Effect of Intercropping Coffee With Fruit Trees on Coffee Eco-Physiological and Soil Factors at Coffee Research Foundation in Ruiru, Kiambu County, Kenya

BY

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DECLA RATION

CANDIDATES' DECLARATION

This Thesis is my original work and has not been presented for any other award either academic or professional award. No part of this work should be reproduced without prior permission of the Author, Coffee Research Foundation and or Kenyatta University

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DEDICATION

This study Thesis is Dedicated to my Parents Cecilia and Patrick and my mother in law Esther, for their strong dedication understanding, prayers and moral support that gave me the strength to move on even when the going got tuff.

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DEFINITION OF TERMS

Carbon sequestration:
This refers to the carbon accumulations into the soil or plant matters. It can be accumulated inform of carbon organic matter in the soils or stored carbohydrates in the plants tissues.

Carbon assimilation
Refers to the uptake of carbon dioxide from the atmosphere mostly by green colouring plants for photosynthesis

Intercropping system:
This refers to growing of two or more crops simultaneously in the same piece of land

Perennial crops:
These are crops that persists in the field for more than two complete seasons. Normally two or more years.

Agro-forestry system:
These refer to growing of trees and crops simultaneously in the same piece of land. Normally trees plants are used for food production

Under- storey system
This is an agroforestry system where one tree species exceeds the interplanted tree in height.

Coffee quality
This refers to the consumers and coffee market expectation of the coffee tastes and bean size. Coffee has coded grades in terms of size (AA,AB,PB……TT) ranging from the best size to worst respectively. In terms of liquor, we have acidity, moldiness and body classified in 1, 2, 3, 4, 5, and 6 when these are combined the overall quality is graded from 1-9.

Green house effect
This refers to the increased levels of anthropogenic gases in the atmosphere that inhibits the outlets of the reflected radiation from the earth surface into the stratosphere resulting to warming of the earth.

ACRONYMMS

ICA: International Coffee Agreement

ICO: International Coffee Organization

CRF: Coffee Research Foundation

CBK: Coffee Board of Kenya

IITA: International Institute for Tropical Agriculture

IPCC: International panel on Climate Change

KCTA: Kenya Coffee Traders Association

KMD: Kenya Meteorological Department

GHGs: Green House Gases

Asl: Above Sea Level

SL 28: Scotts Laboratory (Convectional coffee cultivars Var 28)

R11: Hybrids coffee cultivars

PAR: photosynthetic active radiation

CRF: Coffee Research Foundation

TC: Technical Circular

C&CI: Coffee & Cocoa International

UNEP: United Nations Environmental Programme

CCS: Carbon Capture Sequestration

CO_2: Carbon Dioxide

N : Nitrogen Element

K: Potassium Element

Mg:	Magnesium
Ca:	Calcium
ICO:	International Coffee Organisation
GHGs:	Green House Gases
TACRI :	Tanzania Coffee Research Institute
KCPA:	Kenya Coffee Producers and Traders Association
NCE:	Nairobi Coffee Exchange
IACO:	Inter African Coffee Organization
ICA:	International Coffee Agreement
ITC :	International Trade cooperation
FAO:	Food and Agriculture Organization
SCAA:	Specialty Coffee Association of America.
SMO	Soil Organic Matter
SMC	Soil Moisture Content

ABSTRACT

The coffee plant (*Coffea Arabica* L) originated in the forests of Ethiopia, where it evolved as an understory tree species. Mimicking this native growth habit, coffee farmers have for centuries grown coffee under shade and intercropped with various fruit tree species to provide shade, foods, and income. The impact of these intercrops on coffee production is little known hence the need for this study. The study was carried out in an existing coffee intercropping plot at Coffee Research Foundation (CRF) in Ruiru District, Kiambu County, Kenya between 2010 and 2011. The broad objective was to establish the effect of coffee intercropping with selected fruit trees on coffee eco-physiological and soil factors of production. The specific objectives were to investigate the impact of intercropping coffee with fruit trees on photosynthetic active radiation (PAR), temperatures, rate of transpiration, stomatal Conductance, relative humidity (RH), soil nutrients, soil moisture content and soil organic matter. The study involved matures coffee trees, cultivar SL 28 planted at 2.74m x 2.74m inters and intra rows, intercropped with avocadoes (*Persea americana*), macadamia (*Macadamia ternifolia*), mangoes (*Mangifera indica*), guavas (*Psidium guajava*), loquats (*Eriobotrya japonica*), bananas (*Musa sapientum*), and a sole coffee (*Coffea arabica l.*) as a control plot. Data collected was subjected to analysis of variance using Cohort Stat 2010 statistical analysis programme. Means separation was done using Duncan's Multiple Range Test (DMRT) significance test at $P \leq 0.05$. Results indicated that intercropping coffee with fruit trees significantly reduced coffee PAR and did not significantly influence the leaf temperatures, during the cold season (June 2010) but was higher than the sole coffee. During the dry season, coffee intercropped with all fruit trees depressed the leaf temperatures with mangoes and avocados being significantly low. Intercropping coffee with Mangoes and macadamia gave significantly higher potassium, calcium and magnesium to sole coffee while avocados led to significantly higher phosphorus to sole coffee and coffee intercropped with bananas. Intercropping coffee with fruit trees significantly depressed coffee yields to sole coffee but gave higher Percentage (%) grade A, with mangoes being significantly higher. Intercropping coffee with guavas significantly depressed soil moisture content, organic matter, Potassium and Calcium, coffee yields and percentage grade A. The study concludes that intercropping coffee with fruit trees depressed coffee PAR and coffee yields but improved on percentage (%) grade A and soil nutrients. Intercropping coffee with avocados, mangoes and macadamia ameliorated the leaf temperatures to near optimum required during the two distinctive seasons (June 2010 and February 2011). Both eco-physiological and soil factors improved with distance from the tree. In this regard the study recommends that coffee can be intercropped with avocados, macadamia and mangoes at a distance longer than the study distance used. For this practice to succeed all agronomic practices for both coffee and the fruit trees must adhered to recommendations. Further studies are recommended on coffee fruit trees, intercropping arrangements, appropriate distance from the fruit tree and an economic analysis.

CHAPTER ONE

1.0 INTRODUCTION.

1.1 Background Information

Coffea arabica L**.** belongs to the family Rubiceae which has some 500 genera and 6000 species. They are mostly trees and shrubs. Rubiceaes are commonly found in the lower storey of forests. There are three coffee varieties that are of economic value and all are evergreen plants. The most important of this species *is Coffea arabica* L**.** (Wrigley, 1988).

Coffea arabica L**.** is a shrub or small tree, 4.6 to 6m tall at maturity. It has vertical stem or stems with horizontal branches arising in pairs opposite each others'. These branches (primaries) remain subsidiary as the main stem continues to grow indefinitely by the extension of the apical bud. *Coffea arabica* L**.** has a main central taproot. The central taproot rarely extends more than 30-45cm depth from the surface as a recognizable unit. (Nutman, 1933). *Coffea arabica* L. produces yields two to three years after planting.

Arabica coffee has a long economic life depending on local conditions and husbandry practices. It is sensitive to excessive heat or cold or rapid change of temperature. In the past decades, a harsh weather condition due to global climate change has forced coffee cultivation area into environments unsuitable for its production (IPCC, 2007). This has resulted to reduced coffee yields and quality and consequently coffee income. As a result coffee farms have been neglected, contributing to the low annual coffee production (Karanja, 1992). In some cases massive uprooting and haphazardly intercropping with high value crops to improve on the farm income have been reported (Onsongo, 1997). In this regard appropriate farming measures are required to alleviate factors responsible for the declining coffee production. This will involve identification of appropriate fruit trees for intercropping in coffee farms and dissemination of management techniques of coffee intercropping farms. The results of this study can be used to formulate policies on coffee intercropping and its management.

Intercropping coffee is an old practice in coffee farming, with Arabica coffee existence as an under storey crop in its native country Ethiopia. Benefits of intercropping coffee and agroforesty coffee system are prevention of soil erosion, increased carbon assimilation reduced leaf temperatures, providing soil nutrients, mulch and shade (Retnowarti, 2003, Steiner, 1982; Natarajan and Willey, 1980;). The selected fruit trees for this study are of high economic value both in the export and local market (MOA, 1984) and are of high nutrition requirement. The recommendations of these results will lead to formulation of policies and guidelines on coffee management under intercropping system as well as identification of appropriate fruit trees for intercropping. This will cushion farmers from increased coffee price fluctuations and supplement on food requirements. The expected achievements of this study are in line with the principals of agenda 21, Millenniums Development Goals (MDGs) and Kenya vision 2030. Adoption of these results will also provide adaptation and mitigation measures on the impact of the global climate change in coffee farming.

1.1.1 Coffee history

Arabica coffee (*Coffea arabica* L.) is indigenous to the highland of Ethiopia where the coffee forests still naturally occurs at between 1350- 1850m above sea level. Coffee has been widely placed including South and Central America. In Kenya, coffee was introduced, by missionaries first at Kibwezi, then Nairobi and Kikuyu. Thereafter more coffee estates were established in Kiambu, Ruiru and Thika (In the current larger Kiambu County in Kenya). Later on, Africans were allowed to grow coffee and to engage in good and economical processing by putting them together as cooperative societies.

Arabica coffee is one of the most traded commodities in the world (Kiome, 2011) and its production forms the economic backbone of many countries worldwide. In Kenya coffee supports about 700,000 households representing approximately 4.2m or 10% of Kenyan populations. It is fourth in foreign exchange earnings after tourism, tea and horticulture industries. It earned Kenya Kshs.16.5 billion Kenya shillings in the year 2009/2010 and has earned an average of Kshs.10.5billion Kenya shillings per year for the last five years (CBK 2011).

Coffee farming has had its own shortcomings. In 1989 the international coffee agreement (ICA) collapsed leading to a decline in prices (Karanja, 1992). Between 1999 and 2001, coffee earnings exhibited a high decline due to increased cost of production attributed to increased prices of farm inputs and escalated cost of power (FAO 2003). These incidences compromised coffee quality and quantity, resulting to unsustainable coffee returns. Consequently farmers resulted to either neglecting coffee, intercropping haphazardly or uprooting for better alternatives. This has seen coffee production in Kenya decline to below 50 metric tons, from 130 metric tons in 1990 (CBK 2010).

1.1.2 Ecological requirement for coffee production

Coffee *(Coffea* sp.) grows in subtropical regions that have distinct wet and dry seasons. In Kenya *C. arabica* L, grows at altitudes between 1400-2100 meters above sea level (Asl). It requires temperatures range of between 15^{o}C-32^{o}C with a maximum diurnal temperature of 19^{o}C (Kumar and Tietszen, 1976). Coffee enjoys an average rainfall of 1200-1500mm per year but may also do well with less rainfall with an even distribution (Wrigley, 1988). In Kenya most of the coffee is grown at the foot of Mt Kenya with a small percentage grown along Taita hills and in western Kenya (Appendix 3). These coffee-growing regions enjoy temperatures below 32^{o}C and exhibit a diurnal temperature of 7^{o}C. The rainfall is bimodal with a minimum of 1000mm per year. (Kimemia, 1999 and Njoroge, 1992;

Coffee in Kenya enjoys a three months dry period during which the flower buds are dormant. The flower bud dormancy is broken by a slight decrease in temperature, received rainfall or irrigation. (Gathaara, 1998). As a result there are two coffee seasons in Kenya (Early and late crop) resulting from the two commonly experienced rainfall seasons, short and long rains respectively, occurring in October- December and April-May respectively. Late crop is the main coffee season in the East of Rift Valley and it’s mainly harvested during short rains while early crops are harvested during the long rains.

1.1.3 Global Climate Change Phenomenon.

Climate is the long-term average of a region's weather events lumped together. Climate change thus represents a change of the long-term weather patterns. The patterns may become warmer or colder, annual amounts of rainfall or snow may increase or decrease. Global climate change has occurred as a result of the increased earth's temperature (commonly known as global warming) resulting from increased green house gases (GHGs) in the atmosphere. It is observed that the earth has warmed by about 0.6^oC over the past hundred years. This has lead to changes in rainfall amounts and patterns (UNEP 2008). Camargo and Marcelo (2008) indicated that climatic variability is the main factor responsible for the oscillations and frustrations of the coffee grain yield in the world. IPCC (2007) report indicates that global warming will increases temperatures and rainfall in Brazil by $1\text{-}5^oC$ and 15% respectively. Laderach et al. (2008:), indicated that it is a fact that climate is changing and will change progressively. The paper distinguishes and quantifies for whole globe the areas that in the future will still be suitable for coffee growing, those that will have to change their crop and those that can still maintain coffee through improved and advanced agronomic practices.

Drought or heat in summer can diminish coffee production and quality though it requires a dry period while heavy rains in the spring can disrupt flowering as reported by Gay, *et al.,* (2006). In this case global climate change may have profound impacts on coffee growing and production.

Coffee is mostly disadvantaged due to its sensitivity to temperature variations and its shallow feeder roots (Wrigley, 1988). Therefore global climate change will enhance the coffee vulnerability to drought especially in the coffee marginal areas. Linne and Scherr (2010) observed that in Kenya coffee growing will be limited to the high rainfall zones by the year 2050. Therefore there is need to develop coffee farming strategies geared towards adopting sustainable coffee farming techniques. This will enhance adapting to the impact of the global climate change on coffee farming and possibly widen the coffee growing regions.

1.2 Problem Statement and Justification

1.2.1 Background of the problem

Coffee is a shade-adapted plant and has a very low saturating irradiance for leaf photosynthesis (Ramalho, *et al*. 2000). Exposition to high irradiance can seriously impact on the coffee plant performance by limiting photosynthesis, (Da Matta., 2004). However, it is reported that global warming, has led to an increased temperature rise by 0.74^{o}C in the last 20 yrs (UNEP 2008). Laderach *et al*., (2008), also reported that global warming has threatened the coffee yield potential and quality as well as potential areas for coffee production.

1.2. 2 Problem statement

In Kenya the first coffee plantation was established in 1893 and by 1940s most of the coffee estates and small holder farms had been established. Due to land abundance as per the time, coffee, planting occupied the most fertile land available for farming. But with the current population of over 40million

Kenyans the demand for land for food productions is on the rise. In addition global warming is pushing the existing land on food production from the lower marginal areas to the medium and high marginal areas threatening the existence of coffee farms. In this regard it is necessary to intercrop coffee in the open sun planting system with the fruit trees to address these emerging issues.

Intercropping coffee with fruit trees will also provide income from the fruit tree countering the fluctuating coffee market prices but there is a general belief that intercropping coffee with other crops or trees will compete for nutrients, light and moisture resulting to low coffee yields and poor quality as well as deteriorating the soil conditions rendering it infertile.

Studies on intercropping coffee with bananas in Uganda (TaCRI, 2004), citrus in Tanzania (Bourke 1997), and fruit trees in Kenya (Kimemia, 1999,) have shown that intercropping coffee may have no adverse effect on coffee yields and quality. But these studies were only based on yield and quality without considering the extent of the soil factors and competition on the above ground natural resources for coffee production. In addition the studies were conducted in the first coffee cycle when most of the coffee trees and the fruit trees roots had not grown deep enough to allow for coffee fruit and coffee trees root interactions. Burgless *et al.*, (1998) indicated that inter-planted perennial trees will form a rooting network on maturity that will facilitate the distribution of soil moisture and nutrients. Onsongo (1997) observed that coffee intercropping in the central coffee regions in Kenya is haphazardly done could equally affect coffee production hence the need for this study.

1.2.3 Justification

Coffee is an important commodity in the International Agricultural Trade (IAT). Its production forms the economic backbone of many countries worldwide. It is the second most traded commodity after petroleum and the most widely consumed beverage worldwide (Berecha and Wakjira, 2011). It has a wide significance as a source of livelihoods across the world. The sector stimulates growth and development of industrial and service sectors such as agrochemicals industries, education, health, and tax department. In spite of its broad global significance coffee production has been adversely affected by the impact of the global warming (Linne and Schepp,2010). In addition, coffee occupies a substantial amount of the high potential land available for food production in the small-scale farmers. The selected fruit trees for this study are of high economic value both in the export and local market (MOA, 1984) and are of high nutrition requirement. Intercropping coffee with fruit trees will not only provide shade to coffee to combat on the global warming but also supplement food from the fruit trees (Scherr and Sthapit, 2009).

The recommendations of these results will lead to formulation of policies and guidelines on coffee intercropping management as well as recommendations on appropriate fruit trees for intercropping. Coffee intercropping will cushion farmers from increased coffee price fluctuations and supplement on food requirements. Adoption of these results will also provide adaptation and mitigation measures on the impact of the global climate change in coffee farming

1. 3 Hypotheses

The hypotheses tested were;

- Ha_1: There are significant variations in leaf eco-physiological factors mainly, leaf PAR, temperatures, transpiration and stomatal conductance among treatments.
- Ha_2: There are significant variations in soil fertility, soil organic matter and soil moisture content among treatments.
- Ha_3: The weather conditions and the distance of the fruit tree from the coffee tree has influence on both eco-physiological and soil factors of production
- Ha_4: There is significant variations in coffee yields and percentage Grade A among the intercropped fruit trees.

1.4 Objectives

1.4.1 Main objectives

The main objective of the study was to determine the influence of selected fruit trees on coffee production factors as well identify possible distance of coffee trees from the fruit tree in a coffee intercropping farm.

1.4.2 Specific objectives

The specific objectives were to:-

- Investigate the influence of fruit trees on coffee Photosynthetic Active Radiation, (PAR), leaf temperatures, Leaf Transpiration, Relative Humidity (RH), and stomatal conductance at 2.74m and 5.48m from the fruit trees
- To determine the influence of individual fruit trees in coffee on soil organic matter, percentage soil moisture, soil phosphorus, potassium, calcium and magnesium at 2.74m and 5.48m from the fruit trees
- To assess the coffee yields and quality as influenced by the fruit trees
- Assess the influence, of changes in weather conditions, on coffee factors of production in a coffee intercropping farm

1.5 Significance of the study

Kenya has unique agricultural and manufacturing (GAP and GMP) processes, hence producing some of the best coffee quality in the world. However over the last two decades coffee production has been on the decline (CBK, 2010; IACO, 2011; Karanja, 1992). This has been attributed to the fluctuating coffee prices, declining land resource and the impact of global climate change on coffee. Fruit trees used in this study are of high export and nutrition value and coexist well within the coffee ecological regions (MOA, 1984). Their introduction to coffee farming systems will cushion farmers against the fluctuating coffee prices, address the nutrition and economical issues and improve on food security in the country. The fruit trees will also act as an addition carbon sink increasing the carbon dioxide assimilation from the atmosphere. This is an international milestone since Kenya is a signatory and has ratified the Kyoto protocol in an effort to adhere to the world environmental commitment. The study results distinguishes the role of each fruit tree to the coffee environmental factors which can be used for formulating appropriate policies both locally and internationally to mitigate the impact of global warming in coffee farming.

1.6 Limitations and scopes of the study

The study has a range of limitations.

- Interruptions of unexpected weather conditions, e.g.
  - Rains in January 2010, (Fig 1)
  - Early rainfall cessation

1.7 Assumptions

These results were collected, analyzed and deduced based on the assumptions that:

- The sun remained overhead during the quantum determination period.
- There were no other sources of shade on the coffee tree except the intercropped fruit trees
- All the biomass from the intercropped fruit trees has cumulatively been maintained within the intercropping fields.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 Coffee botany

Coffea arabicae L. is a shrub small tree, 4.6 to 6 m high at maturity. It bears shiny green, oval leaves that persist for three to five years. It has white, fragrant flowers that bloom for only 3-4 days. It takes six to seven months after the appearance of the flower, for the fruit to ripen. Fruit development involves changing from light green to red and, ultimately, to deep crimson when fully ripe and ready for picking. The mature fruit, which resembles a cherry, grows in clusters attached to the branches by very short stems, and it usually contains two seeds, or beans, and in very rare and abnormal occasions one seed (the pea berry), surrounded by a sweet pulp (Wrigley, 1988).

2.2 Coffee trend

There is a strong suggestion that coffee was first planted in Arabia in the 17th century and spread to other countries thereafter as reported by Wrigler (1988). Today the commercial varieties coffee**,** ***C****offea arabicae L.* and C*offea canephora* are grown in over eighty countries in four continents. Over fifty countries export coffee making it the second world most traded export commodity after petroleum (Berecha and Wakjira, 2011). Several millions, of the world population drink coffee with America alone drinking 430,000 cups per day (IACO, 2011).

Coffee was introduced in Kenya by the Christian missionaries in 1839. Its development was fast and soon occupied the most potential land that saw its growth rise to 130 metric tons of green beans in the 1988/89 year. With the sudden collapse of the ICA in 1989, coffee production in Kenya fell from 130metric tons to 50 metric tons by 1992 (Karanja, 1995). Today Kenya produces below 50metric tons of green beans (KCPA, 2010) per year.

Studies have revealed that the sudden drop of coffee production due to drastic change in coffee prices, unfavorable weather conditions, and impact of land fragmentations led to the observed declining coffee production (Karanja, 1992), haphazardly coffee intercropping and replacement with more variable crops such as avocado *(Persea americana*), macadamia (*macadamia ternifolia*) and beans (*physiolus vulgalis*) (Onsongo, 1997). According to (Fritszer, 2002), the uprooting was also aggravated by the second coffee crisis of 1999-2001 caused by increased cost of inputs and insufficient and erratic rainfall resulting to drying of rivers and streams. This led to increased cost of irrigation in addition to irregular rationing of power. These hassles in coffee left coffee farmers poor and helpless for over two decades as reported by (Kiome, 2011).

Kimemia, (2007) in his East African fine coffee association address reported that Kenya produces some of the best coffees in the world that captures the coffee speciality market due to its good agricultural practises (GAP). These coffee speciality by origin (Kenya) may be lost if no measures to adaptation to the increasing global temperatures and its impact in coffee are taken. And if farming practices that can curb or compensate for coffee price fluctuations are not addressed.

2.3 Coffee Nutrition

Coffee being a perennial crop is grown on soils largely depleted of nutrients (Hornack and Olieveri 1998; Michori, 1981). The soil practically shows deficiency of all essential nutrients in Uganda (Zake, 2010). Wringley (1988) indicated that coffee is grown on old soils that are deficient of nutrients due to prolonged cropping. A study in Kenya on the assessment of nutrients requirement on *Coffea arabicae* L. Cv R11 indicated that for optimum production *Coffea arabicae* L requires 200kg, 100kg and 80kg of Nitrogen, phosphorus and potassium per hectare per year (Njoroge, 1992). It was also reported that high nitrogen rates (320kg/Ha) depressed coffee yields. A separate study on nitrogen rates and yield potential (Njoroge *et al.*, 1989) indicated a 90% yield improvement with coffee under a light shade of *Leucena leucocepha l*. Work done in Uganda (Zake, 2010) showed that the rate of nutrient extraction from the soil by coffee harvest is higher than the rate of replenishment. The study further indicated that in Uganda the fertilizer use on average is 0.58 tonnes per hectare against Nitrogen, phosphorus and Potassium (NPK) depletion of 20, 3, and 22 Kg ha $^{-1}$ year $^{-1}$respectively. Studies Yadessa *et al.,* (2008), in SW Ethiopia, on the impact of soil nutrition on coffee quality indicated that the effect of micronutrient on coffee quality was more on site specific. This conclusion arose as a result of the quality response on soil nutrients from the two study sites i.e. Sheko and Yayu. Sample collected from Sheko did not show any correlation with either P or total nitrogen but was correlated to P/N ratio. Those from Yayu did not show any correlation either with P, or total N neither with P/N ratio but was positively correlated to K, Ca, pH, C.E.C. While Zn was associated to poor quality at Sheko, it was associated to better quality at Yayu. The study indicated that the balancing of the soil nutrient is of paramount importance in determining the cup quality of coffee and the Aroma. In Costa Rica, Sile *et al., (*2009) also observed that soil moisture at deeper layers 60-120, 120-150 was lower in agroforesty than in monoculture which was more pronounced during the dry season. The study observed a ten percent lower yield in agro-forestry coffee than monoculture. Bote (2007) from a study in Ethiopia on the assessment of coffee nutrient status under agro-forestry system reported that it is possible to grow organic coffee under the agro-foresty coffee farming system. Moreira, *et al.*, (2008) from their studies in Brazil reported that full sun grown inorganic coffee is more criticized due to lack of biodiversity and high demands for nutrients. Shaded coffee systems recycle more nutrients, they promote biodiversity, and consequently is less dependent on external inorganic fertilizers, insecticide and pesticides. Shaded coffee is known to fix more carbon and nitrogen presenting an opportunity to mitigate global warming.

2.4 Intercropping studies

Intercropping is growing of two or more crops simultaneously in the same piece of land (CRF, 2010; Njoroge and Kimemia, 1995; Njoroge *et al*., 1993). Coffee intercropping is an old practice, which could probably have emerged from the indigenous knowledge of coffee existence as under storey crop in its native land, Ethiopia. Intercropping is widely practiced in most parts of the world for its beneficial effects which includes better use of natural resources weed control and nutrients supply (C&CI, 2010, Bote, 2007 Njoroge *et al.*,1993 and Njoroge 1992). Protection of soil from adverse effects such as soil erosion, crop diversification (Kimemia, 1999, Onsongo, 1997; Njoroge and Kimemia, 1993), providing shade (Kimemia, 2001a), control coffee diseases and frost effects (Kimemia, 2004; Caramori *et al.*, 1996), reducing coffee price fluctuations risk and improving farmers returns in coffee farms (*C&CI*, 2010; TACRI, 2004; Kimemia, 2001b;).

In Brazil studies have indicated the possibility of protecting coffee from frost by inter planting coffee with *Mimosa scabrella* (Caramori *et al.,* 1996). Further studies on *M imosa scrabella* indicated that it is possible for inter-planting agro-forestry system to earn carbon credits with the intercrops sequestrating 65.57ton c/ha as compared to 32.73 tons c/ha in the sun grown coffee (Caramori *et al.,* 2008)**.** In Papua New Guinea and Uganda coffee has been intercropped with bananas without adverse impact on the coffee yields (Oduol and Aluma, 1990; Bourke, 1985;). Intercropping coffee in Tanzania resulted to improved farm earnings (Tacri, 2004). Studies in Uganda have indicated that intercropping bananas with the arrangement of six banana stools after every 3 rows of coffee resulted to 52% higher returns to sole coffee and 42% higher for the commonly farmer practise of one banana stool for every one coffee stem (*C&CI* 2010). In Ethiopia Kufa *et al.*, (2003), indicated that it is possible to interplant citrus with coffee. In Kenya, coffee farmers especially the small-scale farmers have for the past decades intercropped coffee with annual food crops and perennial fruit trees

(Whitaker., 1986). Onsongo (1997) reported that farmers in Kiambu and Murang`a Counties in Kenya were found haphazardly intercropping coffee or replacing it with high value horticultural crops. Studies carried out in Kenya indicated possibilities of intercropping coffee with annual and perennial crops (Njoroge *et al.,* 1993; Njoroge, 1992) These studies indicated adverse impact observed where maize was intercropped with coffee but recommended the possibility of growing beans, tomatoes, iris potatoes, kales and cabbages during the change of cycle. In his studies Kimemia (1999), indicated that some perennial fruit trees could be intercropped with coffee in its first cycle without adverse impact on coffee production but cautioned that more studies may be required in the subsequent management of the intercrops. Kimemia, (2004) indicated the possibility of interplanting young *C. Arabica* L.with *Cordia abysinica, Leucaena divesofilia, Markhamia lutea* and *Albizzia schimperiana* to provide shade and control crinkle leaf in the upper coffee zones in Kenya. This also concurred with Kimemia, (2001b) previous studies on the benefits of intercropping coffee with fruit trees. In Ethiopia it has been shown that organic coffee can be obtained from agroforesty coffee system since no inputs are required (Bote, 2007).

Bourgless *et al.,* (1998) studies indicated that trees in agroforesty systems form a root network that is able to facilitate nutrients and water supply from regions with high concentrations to soil layers with low concentration. Therefore deep rooted trees will extract water from deep soil layer to the top soils where most of the coffee feeder roots thrive. In this case both coffee and the perennial fruit trees intercrops may pose a greater inters and intra competition or form a mutual relationship with age due to increased canopy and root development.

2.5 Shading in Coffee.

Coffee is a shade tolerant crop (Da Matta, 2004). Shading management system is a crop production system that has been considered appropriate for areas that presents risks of high temperatures making the environment unsuitable for coffee production (Carmago and Marcelo, 2008). Studies carried out in Brazil by Carmago and Marcelo (2008), to compare the influence on temperatures on arborized and unshaded coffee indicates an average decrease in air maximum temperatures of about 3^{o}C thereby confirming the recommendations of arborized coffee farming management practices in managing the increasing high temperatures. (Beining, 2009) studies revealed that the eco-physiology of wild *C. arabica* L. populations was strongly influenced by conditions of water deficit, heat and high irradiance, while (Shimber *et al.*, 2002) in Ethiopia indicated that arabica coffee planted between strips of shade trees yielded significantly more than Arabica coffee intercropped with the shade trees of different species. Huxley, (1970), observed that Shade could even out yields over time and reduce overbearing dieback. This concurred with (Kimemia, 2004; Tapley, 1961;) who observed that shade could even out ambient air temperatures and thus reduces the “hot and cold” phenomenon observed mainly in the upper coffee zones. In Sri Lanka, Mohotti and Lawlor, (2002) found that leaf temperatures in the medium and heavily shaded plots of tea plants was 1.5°C and 2.5°C cooler than the unshaded plots, respectively. Research undertaken on association of coffee and shade tree in Central American by Vaast *et al.* (2005) indicated that under sub-optimal condition, shade will reduce the leaf temperature by up to 4^0C. It also reduces the coffee leaf stress, enhances coffee growth and productivity with an adequate shade levels of 20-40 %. This study further indicates that under optimal condition, shade will reduce yields production by up to 20% but improves on the size, biochemical composition and cup quality. Studies in Ethiopia inferred shade coffee as organic coffee since no organic chemicals are used. Studies in Kenya on the effect of *Cordia abysinica, Leucaena divesofilia, Markhamia lutea* and *Albizzia schimperiana* on young *C. Arabica l,* indicated that it is possible to interplant them. The interplanted trees were able to provide shade and control crinkle leaf in the upper coffee zones in Kenya (Kimemia, 2004). Shaded coffee systems recycle more nutrients, promote biodiversity, and consequently are less dependent on external organic agrochemicals.

In Kenya, Gathaara and Gitau, (1998) revealed that physiological parameters may be used to predict coffee trees adaptability under shade from planted shade trees when working on coffee physiological parameter as influenced by the distance from *Cordia abysinica* tree .

Unshaded coffee bushes have a shorter life span than shaded bushes (Bote, 2007; Beer *et al.,* 1998). Moreira *et al.,* (2008) reported that full sun grown inorganic coffee is more criticized due to lack of biodiversity and high demands for nutrients. The use of shelter trees appears to be feasible as it would reduce wind and temperatures and increase relative Humidity (RH) (Caramori *et al.,* 1995; Barrandas and Fanjul, 1986). Hence water use efficiency is expected to improve especially in Sub optimal conditions. Overall comparisons amongst different experiments dealing with effects of shading on coffee production, has shown higher yields under the shade than full sun only during the first harvest or crop cycle as reported by Damaltta (2004)

Kenya is known for its high quality Arabica coffee production which is classified along the Colombians mild coffee with balanced body and acidity and an excellent aroma. (Omondi, 2008). According to Linne and Scherr (2010) the Kenyan coffee quality is highly threatened by the predicted temperature rise. This will result to hastened ripening and reduced flowering resulting to low coffee yields and quality. Adapting to climate change adaptation measures in coffee farming in the increasingly global warming conditions will be necessary in order to safeguard the Kenyan coffee quality.

2.6 Soil moisture Content

Use of soil water resources by vegetation largely determines the agronomic, the ecological, and hydrological outcomes of plants growth. The redistribution of moisture by plants may significantly affect water and nutrient uptake as well as providing larger benefits to other soil biotas and neighbouring plants as observed by Dawson, (1993) and Caldwell, (1990). Caldwell *et al.,* (1998) indicated that there are about 30 tree species that have demonstrated the distribution of water from lower horizons to the surface horizons but Burgress *et al.,* (1998) indicated that soil water distribution is a complex issue that involves the active root system and the soil. The results of the study showed that root hairs were active throughout the dry season, thereby accounting for the rapid redistribution of moisture from the top layer to the drier lower horizons on slight wetting of the top soil. Plants roots transfer water between soil layers of different water potential thereby significantly affecting the distribution and availability of water in the soil profile. Burgress *et al.*, (1998) observed that a E*ucalyptus camaldulensis* and *Grevillea robusta* trees planted fields showed the distribution of water from the wetter deep soil to the drier top soils. And on wetting the soil top layer water was redistributed to the lower drier layers. The active transfer of water from the top wet soil to the deep drier layer prevents shallow rooted competitors from utilizing the water and reduces water loss through soil evaporation. In most cases shade trees particularly those with deep roots seems not to adversely affect the water balance of the coffee crop. Adequate shade management may even improve the water status of the soil.

Percentage soil moisture is the amount of water in the soil expressed as percentage of the given soil quantity (Landon, 1991). A reduction in Soil moisture lead to declines in gaseous exchange and leaf water potential, possibly leading to plant die-back or mortality, depending on the drought severity (Otieno *et al*., 2006; Borchert, 1994;). Soil moisture also affects the stomatal conductance either directly or indirectly. Thus, low soil water potentials directly cause stomatal closure by causing a decrease in leaf water potential. It has also been established that low soil water content leads to stomatal closing even in the absence of a change in leaf water (Gil *et al.*, 2009). Soil moisture content determines the rate of transpiration and hence nutrient uptake and translocation. This consequently determines both the coffee yields and quality.

2.7 Global climate change

Climate change is a deviation from the long-term weather patterns (UNEP, 2008). It is characterized by an increase in temperature, and a changed rainfall patterns and amounts (Linne and schepp 2010). Climate change induced by green house gases (GHG) will affect crops differently from regions to regions and individuals to individual (UNEP, 2008). Coffee requires moderate air temperatures from 20^{o}C to 25^{o}C and a minimum rainfall, 1000mm per year (Laderach, *et al* 2008; Blore, 1965) and it's highly sensitive to extreme weather conditions.

Moderately cool temperatures are known to limit the photosynthetic productivity of sub-tropical fruit trees (Schaffer and Anderson, 1994) while temperatures below 25^{o}C inhibits coffee productivity (Sile *et al*, 2009; Damaltta, 2004; and Nunes, 1969). Exposing the plant to low air temperatures can damage the photosynthetic apparatus, inhibit the synthesis and /or degradation of proteins, damage the thylakoid membrane, and reduce the electron transfer capacity of the plant (Taiz and Zeiger, 1998).

Climate change is real and its effects are already beginning to have impacts on coffee sector (Linne and Schepp, 2010; Steiner, 2010,). Therefore there is no doubt that the earth's climate is changing and everyone will be affected. The UNEP, (2008) report further elaborates that Africa will be hardest hit and the impact of climate change on livelihood and agriculture in countries of the south is inversely proportional to those countries responsible of the problem.

Coffee production could be greatly affected by the temperature rise either by reducing yields or rendering regions suitable for coffee production unsuitable (Laderac *et al.,* 2008). Kimemia, (2008) reported that global warming would in addition to reduced coffee production increase incidences of pest infestation and thereby reducing the coffee quality and increasing the cost of coffee production. In Brazil attempts to identify the future coffee growing regions indicated that coffee may be pushed up to the south and uphill regions (Laderach *et al.*, 2008). Some producers will gain while others will lose.

2.8 Coffee Photosynthesis

Almost all the energy on the earth's surface comes directly or indirectly from the sun. Plants convert this energy from the usable spectral region (PAR) into usable forms through photosynthesis. Photo synthetically active radiation (PAR) designates the spectral range (wave band) of solar radiation (300 to 700 nanometers (nm)) that photosynthetic organisms are able to use in the process of photosynthesis (Da Matta, 2004 and McCree 1972).

Photosynthesis is the process of manufacturing of carbohydrates by green colouring plants using water (H_2O and carbon dioxide (CO_2) in the presence of light (Wrigley, 1988). Nunes *et al.,* (1968) study on the effect of light, temperatures and carbon dioxide concentration on coffee photosynthesis reported that photosynthetic rates in coffee were comparable to other annual crops at 24^{o}C. Above this, any temperature rise by 1^{o}C resulted to increased carbon dioxide concentration of 20ppm. This effect alone resulted to about 7%

decreases in dry matter content. The study also reported the impact of soil moisture on leaf photosynthesis and indicated that the impact of leaf turgidity was minimal due to depressed soil moisture but a significant drop in photosynthesis was realized. This could probably have been attributed to the reduced nutrients uptake from the soil where N & K are significantly required for photosynthesis (Kumar and Tietszen, 1976). Kumar and Tietszen (1976) study on a one-year-old coffee seedling revealed that maximum photosynthesis was observed at between 20-25^{o}C at low light intensity of 600 μe $m^{-2}s^{-1}$ and increased irradiance with an increase in temperature reduced the rate of photosynthesis drastically. These results are in agreement with (Nutman, 1937) whose study on the physiology of *Coffea arabica L*, photosynthesis of coffee leaves under natural conditions reported that photosynthesis increased with increase in humidity but reduced drastically at higher temperatures.

Generally, leaves photosynthesize best over only a narrow range of temperatures. If the leaf is either too hot, or too cold, its photosynthetic ability will be impaired. Environmental conditions between these two extremes provide an optimum air temperature range for plant growth that allows for maximum productivity (Taiz and zeiger 1998, Kumar and Tieszen, 1976, Huxley, 1970). High diurnal temperatures in coffee results to leaf curling a condition referred to as crinkling (Kimemia, 2004). To photosynthesize, a leaf must be exposed to sunlight. Thus a leaf will always be warmed above the air temperature. The study discusses the impact of intercropping fruit tree with coffee on the prevailing temperatures, stomatal conductance and the relative humidity in relation to the observed coffee yields and quality.

2.9 Carbon sequestration

This is defined as the processes of removing carbon dioxide (CO_2) from the atmosphere and "storing" it in plants that use sunlight to turn it into biomass and oxygen (Bohn *et al*., 2007). It is also popularly referred to as carbon capture sequestration (CCS). Nutman (1937 study found that the total daily carbon assimilation was greater under the shade than in full sun. In Indonesia Retnowarti, (2003) indicated that agroforesty increases carbon sequestration hence improving on sustainable land management. Scherr and Sthapit (2009) report on the mitigation of global climate change, recommended the use of perennial trees in removing carbon from the atmosphere. They noted that over 3000 edible perennial trees have been recommended. Their minimum disturbance of the soil and persistence and prolonged foliage was noted to reduce carbon emission from the surface as well as fixing carbon from the atmosphere.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Study Area

The study was carried out in an existing coffee intercropping plot at Coffee Research Foundation (CRF) in Ruiru District, Kiambu County, Kenya. CRF is situated at 1.05^{o}S and 36.45^{o}E at an elevation of 1608m Asl, (Kimemia, 2004). The soils at the trial site are classified as humic nitosols (Shitakha, 1983). The trial site mimics suitability of coffee growing zones as described by (Damatta, 2004). In Kenya it lies centrally to the Kenya most ideal coffee growing zones (Appendix 3). The study site receives an average rainfall of 1000mm per year and an average temperature of 25^{o}C (Njoroge and Mwaka, 1985). The trial was established in 1989. It has been rejuvenated three times through change of cycles. The fruits trees have been freely managed in order to mimic farmers intercropping practices. Coffee management practices have been carried out as recommended (Njoroge, 1991, CRF, 2010). All litter and fruit falls from both coffee and fruit trees were spread within their respective coffee plots as mulch.

3.1.1 Research design.

The study was carried out in an existing intercropping coffee farm at coffee Research Foundation (CRF), with SL 28 coffee varieties and eleven species of fruit trees. The current study was limited to seven fruit trees species namely Avocadoes (*Persea Americana*), macadamia (*Macadamia ternifolia*), Mangoes (*Mangifera indica*), Guavas (*Psidium guajava*), Loquats (*Eriobotrya japonica*), Bananas (*Musa sapientum*) and the Sole coffee (*Coffea arabica*) as the control plot.

The left out fruit trees treatments did not have a uniform shade. Data was collected at 2.74m and 5.48m from the fruit tree. The treatments layout is in 3.2.1 and Appendix 2

3.1.2 Field layout

The sampling field was laid down as shown in the experimental layout (Appendix 2). The experimental plot had 4 study trees on either side of the fruit trees which were enclosed by guard rows (Appendix 1**).** Effective trees were marked in tree numbers 1-8 from East to west for each treatment. The numbers commenced from the eastern part of the shade to the western part ranging from 1-8. Number 1and 2 were the closest coffee tree to the shade tree on the Eastern side while number 7 and 8 was the furthest tree from the fruit tree on the western side. The trees labeled from 1-8 were identified for data collection. The numbers 1,2,5,and 6 represented data collected at 2.74m from either side of the coffee tree while 3,4,7, and 8 were marked for data collection at 5.48m. Selected coffee bushes for data collection were marked at knee height (about 1.25m from the ground) and at 2.5m. A height of 2.5m of coffee tree from the ground is noted as the highest productive height of the coffee tree (Wrigley, 1988). In each labeled tree two health primary branches were selected (one from each marked height). In each marked primary branch a leaf from the fourth leave pair was selected for data collection and labeled with a tape. The fourth leaf pair is identified as the most physiologically active (Kumar and Tieszen, 1976).

3.2 Materials and methods

3.2.1 Treatments:

The study consisted of six fruit trees intercropped with *Coffea arabicae L.* A seventh plot with sole coffee was selected as a control plot totaling to seven treatments as shown below.

T_1 – Avocadoes (*Persea americana*)

T_2 – macadamia (*Macadamia ternifolia*)

T_3 – Mangoes (*Mangifera indica*)

T_4 – Guavas (*Psidium guajava*)

T_5 – Loquats (*Eriobotrya japonica*)

T_6 – Bananas (*Musa sapientum*)

T_7 - Sole coffee (*Coffea arabica* L.) – control plot.

3.2.2 Tools, Equipments and Reagents

Farm tools and equipments used included the soil auger, soil tins with lids, a weighing balance, improvised soil carton (khaki paper bags), 1m ruler, labeling tapes, plastic crates with lids, pens and pencils, a stapler and staple pins to staple the paper bags, plastic crates with lids, a polythene sheet for spreading and mixing the soil samples and polythine tubing. Other equipments included steady state porometer (LI-1600 Licor Incorporation, U.S. light quantum sensor; LI-1400 Licor Incorporation, U.S. Data logger).

Laboratory Equipments and materials used included an electronic weighing balance, a mechanical grinder, a mechanical shaker, a whirl mixer, atomic spectrometer, a PH meter, an assorted beakers and measuring cylinders, while materials used included potassium dichromate, diphenylamine-a-sulphuric acid Ba- salt as an indicator. Phosphoric acid, dilute water, A whatman filter paper No 42, phosphate free charcoal, concentrated Sulphuric acid, hydrated ferrous sulphate, diphenyl amine indicator.

3.2.3 Data collection and sampling procedures

Field data above the ground collected included the Leaf Photosynthetic Active Radiation (PAR), stomata conductance, temperatures, transpiration, and leaf humidity. Except for PAR all these data parameters were recorded simultaneously using a Steady state porometer (LI-1600, Licor Incorporation, U.S) from each identified and labeled leaf. PAR was recorded using an automatic quantum sensor Licor 1400, logged into the data logger and the data was downloaded into the computer on completion. This data was collected between 12.00- 13.00hr (East African time) as this is reported to be the hottest time of the day (Akunda and Kumar, 1982).

The porometer is tied along the waist by use of straps. The sensor head is then gently held up and the clamp opened to clamp the leaf ensuring the aperture is in the middle of the leaf. Within one or two seconds the porometer is switched off and the clamp is opened to release the leaf. Then the display pointer is slowly moved against each parameter to obtain its readings. The procedure was repeated for all identified leaves in each treatment and in all replicates. The recorded data was then summarized and analyzed for significance test using Cohort Start Statistical programme.

The quantum sensor was connected to the quantum cable, then held at 180^o between the two coffee rows at each distances for each identified tree height. In this case the sensor was held at 1.25m and 2.5m high from the ground at 2.74m and 5.48m respectively either side of the fruit tree, thereby giving eight readings in each plot. The data was then down loaded to the computer. The data was saved in note pad which was then copied to an Excel document. Data was summarized per treatment and finally analyzed for significance test using Cohort Start Statistical programme.

Soil sampling was done in August 2010 and 2011 as August has been identified as the most suited time to determine the nutrients requirement of coffee (Michori and Kimeu, 1971). Soil moisture was determined during June-October 2010 and January- February and Aug-Oct 2011 as these are identified as the driest periods of the coffee cycle when moisture supplementation is needed (Gathaara, 1998). The percentage soil moisture was determined by gravimetric method as described by (Landon, 1991).

Soil sampling required 42 stainless tin with lids for putting soil samples for determining the percentage soil moisture content, 126 soil cartons (in this case Khaki paper bags No2 were used), 1m Ruler, an Auger, Pens and Pencils, a polythene sheet for spreading and mixing the soil samples and a stapler to staple the paper bags. Plastic crates with lids were used to deliver the respective soil samples to the laboratories for analysis. The soil tins with lids and soil cartons were each clearly marked for treatment, replicates, distance and direction of sample collection. The tins with their respective lids were weighed using and electric sensitive balance and their weights recorded accordingly.

Soil sampling was done at 2.74m and 5.48m away from the fruit tree on either side of the fruit tree between the two effective rows as shown in (Appendix1**).** During the sampling the ground was swept off any debris within the sampling site. Then using an auger the soil was extracted between 0-50cm depths. The auger which could not hold soil up to 50cm was pulled out each time it filled. In every auger removal it was carefully pulled out ensuring there was no collapse of the sampling hole. The soil in the auger was emptied into a well spread polythene sheet. The 1m ruler which was marked at 50cm and 100cm was placed into the hole every time the auger was removed to ensure the depth was maintained. At 50cm depth the auger was picked and wiped out of any holding soils. The soil sample collected was carefully mixed and put into three paper bags representing a sample for percentage soil moisture determination, organic carbon and mass nutrient extraction sample. The auger was then picked and then placed in the sampling hole which was now at 50cm depth. This was then carefully rolled down emptying it at various depths to a depth of 100cm. the soil samples were collected and placed on a clean spread polythene sheet, mixed and separated into various samples as in the top soil samples. The paper bags were then stapled to ensure they were not contaminated or misappropriated. The samples were then placed into the plastic crates and covered appropriately with a lid. After sampling was completed all samples were then delivered into the respective laboratories for analysis

Soil samples for determining percentage moisture content was packed in well labeled stainless soil tins of 80-100gms with a capacity of about 400gms. The percentage soil moisture determination samples were collected for five months from cessation to onset of rains in June to Oct 2010 and at the peak of dry season January to February and August- September 2011. Total soil moisture was determined following Landon (1991) soil moisture determination procedure.

3.2.4 Deriving the percentage Moisture content (% M.C)

The collected soil sample for percentage moisture content determinations, on reaching the laboratory were placed on the working bench. Each soil tin and its samples content were weighed. The data generated was recorded and calculations for fresh soil moisture content tabulated as:

Weight of Fresh soil + empty Tin	-	weight of empty Tin	=	weight of fresh soil

The samples were well placed in the oven sieves avoiding any direct tin to tin or oven to tin contacts to allow for uniform spreading of the hot air. Soil samples were dried at 105^{o}C for 48hrs. Then removed and weighed. The moisture content was determined as shown below, Weight of fresh Soil + tin - weight of partially Dry soil sample + empty tin = Moisture content (M.C) loss in the soil

The partially dried samples were returned in the oven for 24hrs and then reweighed. Samples with a constant weight from the previous readings were separated with those differing in weight. These were returned back to the oven for further drying. Weighing was then repeated for the returned samples after every 8hrs until a constant weight was attained for all samples.

Using the data generated, the percentage weight of fresh soil was calculated as

$$\% \text{ M.C} = \frac{\text{weight of Fresh soil} - \text{weight of dry soil}}{\text{weight of fresh soil}} \times 100$$

Soil parameters which included soil organic matter, potassium, phosphorous, Calcium and Magnesium were determined from the soil samples delivered for mass nutrient determination in the soil laboratory. Soil samples for organic matter determination on reaching the laboratory were each spread on a clean sheet on the working bench to test for dryness. Then each sample was grinded using a grinding machine and sieved to give a fine sample. 0.5gms of the finely grounded and sieved samples for each treatment was weighed and put into a 500ml wide-neck Erlenmeyer conical flask. Then 10ml of 0.17m potassium dichromate ($K_2Cl_2O_7$) was measured and added to the soil samples using a burette. Then the samples were each swirled gently to disperse soil in the content. Then 20ml of concentrated sulphuric acid was added in each sample including the blank potassium dichromate sample rapidly in the fume chamber. While in the fume chamber the flasks were swirled gently until the soil and reagents were mixed up and then vigorously for one minute. The content was then allowed to settle for thirty minutes. Then 200ml of dilute water was added to the content, mixed and allowed to cool. Then 10ml of 85% phosphoric acid was added and finally 3ml of diphenylamine -4-sulphonic acid, (Ba -salt indicator). This was titrated against hydrated ferrous ammonium sulphate ($Fe.7_2O\ (NH_4)_2SO4$). During titration the colour changed from brown to violet and flashed to green at the end point. Amount of ferrous ammonium sulphate used to reach the end point in each sample was recorded and used to calculate the percentage carbon in the soil.

$$\%Carbon = \frac{\text{corresponding wt of C}}{1ml Fe(NH_4)_2SO_4} \times \underset{\text{(in Blank)}}{Fe(NH_4)_2SO4} - \frac{Fe(NH_4)_2SO4(\text{sample})}{Fe(NH_4)_2SO4(\text{blank})} \times \text{wt 0f soil (gms)}$$

The soil samples marked for mass Nutrient extractions on reaching the laboratory were oven dried at 45^{o}C for 24hrs to ensure complete moisture removal. Then the oven dried soil samples were crashed with a grinding machine to get extractable fine soils. The grounded soil samples were sieved using an 850 micrometer mesh. An extract of 0.1 Sodium and 0.025M concentrated sulphuric acid was made. Then 5gms of each sieved sample was put into a plastic bottle. Then 25ml of the prepared working extraction solution added. The solution was shook for 30min using a mechanical shaker. A whatman filter paper No 42 was placed on filtration bottle and added a scoop of phosphate free charcoal and each solution mixture sample poured into it for filtration. The extracted filtrate was used to determine the soil PH, Phosphorus, potassium, calcium and Magnesium. Soil Nitrogen was determined using

Kjeldahi method while the soil pH was determined using $CaCl_2$ method (Anderson and Ingram1989). Phosphorous was determined through calorimetric method. Calcium and Magnesium were determined through absorption and potassium through emission mode. All solutions were run against known solutions of their standards.

Rainfall and temperature data was collected during the study period in an automatic agro- meteorological station within 200m from the experimental site.

3.3 Data analysis procedure

3.3.1 Soil Data Analysis

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 $P \leq 0.05$. Statistical table of means, standard errors, and co variances were used for results presentation and discussion.

3.3.2 Weather Records

Weather data was pictorially presented (Figure 1 and Figure 2) below

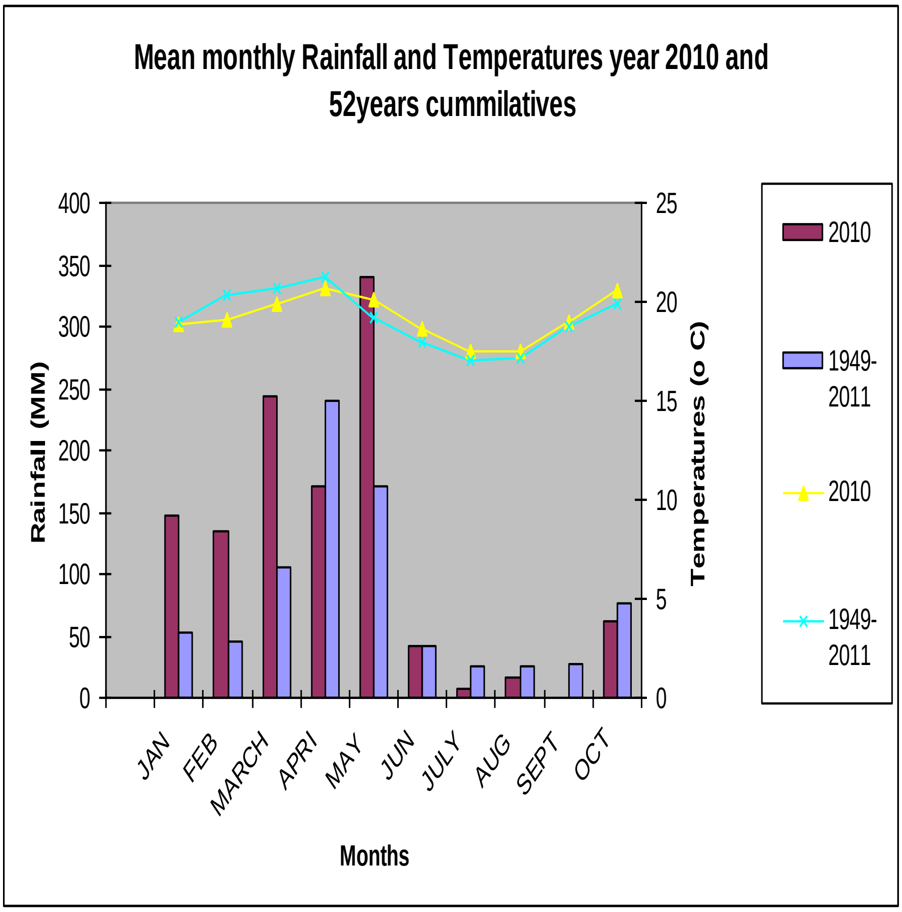

Figure 1. Mean monthly Rainfall and Temperature Data for year 2010 and 52 years Cumulative Data.

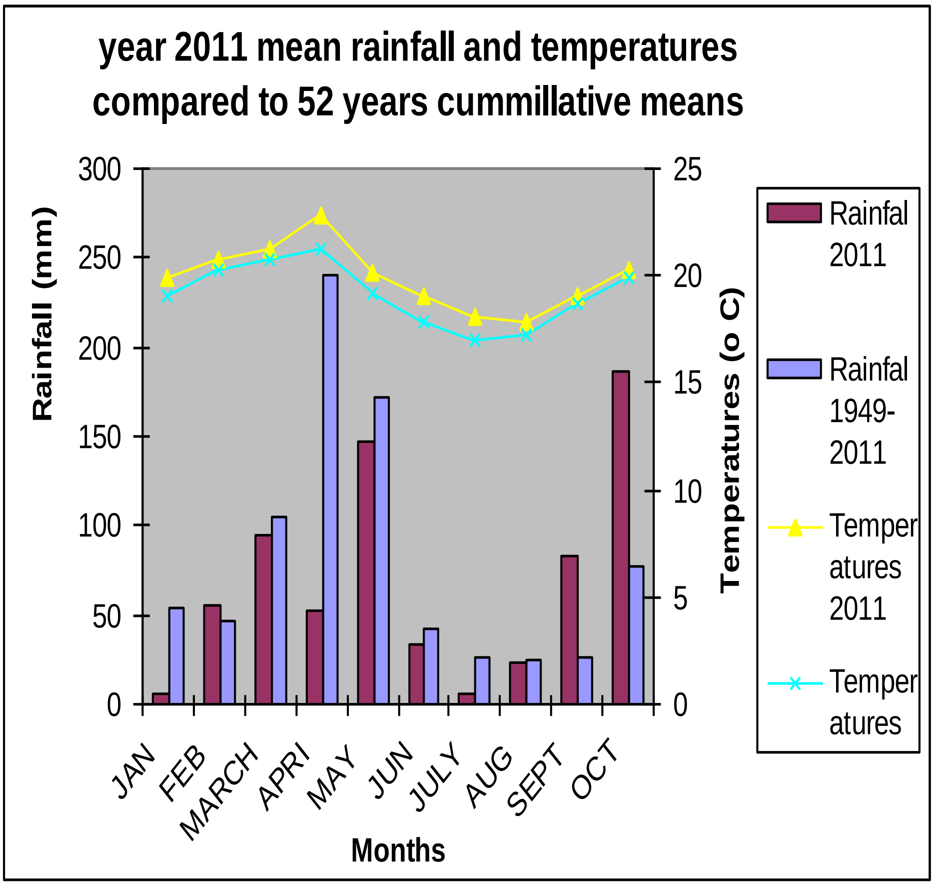

Figure: 2 Mean monthly Rainfall and Temperature Data for year 2011 and 52 years cumulative Data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1. 1 Photosynthetic Active Radiation (PAR)

During the study period coffee trees intercropped with fruit trees had significantly low mean PAR as compared to sole coffee regardless of the month and distance from the fruit trees. Coffee intercropped with the avocados, macadamia and mangoes fruit trees exhibited higher mean PAR at 5.48m than 2.74m. Those intercropped with the guavas, loquats and bananas exhibited lower mean PAR at 5.48m than 2.74m. (Table 4.1).

Table 4.1: The impacts of fruit trees on Intercepted Coffee (PAR) in July and August 2010 at 2.74m and 5.48m from fruit tree

Fruit trees / PAR	July quantum (PAR) (μE $m^{-2}s^{-1}$)		August quantum (PAR) (μE $m^{-2}s^{-1}$)		Mean Quantum (PAR) (μE $m^{-2}s^{-1}$)	
	2.74m	5.48m	2.74m	5.48m	2.74m	5.48m
Avocado	129.32d	168.54f	85.00f	201.63e	107.16e	185.09f
Macadamia	137.49d	367.58c	187.93d	307.24d	162.71e	337.41d
Mango	192.88d	551.48b	132.96e	394.14c	162.92e	472.81b
Guavas	320.78bc	239.48e	320.15c	220.28e	328.78c	229.88e
Loquats	352.74b	277.78d	514.77b	479.27b	433.75b	378.53c
Bananas	267.71c	166.56f	208.34d	133.53f	238.03d	150.04g
Sole coffee	1294.45a	1074.31a	1210.95a	1108.58a	1144.68a	1091.45a
Mean	385.05	496.53	326.01	406.38	358.29	456.46
S/X	8253.50	1125.72	694.06	1877.76	5117.04	760.50
Lsd	74.36	27.46	24.47	35.47	58.55	22.57
Cv	23.59	8.25	7.87	10.66	19.42	6.78

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 ($P \leq 0.05$).

4.1.2 Leaf Temperatures

The leaf temperatures were higher during the dry season (Table 4.4-4.5) than during the wet season (Table 4.2-4.3 regardless of the distance from the tree. During the wet season there was no significant difference in temperatures observed at both study distances. However coffee intercropped with mangoes and Loquats raised the leaf temperatures by 0.18^{O}C and 1.11^{O}C respectively at 2.74m while that intercropped with avocados increased by 1.21^{O}C at 5.48m.

Table 4.2: Coffee Eco-physiological Factors at a distance of 2.74m from the fruit tree during the Mid-day hour from 25th-30th/June 2011

Fruit Trees/ Environmental factors	Leaf temperatures (^{o}C)	Leaf Transpiration (μg cm^{-2}s^{-1})	Stomatal Conductance (cm s^{-1})	Humidity (%)
Avocados	26.22a	25.71c	7.55a	77.32a
Macadamia	26.28a	25.70c	8.17a	77.23a
Mangoes	27.28a	26.97a	7.22a	76.09a
Guavas	26.85a	26.08bc	7.08a	75.98a
Loquats	28.63a	25.91c	6.91a	76.9a
Bananas	26.78a	26.47abc	7.4a	76.42a
Sole Coffee	27.17a	26.77ab	7.10a	75.72a
Mean	27.03	26.23	7.348	76.52
S/x	8.02	0.417	1.285	2.67
Lcd (0.05)	2.32	0.528	0.928	1.338
Cv	10.48	2.46	15.43	2.136

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 ($P \leq 0.05$)

Table 4.3: Coffee eco-physiological factors at a distance of 5.48m from the fruit tree during the Mid-day hour from 25th-30th/June 2011

Fruit Trees/ Environmental factors	Leaf temperatures (^{o}C)	Leaf Transpiration ($\mu g\ cm^{-2}s^{-1}$)	Stomatal Conductance ($cm\ s^{-1}$)	Humidity (%)
Avocados	28.49a	25.46c	7.8ab	77.575ab
Macadamia	26.13a	25.57bc	7.71ab	77.27ab
Mangoes	27a	26.48a	7.17ab	76.32bc
Guavas	26.95a	25.93abc	7.29ab	76.85abc
Loquats	26.5a	25.78abc	7.53ab	76.8abc
Bananas	26.95a	26.39ab	8.44a	78.43a
Sole Coffee	27.28a	26.16abc	6.51b	75.35c
Mean	27.04	25.97	7.49	76.94
S/x	9.06	0.48	1.92	2.26
Lsd (0.05)	2.46	0.57	1.14	1.23
Cv	11.13	2.66	18.51	1.95

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

During the dry season the sole coffee exhibited higher leaf temperatures at both distances and was significantly higher than coffee intercropped with mangoes fruit trees both at 2.74m and 5.48m and avocados at 2.74m (Table 4.4 and 4.5). However, all coffee trees under the fruit trees intercrops exhibited lower leaf temperatures compared to sole coffee during the dry season except for the guava intercrops which raised the leaf temperatures by 0.43^{o}C and 0.91^{o}C at 2.74m and 5.48m respectively. Mango and loquat intercrops reduced the leaf temperature by 1.8^{o}C and 1.17^{o}C respectively at 2.74m while the avocado, mango and loquat intercrops reduced by 3.38^{o}C, 3.10^{o}C, and 1.27^{o}C respectively at 5.48m

4.1.3 Leaf Transpiration.

The rate of transpiration was higher in all treatments during the wet season than the dry season regardless of the distance from the tree. During the wet season avocado, macadamia and loquat intercrops exhibited significantly low rate of transpiration to sole coffee at 2.74m (Table 4.2 and 4.3). At 5.48m the mango intercrop had significantly higher rate of transpiration than the avocado intercrops but this was not significantly different from sole coffee. Sole coffee exhibited significantly higher rate of transpiration to coffee intercropped with all fruit trees during the dry season at 5.48m and to coffee intercropped with avocado, guava and loquat at 2.74m (Table 4.4 and 4.5).

Table 4.4: Coffee eco-physiological Factors at a distance of 2.74m from the fruit tree at Mid-day hour from 25th-28th/Feb 2011.

Fruit trees	Leaf temperatures (^oC)	Leaf transpiration ($\mu g\ cm^{-2}s^{-1}$)	Stomata conductance ($cm\ s^{-1}$)	Humidity (%)
Avocado	34.44 a	0.90 c	0.03 a	3.66 b
Macadamia	33.73ab	1.13 abc	0.03 a	3.98 b
Mangoes	33.33b	1.32 abc	0.04 a	4.52 ab
Guavas	35.56ab	1.09 bc	0.03 a	3.93 b
Loquat	33.98ab	0.92 c	0.03 a	3.61 b
Bananas	34.73ab	1.62 ab	0.05 a	5.08 ab
Sole coffee	35.13 a	1.74 a	0.04 a	5.70 a
Mean	34.27	1.25	0.04	4.36
S/x	1.582	0.24	2.16	1.46
Lsd(0.05)	1.03	0.40	0.01	0.99
Cv	3.67	39.56	41.60	27.78

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 ($P \leq 0.05$)

Table 4.5: Coffee eco-physiological Factors at a distance of 5.48m from the fruit tree at Mid-day hour from 25th-28th/Feb 2011.

Fruit trees/ Environmental factors	Leaf Temperatures (^oC)	Leaf transpiration ($\mu g\ cm^{-2}s^{-1}$)	Stomatal Conductance ($cm\ s^{-1}$)	Humidity (%)
Avocado	31.8 b	0.76 c	0.03 a	3.49c
Macadamia	34.02 ab	1.07 bc	0.03 a	3.69 bc
Mangoes	32.02 b	1.41 b	0.05 a	4.97 ab
Guavas	35.92 a	1.15 bc	0.04 a	3.93 bc
Loquat	33.91 ab	1.01 bc	0.03 a	3.65c
Bananas	35.01 a	1.39 b	0.04 a	4.61 abc
Sole coffee	35.18 a	1.93 a	0.05 a	5.67 a
Mean	33.98	1.25	0.04	4.29
S/x	5.06	0.16	2.94	1.09
Lsd(0.05)	1.84	0.17	0.014	0.85
Cv	6.62	31.56	45.73	24.396

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 ($P\leq 0.05$)

4.1.4 Stomatal Conductance

Stomatal conductance was lower during the dry season than during the wet season in all the treatments. During the wet season the sole coffee exhibited low stomatal conductance to all fruit trees intercrops regardless of the distance from the tree except for guavas and loquats intercrops at 2.74m (Table 4.2 and 4.3). The stomatal conductance was significantly higher in bananas intercrops at 5.48m than the sole coffee. The macadamia intercrops exhibited the highest stomata conductance at 2.74m during the wet season but was not significantly different from the sole coffee. During the dry season there were no significance differences in coffee leaf stomatal conductance among the treatments regardless of the distance of the coffee tree from the fruit tree (Table 4.4 and 4.5)

4.1.5 Relative Humidity

There was higher percentage Relative Humidity (%) during the wet season than the dry season. During the wet season the sole coffee exhibited low % Relative Humidity than the intercropped coffee (Table 4.2 and 4.3). This was not significantly different at 2.74m but was significantly lower than coffee intercropped with the avocados, macadamia and bananas at 5.48m. During the dry season the sole coffee exhibited significantly higher relative humidity to all other coffee-fruit trees intercrops except mangoes and bananas at both study distances (Table 4.4 and 4.5).

4.1.6 Soil Moisture dynamics in a coffee intercropping farm

The study involved collecting percentage soil moisture data from June to October 2010. June being the period immediately after the long rains the soils had substantial amount of moisture content from the previous rains while October is the month just before the short rains (Fig 3), therefore the soils are expected to be dry awaiting the rains. In this case results (Fig 3 and Fig 4) were not significantly different both at the top and the sub soil in the month of June and July 2010, though guavas and loquats gave low % soil moisture to sole coffee in the sub soil. In the subsequent months (August, September and October) coffee intercropped with mangoes indicated significantly low % soil moisture content both at the top soil and sub soil while that intercropped with loquats and guavas were significantly low at the top soil and sub soil respectively.

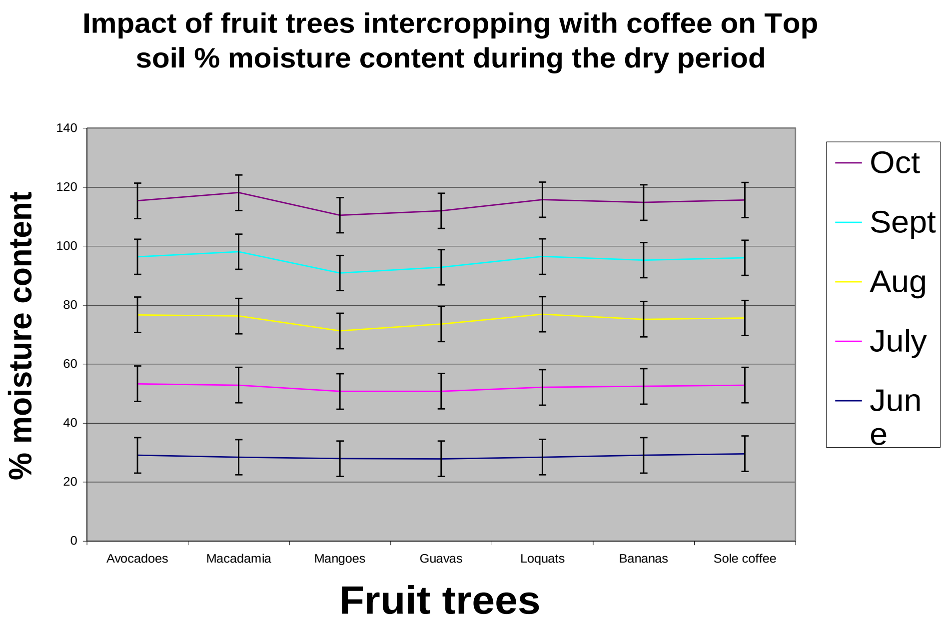

Figure 3: Impact of fruit trees intercropping with coffee on Top soil % M.C

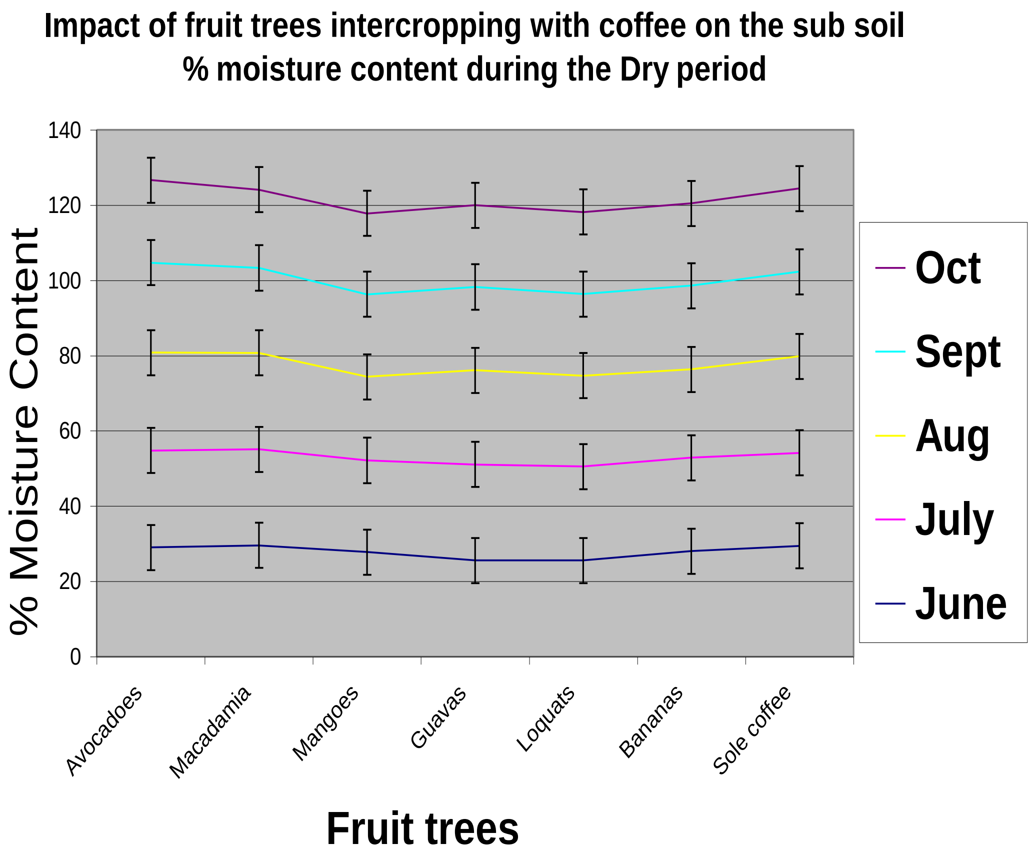

Figure 4: Impact of fruit trees intercropping with coffee on Sub- soil % M/C

Table 4.6: Percentage soil moisture as influenced by the distance from the fruit tree during the study period (Aug-Sept 2011)

SoilDepth/	2.74mm			5.48m		
Fruit trees	0-50cm	50-00cm	Mean	0-50cm	50-00cm	Mean
Avocades	20.83a	22.83ab	21.83a	21.03a	23.37ab	22.20ab
Macadami	19.93a	22.87ab	21.40a	20.53a	23.63ab	22.58ab
Mangoes	19.80a	22.40ab	21.10a	21.73a	23.97ab	22.85a
Guavas	19.43a	22.07b	20.75a	19.80a	23.13ab	21.47b
Loquats	20.60a	22.57ab	21.58a	21.77a	23.20ab	22.48ab
Bananas	20.47a	22.90ab	21.68a	20.70a	22.47b	21.58ab
Sole coffee	19.63a	24.43a	22.03a	19.80a	24.57a	22.68ab
Mean	20.1	22.87	21.48	21.05	23.48	22.26
S/x	1.09	1.09	1.14	1.02	0.81	0.92
Lsd	1.86	1.86	1.27	1.79	1.599	1.14
Cv	5.19	4.58	4.96	4.79	3.83	4.31
Df error	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 ($P \leq 0.05$)

Percentage soil moisture content determined in February 2011 (Table 4.6) indicate that coffee intercropped with all fruit trees resulted to higher % soil moisture content the top soil at both 2.74m and 5.48m (except guavas and mangoes at 2.74m and 5.48m respectively though this was not significantly different. At the sub soil sole coffee gave higher % Moisture content compared to coffee intercropped with all fruit trees. This was significantly higher than coffee intercropped with guavas and bananas at 2.74m and 5.48m respectively.

4.1.7 Soil nutrients as influenced by the distance from the fruit tree

Results indicated that phosphorus and potassium are high at the top soil than sub soil at 2.74m while low at the top soil than sub soil at 5.48m in coffee intercropped with all fruit trees (Table 4.7). Coffee intercropped with all fruit trees gave higher phosphorus to sole coffee at 0-50cm depth at both 2.74m and 5.48m except coffee intercropped with bananas. This was significantly higher in coffee intercropped with avocado (Table 4.7). At 50-100cm depth coffee intercropped with all fruit trees led to higher phosphorus at 5.48m and that at 2.74m it was not significantly different from sole coffee.

Coffee intercropped with all fruit trees led to significantly higher Potassium to sole coffee at 0-50cm depth regardless of the distance from the tree except avocados, macadamia and guavas at 5.48m. This was significantly low in coffee intercropped with guava (Table 4.7) at 50-100cm depth. Coffee intercropped with all fruit trees depressed the soil potassium regardless of the distance from the tree except coffee intercropped with mango and macadamia. These were significantly high at 5.48m. Coffee intercropped with bananas gave significantly higher potassium levels to sole coffee at 0-50cm soil depth but was significantly low at 50-100cm depth regardless of the distance from the tree.

Table 4.7: Soil phosphorus and potassium in coffee in a coffee intercropping farm at a distance of 2.74m and 5.48m from the fruit tree in 2011.

Soil/ Fruit tree	2.74m				5.48m			
	0-50cm		50-100cm		0-50cm		50-100cm	
	P Ppm	K me%	P ppm	K me%	P ppm	K me%	P ppm	K me%
Avocad	18.7a	0.8b	14.7a	0.3c	12.0a	0.5c	17.3a	0.2d
Macada	16.0ab	0.8b	13.3a	0.6a	14.0a	0.5c	15.3a	0.5b
Mangoes	16.0ab	0.9a	13.3a	0.4b	14.7a	0.8b	15.3a	0.6a
Guavas	17.3abc	0.2d	12.0a	0.1d	13.3a	0.3d	14.7a	0.1e
Loquats	17.3abc	0.8b	12.7a	0.2c	14.0a	0.8b	14.0a	0.2d
Bananas	14.0c	1.0a	12.7a	0.1d	12.0a	1.1a	14.7a	0.1e
Sole coffee	15.3bc	0.7c	12.7a	0.3bc	14.0a	0.6c	14.7a	0.4c
Mean	16.38	0.713	13.07	0.27	13.43	0.65	15.15	0.26
S/x	2	0.002	2.82	0.003	4.83	0.0058	6.00	0.001
Lsd (0.05)	2.52	0.087	2.99	0.089	3.91	0.136	4.36	0.59
Cv %	8.63	6.88	12.88	18.26	16.36	11.73	16.18	12.76
Error	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 ($P \leq 0.05$)

Results (Table 4.8) indicated higher calcium and magnesium at 0-50cm depth, than at 50-100cm depth at 2.74m but coffee intercropped with banana and avocados led to significantly low calcium and magnesium both at 0-50cm depth and 50-100cm depth regardless of the distance from the fruit tree. At 5.48m, all fruit trees gave significantly low calcium levels in the 0-50cm depth except Macadamia which gave higher calcium at both 0-50cm and 50-100cm depth regardless of the distance from the fruit tree and was significantly higher than sole coffee at 2.74m at 0-50cm depth.

Table 4.8: Soil calcium and magnesium content as influenced by the fruit trees at a distance of 2.74m and 5.48m from the fruit tree as at Aug 2011

Soil factor/ Fruit tree	2.74m				5.48m			
	0-50cm		50-100		0-50cm		50-100	
	Ca me%	Mg me %	Ca me%	Mg me %	Ca me%	Mg me %	Ca me%	Mg me %
Avocado	3.89d	2.98c	2.7 a	1.58b	4.16c	4.21d	2.4bc	1.46d
macadam	8.66a	5.46a	2.59a	2.17a	8.22a	6.01a	2.5bc	2.6a
Mangoes	8.4ab	4.04b	2.66a	1.9ab	7.31a	5.15b	2.4bc	2.47a
Guavas	5.05c	3.12c	2.63a	1.6b	5.69b	3.45e	2.6bc	1.7cd
Loquats	8.2ab	2.92c	2.86a	1.8ab	8.18a	4.5cd	3.00a	1.9bc
Bananas	5.20c	3.6bc	2.03b	1.57b	4.88bc	2.70f	2.23c	1.60cd
Sole coffee	7.18b	4.0b	2.53a	2.25a	7.23a	4.90bc	2.75ab	2.32ab
Means	6.6	3.73	2.57	1.845	6.53	4.414	2.575	2.01
S/x	0.45	0.172	0.067	0.065	0.268	0.075	0.064	0.061
Lsd(0.05)	1.199	0.74	0.462	0.454	0.922	0.488	0.452	0.439
Cv %	10.21	11.15	10.099	13.84	7.94	6.21	9.87	12.28
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 ($P \leq 0.05$)

Table 4.9: Soil organic matter, and soil PH as influenced by the fruit trees at a distance of 2.74m and 5.48m from fruit tree as at Aug 2011

Soil factor/ Fruit tree	2.74m				5.48m			
	0-50cm		50-100		0-50cm		50-100	
	O.M%	PH	O.M%	PH	O.M%	PH	O.M%	PH
Avocado	1.29b	5.4ab	0.31ab	5.33b	2.51a	5.2b	0.61a	5.2bc
macadam	0.46c	5.7ab	0.36ab	5.73a	1.45b	5.53a	0.69 a	5.8a
Mangoes	0.9bc	5.80a	0.45ab	5.6ab	1.3 bc	5.57a	0.38 a	5.7a
Guavas	1.45ab	5.4ab	0.46ab	4.97c	0.99c	5.2b	0.45 a	5.1c
Loquats	0.9bc	5.2ab	0.23b	5.5 ab	1.2 bc	5.5a	0.53 a	5.6ab
Bananas	1.98a	5.6ab	0.53a	5.6 ab	0.91c	5.4ab	0.31 a	5.5abc
Solecoffe	0.9bc	5.5ab	0.53a	5.5 ab	1.2bc	5.53a	0.53 a	5.5abc
Means	1.16	5.51	0.413	5.462	1.37	5.41	0.5004	5.5
S/x	0.127	0.067	0.194	0.027	0.044	0.028	0.0624	0.051
Lsd (0.05)	0.634	0.461	0.248	0.29	0.372	0.299	0.4444	0.402
Cv %	30.68	4.71	33.71	2.99	15.27	3.12	49.92	12.37
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 ($P \leq 0.05$)

4.1. 8 Soil Organic matter (O.M) and PH

Results indicated that there is more organic matter in the 0-50cm soil depth than in 50-100cm soil depth, both at 2.74m and 5.48m in all treatments as shown in Table 4.9). Avocado, macadamia and mangoes intercrops indicated higher organic matter at 5.48m than 2.74m both at the top and sub soil while guava and banana intercrops gave low organic matter at 5.48m than 2.74m. Loquat intercrops gave significantly low organic matter to sole coffee at 2.74m sub soil while bananas were significantly high in the top soil. Banana and avocado intercrops have significantly higher organic matter to sole coffee at the top soils at 2.74m and 5.48m respectively.

The Soil pH was not significantly different among treatments regardless of the distance from the fruit tree and was within the recommended range (4.5-5.5) calcium chloride method as recommended by (Michori and Kimeu, 1971)

4.1. 9 Impacts of fruit trees on coffee Yields and % Grade A

Results of coffee yields and percentage grade A are shown in Table 4.10. The results indicated that sole coffee exhibited significantly higher yields to all fruit trees intercrops. The mango intercrops led to significantly higher yields than all other fruit trees except the macadamia which was low but not significantly different. Loquat and guava exhibited significantly lower coffee yields to all other fruit trees. The mango intercrops exhibited the highest % grade A which was significantly higher to sole coffee and all other fruit trees except avocado and loquat treatments. Coffee intercropped with guavas gave significantly lower % grade A to all other treatments.

Table 4.10: Impact of fruit trees on coffee yields and Percentage Grade A during the coffee production years from 2009-2011

Soil Depth/ Fruit trees	Coffee Yields (Clean coffee kgs/ Ha)	Percentage Grade A (%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.

4.2 Discussion

4.2.1 Impact of coffee intercropping on Photosynthetic Active Radiation (PAR)

The study result indicates that Photosynthetic Active Radiation (PAR) under sole coffee was significantly higher than coffee intercropped with all fruit trees regardless of the distance from the fruit tree. Coffee intercropped with avocado, macadamia and Mango indicated lower mean PAR at 2.74m ((μE $m^{-2}s^{-1}$) than at 5.48m with coffee intercropped with avocados registering the lowest PAR at both study distances. This was below the recommended range (below 300-700 µmol/s^{-2}) required for optimum photosynthesis in coffee (Kumar and Tieszen, 1976). These observations are in agreement with Odeny *et al.,* (2011) who in their study on the impact of *Cordia abysinica* tree species in coffee shading indicated that the PAR under shaded coffee increased with distance from the shade tree. The results of this study are also in agreement with Retworti, (2003) and *Sile et al.,* (2009) who in their agroforesty coffee study indicated that coffee in the open exhibits significantly higher PAR than shaded coffee. Results also in this study also indicated that guava, loquat and banana intercrops had a low mean PAR (µmol/s^{-2}) at a distance of 5.48m from the tree than at 2.74m from the fruit trees. The amount of PAR received is expected to vary with the type and physiological structure of the tree used for intercropping with coffee. The increased PAR at 2.74m in coffee intercropped with guava and loquat fruit trees could probably be attributed to the fruit tree structural canopy which opens up the middle canopy to enable light penetration to facilitate flowering and hence fruiting while that of banana can be attributed to the high banana stems population density used in this study at 2mx2m. This confirms (TaCri, 2004) results that intercropping coffee with banana with the arrangement of three rows to one resulted to higher returns than the commonly farmer practice of one row of bananas to one row of coffee. Low leaf PAR (µmol/s^{-2}) observed in coffee intercropped with all fruit trees is the main attribute to low coffee yields in coffee intercropped with fruit trees (Table 4.10). This concurs with the findings of Kimemia and Njoroge, (1988) and Wrigley, (1988) who reported that for any intercropping in coffee the selected plants for intercropping should be taller than the coffee tree and should not share production seasons to avoid resource competition. The low PAR under shade may be as a result of the increased fruit tree canopy since the fruit trees are at their maximum growth maturity and therefore exhibiting higher shade on the ground. In addition the fruit trees population used are for pure fruit trees stand as recommended under pure fruit trees orchards. The type and fruit trees densities used in this study provided higher canopies that reduced the potential of the under storey coffee trees resulting to low coffee yields (Table 4.10).

4.2.2 Leaf Temperatures

The study results indicated that there was no significance difference in temperatures during the wet season (Table 4.2 and 4.3) regardless of the distance from the shade tree. However coffee intercropped with mangoes and loquats raised the leaf temperatures at 2.74m while that intercropped with avocados had high temperatures to sole coffee at 5.48m. High leaf temperatures observed in coffee intercropping with mangoes, loquats and avocados are in agreement with (Vaast *et al.*, 2005; Sile *et al*, 2009 and Kufa *et al*, 2011) who according to their respective coffee agroforesty studies indicated that any tree that provide shade to plant would raise coffee temperatures during low temperatures and lower it when the surrounding temperatures are high. These results are also in agreement with (Retworti, 2003) who reported that inter-planted shade trees may raise the leaf temperature during the cold season. During the dry season, all fruit trees exhibited lower leaf temperatures regardless of the distance from the fruit tree except for the guavas at both study distances. The high leaf temperatures in guavas be attributed to the significantly low moisture content observed (Table 4.6). Low soil moisture content results to high leaf diffusion resistance inhibiting leaf transpiration and consequently gaseous exchange thereby raising the leaf temperatures. Intercropping coffee with avocados and mangoes significantly reduced the leaf temperatures during the dry weather in (February 2011) at 5.48m by 3.38^{o}C and 3.10^{o}C in coffee intercropped with avocado and mango fruit trees respectively. These observations are in agreement with (Sile., *et al* , 2009 and Vast., *et al* , 2005) who in their separate studies indicated that under sub optimal conditions shade in coffee reduced the leaf temperatures by 4^{o}C and 5^{o}C respectively. The study indicated a low mean temperature of 25.97^{o}C at 5.48m as compared to a mean of 26.23^{o}C at 2.74m during the dry season. This may be attributed to the fruit trees structural canopy which provides higher canopy with distance from base of the fruit tree as observed in *Cordia abyssinica* shade trees in coffee by Odeny *et al*., (2011).

4.2.3 Leaf Transpiration

Transpiration is the loss of water from a plant either by evaporation or guttation through the stomata. Water can only evaporate from the plant if the water potential is lower in the air surrounding the plant (Fan *et al.*, 2004). Guttation is the loss of water in liquid form from the uninjured leaf or stem of the plant, mainly through the stomata. Results indicate a higher rate of transpiration during the wet season than the dry season. This may be attributed to the high percentage moisture content in the soil resulting to reducing the diffusion resistance hence increased rate of transpiration. Sole coffee had significantly higher rate of transpiration regardless of the distance from the tree. The increased rate of transpiration under sole coffee may be attributed to the lower water vapour concentration in sole coffee than the intercropped coffee. These results concur with Fan et al. (2004) who indicated that transpiration from the leaf depends on two major factors; the difference in water vapor concentration between the leaf air spaces and the external air and, the diffusional resistance (r) of this pathway. Diffusional résistance (r) depends on the mineral uptake which in turn is dependent on the availability of sufficient amounts of essential ions in the soil and therefore available soil moisture.

4.2.4 Relative Humidity

Humidity is the amount of water vapor in the atmosphere, usually expressed as either absolute humidity or relative humidity. The relative humidity is the most commonly used measure of how much water vapor is held in the air and it refers to the amount of water vapor in the air (at a specific temperature) compared to the maximum amount of water vapor air could hold at that temperature, and is given as a percentage value (Bialoglowski,1935). Relative humidity depends on the temperature of the air, as warm air can hold more moisture than cold air. Other underlying factors include the speed of the wind and vegetative canopies. A relative humidity of 100 percent indicates that the air is holding all the water it can at the current temperature and any additional moisture at that point will result in condensation. As the temperature decreases, the amount of moisture in the air doesn't change, but the relative humidity goes up (since the maximum amount of moisture that cooler air can hold is smaller Bialoglowski (1935). The study found that there was higher Relative Humidity during the wet season than the dry season regardless of the distance from the tree. Thus confirming Bialoglowski (1935) report that relative humidity depends on the temperature of the air, as warm air can hold more moisture than cold air. During the wet season there was no significance difference in RH. During the dry season coffee intercropped with avocadoes, macadamia, guavas and loquats had significantly lower relative humidity than the sole coffee at both study distances. The fruit trees intercrops also significantly reduced the leaf temperatures than the sole coffee. Relative humidity is highly influenced by air temperature and wind movements. Fruit trees intercrops may have reduced the wind speed and these accounts for the low RH. These observations are in agreement with (Huxley, 1970), who observed that shade in coffee moderates the ambient microclimate in coffee.

4.2.5 Impacts of fruit trees on stomatal conductance

Stomatal conductance is a numerical measure of the rate of passage of either water vapour or carbon dioxide through the stomata, or small pores of the plant as is defined by (Chen *et al*., 1999). Results indicated low stomatal conductance on sole coffee compared to coffee intercropped with fruit trees regardless of the distance from the fruit trees and the season. This is attributed to its significantly higher PAR. The result also indicates higher stomatal conductance during the wet season than the dry seasons. These results confirm the high rate of transpiration and relative humidity observed during the wet season as compared to the dry season. These could probably be accounted to the high soil moisture content observed in the months of June and July (Fig 3 and Fig4.) These results are in agreement with Gil *et al.,* (2009), who indicated that some plant species open stomata in response to extremely high soil water content and close during low moisture content. These results are an indicator that Stomata regulate gas exchange and water vapour, within the environment allowing the plant to optimize and balance photosynthetic performance with water availability and usage.

4.2.6 Impact of coffee intercropping on Soil Organic matter

Nitrogen in the soil is very unstable. Availability of free nitrogen element in the soil either leads to leaching or volatilization under high temperatures and dry conditions. This condition therefore, leads to Nitrogen being the most limiting plant nutrient as reported by Koen *et al*., (1980). In this case soil nitrogen may be banked on when in form of organic matter and other Nitrogen compounds such as ammonium Nitrates. The study results indicated high organic matter at 0-50cm soil depth at both 2.74m and 5.48m away from the fruit tree on the top soil in coffee intercropped with all fruit trees than sole coffee except for coffee intercropped with macadamia at 2.74m and that intercropped with bananas and guavas at 5.4m away from the fruit tree. Low organic matter at 0-50cm depth could be attributed to above ground biomass production and distribution from the respective fruit trees. Higher organic matter at 0-50cm translates to higher nutrients supply when decomposed. This is particularly beneficial to coffee since it extracts nutrients from the top 0-60cm depth. These results are in agreement with (Bote, 2007) who indicated that coffee under agroforesty system may reduce its demand on inorganic inputs leading to development of organic coffee production. On the other hand coffee intercropped with all fruit trees depressed the soil organic matter at 50-100cm depth except for coffee intercropped with macadamia and mangoes at 5.48m. This is an indication that organic matter accumulated at the 0-50cm decomposed and therefore did not alleviate down the soil profile. Organic matter if not fully decomposed may alleviate down the soil profile where it is further decomposed (UNCE, 1999). Higher organic matter in coffee intercropped with macadamia and mango may be an indication of low decomposition rate in their respective litter and fruit biomass.

Avocados and bananas gave significantly higher organic matter at 2.74m and 5.48m away from the fruit trees. This is an indication that litter and fruit falls decomposition may be influenced by other factors such as leaf temperatures and relative humidity. Higher organic matter in coffee intercropped with banana could also be attributed to the high biomass from the banana stems. It is therefore necessary to uniformly spread the banana biomass away from the banana stem.

4.2.7 Impact of coffee intercropping on Soil Phosphorus and Potassium

The degree of shading interacts with nutrition mainly by modifying the microclimate that results to altering the rate of organic matter decomposition and nutrient uptake. Phosphorus in coffee growth stimulates flower bud development, berry growth and berry expansion. The study results indicated that there was no significance difference in the Phosphorous levels both at 2.74m and 5.48m except in the coffee intercropped with the avocados. This had significantly higher phosphorous levels in the top soil at 2.74m. The significantly high organic matter and percentage soil moisture content observed in the coffee intercropped with avocados (Table 4.7) could possibly have facilitated litter and fruit falls decomposition therefore increasing the amount of phosphorus in the soil. Potassium element in coffee is important for obtaining the cell turgor which in turn is required for cell expansion. According to Mengel and Kirky, (1987) potassium deficiency leads to increased transpiration which leads to the plants withering and therefore reduced yields. This is evidenced by the low coffee yields observed under coffee intercropped with bananas and guavas (Table 4.10). Potassium is also important for the mucilage formation and ripening of the coffee berries. In this case the low potassium content in coffee intercropped with guavas could be attributed to the low coffee quality observed (Table 4.10). On the other hand the significantly high percentage grade A observed in coffee intercropped with mango fruit trees is partly attributed to the positive contribution in both phosphorus and potassium in the soil (Table 4.7). While the low yields and percentage grade A under the guavas intercrops is attributed to its low phosphorus and potassium in the soil (Table 4.7).

4.2.8 Soil calcium and magnesium nutrients in coffee intercropped with fruit trees.

For high coffee performance both major and minor elements are of vital importance to soil. Soil calcium and magnesium are considered as major nutrients and play a vital role in berry development and quality (Appendix 5). Study results indicated that coffee intercropped with macadamia exhibited significantly higher calcium and magnesium levels than all other intercrops at 2.74m top soil. This could be attributed to its upright structural structure (Appendix 6) which would result to most of fruit, flower and leaf falls around the base of the tree, hence decomposition. Sole coffee exhibited significantly low calcium levels in the sub soil than all fruit trees intercrops while coffee intercropped with macadamia, mangoes and loquats persistently maintained high calcium and magnesium levels both at the top and sub soils regardless of the distance from the fruit trees. Magnesium is an essential element in coffee playing a vital role in plant photosynthesis. The ability of the macadamia, mangoes and loquats to contribute higher levels of both calcium and magnesium led to the higher percentage grade A with mangoes being significantly higher than all treatments. The significantly low calcium and magnesium in coffee intercropped with guavas is attributed to its significantly low coffee yields and percentage grade A (Table 10).

4.2.9 Soil moisture dynamics in a coffee intercropped farm

The most important requirement for coffee growing is good soil drainage with well distributed moisture over the growing period. Soil moisture availability is determined by the type of soil, amount of available organic matter and other soil nutrients. In this study, results indicated higher soil moisture content at 50-100cm soil depth but low at 0-50cm depth on coffee intercropped with all fruit trees compared to sole coffee except for coffee intercropped with guavas which gave low soil moisture irrespective of the distance from the fruit tree. Soil moisture has been explained as a function of soil physical and chemical properties. Therefore high soil moisture content (M.C) at the top soil in coffee intercropped with fruit trees is attributed to high organic matter observed at the top soil in their respective plots. Results also indicated that there is no significance difference in soil M.C among the treatments except for coffee intercropped with guavas and bananas which led to significantly low soil MC to sole coffee at the 50-100cm depth at 2.74m and 5.48m respectively. This could be attributed to their low organic matter content and probably low root concentration to distribute soil moisture. In previous studies, Kimemia, (2004) indicated a higher water competition in coffee intercropped with fruit trees on three years old coffee intercropping farm. This could have probably been due to the fact that both the fruit and coffee trees had not fully developed the rooting systems which according to Burgles *et al.*, (1998) will form a root network system which distributes moisture and other nutrients from points of higher concentration to points of low concentrations. At 50-100cm soil depth sole coffee exhibited higher soil moisture to coffee intercropped with fruit trees irrespective of the distance from the fruit trees. This was significantly higher than coffee intercropped with guavas and bananas at 2.74m and 5.48m respectively. These results are in agreement with Sile *et al.,* (2009) studies, who observed that soil moisture at deeper layers 60-120, 120-150 was lower in agro-forestry than in monoculture and was more pronounced during dry seasons.

4.2.10 Impacts of fruit trees on coffee Yields and % Grade A

Coffee yields and quality are the bases of coffee profitability and the heart of coffee farming. Therefore intercropping coffee with other crops should ensure that both coffee yields and quality production will not be compromised (Kimemia, 1993)l. Njoroge and Mwaka 1985; Njoroge and The study results indicated that sole coffee led to significantly higher yields and low percentage grade A to coffee intercropped with all fruit trees. Coffee intercropped with mangoes loquats gave significantly higher percentage grade A while intercropping coffee with guavas significantly depressed percentage Grade A. Percentage grade A is a premium coffee grade and its determined by its size which is retained by the coffee grading screen size 18 (with Apertures 7.22mm). It is therefore possible to compensate the quantity depressed in coffee intercropping with the gains in improved percentage grade A especially in coffee intercropped with mangoes which also had a significantly higher yields to coffee intercropped with all other fruit trees. These results confirms Kimemia,

(2004) and Kumar and Tiezsen, (1976);) findings in their different studies on artificial coffee shading, and coffee intercropped with fruit trees respectively observations that shaded coffee have low coffee yield but of higher quality. The results are also in agreement with Vaast *et al*. (2005) who indicated that coffee under the shade has better quality.

Coffees intercropped with avocado trees have significantly low yields and quality despite its significantly high phosphorus, organic matter and percentage soil moisture content. This has been attributed to its significantly low potassium, calcium, magnesium and leaf PAR at both study distances. The significantly low coffee yields and percentage grade A in coffee intercropped with guavas confirms Njoroge and Kimemia, (1993) findings that intercropping coffee with depressed coffee growth, yield and quality.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Study results showed that, intercropping coffee with fruit trees significantly depressed the leaf PAR. The impact of coffee intercropping on leaf PAR is specific to the fruit tree used and varied with distance from the fruit tree. Mangoes gave a higher leaf PAR at 5.48m while loquats had higher PAR at 2.74m from the fruit tree. This is attributed to the canopy distribution and can be managed by pruning the fruit tree. Intercropping coffee with guavas significantly depressed mean PAR, irrespective of the distance used. There was significantly higher PAR at 5.48m away from the fruit tree compared with 2.74m.

Intercropping coffee with all fruit trees did not significantly influence the leaf temperatures in June 2010 but depressed it in February 2011. In June 2010 the leaf temperatures was higher in coffee intercropped with fruit trees than sole coffee except for coffee intercropped with guavas. The influence on leaf temperatures deffered among the fruit trees used and also between the distances. June 2010 had low air temperatures (Figure 1) as compared to February 2011(Figure 2). Therefore it is concluded that intercropping coffee with the selected fruit trees ameliorates Leaf temperatures. This would reduce the diurnal, leaf temperatures. Mangoes significantly depressed the leaf temperatures by 1.8^{o}C in February 2011.

The leaf transpiration, stomatal conductance and relative humidity were not significantly influenced in June 2010 but were significantly enhanced in

February 2011 in coffee intercropped with fruit trees as compared to sole coffee. These results therefore concluded that intercropping coffee with fruit trees significantly depressed the leaf transpiration and Relative Humidity, during the dry season but not during the wet weather.

The impact of intercropping coffee on the coffee eco-physiological factors of production was significant in February 2011 as opposed to June 2010. February 2011 was a hotter and drier month as compared to June 2010 (Figure 1 & 2). Therefore the result concludes that intercropping coffee with fruit trees would have higher benefits in marginal coffee growing areas as opposed to optimal coffee growing regions. The practice may also be viewed as a mitigation measure for the impact of global warming in coffee farming.

Intercropping coffee with fruit trees enhanced soil phosphorus and potassium, at 0-50cm depth except bananas and guavas respectively nullifying the perception that intercropping coffee with fruit trees may cause nutrients competition. Coffee intercropped with avocados led to significantly higher soil phosphorus while mangoes and macadamia led to significantly higher soil potassium.

Intercropping coffee with the fruit trees enhanced soil organic matter at 0-50cm soil depth but did not significantly influence soil moisture content except for guavas and bananas which led to depressed soil moisture content at 50-100cm depth at 2.74m and 5.48m respectively. Coffee intercropped with all fruit trees depressed soil moisture content at 50-100cm soil depth compared to sole coffee. This is evidenced by high soil moisture content in sole coffee at 50-100cm depth irrespective of the distance from the fruit trees. Therefore intercropping coffee with the fruit trees may result to efficient moisture and nutrients utilization in the lower soil profiles.

Intercropping coffee with all fruit trees depressed the coffee yields but improved on the percentage grade A except coffee intercropped with guavas and bananas. Intercropping with mangoes improved the coffee yields significantly and also gave a higher percentage grade A to coffee intercropped with other fruit trees. Percentage grade A is a premium coffee grade and may fetch higher prices hence may compensate for the loss in coffee yields in coffee intercropped with fruit trees.

5.2 Recommendations

The impact of fruit trees on coffee factors of production was specific for each fruit tree used. The study therefore recommends that farmers can intercrop coffee with the selected fruit trees except guavas and bananas. Coffee intercropped with the selected fruit trees may improve the soil nutrients, soil organic matter and soil moisture at 0-50cm depth which is the main coffee feeding zone. Coffee intercropping with the fruit trees should be done at a longer distance than the one used in this study. The fruit trees should be regularly pruned to allow for proper penetration of quality light mainly the leaf PAR. Intercropping coffee with mangoes and macadamia are particularly recommended to improve on the soil potassium while avocados may be used to improve on soil phosphorus.

Intercropping coffee with bananas significantly enhanced potassium but depressed calcium at 0-50cm depth. It also significantly depressed both potassium and calcium at 50-100cm depth. This is attributed to its high deposition of the banana pseudo-stem at the soil service. These observations suggest that the banana stem may be absorbing all the deposited potassium at 0-50cm depth. This is further evidenced by the low potassium at 2.74m at 50-100cm soil depth compared with coffee intercropped with other fruit trees. In this regard bananas can be planted away from the coffee as pure stand or wind breakers and their pseudo-stem used as source of potassium in coffee intercropped with other fruit trees.

When intercropping with the selected fruit trees farmers are advised to uniformly spread and dug into the soil all litter and fruit falls to ensure uniform nutrient distribution. Farmers are also advised to ensure the management of both the fruit and coffee trees are adhered to their recommendation. Use of different fruit trees species in coffee intercropping is recommended to enrich the soil with nutrients as opposed to a single tree species. This should be done at longer distance than 5.48m from the fruit tree.

The impact of intercropping coffee on the coffee eco-physiological factors of production was significant in February 2011 as opposed to June 2010. Therefore the study recommends coffee intercropping in the marginal coffee growing areas to mitigate impact of high temperatures and longer dry periods which would result to depressed coffee yields and percentage grade A.

The study recommends further research to establish appropriate farm arrangements and practices for intercropping coffee with fruit trees to improve on PAR, soil moisture, organic matter and other nutrients distribution and particularly to coffee intercropped with avocados, macadamia and mangoes.

Guavas and bananas significantly depressed soil moisture content, potassium, coffee yields and coffee quality. Due to the high significance of potassium and soil moisture in coffee growth and development the study recommends that guavas and bananas should not be intercropped with coffee but research on other farm arrangements in coffee intercropped with bananas may be done.

The study recommends further studies to establish appropriate distance of the fruit tree from coffee that will provide optimal PAR of (600-700 $\mu E\ m^{-2}s^{-1}$) and the irrigation water requirements in coffee farms intercropped with fruit trees during the dry season to enhance on leaf transpiration and by extension nutrient uptake.

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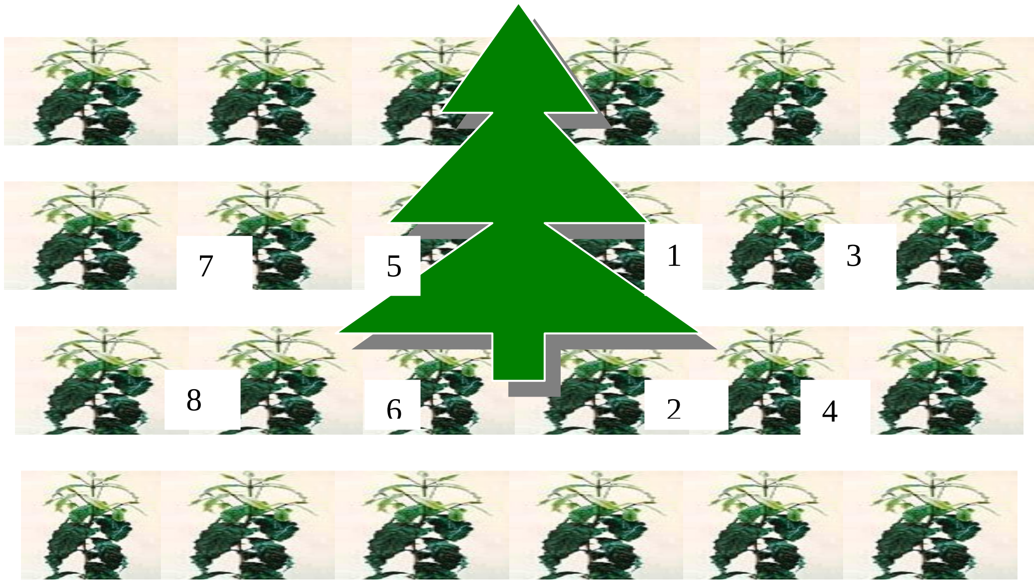
APPENDICES

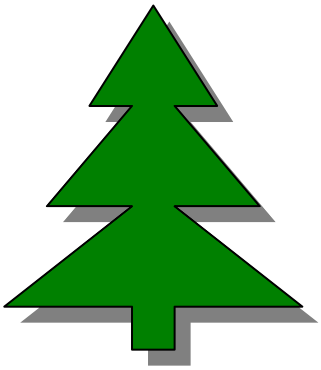
Appendix 1: Field Experimental Plot Layout

Fruit Tree



KEY

COFFEE TREE



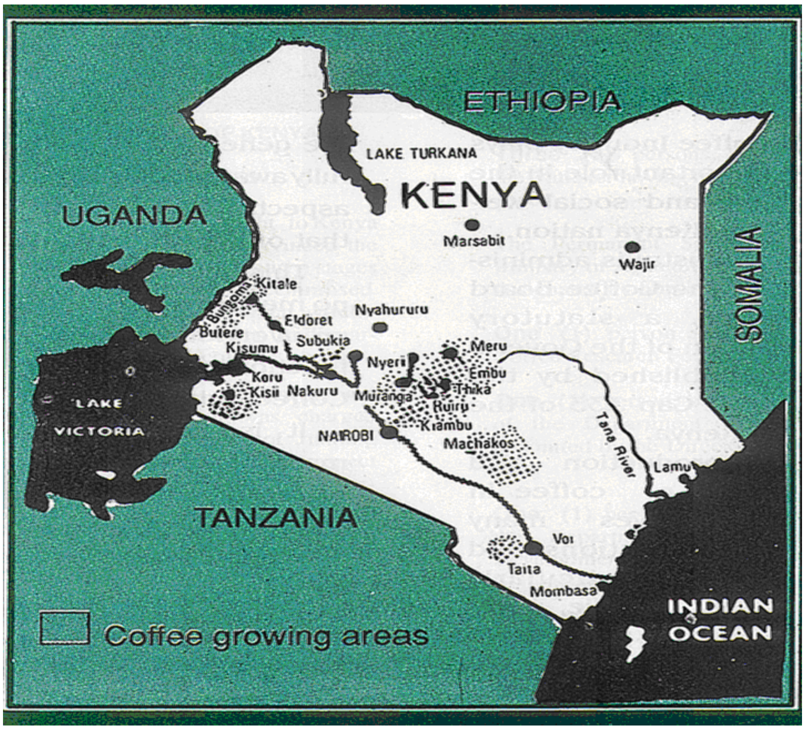
FRUIT TREE

Appendix 2: Experimental Field Layout

Reps 1	**T_7**	**T_3**	**T_6**	**T_4**	**T_5**	**T_6**	**T_1**
Reps 11	**T_7**	**T_3**	**T_4**	**T_2**	**T_5**	**T_6**	**T_1**
Reps 111	**T_7**	**T_6**	**T_3**	**T_2**	**T_1**	**T_5**	**T_4**

T_1 – Avocadoes (*Persea Americana*)
T_2 – macadamia (*Macadamia ternifolia*)
T_3 – Mangoes (*Mangifera indica*)
T_4 – Guavas (*Psidium guajava*)
T_5 – Loquats (*Eriobotrya japonica*)
T_6 – Bananas (*Musa sapientum*)
T_7 - Sole coffee (*Coffea arabica l.*) – control plot.

Appendix 3: Kenya Coffee Growing Ecological Zones



Appendix 4: A Pure SL28 Traditional Coffee Variety

Appendix 5: Coffee Production Trends in Kenya (2000-2010).

Production year	Total Production in Metric Tonnes
2000/2001	50,543
2001/2002	51,895
2002/2003	55,443
2003/2004	48,431
2004/2005	45,245
2005/2006	48,835
2006/2007	54,340
2007/2008	43,000
2008/2009	54,000
2009/2010	43,988

Source: - Coffee Board of Kenya.

Appendix 6**:** Macadamia production (Tons in-shell) in major macadamia growing countries in the years 2006 and 2007

	Tons in-shell	
Country	**2006**	**2007**
Australia	42000	39700
Hawaii	22000	20000
S. Africa	17230	19230
Kenya	11400	11100
Guatemala	7000	8300
Malawi	4230	7110
Brazil	3125	3750
Zimbabwe	800	770
Costa Rica	500	500
Others	2200	2500
Total	108285	110460

Source: Hormarc and Olieveri 1998 from Adapted from Wilkie (2008).

Appendix 7: The nutrients removed in the bean, pulp and parchment equal to 1 ton of arabica green beans

In beans	45.50	kg N	7.67	kg P_2O_5	37.90	kg K_2O
In parchment	2.27	kg N	0.30	kg P_2O_5	1.87	kg K_2O
In pulp	15.33	kg N	3.67	kg P_2O_5	27.40	kg K_2O
Totals	63.10	kg N	11.64	kg P_2O_5	67.17	kg K_2O

Source: Hormarc and Olieveri 1998 from Ripperton et al 1935:1955).

Appendix 8: Soil nutrient requirements

Macro and micro-nutrients required by coffee for health development

Mineral/ element	**chemical symbol;**	**Main requirements/ use by plant**
Macronutrients		
Nitrogen	N	Plant growth; proteins; enzymes; hormones; photosynthesis
Sulphur	S	Amino acids and proteins; chlorophyll; disease resistance; seed production
Phosphorus	P	Energy compounds; root development; ripening; flowering
Potassium	K	Fruit quality; water balance; disease resistance
Calcium	Ca	Cell walls; root and leaf development; fruit ripening and quality
Magnesium	Mg	Chlorophyll (green colour); seed germination
Micronutrients		
Copper	Cu	Chlorophyll; protein formation
Zinc	Zn	Hormones/enzymes; plant height
Manganese	Mn	Photosynthesis; enzymes
Iron	Fe	Photosynthesis
Boron	B	Development/growth of new shoots and roots; flowering, fruit set and development
Molybdenum	Mo	Nitrogen metabolism
Chloride	Cl	Photosynthesis; gas exchange; water balance

Source: Hormarc and Olieveri 1998.

Appendix 10.0: ANOVA

10.1: PAR ANOVA (July- Sept Quantum Means) 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	16470.09	8235.05	1.61	.2095 ns
Main Effects					
Fruit tree	6	9338638.93	1556439.8	304.17	.0000 ***
Canopy	1	301952.57	301952.57	59.01	.0000 ***
Direction	1	277468.61	277468.61	54.22	.0000 ***
Interaction					
Fruit tree x Canopy	6	96285.81	16047.64	3.14	.0104 *
Fruit tree x Direction	6	143291.50	23881.92	4.67	.0007 ***
Canopy x Direction	1	7696.77	7696.77	1.50	.2254 ns
Fruit tree x Canopy x Dir	6	53543.58	8923.93	1.74	.1285 ns
Error	54	276320.03	5117.04<-		
Total	83	10511667.88			
Model	29	10235347.85	352943.03	68.97	.0000 ***

R^2 = SSmodel/SStotal = 0.97371301774
Root MSerror = sqrt(MSerror) = 71.5334714464
Mean Y = 368.290119048
Coefficient of Variation = (Root MSerror) / abs(Mean Y)*100% = 19.423131%

10.2: PAR, ANOVA (July- Sept Quantum Means) at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	711.62	355.81	0.468	.6289 ns
Main Effects					
Fruit tree	6	7501117.51	1250186.30	1643.905	.0000 ***
Canopy	1	845980.61	845980.61	1112.404	.0000 ***
Direction	1	183414.32	183414.32	241.177	.0000 ***
Interaction					
Fruit tree x Canopy	6	241051.59	40175.27	52.828	.0000 ***
Fruit tree x Direction	6	120631.64	20105.27	26.437	.0000 ***
Canopy x Direction	1	4630.23	4630.23	6.088	.0168 *
Fruit tree x Canopy x Dir	6	3515.02	5752.51	7.564	.0000 ***
Error	54	41066.89	760.50<-		
Total	83	8973119.42			
Model	29	8932052.54	308001.81	405.0002	.0000 ***

R^2 = SSmodel/SStotal = 0.99542334317
Root MSerror = sqrt(MSerror) = 27.5771269533
Mean Y = 406.456547619
Coefficient of Variation = (Root MSerror) / abs(Mean Y)*100% = 6.7847663%

10.3: Leaf Transpiration ANOVAs during the wet season (25-30t June 2010) 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.254088095	0.127044	0.2663786	.7671 ns
Main Effects					
Fruit Tree	6	11.17681667	1.8628028	3.9058163	.0026 **
Direction	1	0.864171429	0.8641714	1.8119443	.1839 ns
Canopy	1	0.31207619	0.3120762	0.6543432	.4221 ns
Interaction					
Fruit Tree x Direction	6	1.925378571	0.3208964	0.6728369	.6720 ns
Fruit Tree x Canopy	6	2.260240476	0.3767067	0.7898567	.5818 ns
Direction x Canopy	1	0.093333333	0.0933333	0.1956959	.6600 ns
Fruit Tree x Directionx	6	1.777116667	0.2961861	0.6210258	.7126 ns
Error	54	25.75424524	0.4769305<-		
Total	83	44.41746667			
Model	29	18.66322143	0.6435594	1.3493777	.1686 ns

R^2 = SSmodel/SStotal = 0.4201775299
Root MSerror = sqrt(MSerror) = 0.69060152575
Mean Y = 25.9666666667
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 2.6595694%

10.4 Impact of intercropping coffee with fruit trees on coffee yields.

Source	df	Type I SS	MS	F	P
Blocks	2	18104	9052	5.6260488	.0189 *
Main Effects					
Fruit tree	6	72065 4.9524	120109.16	74.650905	.0000 ***
Error	12	1930 7.33333	1608.9444<-		
Total	20	75806 6.2857			
Model	8	738758.9524	92344.869	57.394691	.0000 ***

R^2 = SSmodel/SStotal = 0.97453081123
Root MSerror = sqrt(MSerror) = 40.1116497348
Mean Y = 757.285714286
Coefficient of Variation = (Root MSerror) / abs(Mean Y) *100% = 5.2967657%

10.5: Impact of intercropping coffee with fruit trees on coffee percentage Grade A

Source	df	Typ I SS	MS	F	P
Blocks	2	15.5 5809524	7.7790476	2.119219	.1629 ns
Main Effects					
Fruit tree	6	225.5 8285713	7.597143	10.24246	.0004 ***
Error	12	44.04 857143	3.6707143<-		
Total	20	285.1895238			
Model	8	241.1409524	30.142619	8.2116495	.0007 ***

R^2 = SSmodel/SStotal = 0.84554632007
Root MSerror = sqrt(MSerror) = 1.91591082405
Mean Y = 88.1619047619
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 2.1731731%

10.6: Impact of intercropping coffee with fruit trees on top Soil Organic Matter at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.142828571	0.0714143	0.561174	.5848 ns
Main Effects					
Fruit tree	6	4.037495238	0.6729159	5.2877777	.0070 **
Error	12	1.527104762	0.1272587<-		
Total	20	5.707428571			
Model	8	4.18032381	0.5225405	4.1061268	.0142 *

R^2 = SSmodel/SStotal = 0.73243558937
Root MSerror = sqrt(MSerror) = 0.35673341609
Mean Y = 1.16285714286
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 30.677321%

10.7: Impact of intercropping coffee with fruit trees on top Soil Organic Matter at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.181371429	0.0906857	2.0769231	.1680 ns
Main Effects					
Fruit tree	6	5.15072381	0.858454	19.660681	.0000 ***
Error	12	0.523961905	0.0436635<-		
Total	20	5.856057143			
Model	8	5.332095238	0.6665119	15.264741	.0000 ***

R^2 = SSmodel/SStotal = 0.9105265041
Root MSerror = sqrt(MSerror) = 0.20895811079
Mean Y = 1.36857142857
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 15.268338%

10.8: Impact of intercropping coffee with fruit trees on top Soil Phosphorus content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	10.66666667	5.3333333	2.6666667	.1101 ns
Main Effects					
Fruit tree	6	42.28571429	7.047619	3.5238095	.0301 *
Error	12	24	2<-		
Total	20	76.95238095			
Model	8	52.95238095	6.6190476	3.3095238	.0307 *

R^2 = SSmodel/SStotal = 0.68811881188
Root MSerror = sqrt(MSerror) = 1.41421356237
Mean Y = 16.380952381
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 8.6332805%

10.9: Impact of intercropping coffee with fruit trees on top Soil Potassium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.024695238	0.0123476	5.1261944	.0246 *
Main Effects					
Fruit Tree	6	1.334066667	0.2223444	92.307743	.0000 ***
Error	12	0.028904762	0.0024087<-		
Total	20	1.387666667			
Model	8	1.358761905	0.1698452	70.512356	.0000 ***

R^2 = SSmodel/SStotal = 0.97917024124
Root MSerror = sqrt(MSerror) = 0.04907881578
Mean Y = 0.71333333333
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 6.8802078%

10.10 Impact of intercropping coffee with fruit trees on top Soil Calcium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.331228571	0.1656143	0.3646929	.7018 ns
Main Effects					
Fruit Tree	6	73.49453333	12.249089	26.973252	.0000 ***
Error	12	5.449438095	0.4541198<-		
Total	20	79.2752			
Model	8	73.8257619	9.2282202	20.321112	.0000 ***

R^2 = SSmodel/SStotal = 0.93125923246
Root MSerror = sqrt(MSerror) = 0.67388414529

Mean Y = 6.6
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 10.210366%

10.11: Impact of intercropping coffee with fruit trees on top Soil potassium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.005685714	0.0028429	0.4893443	.6247 ns
Main Effects					
Fruit Tree	6	1.3264	0.2210667	38.052459	.0000 ***
Error	12	0.069714286	0.0058095<-		
Total	20	1.4018			
Model	8	1.332085714	0.1665107	28.66168	.0000 ***

R^2 = SSmodel/SStotal = 0.95026802275
Root MSerror = sqrt(MSerror) = 0.07622023228
Mean Y = 0.65
Coefficient of Variation = (Root MSerror/abs(Mean Y) * 100% =11.72619%

10.12: Impact of intercropping coffee with fruit trees on Sub Soil potassium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.006066667	0.0030333	2.7164179	.1064 ns
Main Effects					
Fruit Tree	6	0.993657143	0.1656095	148.30704	.0000 ***
Error	12	0.0134	0.0011167<-		
Total	20	1.01312381			
Model	8	0.99972381	0.1249655	111.90938	.0000 ***

R^2 = SSmodel/SStotal = 0.986773581
Root MSerror = sqrt(MSerror) = 0.03341656276
Mean Y = 0.2619047619
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 12.759051%

10.13: Impact of intercropping coffee with fruit trees on top Soil calcium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	1.6098	0.8049	2.9947291	.0881 ns
Main Effects					
Fruit Tree	6	47.29344762	7.8822413	29.326845	.0000 ***
Error	12	3.225266667	0.2687722<-		
Total	20	52.12851429			
Model	8	48.90324762	6.112906	22.743816	.0000 ***

R^2 = SSmodel/SStotal = 0.93812855189
Root MSerror = sqrt(MSerror) = 0.5184324664
Mean Y = 6.52571428571
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 7.9444555%

10.14: Impact of intercropping coffee with fruit trees on Sub Soil calcium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.466752381	0.2333762	3.1034723	.0820 ns
Main Effects					
Fruit Tree	6	21.61539048	3.6025651	47.907462	.0000 ***
Error	12	0.902380952	0.0751984<-		
Total	20	22.98452381			
Model	8	22.08214286	2.7602679	36.706464	.0000 ***

R^2 = SSmodel/SStotal = 0.96073962811
Root MSerror = sqrt(MSerror) = 0.27422328985
Mean Y = 4.41476190476
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 6.211508%

10.15: Impact of intercropping coffee with fruit trees on top Soil Magnesium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	6.666667	5 3.33335	5.15774	.9995 ns
Main Effects					
Fruit Tree	6	1.52492381	0.254154	3.932581	.0209 *
Error	12	0.775533333	0.0646278<-		
Total	20	2.30052381			
Model	8	1.524990476	0.1906238	2.9495647	.0448 *

R^2 = SSmodel/SStotal = 0.66288836911
Root MSerror = sqrt(MSerror) = 0.25421993977
Mean Y = 2.57523809524
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 9.8717062%

10.16 Impact of intercropping coffee with fruit trees on Sub Soil Magnesium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.218095238	0.1090476	4.0650888	.0449 *
Main Effects					
Fruit Tree	6	1.12952381	0.188254	7.0177515	.0022 **
Error	12	0.321904762	0.0268254<-		
Total	20	1.66952381			
Model	8	1.347619048	0.1684524	6.2795858	.0025 **

R^2 = SSmodel/SStotal = 0.80718767827
Root MSerror = sqrt(MSerror) = 0.16378460497
Mean Y = 5.4619047619
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 2.9986719%

10.17: Impact of intercropping coffee with fruit trees on Sub Soil Magnesium content at 5.48m

Source	df	Type I SS	MS	F	P
Blocks	2	0.15272381	0.0763619	1.2498831	.3213 ns
Main Effects					
Fruit Tree	6	3.683314286	0.6138857	10.048012	.0004 ***
Error	12	0.733142857	0.0610952<-		
Total	20	4.569180952			
Model	8	3.836038095	0.4795048	7.8484801	.0009 ***

R^2 = SSmodel/SStotal = 0.83954611017
Root MSerror = sqrt(MSerror) = 0.2471745094
Mean Y = 2.01238095238

Coefficient of Variation = (Root MSerror)/abs(Mean Y*100% = 12.28269%

10.18: Impact of intercropping coffee with fruit trees on sub Soil Potassium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.007380952	0.0036905	1.4654901	.2695 ns
Main Effects					
Fruit Tree	6	0.44552381	0.074254	29.486291	.0000 ***
Error	12	0.030219048	0.0025183<-		
Total	20	0.48312381			
Model	8	0.452904762	0.0566131	22.48109	.0000 ***

R^2 = SSmodel/SStotal = 0.93745071755
Root MSerror = sqrt(MSerror) = 0.05018220769
Mean Y = 0.27476190476
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 18.263888%

10.19: Impact of intercropping coffee with fruit trees on Sub Soil Calcium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	1.784009524	0.8920048	5.1591027	.0242 *
Main Effects					
Fruit Tree	6	14.35698095	2.3928302	13.839451	.0001 ***
Error	12	2.074790476	0.1728992<-		
Total	20	18.21578095			
Model	8	16.14099048	2.0176238	1.669364	.0001 ***

R^2 = SSmodel/SStotal = 0.88609928492
Root MSerror = sqrt(MSerror) = 0.41581150339
Mean Y = 3.72904761905
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 11.150609%

10.20: Impact of intercropping coffee with fruit trees on sub Soil Magnesium content at 2.74m

Source	df	Type I SS	MS	F	P
Blocks	2	0.111666667	0.0558333	0.8566314	.4490 ns
Main Effects					
Fruit Tree	6	1.37332381	0.2288873	3.5117383	.0305 *
Error	12	0.782133333	0.0651778<-		
Total	20	2.26712381			
Model	8	1.484990476	0.1856238	2.8479616	.0500 ns

R^2 = SSmodel/SStotal = 0.65501075413
Root MSerror = sqrt(MSerror) = 0.25529938852
Mean Y = 1.84476190476
Coefficient of Variation = (Root MSerror)/abs(Mean Y)*100% = 13.839151%