertrand et al., 2001).

The propagation of the clone was made using the somatic embryogenesis method described by Etienne and Bertrand (2003).

Resistance evaluation in field conditions

At the Research Station of Costa Rica Coffee Institute (CICAFE), population (eggs + juveniles) of nematodes *M. exigua* and *Pratylenchus* sp. were recorded every month from August 2001 to August 2002 from roots of coffee trees following the protocol of Taylor y Loegeing (1953). The population of *Meloidogyne exigua* was previously characterized by electrophoresis patterns (Hernandez et al., 1996)

Seven year old trees of susceptible (cv. CR-95), partial (F1 hybrid T-5296 x ET-6) and complete resistant (cv. IAPAR-59) *C. arabica* cultivars to *M. exigua* were compared. For each cultivar 10 plants were randomly chosen with three replicates. Mean values were compared by Duncan test at (P = 0,05).

RESULTS AND DISCUSSION

High number of *M. exigua* individuals with low levels of *Pratylenchus* sp. was present in roots of the susceptible cultivar cv. CR-95, (Figure 1). In contrast, a high number of *Pratylenchus* sp. with none *M. exigua* was observed in the complete resistant cultivar cv. IAPAR-59. A low density of both nematode populations was recorded in the partially resistant F1 hybrid (T-5296 x ET-6).

Noir et al. (2003) mentioned that an intermediated resistance to *Meloidogyne exigua* probably exists in *C. arabica*. In this study, we demonstrated clearly the existence of such phenomena. The F1 hybrid studied, cultivated in conditions of strong infestations, and expressed an intermediate level of resistance to the root-knot nematode as compared with well known susceptible and resistant cultivars.

The susceptible cultivar 'CR-95' exhibited great amount of large galls while the resistant cultivar only exhibited a few small galls (results not shown). The hybrid T-5296 x ET-6 showed only small galls, but in higher proportion than in the resistant cv. IAPAR-59.

The results showed that the introduction of partially or completely resistant coffee cultivars to *M. exigua* can modify the pre-existing competition between two nematode populations previously established in a field. Since mixed nematode populations are highly frequent in most coffee fields in Latin America, it seems necessary to make similar studies before doing massive commercial diffusion of nematode resistant cultivars.

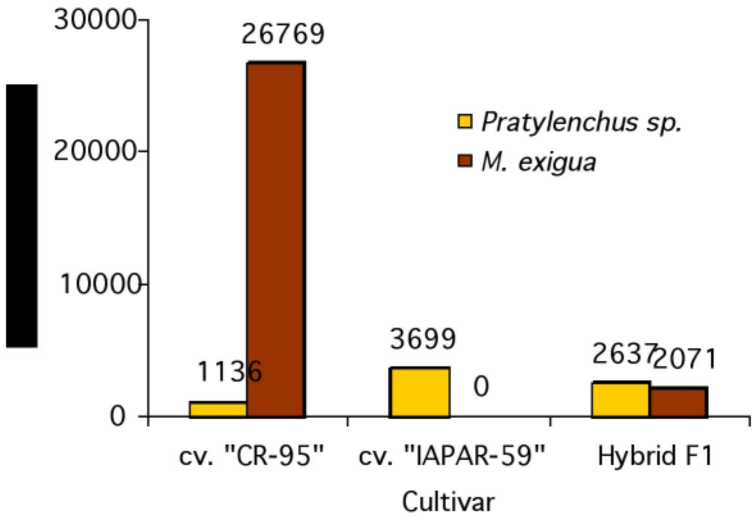

Figure 1. Average number of individuals of *Meloidogyne exigua* and *Pratylenchus* sp. for three coffee cultivars (I-59, CR-95 and clone F1) Heredia (CR). (August 2001- August 2002).

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Coffee Disease Survey in Tanzania

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SUMMARY

In Tanzania, the coffee plantations mainly suffer from Die Back due to physiological weakness. Leaf Minor and Leaf Rust are commonly observed, the latter causing significant leaf damage. In the Kilimanjaro area, Stem Borers are the pest causing most damage, with high plant destructive potential. The presence of CWD has been confirmed, it was exclusively found on Robusta coffee in the Kagera region. Other diseases on root and bark are of limited importance at the national level.

RÉSUMÉ

En Tanzanie, la zone caféicole est principalement victime de Die Back dû à la faiblesse des plantes. Mineuse des feuilles et rouille orangée sont très fréquentes, la dernière ayant un plus fort impact. Les foreurs et mineurs du tronc sont les plus dommageables dans la région Kilimanjaro. L'avancée de la trachéomycose exclusivement sur café Robusta est confirmée à partir de l'Ouganda, dans la région de Kagera. Les maladies de l'écorce et des racines sont peu présentes à l'échelle nationale.

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Tanzania covers an area of 94,500 km^2 of which, 262,000 ha contain coffee (Figure 1) (Tanzanian Coffee Board 2004). With an annual production of 50,000 tons, it is the 18th largest coffee producing country (among 51, ICO 2004). The main production is Arabica (75%-80%), mainly Kent and Bourbon varieties, planted at an altitude of 1500-2000 m. Robusta coffee represents 20%-25% of the total production. It is grown in the lower altitude regions of Kagera (Uganda border) and Morogoro.

A coffee disease survey was conducted in Tanzania to identify the significant pest & disease constraints affecting the crop and assess their distribution. Between October 2002 and February 2003, 981 randomly chosen coffee farms were visited, stratified to cover 9 regions and 30 districts (Figure 1). On each farm, 30 randomly chosen trees were assessed for pest and disease presence and severity. Special attention was given to Coffee Wilt Disease (CWD), due to *Fusarium xylarioides*, a re-emergent disease with a high destructive potential. The results are presented in Table 1.

At this time of year when the plants are non-bearing, **berry** problems were rarely observed: very low levels of CBD and an absence of Coffee Berry Borer. **On leaves**, orange rust was seen in all regions on both Arabica and Robusta. The level of infection was high, slightly less in Mbeya region where growing conditions may be better; leaf minor was commonly observed, but with low impact. Also present was leaf spot, seen nearly everywhere in the coffee zone but at very low levels (except in Morogoro) It was most commonly observed on Robusta coffee and in lowland Arabica zones. **On branches**, die back is prevalent, revealing the poor physiological stage of the plants and the general weakness of the Tanzanian coffee plantations. **On the trunk**, 2 important constraints, with a strong destructive potential, were observed: stem borers and coffee wilt disease. Stem borers were widespread but not observed in the northern part of Kagera on Robusta. Their impact was severe in Kilimanjaro and Songea area. Coffee wilt disease was observed on Robusta coffee only (see below). **Bark and root diseases** were rarely observed. **Potential pest and disease threats** that were insignificant at the national level but which may become a problem in a given district were: scales in Monduli, Karatu and Mbeya, Fusarium bark disease in Hai and Mbeya, root disease in Songea.

Figure 1. Tanzania administrative map and coffee producing districts.

Coffee Wilt Disease was first observed in Tanzania in 1997 in the northern part of the Robusta growing area of Kagera (Kilambo et al., 1997). Six years later, this survey confirmed that the disease is still present, has not infected the adjacent Arabica growing area and has not reached the Robusta growing area of Morogoro (Table 1, Figure 2). These observations suggest the possible physiological specialization of *F. xylarioides* and, in the region, its adaptation to the Robusta host plant. This may indicate that the strain(s) of the fungus that currently develops in Kagera is different from the *F. xylarioides* strain(s) present in Ethiopia where it is known to infect Arabica coffee (Lejeune 1958). The infection level in Kagera follows a declining level gradient, from North to South, with the highest level of infection observed at the Ugandan border. This strongly suggests that CWD has crossed over into Tanzania from the Robusta growing area of Uganda where the disease has been observed since 1993 (Birikunzira and Lukwago, 1997). In the northern part of Kagera, groups of infected farms were observed while in the southern part only isolated farms were seen. This suggests that the disease inoculums may travel long distances and initiate local infection that progress according to a focus pattern. Unless human factors are involved to explain the long distance transportation of the pathogen, these observations suggest 2 different patterns of dissemination of *F. xylarioides*, efficient at both long and short distances.

Table 1. Major coffee pest and diseases in Tanzania districts.

Region	District	Leaf minor (*Leucoptera spp*)	Leaf rust (*Hemileia vastatrix)*	Stem Borers (*Bixadus sierricola, Apate monachus*)	Leaf spot (*Cercospora coffeicola)*	Coffee Wilt Disease (*Fusarium xylarioides;* on Robusta only)	Coffee Berry Disease (*Coletotrichum kahawae)*	Bark disease (*Fusarium stilboides (*not confirmed*)*)	Scales	Root disease (unspecified)	Die back	Visited farms
Arusha	Monduli	68	36	1	1	0	0	0	2	0	41	12
Arusha	Karatu	53	18	2	2	0	9	0	2	0	23	28
Arusha	Babati	49	19	24	1	0	1	0	0	0	55	19
Arusha	Arumeru	29	54	40	2	0	0	0	0	0	20	41
Iringa	Makete	33	0	0	3	0	2	0	1	0	6	5
Iringa	Njombe	45	31	0	8	0	4	0	0	0	18	18
Iringa	Iringa	63	21	0	1	0	7	0	1	0	40	19
Iringa	Ludewa	41	0	1	0	0	15	0	2	0	33	16
Iringa	Mufindi	85	30	0	1	0	20	0	0	0	34	31
Kagera	Musoma	55	3	0	5	0	0	0	0	0	47	7
Kagera	Ukerewe	15	9	1	0	0	0	0	0	0	98	13
Kagera	Karagwe	18	17	0	7	0	2	0	0	0	74	67
Kagera	Muleba	8	18	0	9	2	0	0	0	0	89	55
Kagera	Bukoba(V)	13	32	0	4	10	1	0	0	0	57	78
Kagera	Ngara	19	11	1	1	0	0	0	0	0	84	34
Kagera	Biharamulo	18	19	0	6	0	0	0	0	0	88	23
Kilimanjaro	Mwanga	19	42	41	0	0	1	0	0	0	26	40
Kilimanjaro	Rombo	26	21	19	0	0	5	0	0	0	35	42
Kilimanjaro	Hai	28	64	27	0	0	3	10	0	0	15	40
Kilimanjaro	Same	23	22	45	0	0	2	0	0	0	33	61
Kilimanjaro	Moshi (V)	28	72	46	2	0	0	0	1	1	32	43
Mbeya	Ileje	27	1	0	0	0	0	0	1	0	54	28
Mbeya	Mbozi	34	9	1	0	0	0	0	0	0	45	42
Mbeya	Mbeya	34	1	2	1	0	0	0	3	0	38	31
Mbeya	Rungwe	75	78	4	0	0	0	1	0	0	55	36
Mbinga	Mbinga	14	22	5	3	0	0	0	0	0	78	38
Mbinga	Songea	34	61	15	2	0	0	0	0	2	42	18
Morogoro	Morogoro	48	32	4	21	0	0	0	0	0	27	27
Tanga	Lushoto	39	50	9	10	0	2	0	1	0	33	34
Tarime	Tarime	35	19	1	0	0	0	0	0	0	72	35
	National % of infected trees	31,3	29,4	11,8	3,1	2,5*	2,1	0,5	0,4	0,1	48,5	981

**: % calculated on robusta coffee only*

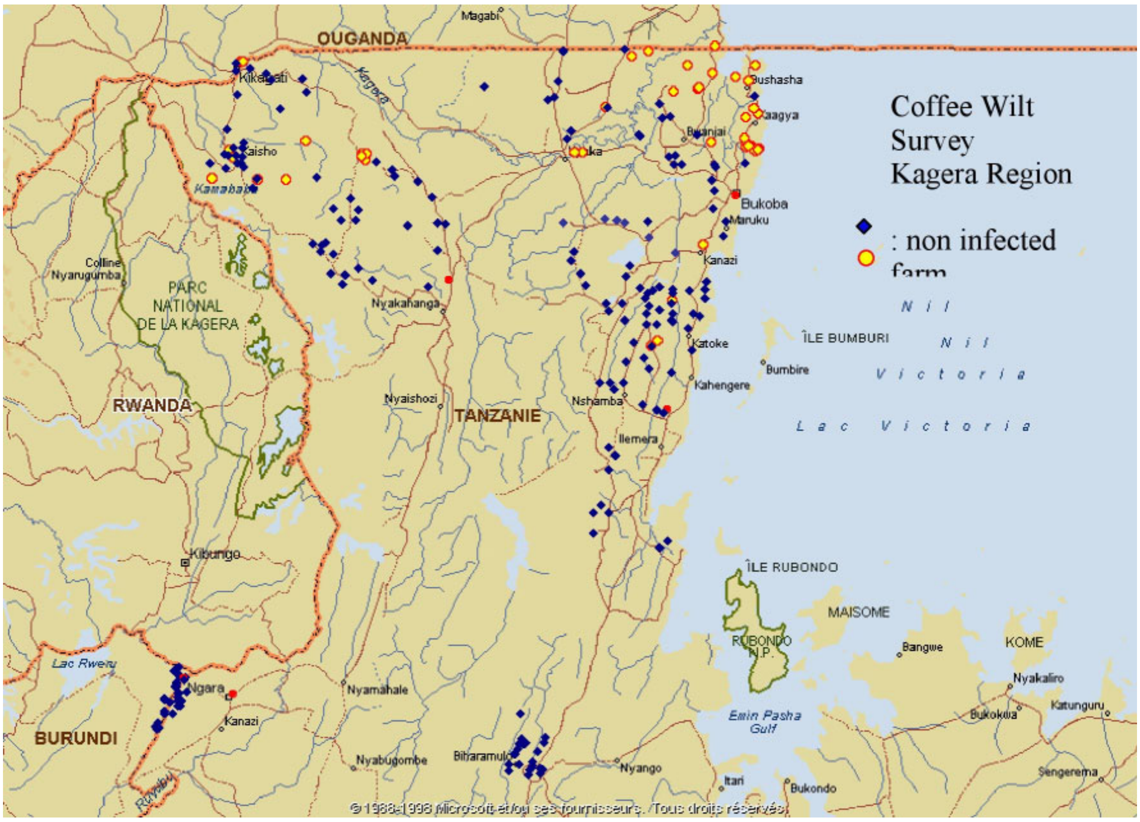

Figure 2. Presence of Coffee Wilt Disease in Kagera region of Tanzania.

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Evaluation of Three Fungicides for Performance Enhancement and the Control of Half-node Cutting Rot of Coffee (*Coffea canephora* Pierre ex Froehner) in Nigeria

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SUMMARY

An experiment was initiated at the Headquarters of the Cocoa Research Institute of Nigeria (CRIN) Ibadan, Nigeria to evaluate the effect of fungicide treatments on the performance of half node stem cutting of robusta coffee and the extent of decay likely to result from the exposure of the internal tissues of the stem. Four fungi were frequently isolated from the samples of rotten cuttings viz: *Botryodiplodia theobromae, Fusarium sp, Aspergillus fumigatus and Aspergillus flavus.* Pathogenicity test implicated *Botryodiplodia theobromae* as the casual organism of the cutting rot. However the treatments with fungicides showed just slight improvement in cutting performance in terms of callus formation, percentage sprouted, rooted and length of root (primary and secondary roots). Funguran OH performed better than all other fungicidal treatments.

INTRODUCTION

Coffee is an important export crop traded globally. However to obtain good yield, improved quality, pest and disease resistance as well as any other desirable traits, coffee is best propagated through cuttings. The use of cuttings as propagation material is not new in Nigeria. One and multiple-node cuttings have been perfected by the Cocoa Research Institute of Nigeria, however the use of half node propagule which provide more planting materials as against multiple nodes cutting of 15-20 cm length (Oyebade, 1981) is at its infancy. Production of half node cutting by CRIN commenced in 2002. The opening of the vascular tissues of the plant, which pre-supposes that the materials would be predisposed to pathogenic attack especially going by the results of previous works that coffee is being affected by some root and seedling diseases such as root rot disease caused by *Armilleria mellea* (Vall.) Quelet; pre-emergence seed decay caused by complexes of *Fusarium, Rhizoctonia* and *Botryodiplodia spp*. (Filani, 1972) and post-emergence seedling damping off caused by *R. Solani* and Fusarium sp, necessitate the use of fungicide to treat the propagules. This study therefore was planned to evaluate the effectiveness of three fungicides on the performance of half node cuttings of coffee and their ability to control cutting rot.

MATERIALS AND METHODS

Two different replicated trials were laid out under Cocoa shade in year 2002 and 2003 respectively. In the first experiment, a systemic fungicide, hormone and leaf were made treatments while the control was free of all the three factors. Second experiment, however had three fungicides (Fungran O.H, Champ D-P and CuS04) as treatments and water was used as the control. The fungicides were tested at the rate of 4.0 g/litre of water. The half nodes were prepared with sharp sterile scalpels and were later dipped into the fungicide solutions for 3 minutes before inserting into about 3 kg of naturally infested soil weighed into 15cm diameter and 30cm deep black polythene bags. The cuttings so set were covered with transparent polythene sheet for 9 weeks.

Isolation of the cutting rot fungi

Infected coffee cutting with distinctly recognizable symptoms of the rot disease were collected from plants grown in naturally infected soil contained in polythene bags arranged on the nursery beds. The infected pieces were thoroughly washed with fine jets of tap water and blot dried on filter paper. The samples were cut into 2-3 mm portions and then surface-disinfected in one percent sodium hypochlorite solution for 30 seconds, washed thrice with sterile distilled water then blot dried, plated out on potato dextrose agar and incubated for 5 days. The pure cultures of the isolated fungi were kept for the Pathogenicity test.

Pathogenicity Test

Cuttings were inoculated at three different stages viz.: before inserting the cutting into the soil, two week and four weeks after. Steam sterilized garden soil in 20 cm polythene bags were used in all the treatments. The isolated fungi were tested by growing the fungi on potato dextrose agar contained in 9 cm diameter petri-dishes for seven days at 25^{o}C. Two Petri-dishes of the fungus were mixed with the soil in the polythene bags at about 3cm away from the cuttings. In the control, similar procedures were followed using sterile agar. The cuttings were later assessed for rot symptoms. Re-isolations were done to confirm whether the inoculated fungus was the one producing the observed symptoms in the infected plants.

Table 1. Effect of treatments on the rate of infection on coffee cuttings.

Treatment	Infection rate
A**	56.25 ab*
B	43.75 b
C	37.5 bc
D	68.75 a
E	12.25 d
F	18.75 cd
G	50.0 ab
H	6.5 d

** Means not followed by the same letter are not significantly different (P= 0.05)*
*** A - No fungicide, no hormone, no leaft (control)*
B - No fungicide, hormone present no leaf
C- Fungicide present, no hormone, no leaf
D - Fungicide present, hormone present, no leaf
E - No fungicide, no hormone, leaf present
F - Fungicide present, hormone present, leaf present
G - Fungicide present, hormone present, leaf present.
H -Fungicide present, hormone present, leaf present

RESULTS

Table 2 shows that *Botryodiplodia theopomae* and *Fusarium sp*. were frqeuntly isolated from both soil and piece of cuttings, however *Aspergillus fumigtus* and *Aspergillus flavus* could not be isolated with any appreciable frequency from the nursery soil used. Table 1 shows the effect of treatment on the rate of infection in C36 coffee variety. The combination of leaf, fungicide and growth hormone produced the best result. Results of the pathogenicity tests

(Table 3) indicated that *Botryodiplodia theobromae* was the primary organism associated with the rot of half node cuttings of coffee, however the degree of its infection reduced as the age of cutting developments progresses. In the second experiment, Funguran O.H (Fungicide) as a factor had overall best performance above all other treatments (Champ DP, CuS04 and control) (Table 4). This performance is however not different significantly (P = 0.05) from the control.

Table 2. Fungi isolated from the infected cutting tissues of coffee and nursery soil.

Fungus	**Isolation from a _n***	
	Cutting	**Soil**
1. *Aspergillus flavus*	19	0
2. *Aspergillus fumigatus*	16	0
3. *Fusarium sp.*	41	40
4.*Botryodiplodia theobromae*	60	62

**1/2 n: Figure represent number of times fungus was isolated from pieces of infected half node cuttings plated on potato dextrose agar (PDA).*

Table 3. Pathogenicity of *Botryodiplodia theobromae, Fusarium* sp., *Aspergillus fumigatus* and *Aspergillus flavus* on half node cuttings of coffee.

	Fungi			
State of cutting at inoculation	*Botryodiplodia theobromae*	*Fasarium sp*	*Aspergillus fumigatus*	*Aspergillis flavus*
At the beginning of preparation	45*	0	0	0
Two weeks after cutting preparation	21	0	0	0
Four weeks after cutting preparation	09	0	0	0

**Figure represents percent of cutting rot.*

Table 4. Effect of three fungicides on the performance of 1/2 node cuttings of Coffee.

Means of the Parameters measured.						
Fungicide	%Callusedcuttings	%sprouted cuttings	%rooted cuttings	No of roots	Length of roots(cm)	% Infected cuttings
Fungran O.H	80.0	80.0	36,7	2.3	2.9	6.67
Champ D-P	63.3	63.3	40.0	6.1	4.53	36.67
CuS04	6.7	6.7	6.7	1.6	0.83	20.0
Control (H_20)	76.7	86.7	53.3	4.50	5.27	50.0
LSD (0.05)	26,68	28,3	24.95	NS	2.75	NS

DISCUSSION

The four isolated organisms have been in one time or the other implicated in root or nursery diseases of tree crops (Filani, 1972; Olunloyo and Esuruoso, 1975). *Botryodiplodia theobromae*, though a weak pathogen that infects through wounds (Njoroge and Kimemia, 1995) has been reported to cause different plant diseases such as kolanut rot, rot of kola cuttings and brown blight of kola (Adebayo, 1966). Pre and post-emergence decay and damping off of coffee seedlings have also been attributed to *B. theobromae* (Olunloyo, 1974). It is also responsible for the floral shoot die-back disease of cashew (Olunloyo, 1975). Its therefore not surprising that the pathogenicity tests in this study confirm that *B. theobromae* initiated the cutting rot of the half node cuttings. This could be due the presence of wounds and exposure of vascular tissue that serve as entrance for the pathogen. The ability of *B. theobromae* to infect the cuttings reduces as the number of weeks increase (Table 3), this could be due to the fact that the wounds of the cutting have started to heal up, hence leaving little opening for the pathogen to infect. *Fusarium sp*., *Aspergillus fumigatus* were mainly secondary parasites which did not produce any symptoms. Funguran-OH a copper hydroxide based fungicide (equivalent to 50% copper) performed best in virtually all the parameter evaluated, especially in prevention of cutting rot. This performance in particular above Champ D.P recorded corroborate the findings of (Agbeniyi and Adedeji, 2000) in the control of black pod disease of cacao. Final recommendation of this fungicide for half node production would however, be better done after evaluation of field establishment performance of these cuttings. The first trial of this study established the importance of leaf on the performance of coffee half node cuttings, hence suggesting continuous photosynthesis by developing cuttings. It is worthy of mentioning that CuS04 should be avoided in the treatment of half node production going by the results obtained from this study, which confirmed the assertion of (Castilo and Jaime parra, 1959): that Bordeaux mixture ($CuS0_4$ + Lime) hindred normal root development in the germinating seedlings of coffee.

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Pathogen-Induced Systemic Acquired Resistance in Coffee

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SUMMARY

Coffee is the largest traded commodity in the world market after oil and the earnings from coffee trade sustain the economics of many developing countries producing this crop. A major disease causing economical significant crop losses in coffee is leaf rust caused by *Hemileia vastatrix.* Coffee-leaf rust relationship is one of the well studied host pathogen systems to understand the resistance- virulence interactions. The gene-for gene model was utilized to explain the manifested interactions of coffee and leaf rust. Our recent research revealed interesting deviations from this mechanism. Hibrido de Timor (Spontaneous hybrid of Arabica and Robusta) and other hybrids derived from interspecific crosses were exploited commercially in many coffee-producing countries. New races of rust fungus were reported from these hybrids that express vertical resistance. Present paper describes the incidence and infectivity of a new race on two differential hosts *C. congensis* and Kawisari and the operation of systemic acquired resistance (SAR) defense mechanism in *Coffea* was also proposed in the light of these studies. *Coffea canephora*, *C. congensis* and *C. liberica* were believed to have contributed genes to some breeding stocks of *C. arabica*. In our studies, spores collected from the hostdifferentials, *C. congensis* (B-type) and Kawisari (Natural hybrid of *C. arabica* and *C. liberica*, M-type) failed to re-infect the respective hosts as well as the other differentials carrying the genes from the above mentioned species of *Coffea*. This is a pointer in the direction of SAR playing an important role in the resistance of coffee to leaf rust. From our various observations in inoculation experiments, it is evident that systemic acquired resistance against leaf rust is operating in the diploid species of *Coffea* and interspecific hybrids at a higher level than in tetraploid *C. arabica*. This is the first record of occurrence of SAR in coffee.

INTRODUCTION

In nature, plants co-exist with microbes and other organisms. Many microbes are potentially capable of parasitizing plants and are perceived as pathogens, i.e. they are capable of causing disease. The most important pathogens of economically important crop plants are biotrophic and necrotrophic fungi. There are three possible relationships of plants with the co-existing microbes viz. (1) neutral or non-interaction, (2) symbiotic or beneficial interaction and (3) parasitic or harmful interaction. Out of the three, the third relationship causes disease and damage to the plants. This is conditioned by the ability of the pathogen to recognize and colonize the host plant and the ability of the plant to counteract or otherwise of the pathogen's activities. Final outcome of these interactions is controlled by the genetic constitution of the host and the pathogen as well as the environment to some extent (Ram, 2000). A plant is said to be resistant if the pathogen is unable to colonize and spread within the host plant tissues, whereas in a susceptible plant the pathogen can spread systemically in the host plant tissues causing widespread damage. Analysis of these interactions revealed the genetic aspects such as gene-for-gene host-pathogen association, biochemical basis of disease resistance and molecular mechanisms related to disease resistance (Flor, 1956; Keen, 1990; Kombrink et al., 1988; Kerr, 1987; Leong and Holden, 1989). The most recent approach to manage plant diseases in the field is, induction of resistance by chemicals or pathogenesis derived natural compounds including volatiles such as methyl jasmonates and salicylates (Kessmann et al., 1994; Farmer and Ryan, 1990; Hammerschmidt and Kuc, 1995; Ryals et al., 1996; Shulaev et al., 1997). This approach was termed the induction of systemic acquired resistance (SAR). Many natural compounds derived from pathogenesis and plant groth promoting bacteria and synthetic chemicals were found to induce SAR in a wide range of plants (Mauch-Mani and Slusarenko, 1994; Cohen and Kuc, 1981; Alstrom, 1991; Cloud and Deverall, 1987; Gessler and Kuc, 1982; Greenberg et al., 1994; Mahuku et al., 1996; Penninckx et al., 1997). Genetic basis of the induction was also proposed in many studies (Xu et al., 1994; Hammond-Kossack and Jones, 1996; Century et al., 1995; Bowling et al., 1994).

In Arabica coffee, vertical, horizontal and incomplete resistance to the leaf rust disease was reported (Rodrigues, 1985; Eskes, 1989; Varzea et al., 1985). In the course of coffee-leaf rust studies it was noticed that a situation similar to SAR prevails in the relationship of some genotypes of coffee and leaf rust. These observations are reported in the present paper.

MATERIALS AND METHODS

Coffea congensis (B-type) and Kawisari (M-type) are important differentials used in race differentiation of coffee leaf rust. These differentials are maintained in the glass house at the Regional Coffee Research Station at Thandigudi for studies on leaf rust. The susceptibility spectra of these differentials are considerably different. However, the incidence of leaf rust disease was noticed in the field on very few leaves of these plants since 1977. The original clones were grafted on to stumped plants in the field. In each case one or two pustules producing uredospores were found and the spore bulk from these sori was utilized to multiply the race culture on a susceptible host. Details of infection on the original host plants and spore collection are given in Table 1. The multiplied spores were used for inoculation on a wide range of differentials that were considered potential hosts (Table 2). Spores collected from susceptible hosts like Matari (β-type), Bourbon (E-type), Kents (D-type) and *C. racemosa* (F-type) were used to re-infect the original host in a repeat test. The inoculation test was conducted twice on the leaves attached to the host plant and once on leaf disks. Observations are recorded periodically and the results are presented in Table 2.

Table 1. Details of spore collection from *C. congensis* and *kawisari.*

Details	Congensis	Kawisari
Description	263/1, *C. congensis* Uganda	644/18, H. Kawisari
Date of collection	03.09.2002	18.09.2002
Type of sporulation	Medium	Medium
Spots/leaf	One to 2	2
Leaves infected/plant	8 leaves	One leaf only

RESULTS AND DISCUSSION

Only four differentials, Matari, Bourbon, Kents and *C. racemosa* took infection to the level of sporulation while all other differentials remained free of infection. The infected types were generally known to be highly susceptible to many races of the rust fungus. Among them, Kents was a relatively more resistant host carrying two resistance genes S_H2 and S_H5 while Bourbon carries only one gene S_H5. Matari was reported not to be carrying any resistance genes. The F-type, *C. racemosa* was also known to be a universal suspect (Rodrigues et al., 1975). The disease manifestation patterns in the inoculation tests are commensurate with these genotypic constitutions with the exception of *C. racemosa*. The genotype of *C. racemosa* is not yet known. However, this differential manifested resistance similar to Kents. In India, *C. racemosa* was never observed to be severely infected by rust in the field and its resistance appears to be horizontal.

Table 2. Results of inoculation experiments.

Differentials	Congensis			Kawisari		
Inoculation	I	II	Leaf discs	I	II	Leaf discs
Date of inoculation	03.09.2002	12.02.2003	28.12.2002	18.09.2002	12.02.2003	28.12.2002
Date of observation	13.11.2002	31.03.2003	10.02.2003	13.11.2002	31.03.2003	10.02.2003
Differentials						
Matari - _	4	4	4	4	4	3
Dilla & Alghe - α	0	0	0	0	0	NI
HDT - R	0	0	0	0	0	0
Group - 5	0	0	0	0	0	NI
Group - 8	0	0	NI	0	0	NI
S_{12} Kaffa - I	0	0	0	0	0	NI
C. canephora P	0	0	0	0	0	NI
C. congensis Q	0	0	0	0	0	NI
Kents - D	1	2	2	1	0	0
Group - 1	0	0	0	0	0	0
Bourbon - E	2	3	3	3	4	3
C. racemosa F	2	2	2	2	2	2
C. congensis B	0	0	0	0	0	0
C. canephora K	0	0	0	0	0	0
C. canephora V	0	0	0	0	0	NI
S.353 - H	0	0	NI	0	0	NI
Agaro - J	0	0	NI	0	0	0
HDT – A 832/1	0	0	NI	0	0	NI
Geisha - C	0	0	NI	0	0	0
Group - 2	0	0	0	0	0	0
Group - 3	0	0	NI	0	0	NI
Kawisari - M	0	0	0	0	0	0

Note: 0 – Resistant, 1-Necrotic spot, 2-Mild sporulation, 3-Medium sporulation, 4- Severe sporulation, NI – not inoculated.

A conspicuous result of interest is that in all the tests, the original hosts failed to take infection up on inoculation of multiplied spores. This behaviour is similar to SAR in that the stimulation of resistance response appears to have been is provided by the pathogen itself as observed in Arabidopsis (Mauch-Mani and Slusarenko, 1994), Tobacco (Cohen and Kuc, 1981), Bean (Alstrom, 1991), Cucumber (Gessler and Kuc, 1982) and Oil seed rape (Mahuku et al., 1996)

Another interesting observation is the failure of multiplied spores to infect a majority of the differentials considered to be potential hosts (Table 2). Many of these differentials such as HDT-R, HDT-A, Groups -1, -2, -3, -5, -8 are derived from the all-resistant HDT (carrying the resistance genes S_H6,7,8,9 of *C. canephora*) directly or indirectly. A few of the inoculated differentials are derived from other spontaneous tetraploid interspecific hybrids such as H-type and V-type carrying the S_H3 gene of *C. liberica*. The differential types P and K are *C. canephora* types and type-Q is *C. congensis*. The resistance manifested by these hosts cannot be SAR as they were freshly infected with the multiplied spores. Similar resistance was manifested by pure Arabica types I, J, C and α. This manifestation must be on account of the residual horizontal resistance or incomplete resistance present in these types that also appears to be needed for the expression of SAR.

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Laboratory Rearing of Coffee White Stem Borer *Xylotrechus quadripes* Chevrolet in Artificial Diet

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SUMMARY

Artificial diet has been prepared for rearing Coffee White Stem Borer *Xylotrechus* q*uadripe*s (Chevrolet), major coffee pest in India, the chemical composition of the diet and methodology for culturing the beetle in the laboratory are described. The beetle could successfully complete the life cycle from egg to adult in artificial diet with a shortest span of 72 days and longest span of 171 days. By this method adults and larvae in large numbers could be made available for parasite rearing and other laboratory studies.

INTRODUCTION

Coffee White Stem Borer *Xylotrechus quadripes*, (Coleoptera: Cerambycidae) a major pest on coffee has been existence in coffee estates in south India for more than a century. Stokes (1838) made the first reference about the borer attack on arabica coffee from the erstwhile Mysore state (Karnataka). The pest was reported in Robusta coffee also. Apart from India, this pest also occurs in Vietnam, Sri Lanka, Thailand and China.

There are two flight periods for this insect, one in April to May and the other in October to December. The adult borer is a slender beetle 1-2 cm long. The forewings are black with white bands and they are diurnal in habit. Female beetle deposits eggs in the cracks and crevices and under the loose scaly bark of the main stem and thick primaries, preferring plants exposed to the sunlight. The young grubs feed on the corky portion just underneath the bark for few months. Later, the larva enters the hard wood and tunnel in all direction. And grub stage lasts for about 9-10 months. The larva pupates in the chamber close to the periphery of the stem. The pupal stage lasts for about one month, after which it transforms into an adult. Kurian and Surekha (2000) reported that in robusta coffee the flight season is throughout the year and the peak emergence is during November, December and May. During the month of March, July and September the emergence is relatively low.

As there are two flight periods in a year it is difficult to get adults and various stages of grubs in all the months for various studies. To tackle this non-availability of the beetles except in the flight season, studies were initiated to rear in artificial diet. The development of plant biotechnology during the last decade has brought means of controlling strict endocarpic insect through the development of transgenic plants producing *Bacillus thuringiensis*, insecticidal proteins. For screening *Bacillus thuringiensis* activity on neonate larvae regular supply of beetles at the laboratory are required. Hence, for culturing the white stem borer beetle in laboratory, apart from coffee stems as natural way, artificial diet also standardized.

Insect reared on artificial diet has several advantages over those reared on natural foods. For example, by using the artificial diet rearing of insects can be possible and stages will be available throughout the year for various experiments; insects of known and reproducible nutrition are available for tests; studies on nutrition and metabolism can be undertaken by varying the chemical and physical characteristics of diets and environment conditions; and finally the quality of the test insect is controlled. Artificial diets have been used for many purposes, viz., toxicological studies by incorporating Bt toxins, studies on nutritional requirements and physiological pathways, production of insect pathogen, production of attractants and hormones, in mass rearing for bio control programmes and application of sterile male techniques.

MATERIALS AND METHODS

Following are the combinations of diet for the quantity of 1000ml weight in grams. Agar- 40, Sucrose- 20, Fructose- 10, Glucose- 10 *Wesson's salt mixture – 25, Soybean protein – 20, Yeast extract-50, P- hydroxy benzoic acid (methyl paraben) – 1, Cholesterol-1, Fresh arabica stem powder – 42, **Vanderzants fortification mixture- 15, Antibiotic tablet preferably tetra cyclin compound- 1 mg, Sorbic acid- 2.4.

- *Wesson's salt mixture (%): Calcium carbonate – 21, Copper sulphate (5 H_2O) – 0.039, Ferric phosphate – 1.470, Manganous sulphate (anhydropus) -0.020,Magnesium sulphate (anhydrous) - 9.00, Potassium aluminium sulphate - 0.009, Potassium chloride – 12, Potassium dihydrogen phosphate- 31, Potassium iodide- 0.005, Sodium chloride – 10.500, Sodium fluoride- 0.057, Tri calcium phosphate – 14.900.
- **Vanderzant's fortification mixture (for 1000g ,wt. in gms), Tocopherol- 8, Ascorbic acid- 270, Biotin 20 mg, Calcium panthothenate – 1, Choline chloride- 50, Folic acid, crystalline – 250 mg, Inositol- 20, Niacinamide- 1, Pyridoxine hydrochloride – 250 mg, Riboflavin – 500 mg, Thiamine hydrochloride – 250 mg, Vitamin B 12 trituration in Mannitol 5mg.

The composition of the diet based on the formula of Galford (1969 b) in Pritam Singh (1974) with little modification as above. The chemicals except the Vanderzant's fortification mixture and the antibiotic are dissolved in required volume by using distilled water. Mouth of the container was closed with aluminum foil and sterilized in an autoclave for 20 minutes. Allowed to cool the medium in the water bath set 45°C and Vanderzant's fortification mixture and antibiotic were added and mixed by using vortex till it gets mixed. Before solidification the mixture was poured in sterilized cell well plates of 4x3 wells or sterilized petriplates, under the laminar air flow hood and switched on the UV light for 30 minutes. Allowed to cool the medium and made a small incision on the surface of the diet and neonate grubs were released 2 to 4 numbers in a single well. Placed the lid of the cell plates and covered with aluminium foil in order to prevent the entry of the light and placed in BOD growth chamber of temperature set 24°C and RH 80%.

RESULT AND DISCUSSION

Observation was made on the next day of release to make sure that grubs are able to feed on the diet. Neonate grubs were found started feeding with in 1 or 2 hours of release. The size of the grubs was found increasing and the production of excretory material was also recorded. During one life cycle period, weekly observations were made to check whether any fungal infection of the diet. If any fungal pathogen noticed the entire culture will be discarded. Whenever the diet found exhausted the grubs were transferred on to the refrigerated diet. After pupation the specimens were kept in laboratory temperature of 26-30° C.

Table 1. Developmental period of larval stages of *Xylotrechus quadripes* (arabica coffee) in artificial diet.

Stages of grubs	Days taken for moulting	Mean	Mortality (in %)
I instar	6 – 24	15	0.5
II instar	13 – 24	18.5	3
III instar	13 – 30	21.5	5
IV instar	14 – 29	21.5	5
V instar	14 – 28	21	2
Pupation	12 – 28	20	1

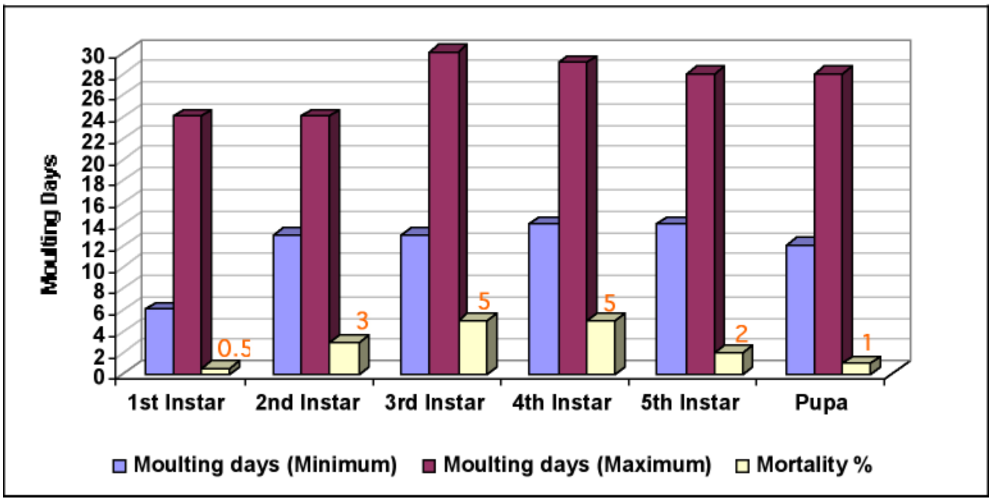

Figure 1. Development period of larval stages of WSB (Arabica) in artificial diet.

The beetles emerged from the diet resembled in all characters of naturally occurred ones with out any apparent decline in the vigor of the beetle. The emerged adults were allowed to breed and found to be successful in laying eggs and the eggs hatched and were used for further rearing in the artificial diet. Diet was also prepared for robusta grubs by using the robusta stem powder and it was found that robusta grubs could also successfully completed life cycle in artificial diet (shortest life span of 85 days and longest life span of 184 days)

Sreedharan et al. (1989) made an attempt on laboratory rearing of Coffee White Stem borer on artificial diet and recorded that when freshly hatched grubs were released on the diet failed to feed and all of them died. In the same paper they mentioned that De Viedma et al. (1985) also reported newly hatched larvae died, when they were transferred into the diet. For the present studies, successful rate of moulting were recorded the first instar grubs onwards and has proved that white stem borer can be reared in the laboratory using the prescribed artificial diet formula.

Galford (1969b) recorded *Xylotrechus colonus* (Fabricius) reared from the artificial diet media along with other ten species. Since the lifecycle of the beetle is very long, utmost care has been taken for the prevention of fungal infection and drying of the diet. There is no difficulty for culturing the neonate grubs till first moulting. As the purpose of the study is to undertake the bioassay of the white stem borer, *Bacillus thuriengiensis* toxins always act on neonate grubs, and grubs grow bigger in size, the intestinal structure will be more complicated and the toxins will act very slowly or doesn't act. Hence, emphases were given for the successful feeding and rearing of the neonate. Successful rate of emergence was also recorded for testing the F2 generation. In natural condition, the life cycle of the beetle is 10-

12 months depending on the climatic factors. The early emergence in artificial diet is achieved due to favourable condition such as ideal temperature, humidity, and nutrients for normal development of the grub.


I instar


II and IIII instar


IV Instar


V instar


Pupae

Figure 2. Larvae feeding in diet.

The present studies revealed that the beetle (arabica) could successfully complete the life cycle from neonate to adult in artificial diet with a shortest span of 72 days and longest span of 167 days. However, the grubs kept in diet under laboratory temperature (26-30°C) took a maximum of 257 days to complete its life cycle (neonate-adult emergence). During the years 2003 and 2004 a total of 177 adults (98 males and 83 females) were emerged from the artificial diet prepared in the laboratory. By application of this method various stages of white stem borer could be made available for different studies throughout the year.

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Field Evaluation of the Coffee Berry Borer Parasitoid, *Cephalonomia Stephanoderis* (Betrem) in the Coffee Tracts of Wayanad, Kerala

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SUMMARY

Large scale release of the berry borer, parasitoid, *Cephalonomia stephanoderis* in estates heavily infested with Coffee Berry Borer resulted in good reduction of the pest. Comparative studies were made to assess the pest level in parasite released and non-released sites. Follow up observations showed good establishment of the parasitoid in all the released estates and migration of the parasitoid into non-released estates also. The paper discusses the suitability of *Cephalonomia stephanoderis* as an effective parasitoid in the integrated management of the Coffee berry borer.

INTRODUCTION

Cephalonomia stephanoderis (Hymenoptera: Bethylidae) was introduced into India from Mexico during the year 1995. This wasp, once inside the berry, feeds on eggs, larvae, prepupae and adults of the Coffee berry borer. Eggs are laid singly on the ventral side of the late larvae or prepupae and the dorsal side of the abdomen. Rearing of this parasitoid was initiated at RCRS, Chundale during 1996. Since then, the parasitoids were multiplied and released enmass by using naturally infested coffee fruits collected from the field. The study evaluates the performance of *Cephalonomia stephanoderis* against Coffee Berry Borer, *Hypothenemus hampii* (Ferrai) in the field.

MATERIALS AND METHODS

The study was conducted at Wayanad, Kerala State, India. *Cephalonomia stephanoderis* was mass produced in the laboratory and released in to 10 estates infested with coffee berry borer, after harvest. Evaluation of the establishment of the parasitoid was made by collecting 100 fruits at random from each released estate, observing them for the presence of various stages of the parasitoid. Similarly neighbuoring non-released estates also were examined for the presence of parasitoids. Follow up observations were made on the Coffee berry borer level in the next year crop to study the impact of parasites. Data are presented in Table 1 and 2.

RESULTS AND DISCUSSION

Coffee berry borer infestation was found to be low in the estates where parasitism was high. Maximum parasitism was recorded at Warriyat estate followed by Asoka estate where large number of parasitoids were released. In the parasite-released estates, Coffee berry borer infestation level ranged between 0.68 and 2.65. In the non-released estates, Coffee berry borer infestation level ranged between 3.8 and 12.2. From the results it could be deduced that large scale release of the parasitoids at the post harvest period resulted in good reduction of the pest. As found from the results migration of the parasite could be recorded form neighbuoring plantations where no release was made.

Table 1. Percentage parasitism and level of infestation in parasite released estates.

Name of the estate	No. of parasite released after harvest	Percentage parasitism	Berry borer infestation in the next year crop
Warriat Estate	55,000	60	0.68
Ashoka Estate	16,850	34	1.9
Rock side Estate	10,250	10	0.88
KPK Plantation	10,000	0	2.65
Kulathanal Estate	5,000	24	0.66
Snehadeepam	2,500	0	1.63
Ramdham Estate	2,500	1.5	0.98
Crother Estate	10,000	5.8	1.48
Krishna Estate	5,000	6	1.03
Manjima Estate	5,000	16	1.05

Table 2. Percentage parasitism and level of infestation in non-released estates.

Name of the estate	Percentage of parasitism	Berry borer infestation
Pambra Estate	0	6.03
Lovely Hills	0	9.11
Pookunnu estate	0	9.38
Karimbil Estate	*	4.78
Ratnagiri Estate	0	12.2
Padma Estate	*	7.09
Sathya Estate	0	4.35
Peace Cottage	0	5.09
Karimk ulam Estate	0	4.70

** Parasite found*

CONCLUSION

The observational study indicates that *Cephalonomia stephanoderis* released during the post harvest period can effectively check the spreading of Coffee berry borer. The migrating behaviour of the parasitoid opens up its possibility to be a highly useful and effective parasitoid in the integrated management of Coffee berry borer. Considering the feeding habit of the parasitoid, *Cephalonomia stephanoderis* will be a suitable alternative when insecticides fail to reach the brood inside the berry in the ripening stages.

Production of Compost using Thermophilic Fungi *Mycotypha* sps Strain No. AKM-1801, from Coffee Husk and Its Impact on Plant and Soil

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SUMMARY

Coffee cherry husk is one of the major by product of coffee industry. Due to the presence of polyphenolic material and highly acidic pH, its management has been a tough task. *Mycotypha sps*. Strain No.AKM -1801, a thermophilic fungi isolated from coffee husk heap helps in converting coffee husk into Compost. Studies indicated that the pH of the husk changed from 3.6 to 8.4 in 20 days. Investigation revealed that the compost increased the germination percentage and Vigour index on various plants like. *Pisum sativum, Arachis hypogea, Brassica nigrum, Dolichos lablab, Dolichos biflorus, Phaseous aureus, Vigna sinensis and Vigna catjang*. The Compost showed accelerated growth of the plant in pot and field experiment due to the production of phytoharmones. These Phytoharmones are yet to be identified. The plantation soil being highly acidic, addition of lime to stabilize the pH is a common practice. Our effort to amend the pH of the soil using this Compost showed promising results. Incorporation of this compost even at 2.5% level neutralized the pH of the soil for one cropping season. A detail investigation on long-term effects of soil amendment is under progress.

INTRODUCTION

Coffee husk is one of the most abundantly available agro- industrial wastes produced after processing of coffee by dry method (Zuluaga, 1981). For every ton of Coffee cherry, nearly 0.18 ton of coffee husk is generated (Adams and Dougan, 1981). About 1,300,000 tons of coffee husk is produced annually around the globe (Orne & Bahar, 1985). Coffee husk is rich in nutrients and contains 1,026 g of nitrogen, 60 g of phosphorous, 918 g of potassium, 162 g of calcium, 90 g of magnesium, 72 g of sulfur, 0.96 g of boron, 0.80 g of copper, 3.6 g of iron, 1.2 g of manganese, 0.002 g of molybdenum, and 0.72 g of zinc / 60 kg of the husk. Along with this it also contains carbohydrates especially high amounts of pectin. Due to the presence of polyphenols which are considered as anti-nutritional / phytotoxic factors such as caffeine, tannin, etc., its use in agriculture has been restricted to larger extent. (Bressani, 1979a). Even though there has been many reports describing the composition, upgrading and utilization of coffee husk, there are few reports on its natural microflora and it's utility for agricultural purpose due to above reasons (Calle, 1951,1954; Ledger & Tilman, 1972; Bressani, 1979b; Christensen, 1981; Orne & Bahar, 1985; Martinez-Carrera, 1987).

With the realization of the deleterious effect of chemical fertilizers and pesticides, the emphasis on organic cultivation has become the norm of the day. Conversion of agro waste to Compost is one of the traditional practices in agriculture. To meet this ever-increasing demand of compost, a number of slowly degrading and phytotoxic agro waste is being exploited as organic fertilizer, using microorganisms (Murthy et al.,1996).

The present investigation works emphasizes on effects of coffee husk waste in agricultural fields as Compost using *Mycotypha sps* to enrich the soil nutrients and their impact on plant growth.

MATERIALS AND METHODS

Microorganism

Mycotypha sps strain No.AKM-1801, isolated from coffee husk heap by Venugopal, (2001) and identified as described by Barnett and Hunter (1972); Alexopoulous et al. (1996) was used for the present study. It was maintained on the coffee husk media (Brand et al., 2000) at $\pm$ 45°C for 4 days. Inoculum was prepared by suspending the spores in Tween 80 solution and counted in Neubauer chamber as explained by Aneja (1996).

Production of Compost

Preliminary investigation showed that 60%WHC is suitable for the growth of *Mycotypha sps*.. Thus Coffee husk was moistened to 60% WHC. The *Mycotypha* spores *were* inoculated into the coffee husk at the rate of 10^4 spore /ml. The initial pH of the coffee husk was found to be 4.3. The heap was covered with polythene and allowed to degrade for 20 days The core temperature of the coffee husk heap was recorded to be at 40-50° C, during composting.

Standardization of application of Compost

The coffee husk compost, which was produced from *Mycoytypha sps*. was applied at the rate of 2.5%, 5%, 10%, 30% and 50% to the total volume of the soil. The test crops, *Pisum sativum, Arachis hypogea, Brassica nigrum, Dolichos lablab, Dolichos biflorus, Phaseous aureus, Vigna sinensis, Vigna catjang* was taken for the present experiments.

RESULTS AND DISCUSSION

Effect of water and pH on Compost

The water content of the substrate strongly affects the growth & activity of the organism intern water activity depends on the type of supporting material (Turner et al., 2001). In this study the alkalization of coffee husk occurred in 20 days, at 60% WHC. The drastic increase in pH to 7 and above may be due to production of alkalinizing compounds produced during fermentation. After 20 days, the compost sample did not show any significant changes in pH. The production of such alkalinizing compounds was observed by Penaloza et al. (1985) during the growth of *Aspergillus* on Coffee pulp. Bressani et al. (1979b) has reported that dry coffee husk contain 6.5% of pectinaceous material, they require higher amount of water for hydration. Thus, regulation of available water is one of the major constraints in production of good Compost. The preliminary investigation indicates the WHC of 60% is required to support the growth of *Mycotypha*. At higher percentage of moisture there was not much change and showed accumulation of free water in the substrate (Venugopal, 2001), so it should be between 30% -75% (Lonsane et al., 1985). As the change in moisture percentage varies it affects the physical – chemical factors during the growth of microbes. (Penaloza 1985). In the present experiment, the pH changed from 4.3 to 9.0 within the short span of 20 days at 60%WHC as in Figure 1. These results correlates with the work of Fang, and Zhong, (2002) who reported that the pH increased towards the end of the fermentation, coinciding with the exhausting of sugar. Only when the sugars are exhausted or present in very low concentration are the respiratory enzyme derepressed leading to sporulation (Polakis, et al., 1965), which is considered as end of the farm yard manure production along with other parameters.

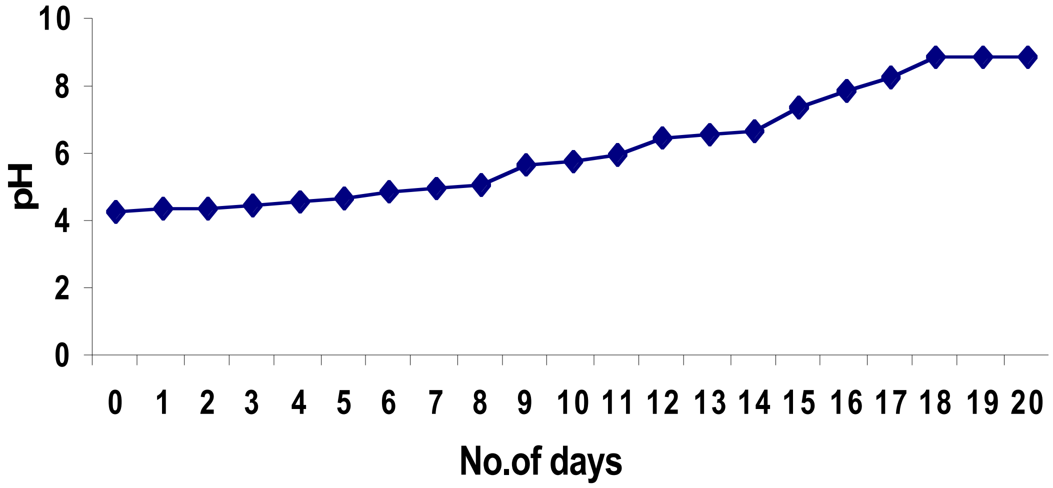

Figure 1. Change in pH during production of compost by *Mycotypha sps.*

Effect of pH on soil

The pH of the soil before the amendment was found to be 5.3, but after application of compost at 10%, pH of the soil showed the drastic change and by the end of the experiment remained almost constant i.e. near to neutral as in table.2. The application of compost even at the rate of 2.5% shows its influences on soil pH with *Raphanus sativus* (Table 1). This would be a promising factor for the usage of compost to alkalinize the soil without usage of chemicals and one the main factor to consider as good compost. The ideal soil pH for the production of common crops should be between 6.0 to 6.8. Soils with a pH below that level usually cannot provide plant nutrients in sufficient quantity for maximum yield even though the soil might be high in those nutrients. Many beneficial soil microorganisms do not thrive in strongly acid soils. Soil pH in the range of 6.0 to 7.0 increases microbial activity and helps reduce thrash. Both plant and microbial enzymes are greatly influenced by pH. Soil drainage, texture, porosity, adsorption, absorption are all affected by pH of the soil.

Standardization of Compost application rate and their effect on Plant growth and Nodulation

Coffee husk manure was applied at different percentage (2.5%, 5%, 10%, 30%, 50% to the total volume of the soil). At higher percentage (above 10%) the irrigated water and nutrients leached to near by plots rapidly due to the loose texture of the coffee husk which increased the soil porosity (Subba Rao, 1998). This also induced lodging of plants. Compost at 10% was suitable for leguminous plants compared with control and untreated husk. In case of stem and leafy vegetables incorporation of compost at 10% induce the germination but the beneficial effect was not pronounced during growth, but such effects will no longer remains, but the effect of compost at 2.5% found to be better and consistent as in Figure 2 and Table 1.

Figure 2. Effect of coffee husk compost on growth of *Raphanus sativus* at different percentage.

Table 1. Effect of Coffee husk compost at different percentage using *Mycotypha sps.* on *Raphanus sativus*

% of Compost	Type of treatment	Length of Shoot (cm)	(%)	Leaf size (cm)	(%)	Length of leaf (cm)	(%)	Shoot	Stability of Shoot	pH
10%	Treated coffee husk	8	84	3	120	4	267	Normal	13/20	6.72
	Untreated coffee husk	9	98	2.5	100	1	67	Thin	12/20	4.67
	*Control	9.5	100	2.5	100	1.5	100	Normal	15/20	6.12
5%	Treated coffee husk	13.5	142	3.5	140	5	333	Thick	14/20	6.53
	Untreated coffee husk	8	84	2.8	112	5	333	Thin	12/20	5.13
	*Control	9.5	100	2.5	100	1.5	100	Normal	1520	6.12
2.5%	Treated coffee husk	14	147	4.5	180	8	533	Thick	18/20	6.37
	Untreated coffee husk	8	84	3.5	140	5	333	Thin	12/20	5.27
	*Control	9.5	100	2.5	100	1.5	100	Normal	15/20	6.12

**Control: – 50ml of water was added/ kg of soil once in 3 days*
***Mean of 30 plants*

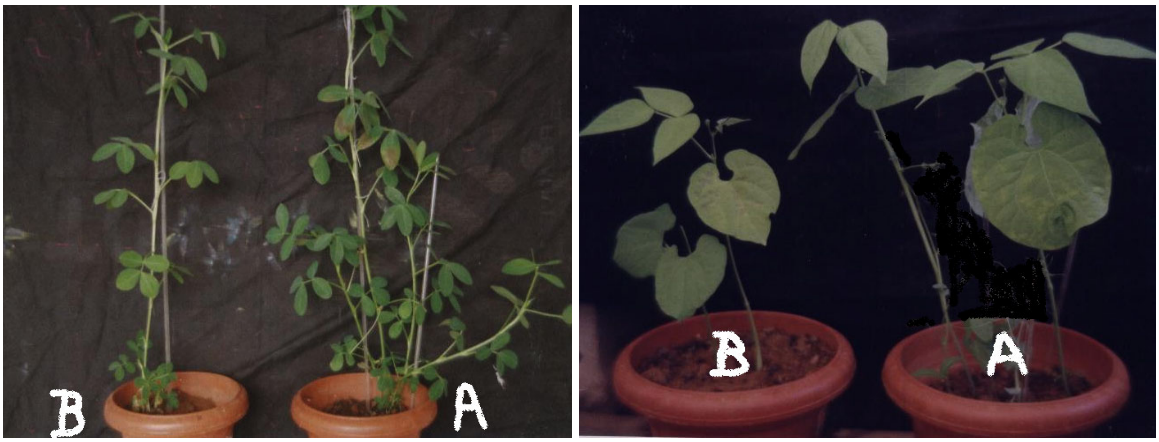

Figure 3. Effect of coffee husk compost on the growth of *Arachis hypogea, Dolichos lablab* (A –Treated, B –Untreated).

All the tested plants show the positive effects towards coffee husk compost produced by *Mycotypha sps.* on leaf (number and size), Biomass, Shoot (length) as in the Figure 3 and Table 4. Positive results were observed in all the cases among leguminous plants. Of all Groundnut shows a noticeable improvement in inducing nodulation of about 73% increased compare to control as in the Figura 4 and Table 3. Nodule forming organism in legumes are adversely affected as the pH of the soil decreases. (ICAR, 1997). This in turn favored fruit for maturing which showed a 71% increase. pH is also one of the main factor where the pH should be between 5.3-6.6 for *Arachis hypogea,*, 5.5-7.0 for *Dolichos lablab*, 6.0-7.5 for

Raphanus sativus etc. which aids in availability of the nutrients in plant growth. (ICAR, 1997).

Table 2. Effect of coffee husk compost produced by *Mycotypha sps.* on soil pH.

Crop		pH of the soil		
		0 day	45 days	90 days
Pisum sativum	Treated coffee husk	5.43	7.37	6.94
	Untreated coffee husk	5.43	4.34	6.12
	*Control	5.43	6.12	6.53
Arachis hypogea	Treated coffee husk	5.43	8.13	6.98
	Untreated coffee husk	5.43	4.17	5.92
	*Control	5.43	5.80	6.34
Brassica nigrum	Treated coffee husk	5.43	7.87	6.47
	Untreated coffee husk	5.43	4.63	5.9
	*Control	5.43	6.12	6.13
Dolichos lablab	Treated coffee husk	5.43	7.97	6.57
	Untreated coffee husk	5.43	4.87	6.06
	*Control	5.43	6.12	6.0
Dolichos biflorus	Treated coffee husk	5.43	7.13	6.57
	Untreated coffee husk	5.43	4.91	5.93
	*Control	5.43	6.12	6.34
Phaseous aureus	Treated coffee husk	5.43	7.61	6.73
	Untreated coffee husk	5.43	4.29	5.91
	*Control	5.43	6.12	6.03
Vigna sinensis	Treated coffee husk	5.43	7.52	7.05
	Untreated coffee husk	5.43	4.09	5.43
	*Control	5.43	6.12	6.03
Vigna catjang	Treated coffee husk	5.43	7.87	6.63
	Untreated coffee husk	5.43	4.63	5.57
	*Control	5.43	6.12	6.27

**Control: – 50ml of water was added/ kg of soil once in 3 days*
***Mean of 30 plants*
****Treated & untreated coffee husk was added at 10% level*

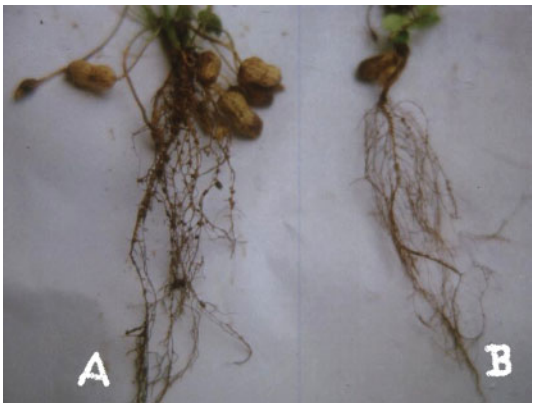

Figure 4. Effect of coffee husk compost on the nodulation in *Arachis hypogea* (A – Treated, B – Untreated)

Table 3. Effect of coffee husk compost by *Mycotypha sps*. on nodulation in *Arachis hypogea.*

Ground nut	Nodules (%)		Fruits (%)	
Treated coffee husk	123	173	12	171
Untreated coffee husk	49	69	3	43
Control	71	100	7	100

**Control: – 50 ml of water was added/ kg of soil once in 3 days*
***Mean of 30 plants*
****Treated & untreated coffee husk was added at 10% level*

Table 4. Effect of coffee husk compost produced by *Mycotypha sps*. on different crops.

Crop	Type of Treatment	Length of shoot (cm)	(%)	Leaf size (cm)	(%)	Biomass (gm)	(%)	No. of leaves	(%)
Pisum sativum	Treated coffee husk	21	105	3.7	109	148	117	26	130
	Untreated coffee husk	8	40	3.4	100	87	69	8	40
	*Control	20	100	3.4	100	127	100	20	100
Arachis hypogea	Treated coffee husk	6	200	4.8	107	290	135	15	167
	Untreated coffee husk	2	67	4.8	107	230	107	7	78
	*Control	3	100	4.5	100	215	100	9	100
Brassica nigrum	Treated coffee husk	11.15	110	2.5	167	18	120	2	100
	Untreated coffee husk	9.5	90	2.0	133	15	100	2	100
	*Control	10.5	100	1.5	100	15	100	2	100
Dolichos lablab	Treated coffee husk	21	110	14.5	132	350	245	3	150
	Untreated coffee husk	14	78	12	109	195	137	2	100
	*Control	18	100	11	100	143	100	2	100
Dolichos biflorus	Treated coffee husk	7.5	115	5	152	55	183	6	150
	Untreated coffee husk	6.8	104	2.6	79	33	110	4	100
	*Control	6.5	100	3.3	100	30	100	4	100
Phaseous aureus	Treated coffee husk	23	209	5.3	123	130	145	2	100
	Untreated coffee husk	18	164	3.3	77	70	78	2	100
	*Control	21	100	4.3	100	90	100	2	100
Vigna sinensis	Treated coffee husk	16	133	1.35	150	165	114	10	100
	Untreated coffee husk	9	75	0.87	97	137	95	10	100
	*Control	12	100	0.9	100	145	100	10	100
Vigna catjang	Treated coffee husk	18	129	13.5	123	61	100	8	100
	Untreated coffee husk	13	93	10	91	59	143	8	100
	*Control	14	100	11	100	43	138	8	100

Control – 50 ml / kg of soil / 3 days
***Mean of 30 plants*

CONCLUSION

As there are hardly any reports on utilization of *Mycotypha sps* for the production of compost and there are no reports of it s application in agriculture. The present results indicate that *Mycotypha* is an ideal candidate for compost production. Thus it will reduce the cost of chemical fertilizers and opens up wide applications of such strains in the utilization of similar type agro – selvicultural wastes to a larger extent. This also improves seed germination, nodulation, alkalinize the soil and also to pretreated coffee husk for vermicomposting.

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Control of Coffee Wilt: Study of Genetic Diversity of *Fusarium xylarioides* and *Coffea canephora* in Uganda

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SUMMARY

Coffee Wilt Disease (CWD) or Tracheomycosis was first seen in 1927 in Central Africa Republic. From 1938 to the early 50's it spread on *Coffea excelsa* and attacked *C. neo-Arnoldiana*, to a lesser extend *C. canephora* var. robusta. At the same time a general decline of coffee trees in Ivory Cost was attributed to the same disease. It attacked two local varieties of *C. canephora* and *C. abeokutae* or Indénié as well. In Ethiopia, CWD infects Arabica coffee. From 1935 to 1960, coffee wilt became the most serious disease of *Coffea sp* throughout West and Central Africa. The damages were very severe and lead to the death of millions of trees. As a consequence, *Coffea excelsa* and related species as *C. abeokutae* disappeared from these regions.

During the 50's the systematic elimination of affected plants over vast areas was required. Additionally, the collect of sources of resistance in both wild populations and in the cultivated varieties for use in breeding programmes should be undertaken so that resistant varieties could be developed and replanting could begin.

These two strategies proved to be highly successful.

The Coffee wilt disease "disappeared" towards the end of the 1960s, "reappeared" at the beginning of 1980's in DRC and 1993 in Uganda.

Given the inefficacy of phytosanitary control methods, the impossibility of replanting on infected soil and the absence of commercial resistant cultivars, a genetic control strategy was initiated. Two lines of research were developed: a study of pathogen diversity and an analysis of the biodiversity of wild *Coffea canephora* trees in Uganda, which would be resistant to vascular wilt.

GENETIC DIVERSITY OF *FUSARIUM XYLARIOIDES*

The genetic diversity of *Fusarium xylarioides* was studied using microsatellite markers. Eleven primer sequences defined from a reference strain were used to study a collection of 150 isolates collected from Uganda, the Democratic Republic of Congo, Tanzania and Ethiopia, which are representative of the geographical diversity of the infected zones, isolated on a set of *Coffea canephora* clones with known field resistance or in plantations and 2 other *Coffea* species: *C. arabica* and *C. liberica*.

The results revealed that

1- *Fusarium xylarioides* is categorized into two groups, directly correlated to the host species from which the pathogen was collected, i.e. the species *C. canephora/C. liberica* and the species *C. arabica*.
2- No population structure is in relation with any geographical distribution.
3- There is a low genetic diversity within the species, suggesting the predominance of vegetative propagation despite the presence of the sexual form *Gibberella xylarioides*. A comparison of contemporary and "historical" strains collected in the 1950s and 1960s suggested limited genetic evolution of the species *Fusarium xylarioides* over that period.

GENETIC DIVERSITY OF *COFFEA CANEPHORA* IN UGANDA

The study on genetic diversity of *C canephora* in Uganda is in progress. Although *C. canephora* trees in Uganda display quite a wide phenotypic diversity, no systematic studies have been undertaken to understand underlying genetic variability for systematic exploitation. In this study wild canephora individuals were collected from several locations in Kibale forest/National Park in western Uganda. In addition, 12 individuals from the botanical garden at Entebbe, 16 hybrids and their 7 progenitors, 20 'erecta' type and 20 'Uganda' type individuals from collections and experimental plots at the Coffee Research Institute are currently being analysed for genetic diversity using 20 microsatellite markers. These Ugandan *canephora* trees will be inoculated for resistance against the coffee wilt disease. Where appropriate, the resistant individuals will be used in the genetic improvement scheme for incorporation of their resistance into elite/commercial clones or lines.

CONCLUSION

Low genetic diversity of *Fusarium xylarioides* will allow to propose a breeding strategy in order to select coffee plants resistants to coffee wilt disease. Once their genetic diversity highlighted, Ugandian coffee trees could constitute a source of resistance to Coffee Wilt Disease

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Socio-Economic Analysis of Smallholder Coffee Farms with Reference to Integrated Management of White Stem Borer in Karnataka, India

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SUMMARY

Coffee white stem borer, *Xylotrechus quadripes* is the most destructive pest of arabica coffee in India, causing severe economic losses. In this context, a socioeconomic survey of 340 growers, randomly selected over three principal arabica coffee growing districts in Karnataka was carried out during 2003-04 cropping season. The study investigated farmers' perceptions of the importance of stem-borer and farm practices influencing the pest. All the growers rated white stem borer as the major constraint in arabica cultivation by all growers. Unable to bear the economic burden, several small plantations have been left neglected, without use of any inputs like fertilizers and plant protection measures. Lack of proper shade because of the extraction of timber to sustain themselves, prolonged drought since three years and poor management have increased the borer problem in the holdings. Many farmers expressed that BHC was more effective than other plant protection chemicals against borer. The major constraints faced by the growers in arabica coffee cultivation are severe incidence of WSB causing reduced yields (93.57%), low prices (90.71%), higher labour wages & lower level of work efficiency (45.71%), lack of skilled labours (12.14%), high cost of fertilizers and plant protection chemicals (74.29%), failure of rainfall (87.14%) and high rate of interest on borrowings (42.86%). Growers adopt mainly mechanical control measures like tracing and uprooting, swabbing lindane during April-May and September-December. The growers want newer technologies like acoustic detectors/sensors for the exact identification of borer-infested plants and also for better management of the pest.

INTRODUCTION

White stem borer, *Xylotrechus quadripes* is the most serious pest of arabica coffee in India (Anonymous, 2000). It is prevalent in all the arabica areas in the country. The stem borer larvae feed inside the stem, thus weaken the plant and cause death. The borer incidence is reported to be on higher side during the past few years and a critical study on the socioeconomic aspects of stem borer management is found to be useful in getting a feedback from the coffee growers based on which better strategies could be developed. Similar studies were reported in the case of many important pests in several crops world over (Norton, 1995; Yong Gong and Guo Jun, 2001; Tafera, 2004; Nyankanga et al., 2004). However, such studies were not carried out in the case of white stem borer management and hence a study on the socioeconomic aspects of this important pest of coffee was planned as a part of the ongoing Multicountry Project on the IPM of coffee stem borers in India, Malawi and Zimbabwe.

The major objectives of the present study were:

a) To document the socio-economic status of smallholders of arabica coffee

b) The level of uptake of technologies by farmers and analyze their problems and perceptions

METHODOLOGY

Study area and Sampling design

The study was conducted in the three traditional arabica coffee growing districts of Karnataka, India viz., Chikmagalur, Kodagu and Hassan. A multistage stratified purposive sampling procedure was used to select the growers at different levels to get a representative sample for this study. Primary data were collected by personal interviews using a well-structured and pre-tested questionnaire from a sample of 340 small growers who own less than 25 acres, distributed across the three districts, during the 2003-2004 cropping season.

Analytical techniques

The data collected were analyzed using the technique of tabular analysis to denote the basic characteristics of the sample with respect to grower socio-economic profiles and opinion survey outcomes etc.

RESULTS

Most of the growers were literate and education level was also high (graduation level) in many of the cases. Coffee is a vital source of income for majority of the smallholder farms. Crops like pepper, orange, cardamom; areca nut and vanilla are grown as subsidiary crops, which become the good source of income at present condition.

The growers opine that the incidence of stem borer is on increase for the past three to four years mainly due to eth prevalence of continuous drought situation in coffee areas. Other reasons attributed were financial crisis and extraction of timber from the plantations.

Table 1. Reasons for WSB flare up- growers' views.

Reasons	%
Prevalence of drought conditions consecutively for the last three years	97.86
Financial crisis and hence poor crop management	61.43
Extraction of timber from estates to meet farm expenditure	54.29

Cauvery and Sln-795 are the varieties severely affected by WSB Infestation. Sln-6 and 9 are less prone to WSB attacks. Majority of the growers are in severely bad debt condition and unable to clear the loans and hence got declared as Non Performing Assets (NPAs) by the banks. Many ventured into coffee planting after higher coffee prices realized during the 1990s. During that period many new plantations got established on barren and agricultural land under mono-shade (silver oak as the major shade tree) and hence more than 340% of eth estates surveyed had only silver oak as mono shade (Table 2).

Table 2. Shade pattern on the estates.

Shade type	%	Shade level	%
Mono shade	40.71	Thin	6.43
Mixed Shade	59.29	Medium	89.28
		Thick	4.29

White stem borer and leaf rust have been prioritized as the most important pest and disease. Berry borer is the next major pest in Coorg region. Many expressed that BHC (banned since 10 years) more effective than other plant protection chemicals (lindane or chlorpyrifos) against WSB. The growers wanted the pilot scheme on Catch & Kill (mechanical method) programme implemented by the Coffee Board providing incentive based on the pest stages collected and destroyed to be continued at least for two years. The programme made the growers better aware about the pest. Growers also wanted the enforcement of the Pest Control Act, so as to make borer management programme a community activity.

Identification of borer infested plants and control measures adopted

The growers use different methods to identify the borer-infested plants (Table 3).

Table 3. How do growers identify the infested plants for uprooting?

Symptoms	%
Drooping nature of the plant	88.07
Rings/ridges on the stems	72.80
Slow drying/wilting of the plant	82.91
Yellowing of the plant	54.55
By making small cuts on the stem	30.00
Breaking of the plant with a slight pull	25.00
Exit holes	60.80

With regards to management practices, majority of the small growers does only one round of tracing during the period of May-September. About 50% of the growers adopted bark scrubbing and majority does this operation with sharp tools in the months of August and September due to labour availability at that time. Though most of the growers resorted to the on the spot burning of the uprooted infested stems, there are also cases of selling the uprooted stems to local buyers and also storing them for using as firewood (Table 4). Very few practice spraying lime on the main stem, as it is labour intensive activity. Majority follows chemical control measure and mostly swabbing is done to the main stem as it gives scrubbing effect. Lindane is the common pesticide used for swabbing and very few use chlorpyrifos. Some growers add neem oil (200-300 ml per barrel). Only very few growers were aware of the biological control measures and use of /pheromone traps (2-3%). The growers want the evolvement of better control measures and developing devises like acoustic detectors/sensors for the exact identification of borer infested plants.

Table 4. Mode of disposal of uprooted infested stems.

Method	**%**
Burn them immediately	82.86
Sell them to local buyers	44.29
Store for fuel after immersing in water	31.43
Store as fuel wood	8.43

General problems /constraints in arabica coffee cultivation

Severe incidence of white stem borer and low coffee prices are considered to be the most serious problems in arabica cultivation as opined by majority of the growers. The other constraints reported are drought condition, high cost of inputs, financial problem etc (Table 5).

Table 5. Problems/Constraints faced by the growers in the cultivation of arabica coffee.

Sl.No.	Problems/Constraints	%
I.	**Production Problems**	
1.	Severe incidence of WSB causing reduced yields	93.57
2.	Failure of rainfall	87.14
3.	High cost of fertilizers and PPC	74.29
4.	Higher labour wages & lower level of work efficiency	45.71
5.	Problem of neglected estates	28.57
6.	Prevalence of spurious plant protection chemicals	13.57
7.	Non availability of laborers	12.14
8.	Lack of skilled labour	12.14
II.	**Financial Problems**	
1.	Financial crisis/ no money	55.00
2.	High rate of interest on borrowings	42.86
3.	Non-availability of institutional finance	30.71
4.	Lack of credit facilities	3.57
III.	**Marketing Problems**	
1.	Low price	90.71
2.	Price volatility	12.86
3.	Lack of Minimum Support Price (M.S.P.)	15.57

Transfer of technology

The local Coffee Board Extension Units were the preferred sources of information on coffee cultivation, especially pest management information for majority of the respondents. Growers also relied on local dealers agrochemicals for details on the use of pesticides.

CONCLUSION

The present study clearly brought out the significant importance of white stem borer management in the cultivation of arabica coffee. Though the growers generally follow the recommended packages of practices, there are some shortcomings in the adoption level of certain components. This warrants adoption of more effective transfer technology methods and also improvement in the current package of practices.

The watchword of the coffee growers at present is "how to survive?" as they are getting very low income, which is not covering the production costs. Still growers are in a hope for a recovery of prices in near future and want to continue coffee cultivation mainly because of lack of viable alternatives. Growers are slowly diversifying to other cash crops such as pepper, vanilla, banana etc., to manage the present situation. Coffee being a perennial crop, once planted coffee trees become fixed assets with huge investment. Switching over to food crops is very difficult and not an alternative as coffee is grown in eco-sensitive zones of the Western Ghats where such a conversion could lead to ecological imbalance. This study, thus, brings out the need for development of an improved IPM strategy for the management of this serious pest of arabica coffee in the context of present environmental and economical situation.

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Effect of Growth Temperature on Aggressiveness of *Colletotrichum Kahawae* Isolates Towards Coffee

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INTRODUCTION

The fungus *Colletotrichum kahawae* Waller & Bridge is responsible for the coffee berry disease (CBD) in Africa, infecting leaves and coffee berries at any stage of their development and inducing losses that reach 70-80% (Griffiths et al., 1971). The study of this disease is very important not only for African coffee growing countries, which depend on this crop for export revenues, but also for those where the disease, although still absent, is a constant threat. In the present study we intended to ascertain whether growth of the fungus at different temperatures in agar media had any influence on its aggressiveness.

MATERIALS AND METHODS

Fungi and plant materials

Four single spore isolates of *C. kahawae* [Cam1 (Cameroon), Mal2 (Malawi), Que2 (Kenya) and Zim1 (Zimbabwe)] from Coffee Rust Research Centre (CIFC-IICT) collection were maintained on malt extract agar (MEA) in the dark at 22ºC. Detached young leaves and green fruits as well as 6-7 week-old hypocotyls from *Coffea arabica* var. Caturra were used for inoculation tests.

Daily growth rate, sporulation capacity, conidia germination and pathogenicity tests

The effect of growth temperature (GT) on mycelium daily growth rate (DGR), sporulation capacity (SC), percentage of germinated conidia (GC), appressoria (Ap) formation and isolate aggressiveness was determined by growing the isolates at constant temperatures of 17, 22, 25 and 28ºC. The parameters DGR, SC, GC, and Ap were evaluated according to the usual methodology (Santos Eichler, 1998). For the pathogenicity tests, detached young leaves, green berries and hypocotyls were inoculated with droplets of conidia suspensions prepared from cultures grown at the above mentioned temperatures. Hypocotyls trials had a mean duration of 30 days and the results were expressed by a disease severity index using van der Graff's scale (Santos Eichler, 1998; van der Graaff, 1981).

Data were subjected to an analysis of variance or co-variance. For multiple regression analysis Turkey's test was used. Data in percentage were previously arc sen $\sqrt{\%}$ transformed (Sokal & Rohlfs, 1981).

RESULTS AND CONCLUSIONS

The cultural characteristics on MEA of the four *C. kahawae* isolates studied showed the existence of interaction between the GT and the isolates with higher and lower DGR at 25ºC and 17ºC, respectively (Table 1). It was also observed an interaction GT-SC, with higher values of sporulation on the isolates grown at 28ºC (Table 2).

Table 1. Daily growth rate (cm) of isolates Cam1, Mal2, Que2 and Zim1 on MEA, at the temperatures of 17, 22, 25 and 28ºC, in the dark.

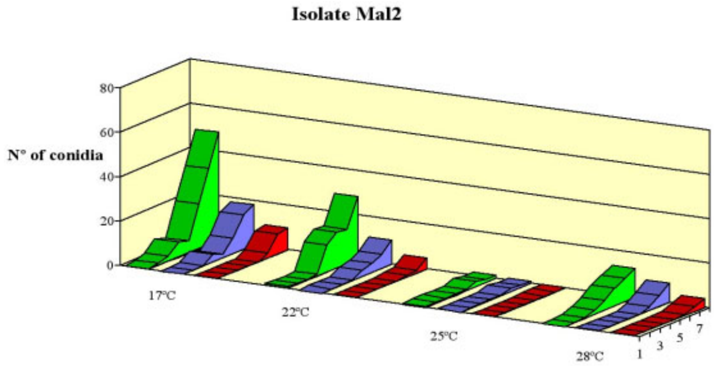
	Isolates			
T (ºC)	**Cam1**	**Mal2**	**Que2**	**Zim1**
17	0,31 **a**	0,37 **a**	0,33 **a**	0,39 **a**
22	0,76 **c**	0,57 **b**	0,58 **b**	0,67 **c**
25	0,89 **d**	0,66 **c**	0,79 **c**	0,84 **d**
28	0,40 **b**	0,55 **b**	0,64 **b**	0,58 **b**

In the same column, values with the same letter are not significantly different according to Tuckey's multiple range test (P = 0,001).

Table 2. Number of spores ($x10^4$) per cm^2 of 14 day-old colonies from isolates Cam1, Mal2, Que2 and Zim1 grown at 17, 22, 25 and 28ºC, in the dark.

	Isolates			
T (ºC)	**Cam1**	**Mal2**	**Que2**	**Zim1**
17	4,9 **b**	6,7 **b**	14,9 **a**	12,2 **c**
22	3,4 **a**	22,6 **c**	25,9 **b**	9,8 **b**
25	24,0 **c**	6,4 **a**	32,5 **c**	5,6 **a**
28	257,5 **d**	26,0 **d**	62,5 **d**	48,6 **d**

In the same column, values with the same letter are not significantly different according to Tuckey's multiple range test (P = 0,001).



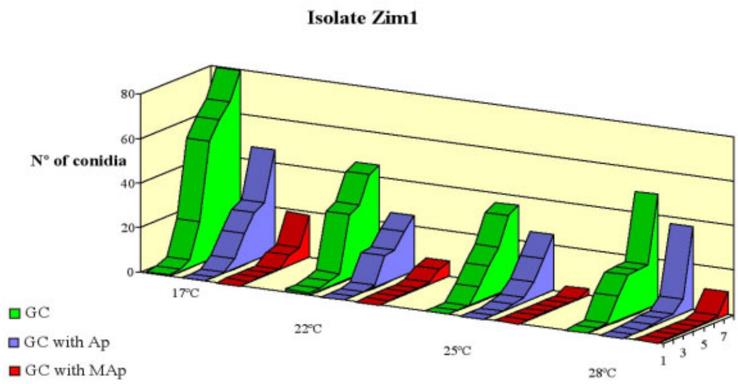


Figure 1. Effect of GT (17, 22, 25 and 28ºC) on the production of GC and Ap (total and melanized) during 8 hours of germination in water at 22ºC for isolates Mal2 and Zim1.

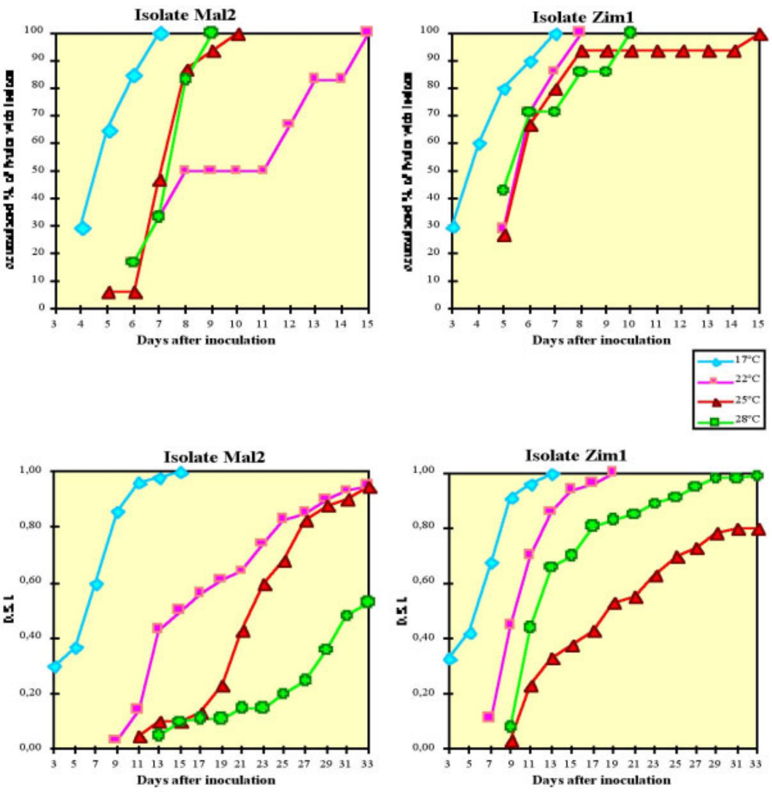


Figure 2. Accumulated percentage of fruits with lesions (A) and Disease Severity Index (DSI) of hypocotyls (B) inoculated with isolates Mal2 and Zim1 previously grown at temperatures of 17, 22, 25 and 28ºC.

The number of GC and of total Ap formed on the Mal 2 and Zim1 isolates showed that GT of 17ºC led to the highest values in experiments made during 8 hours and after 20 hours of incubation. At this GT of 17ºC it was also observed a quicker conidia germination and melanized Ap formation (Figure 1). At this same GT it was observed, in the pathogenicity tests, a quicker symptoms appearance and death of the inoculated organs (Figure 2). Since with the other studied temperatures no pattern of aggressiveness was observed, it is suggested that GT of 17ºC might, to a certain measure, justify the higher aggressiveness of the four isolates. Further studies with other isolates and temperatures need to be investigated. Also, studies of biochemical nature should be advisable for a better knowledge of this phenomenon.

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