International Scholars Journals

International Journal of Enology and Viticulture ISSN 3426-7212 Vol. 4 (7), pp. 222-227, December, 2017. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Impact of intercropping coffee with fruit trees on soil nutrients and coffee yields

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Accepted 17 November, 2017

Coffee occupies some of the most potential land for crop production in Kenya and is mostly planted as a mono-crop. Intercropping has been assumed to compete for nutrients, which may reduce coffee yields and quality. Consequently, policies promoting mono- cropping are preferred, irrespective of environmental degradation. In this regard, a study was carried out at Coffee Research Foundation (CRF), Kenya, to investigate the effect of intercropping coffee on soil quality and coffee yields. The trial was set in a Complete Randomized Block Design (CRBD) with seven treatments. Mature coffee trees (*Coffea arabica* L.) intercropped with avocadoes (*Persea americana*), macadamia (*Macadamia integrifolia*), mangoes (*Mangifera indica*), guavas (*Psidium guajava*), loquats (*Eriobotrya japonica*), bananas (*Musa sapientum*) and pure coffee stand), replicated thrice. Intercropping coffee with Mangoes and macadamia led to significantly higher potassium in the soil whereas coffee intercropped with avocados resulted in significantly higher phosphorus. Intercropping coffee with various fruit trees significantly depressed coffee yields but gave higher percentage Grade A beans. In contrast, guavas depressed both yields and percentage Grade A. This study shows that the impact of intercropping coffee is specific to the fruit tree used. It is recommended that for successful intercropping, good agronomic practices for both coffee and fruit used are paramount.

Keywords: Intercropping, soil nutrients, coffee yields, coffee quality, fruit trees.

INTRODUCTION

Coffee originated from the highlands of Ethiopia where it is known to have existed as an under-storey crop but due to commercialization and demand for large quantities of quality coffee the farming system has mainly being adopted as a mono-crop to increase yields production (Dalmatta 2004). Coffee, being a perennial crop extracts large quantities of nutrients from the soil leading to higher nutrients depletion (Michori, 1981; Hornark and Olieveri, 1998; Wrigley 1988). Studies in Uganda have reported that the rate of nutrient depletion in coffee farming is higher than the rate of replenishment (Zake, 2010). The same author reported that the fertilizer use on average is 0.58 tons per hectare against NPK depletion of 20, 3, and 22 Kg/Ha/year respectively subjecting the soil to higher rate of degradation leading to reduced coffee productivity. In Kenya it has been reported that for optimum coffee production the Arabica coffee (Ruiru 11 cultivar) requires external application of 200kg N, 100Kg P and 80Kg K per Ha per year (Njoroge, 1992). In addition, soil organic matter of at least 4-6% is necessary to allow for plant nutrients absorption and retention as well as moisture conservation

Each nutrient plays a vital role in plants metabolic activities, determining its subsequent growth and yield (Clarkson and Hanson 1980, Nair 1983, Reid and Hayes 2003). Lack of nutrients in the soil results to low coffee yield and quality and the trees may subsequently die (Yadessa, *et al.,* 2008).

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Generally, mono-cropping is widely preferred to intercropping due to its potential to increase yields per given farming unit. Mono-cropping is susceptible to environmental degradation as opposed to intercropping which promotes soil and moisture conservation, ecosystem and biological diversity (Machado 2009, Bote 2007).

Intercropping is an ancient farming practice that has widely being used all over the world before being overshadowed in the modern agricultural practice that involves heavily mechanized farming operations and increased use of inorganic fertilizers to optimize yields productions. Intercropping involves growing of more than one crop in the same piece of land either at the same time or on alternate seasons. This has positive and negative interactions that may also affect crop production. It provides increased ecological diversity, nutrients through litter and fruit falls, decomposing biomass, soil and water conservation, pests and disease control (Maundo 2009, Bote 2007). Intercropping practices include mixed intercropping, row intercropping, strip and alley cropping system (Machado, 2009). Row intercropping (Also commonly practiced in agro-forestry systems) has been reported as an alternative option for sustainable production management (Burgles *et al.,*1998). Agro-forestry system contain trees mostly leguminous that absorb nutrients from deeper layers of the soil and leaf litter that decomposes in the soil improving its physical and chemical quality. Higher phosphorus and exchangeable potassium have been reported in soils under agro-forestry farming system compared to a coffee pure stand Notaro *et al*., (2013).

Fruit trees provides both litter and fruit falls that are essential in the improvement of soil organic matter which decomposes to release nutrients in the soil. In addition, coffee shading by the fruit trees do modify the microclimate that results to altering the rate of organic matter decomposition and rate of nutrient uptake (Scherr, and Schapit, 2009). Burgles *et al.,* (1998) observed that in agro-forestry farming systems the interactions of the trees root system improves both nutrient and water uptake. Studies in Kenya have indicated that coffee intercropping with fruit trees and food crops such as avocados, macadamia, tomatoes and Irish potatoes gave higher returns than sole coffee without negatively impacting on the coffee yields (Njoroge *et al.,* 1993; Njoroge and Kimemia, 1993,). Intercropping coffee with fruit trees, did not affect soil nutrient in the first five years of the coffee cycle (Kimemia, 1999, 2001). The study results indicated that it is possible to intercrop coffee with fruit trees but more research was necessary to determine the long term effect on coffee fruit trees interactions. Therefore this study was aimed at evaluating the soil nutrient status in mature Arabica coffee cultivar SL28 intercropped with various fruit trees.

MATERIALS AND METHODS

The study was carried out at Coffee Research Foundation (CRF), Currently Coffee Research Institute (CRI), Ruiru station in Kenya in 2009 - 2011. CRI is situated at 1.05^{o}S and 36.45^{o}E at an elevation of 1608m above sea level. It receives an average rainfall of 1000mm per annum. The mean air temperature averages 25^{o}C. The soils are humic nitosols (Shitakha, 1983). The trial was carried on mature Arabica coffee cultivar SL28 planted in 1989 at a spacing of 2.74m inter and intra row. Coffee trees were managed as recommended (Mwangi, 1983). The study involved mature coffee trees intercropped with avocadoes (*Persea americana*), macadamia (*Macadamia integrifolia*) mangoes (*Mangifera indica*), guavas (*Psidium guajava*), loquats (*Eriobotrya japonica*), bananas (*Musa sapientum)* and sole coffee *(Coffea arabica)* as the control plot. During the study, fruit trees provided shade of about10 – 50 percent depending on the distance of coffee tree from the fruit tree and the type of fruit tree. Coffee trees and the fruit trees were managed as recommended (Mwangi, 1983) and (MOA 1984) respectively and planted at the following spacing as shown in Table 1 .

The trial was laid in a complete randomized block design (CRBD) replicated thrice. Data was collected from eight effective coffee trees, four trees each, from east and west of the middle fruit tree/trees. Soil sampling was done in August 2010 as August is recommended as the most suitable time for soil analysis in coffee farms (Michori and Kimeu, 1971). Soil samples were collected at (0–50 cm) and (50 – 100 cm) soil depth on the effective inter rows at 2.74m and 5.48m away from the fruit tree using a soil auger. Soil samples of the same depth collected at the same distance from both directions were thoroughly mixed and a 500 gm soil sample taken for the nutrients analysis. Soil analysis for both phosphorus and potassium were determined as recommended by Anderson and Ingram, (1989).

Coffee yield and percentage Grade A was determined from ripe coffee berries picked from the effective trees in each experimental plot. Total coffee picked per plot was weighed after every picking. Then a ten per cent sample or 500gms cherry which ever was higher was taken after every picking for determining the percent Grade A. The cumulative total cherry yield was calculated annually and converted to clean coffee at the ratio of 6:1. Out of the cumulated percentage Grade A clean coffee beans, 200 gm were passed through the coffee bean grader with various screen sizes. Coffee beans retained by screen size 18 were the Grade A sized beans (CRF 2011). These were weighed using electronic weighing balance. Determined weight of the percent Grade A beans obtained was divided by 200 gm (original grading sample size), then multiplied by 100 to determine the percentage Grade A beans. Data collected was subjected to analysis of variance using Cohort Stat 2010 statistical analysis programme. Means separation was done using Duncan's Multiple Range (DMRT) significance test at $P \leq 0.05$

RESULTS

Impact of coffee intercropping on soil phosphorus and potassium

Intercropping coffee with all fruit trees led to higher soil phosphorus at 0-50cm soil depth at 2.74m from the fruit

Table 1. Fruit trees used in the study and their corresponding spacing.

Fruit tree	Experimental Plot size	Number of fruit trees per plot	Spacing (m)
Avocadoes (*Persea americana*)	157.7m^2	3	9x9
Macadamia (*Macadamia integrifolia*)	157.7m^2	3	9x9
Mangoes (*Mangifera indica*)	247.7m^2	3	14x14
Guavas (*Psidium guajava*)	112.6m^2	6	6x6
Loquats (*Eriobotrya japonica*)	157.7m^2	3	9x9
Bananas (*Musa sapientum*)	112.6m^2	6	6x6
Coffee (*Coffea arabica*)	112.6m^2	6	2.74 x 2.74

Table 2. Mean soil phosphorus (P) and potassium (K) at 2.74m and 5.48m from the fruit tree.

	Phosphorous (ppm)				Potassium (Kme%)			
	0-50cm		50-100cm		0-50cm		50-100cm	
Nutrients/Fruit tree	2.74m	5.48m	2.74m	5.48m	2.74m	5.48m	2.74m	5.48m
Avocadoes	18.67a	12.00a	14.67a	17.33a	0.79b	0.25c	0.47c	0.19d
Macadamia	16.00ab	14.00a	13.33a	15.33a	0.79b	0.55a	0.52c	0.49b
Mangoes	16.00ab	14.67a	13.33a	15.33a	0.93a	0.36b	0.83b	0.61a
Guavas	17.30b	13.33a	12.00a	14.67a	0.22d	0.08d	0.28d	0.01e
Loquats	17.30b	14.00a	12.67a	14.00a	0.78b	0.24c	0.81b	0.14d
Bananas	14.00c	12.00a	12.67a	14.67a	0.99a	0.12d	1.08a	0.02e
Sole coffee	15.33bc	14.00a	12.67a	14.67a	0.47c	0.31bc	0.56c	0.38c
Means	16.38	13.43	13.07	15.15	0.713	0.274	0.65	0.26
S/x	2	4.83	2.82	6	0.002	0.0025	0.0058	0.001
Lsd (0.05)	2.52	3.91	2.99	4.36	0.087	0.089	0.136	0.59
Cv %	8.63	16.36	12.88	16.18	6.88	18.26	11.73	12.76
Df total	20	20	20	20	20	20	20	20

Means followed by different alphabetical letter/s down the column are significantly different. The higher the deviation of the alphabets the higher the significant at ($P \leq 0.05$)

tree (Table 2) except coffee intercropped with bananas. This was significantly higher for coffee intercropped with avocados. Soil phosphorus was not significantly influenced by intercropping coffee with the fruit trees at the lower soil depth (50-100cm soil depth) irrespective of the distance from the fruit tree. The overall mean phosphorus was higher in soils taken at 5.48m than at 2.74m from the fruit with a mean of 14.67ppm against 12.67ppm respectively.

The results further indicated that coffee intercropped with all fruit trees gave significantly higher potassium at 0-50cm soil depth at 2.74m except coffee intercropped with guavas (Table 2). Coffee intercropped with guavas significantly depressed the soil potassium at both 2.74m and 5.48m distance from the fruit tree irrespective of the soil depth. Coffee intercropped with macadamia had significantly higher potassium at 5.48m from the fruit tree at both 0-50cm and 50-100cm soil depth. Coffee intercropped with mangoes gave significantly higher potassium at both 2.74m and 5.48m distance from the fruit tree. The mean potassium (K) was higher at 2.74m than at 5.48m away from the fruit tree. Coffee intercropped with bananas significantly increased the soil potassium at 0-50cm but significantly depressed it at 50-100cm soil depth.

Impact of coffee intercropping on Coffee Yields and Coffee Bean size (percentage GradeA)

Coffee intercropped with all fruit trees led to significantly low coffee yields to sole coffee but gave higher percentage Grade A (Table 3). Intercropping coffee with loquats and guavas gave significantly low yield to coffee intercropped with all other fruit trees. Coffee intercropped with mangoes gave significantly higher yields to coffee intercropped with all other fruit trees except coffee intercropped with macadamia. Sole coffee gave low % GradeA to coffee intercropping with all fruit trees with mangoes and loquats being significantly higher.

DISCUSSION

Effect of intercropping coffee with fruit trees on soil phosphorus

Phosphorus facilitates healing of coffee wounds after picking, revitalization and regeneration of roots after a heavy coffee stress. It is also incorporated in coffee metabolic activities to provide energy and improve production (Kruster and Schroder, 2010).

Table 3. Cumulative mean clean coffee yields and percentage grade A during the coffee production years from 2009-2011.

Fruit trees	Clean coffee (Kg/ha/ Ha)	% Grade A
Avocadoes	707.67d	89.70abc
Macadamia	785.67bc	88.70bc
Mangoes	839.67b	92.40a
Guavas	522.00e	81.70d
Loquats	563.33e	91.13ab
Bananas	755.00cd	86.70c
Sole coffee	1127.67a	86.80c
Mean	757.29	88.16
S/x	1608.94	3.67
Lsd	71.36	3.41
Cv	5.3	2.17
df error	20	20

Means followed by different alphabetical letter/s down the column are significantly different. The higher the deviation of the alphabets the higher the significant at ($P \leq 0.05$).

Coffee intercropped with avocados led to significantly higher phosphorus to sole coffee and coffee intercropped with bananas at 0-50cm soil depth at 2.74m from the fruit tree. High phosphorous content in coffee intercropped with avocadoes is attributed to litter and fruit fall from the avocado tree as well as waste from birds feeding on the avocado fruits. In South Africa (Koen and Langenegger 1980) reported that, avocados yield of 9000 pounds (4090 kg) of fruit per acre removes 10 pounds (4.5 kg) of N and 17 pounds (7.7 kg) of K while falling leaves return to the soil about 60 percent of their N-P-K, 40 percent of their Ca, and 25 percent of their Mg content. This is further strengthened by the fact that the phosphorous levels were higher closer to the tree (2.74m distance) and in the top soil (0-50 cm) where most of the litter falls. Phosphorus in the soil is not mobile (UNCE, 1999), therefore the fruit tree may not access available phosphorus at 5.48m away from the fruit tree concentrating all its phosphorus extraction at 2.74m at 50-100cm depth.

Effect of intercropping coffee with fruit trees on soil potassium

Soil potassium in coffee improves the bean quality and size (Hornack and Olieveri 1998). The study indicated that intercropping coffee with all fruit trees except guavas resulted at high potassium levels at 0-50cm soil depth regardless of the distance from the fruit tree. Unlike phosphorus, potassium is highly mobile in the soil (UNCE 1999) and can be drawn by plants from high concentrated zone to low concentrated zones or where its, in demand. This has resulted to high potassium at 2.74m at both 0-50cm and 50-100cm soil depth. The high potassium levels in the banana intercrop could be attributed to higher deposition of both the leaves and banana pseudo stem which have been reported to have high concentration of potassium (MOA 1984). Therefore, intercropping coffee with bananas could improve potassium availability in the soil for coffee uptake. On the other hand, high potassium levels in the mango and macadamia intercrop could be attributed to their low demand for potassium as reported in mangoes (MOA 1984) and Macadamia (Ondabu *et al.,* 1997) respectively

Coffee yields and percentage Grade A in coffee intercropped with fruit trees

Coffee production per given unit is dependent on good agricultural practices such as timely weeding, enhanced soil fertility with sufficient macro and micro nutrients, soil moisture and light to facilitate photosynthesis. Soil fertility can be enhanced through organically decomposing materials or addition of inorganic fertilizers or a synergy of both. The latter is well achieved under shade and intercropped coffee (Machado 2009, Siles et al., 2010). Shade in coffee increase biodiversity and enhance soil fertility but limits coffee production by reducing photosynthetic activity (DaMatta, 2004) but it's also known to increase the coffee bean size (Bosselmann et al. 2009). The results in this study indicated that coffee intercropped with all fruit trees gave significantly lower coffee yields compared to sole coffee. This is in agreement with results found by Kimemia (1999), although the fruit and coffee trees used in his study were still in their early establishment stage. Low coffee yields in coffee intercropped with guavas and loquats may be attributed to significantly low potassium at 0-50cm soil depth. Fruit trees extract large quantities of both phosphorus and potassium from the soil (Scherr and Schept 2009), which are also the main component of the coffee berry development and quality formation (Hornack and Olieveri (1998).

Coffee intercropped with avocados resulted in low yields (Table 3), despite significantly higher phosphorus (Table 2). This could be attributed to the influence of shade and also its high demand for phosphorus uptake from the soil.

(Damaltta, 2004; Koen and Langenegger, 1980). The low phosphorus mobility in the soil (UNCCE 1999) may also result to reduced uptake by coffee plants. To enhance phosphorus uptake in coffee intercropped with avocados, litter and fruit falls from avocados may be frequently distributed in the coffee farm and possibly incorporated into the soil.

Coffee intercropped with mangoes resulted to high coffee yields and significantly higher percentage grade A. This is attributed to high phosphorus and potassium (Table 2). Both phosphorus and potassium are essential for flowering and fruiting in coffee and should be supplied at least 6 months before coffee flowering period.

Phosphorous supply in mangoes is of particular concern during periods of root development, flowering and early fruiting while potassium is essential during the fruit and ripening stages (Oosthuyse, 2006). Both phosphorous and potassium are mobile in the phloem, and hence, can be translocated between tree organs enabling the tree to have sufficient supply during the fruiting period (Oosthuyse, 2006).

Flower formation and fruiting in mangoes requires 2-3 months of dry spell followed by rains (MOA,1984; Griesbach, 2003) In Kenya, mango flowering may commence as early as February and March and lasts from July to November (Griesbach, 2003). The main coffee flowering season under the experimental climatic conditions is April. Both phosphorus and potassium are essential for coffee flowering but must be supplied 6 months before flowering which is normally done in October. This reduces the phosphorus and potassium competition between the coffee and the mango tree. This explains the high occurrence of potassium and phosphorus in coffee intercropped with mangoes and consequently high coffee yields and significantly higher percentage Grade A beans as opposed to coffee intercropped with other fruit trees.

CONCLUSIONS

Intercropping coffee with avocados significantly improved the soil phosphorus at 0-50cm at 2.74m while Macadamia and loquats improved exchangeable potassium at 2.74m irrespective of the distance from the fruit tree. The benefits of coffee intercropping with the fruit trees on soil nutrition are more pronounced at 2.74m than at the 5.48m distance from the fruit tree. Coffee intercropped with all fruit trees significantly depressed coffee yields but improved the percent Grade A except coffee intercropped with guavas. In this regard it is possible to intercrop coffee with macadamia, mangoes and avocados in their respective ecological zones. In order to achieve full benefits in coffee intercropping, agronomic activities such as proper spreading of the fruits and litters falls, pruning of fruit trees and forking are necessary. Intercropping coffee with mixed fruit trees varieties would enhance and enrich the soil nutrients. At the same time, routine soil analysis is encouraged for routine nutrient balancing.

ACKNOWLEDGEMENT

This paper is written with the permission of the Institute Director, Kenya Agricultural & Livestock Research Organization - Coffee Research Institute. Great acknowledgement also goes to the Head and staff of Agronomy and chemistry section at Coffee Research Institute for the assistance provided during the data collection. The authors also acknowledges the support of the Chairman and staff of the department of environmental Science of Kenyatta University, Kenya who relentlessly devoted most of their time in ensuring quality of data collection, Analysis and reporting during this research

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