EFFECTS OF LEGUME COVER CROPS ON SOIL PROPERTIES AND PRODUCTIVITY OF GRAFTED ORANGES (*Citrus sinensis*) IN THE COASTAL LOWLANDS OF KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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To my father Benson Yumbya, my late mother Alice, my wife Rebecca, my children; Ann, Daniel, Lydia and my grandchildren Mutanu, Wambui and Mwendwa.

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LIST OF ABBREVIATIONS

AEC	Anion Exchange Capacity
AEZ	Agro Ecological Zone
ANOVA	Analysis of Variance
APVC	Agricultural Product Value Chain
ASDSP	Agricultural Sector Development Support Programme
BNF	Biologically Nitrogen Fixation
CBO	Community Based Organization
CEC	Cation Exchange Capacity
CL3	Coastal low land zone three
CL4	Coastal low land zone four
C/N	Carbon Nitrogen ratio
CV	Coefficient of Variation
DR_d	Dry Root density
DR_m	Dry Root Mass
DR_w	Dry Root Weight
FBO	Faith Based Organization
FAO	Food Agricultural Organization
GLM	General Linear Model
GOK	Government of Kenya
HCD	Horticultural Crops Directorate
HCDA	Horticultural Crops Development Authority

ICIPE	International Centre for Insect Physiology and Ecology
ICRAF	International Centre for Research in Agroforestry
IPDM	integrated Pest and Disease management
ISFM	Integrated Soil Fertility Management
KALRO	Kenya Agricultural and Livestock Research Organization
KEBS	Kenya Bureau of Standards
KEPHIS	Kenya Plant Health Inspectorate Service
KES	Kenya Shilling
KIRDI	Kenya Industrial Research and Development Institute
L/R	Long Rains
LS	Loamy Sand
LSD	Least Significance Difference
MoALF	Ministry of Agriculture, Livestock and Fisheries
NACOSTI	National Commission for Science, Technology and Innovation
NARL	National Agricultural Research Laboratory
NGO	Non Governmental Organization
PCPB	Pest Control and Products Board
ρ_b	Soil bulk density
ρ_w	Density of water
PSD	Particle Soil Distribution
RCBD	Randomized Complete Block Design
SCL	Sandy Clay Loam

SDG	Sustainable Development Goal
SMC	Soil Moisture Content
S/R	Short Rains
TC	Tissue Culture
Temp.	Temperature
TS	Topsoil

ABSTRACT

Orange (*Citrus sinensis*) is an important food and cash crop in coastal lowland of Kenya. The average orange production in Kenya is 12 tones/ha Compared to world production of 16 tones/ha due to low soil fertility, diseases and high costs of inputs. There is, therefore, a need to develop a sustainable and low input production system for increased orange productivity and improved fruit quality in coastal lowland of Kenya. This study was tconducted at KALRO-Matuga, Ganda and Vitengeni within the coastal region of Kenya from May 2012 to April 2015. The effects of legume cover crops on soil moisture, orange feeder root distribution, soil pH, plant nutrients, orange yield and fruit quality was evaluated. There were four treatments; mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), dolichos (*Lablab purpureus*) cover crops and a fallow as the control. The experiment was laidout in a randomized complete block design (RCBD) where the treatments were replicated four times within four blocks in an existing grafted Valencia orange orchard. Soil and orange root sampling was between 2m and 3m radius from the orange trees trunk at two depths topsoil (0-20 cm) and sub-soil (20-40 cm). Fruit and leaf samples were taken from the orange trees. Data collected was subjected to analysis of variance (ANOVA) at ($P \leq 0.05$) using procedures of R statistical analysis version 3.3.2. Mean separation was done using the least significant difference (LSD) at ($P \leq 0.05$) level of significance. Mucuna, dolichos and cowpea increased soil moisture content in orange orchard for all the site topsoil while in the sub-soil is only mucuna and dolichos increased moisture content in the soil. Mucuna and dolichos increased orange root density in the top and sub-soils. Mucuna, cowpea and dolichos increased soil nitrogen in the orange orchard top and sub-soil. Mucuna, cowpea and dolichos increased soil organic carbon in the orange orchard top and sub-soil. Mucuna increased phosphorous in the top and sub-soil of orange orchard. Dolichos increased phosphorous in the topsoil of orange orchard.. Cowpea and dolichos increased phosphorous in the sub-soil of orange orchard. Mucuna, dolichos and cowpea increased the potassium in the topsoil of orange orchard while in the sub-soil, potassium increase due to mucuna and cowpea. Mucuna dolichos and cowpea increased orange leaf chlorophyll content. The orange fruit number increased due to mucuna and dolichos. Orange fruit weight increased due to mucuna and dolichos. Fruits size increased due to mucuna and dolichos. Fruits juice increased due to mucuna and dolichos. Orange fruit brix increased due to mucuna and dolichos. In conclusion, mucuna, dolichos and cowpea are effective in improving soil moisture, root distribution and nutrients in the soil and orange yield and fruit quality. The use of mucuna however, had the highest increase and it is strongly recommended as a cover crop in orange production. Further research is however recommended to evaluate the long term (>3years) effect of the cover crops under different Agro-ecological zones.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Orange production in Kenya

Orange (*Citrus sinensis*) belongs to the family *Rutaceae*, species citrus genera. This crop is a native of the tropical and sub-tropical regions of South East Asia where it was first cultivated in China around 2500 BC. The area under cultivation globally is over 9.4 million hectares with an estimated production of over 182.3 million tonnes, of which 60% is of the sweet orange variety. The leading orange producing countries in the world are Brazil, China, USA, and India (Xu *et al.*, 2013). Orange was introduced in Kenya by Asians who came during the building of the Kenya – Uganda railway in 1893 – 1902. Orange productions in cooler areas were very much affected by the citrus greening disease. The bacteria species affecting citrus greening disease in Kenya is *Liberibacter africanum* which is heat sensitive and cannot survive in warm areas like the coastal region of Kenya (Batool, *et al.*, 2007).

1.1.1 Constraints in orange production

In Kenya, small-scale farmers constitute 86% total orange producers while in coastal lowlands they constitute 91% (HCDA, 2013). The production area and yield of orange have declined overtime due to poor planting materials, low soil fertility, pests and diseases (Wasilwa *et al.*, 2007; Horticultural Crops Directorate, 2015). The major constraints limiting on-farm production of oranges included lack of adequate planting materials, low soil fertility, diseases mainly the citrus greening disease and pests (HCD, 2015). Despite the low yields of orange fruits per hectare and low production, there is great potential for increased orange production both for the domestic and export markets (HCDA, 2013).

Soil fertility to sustain optimal orange fruit production has declined over time (Kanyanjua *et al.*, 2000) because of over-cultivation and subsequent mining of nutrients in the topsoil (Chen *et al.*, 2007). In addition, the orange production has also declined because of aging orange trees (Paudyal and Haq, 2008). The soils of coastal Kenya are mainly sandy; deficient in nitrogen and low in organic matter and hence poor in water holding capacity (Jaetzold *et al.*, 2012). Some areas receive an average 400 mm of rainfall per year that is erratic and poorly distributed hence exposing the orchards to periods of water stress (Indeje *et al.*, 2000). The coastal region of Kenya experiences strong winds during the month of June. When these winds coincide with the flowering and early stage of fruit development, high fruit abortion is observed (Muti and Kibe, 2009).

The challenges mentioned in this chapter justify the need for an assessment of orange crop production systems in a holistic way, considering production issues, livelihoods and environmental quality. The results will also be used to develop agricultural extension information which is area-specific.

1.1.2 Orange value chain

The level of value addition particularly in terms of agro-processing is very low among the small scale farmers, resulting to wastage during times of peak production (Babbar *et al.*, 2011). In a priority setting exercise of 2010, spearheaded by Kenya Agriculture Research Institute (Now Kenya Agricultural and Livestock research Organization), Orange fruit were ranked as the 5th most important tropical fruits in Kenya (Njuguna *et al.*, 2011; Wasilwa *et al.*, 2014). Oranges are mainly sold in the local markets for fresh consumption. Grapefruits and lemons are bought by canning factories for making marmalade and some are sold for fresh consumption. Limes are mainly exported although substantial quantities are used locally (HCD, 2011). Besides being eaten while fresh, orange fruits are used for making juices, squashes and marmalades as well as for extraction of oils and flavourings for use in perfumery, confectionery and soft drink industries (Alvarez, *et al.*, 2012). Citric acid is extracted from the pulp after juice extraction. In every 100 ml of orange juice contains 370 to

500 I.U (Plaza, *et al.*, 2011). Vitamin A, 35-80 mg of vitamin C, 0.08 mg of vitamin B, 20-28 mg of calcium and 1.2 mg of iron, 11.4 mg of Mg, 0.5 of protein, 16.4 carbohydrate plus 91.4 water and 3.62 fibre (Marin, *et al.*, 2007). Citrus fruits processing and value addition: Orange marmalade, orange syrup and orange juice and extracted from the orange fruit (Ede, *et al.*, 2008). Fruit de-greening and waxing improve fruit appearance, marketing and storage,

1.2 Role of legume cover crop

Cover crops provide soil cover that reduces soil erosion, soil moisture loses and enriches the nutrient concentration (Singer *et al.*, 2007). Organic matter from crops improves soil porosity and water holding capacity (Steenwerth and Belina, 2008). The use of legume cover crops legume cover crop regulates the soil pH level through the carbon and nitrogen cycle and this may have effects on the soil cation exchange capacity (CEC). Soil pH level is influenced by legume residue depending on the nitrogen concentration and excess cations/ organic anions level (Xu *et al.*, 2006).

The use of cover crops in orange orchards reduces weed growth hence less use of farm equipment that compact the soil restricting root growth (Homma *et al.*, 2012). Soil compaction due to inappropriate tillage practices or use of heavy equipment reduces root distribution and penetration in soil. Chen and Weils (2010) stated that soil compaction due to heavy machines reduces crop productivity. Beylich *et al.* (2010) results showed that soil compaction affects the physical, microbial population and biological processes in the soil. William *et al.* (2013) reported that cover crop root channels alleviate soil compaction.

The use of legume cover crops in orange orchards is not a common practice in the coastal lowlands of Kenya and if so, not documented. This study was conducted to develop a sustainable and adaptable land use systems that fits within the existing farmer's farming conditions to improve orange production. This study thus evaluated the effect of cover crops on soil moisture, orange root distribution, soil fertility, leaf chlorophyll, orange yield and fruit quality.

1.3 Problem Statement

The orange productivity has continued to decline over the years due to continuous nutrient mining by the crops. The small-scale orange farmers are resource poor and hardly apply inorganic or organic fertilizers in their orchards (Jaetzold *et al.,* 2012). There is limited research reported on the effects of legume cover crop on perennial crop such as oranges.

1.4 Research hypotheses

(i) Use of mucuna, cowpea and dolichos cover crops has no effect on soil moisture and orange root distribution in the soil profile.

(ii) Use of mucuna, cowpea and dolichos cover crops has no effect on soil pH, available plant nutrients and orange leaf chlorophyll.

(iii) Use of mucuna, cowpea and dolichos cover crops has no effect on orange yield and fruit quality

1.5 Study Objective

To develop a sustainable and low input production system by incorporating legume cover crops for an increased orange production and productivity in coastal Kenya

1.5.1 Specific Objectives

(i) To determine the effects of mucuna, cowpea and dolichos cover crops on soil moisture and orange feeder root distribution in the soil profile.

(ii) To determine the effects of mucuna, cowpea and dolichos cover crops on soil pH, plant nutrient content and orange leaf chlorophyll.

(iii) To determine the effects of mucuna, cowpea and dolichos cover crops on orange yield and fruit quality.

1.6 Justification of the study

Kenya has been importing citrus concentrate to supplement the limited local production that has contributed to low orange supply in the Kenyan market. Legumes have been reported to play several important roles in the improvement of soil properties and environment. Hoorman (2009) showed that legume cover crops fix nitrogen from the air and with the help of rhizobial bacteria they enrich the soil by adding between 60–170 kg of N per hectare per year. Mucuna has been reported to fix up to 150 kg N/ha, in addition to producing 35 tons of organic matter (OM) per year (Ojo, 2001; Kaizzi *et al.*, 2006). Cowpea has been reported to fix up to 100 kg of N per year (Martins *et al.*, 2003) and 3.4 to 4.5 tonnes/ha of organic matter (Jeranyama *et al.*, 2000) in the soil.

When used as intercrop with maize, mucuna has the potential of improving soil fertility (Ngome *et al.*, 2012) and suppressing weed in the field (Abdallah *et al.*, 2015). The crop has also been reported to have insecticidal and repellent properties (Kaizzi *et al.*, 2006). Use of legume cover crops in orange orchard would provide farmers with immediate benefit of cheaper way of increasing soil fertility for increased yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Orange crop

The orange tree is evergreen and grows from an altitude of 0-1,500 m above sea level. Oranges perform well in temperatures ranging from 25-30°C. Although orange trees grow in a wide range of soils, the optimum conditions are deep fertile soils high in organic matter, well draining with a soil pH of 6.5. The orange tree has potential to grow to a height of 7 to 9 m with an average canopy diameter of 8 m when not budded or pruned. A budded orange tree grows to an average height of 4 m with an average canopy diameter of 6 m. Budded orange trees have deep tap root averaging 2 to 4 m depending on soil density. In sandy soils, the tap root may grow up to 6m deep with fibrous roots occupying 10-30 cm of the topsoil profile (Morgan *et al.*, 2007). Orange trees are sensitive to low soil moisture particularly during its fruiting season, and produce high yields in well distributed average annual rainfall of 1,000 mm (Ouma, 2008).

An orange fruit has a range of economic and nutritional benefits and is known to be low in calories, cholesterol and improves body immunity (Vicente *et al.*, 2009). This fruit is high in vitamin C (ascorbic acid - 35-56 mg in100mls), thiamine (60-145 μg), riboflavin (11-90 μg), niacin (200-300(μg), vitamin B-6 (25-80μg), folic acid (120-330μg), pantothenic acid (130-210 μg) and potassium (300 mg in 178 mls), iron, magnesium, zinc and calcium (Nagy *et al.*, 1977).

There are four types of citrus species grown in Kenya namely orange (54%), tangerine (26%), lemon (13%), lime (5%) and grapefruit (2%). There are four varieties of sweet orange grown in Kenya including Valencia, Washington naval, Hamlin and Pineapple. Valencia is the most popular variety of sweet orange in the coastal lowlands of Kenya because of its performance (Kilalo *et al.*, 2009). The demand for oranges in Kenya has remained high due to low production and supply in the market (HCDA, 2013). The main orange growing regions in Kenya include; Coast, Eastern, Central, Rift Valley, Nyanza and Western Regions (Kilalo *et al*., 2009; Njoroge *et al*., 2005; Horticultural Crop Development Authority (HCDA, 2013). In 2014, Kenya produced 79,211 tonnes of orange from 6,650 ha and earned the country over Kenya shillings (KES) 1.62 billion (US$ 15.87 million). The country produces an average of 12 tons/ha compared to global average of 17 tons/ha.

In 2014 orange yield was 55,448 tons valued at about KES 1.13 billion (US$ 11.12 million) from a total of 3,900 hectares in coastal lowlands of Kenya (HCD, 2015). The yield of orange in the coastal lowlands translates to 14.2 tons/ha. Kwale County accounts for 52% while Kilifi County accounts for 17% of the total orange production in Kenya (HCD, 2015).

2.2 Legume cover crops

Legume cover crops are plant species, widely cultivated as rotation crops or intercrops with annual or perennial crops (Abdel Aziz *et al*. 2008; Abayomi *et al*. 2001). The crops are known to aid in soil and water management through reduction of soil erosion and runoff and reduced evaporation (Ramroudi and Sharafi, 2013). They also contribute in nutrient management through reduced losses and incorporation of plant nutrients into the soil (Kaspar and Singer, 2011). Inclusion of legume cover crops in intercropping systems, supplements inorganic fertilizers and reduces the amount of nitrogen fertilizer required thus offering an affordable production package for small-scale farmers. Wasike *et al*. (2009) study on soybean reported increased nodulation due to indigenous bradyrhizobium strain inherent in soils which ultimately improved biological nitrogen fixation in the soil. The nitrogen added into the soil by such leguminous crops can be utilized by subsequent crops.

The cover crops could also be used as food crop and/or as livestock feed. Legumes such as dolichos maybe used as a cover crop, food crop or grown forage as livestock fodder

(Olorunmaiye, 2010; Mugendi *et al.*, 2011). Maass *et al.* (2010) work on dolichos observed that it is an important legume crop for Africa as a cover crop and food crop.

Cover cover crops in their live time accumulate organic matter in the soil after decomposing of dropped leaves and the plants in the soil. Abayomi *et al.* (2001) evaluated selected legumes on their biomass production ability, dry season survival and soil fertility improvement ability and found that the best were mucuna (*Mucana pruriens*), pigeon pea (*Cajanus cajan*), crotalaria (*Crotalaria ochroleuca*) and dolichos (*Lablab purpureus*). The biomass which accumulated in the soil as a result of using legume cover crops decomposes in the rhizosphere improves the soil water holding capacities. The released decomposed organic matter in the soil in form of biofertilizer supports the plant growth and also improve fruit yield. Imoro *et al.* (2013) study reported an increase in plant nutrients and organic matter in the soil when crotalaria and mucuna were grown. A study by Shamseldin *et al.* (2010) showed that rhizobacteria change soil biomass and when decomposed, release substantial nitrogen and other plant nutrients to the soil rhizosphere leading to improved fruit yield and weight.

Some of the cover crops apart from improving soil properties have been observed to control pests hence promoting eco-friendly farming (Begum *et al.*, 2009). The use of such cover crops could lead to a significant reduction in pesticides use. Plants release chemicals which can attract or repels insect pests a strategy referred to as Push and Pull. Pull strategies involve the behavioural manipulation of luring pest toward an attractive source from where the pests are subsequently removed from potential point. The push is where pests are repelled away due to release of element/chemical by the legume. The legume cover crops are suppressing weed growth due to their ability to cover the ground. Olorunmaiye (2010) in his study reported that the use of legume cover crop was an effective weed control method in maize/cassava. In China and Eastern parts of India, this legume is grown as herbal crop for the purpose of extracting medicinal chemicals (Lampariello *et al.*, 2012).

2.2.1 Mucuna (*Mucuna pruriens*)

Mucuna (*Mucuna pruriens)* belongs to the family Fabaceae/ Leguminoceae, sub family Papilionaceae. The plant is a vigorous annual climbing legume originally from southern China and eastern India, where it was at one time widely cultivated as a green vegetable crop (Lampariello *et al.*, 2012) before spreading to Asia, America, Africa, and the Pacific Islands. The plant thrives best under warm type of climate, 0- 1,500 m above sea level areas with high rainfall (Roose *et al.*, 2011). It is both a creeping and a climbing shrub; the vines with support can grow to a length of 10 m. The vine has a large alternate, hairy and ovate shaped leaves 10-12 cm long, branch at each node and forms a thick vegetative ground cover 60-90 cm in thickness (Plate 2.1) (Othman *et al.*, 2012).

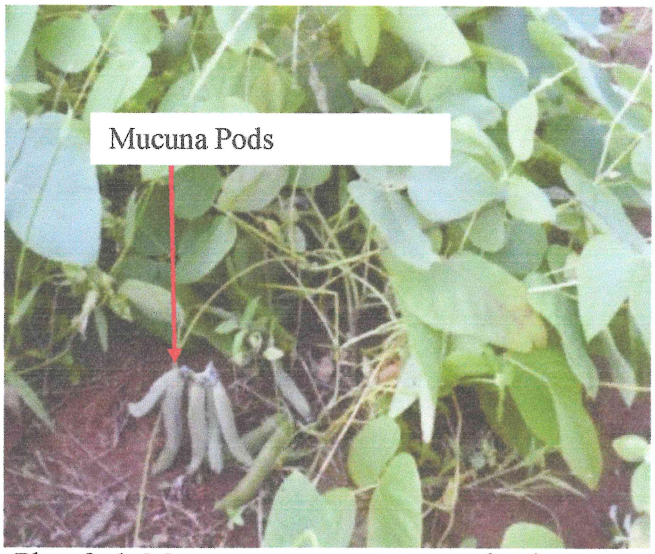


Plate 2. 1: Mucuna cover crop at reproductive stage

It has white flowers with a bluish-purple, butterfly-shaped corolla. The pod is hairy, thick, and leathery born in clusters of 4-6 per cluster each pod length averaging 6-10 cm which contains four to six seeds (Othman *et al.*, 2012) (Plate 2.2).

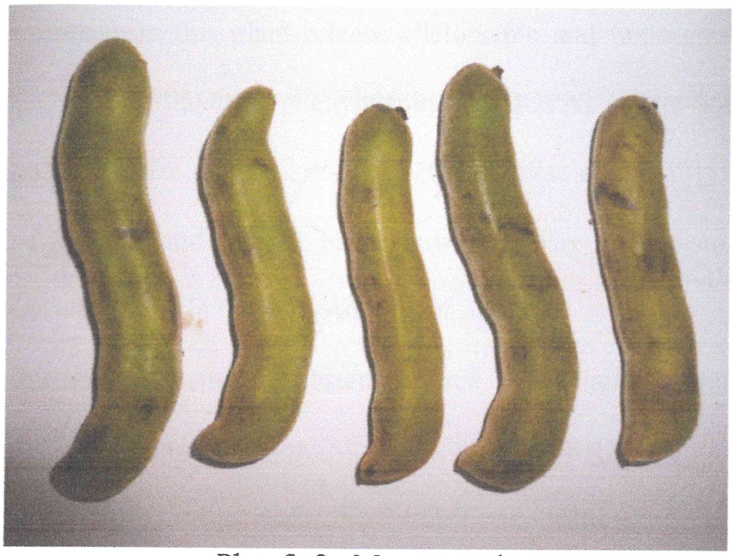


Plate 2. 2 : Mucuna pods

The mucuna seed colour varies from rich dark brown to shinny black (Plate 2.3) depending on cultivar.

Plate 2. 3 : Mucuna seeds;

It has lateral roots and deep tap root system which grows 2-3m long depending on soil type and structure (Van Noordwijk *et al*., 2015). It forms fibrous roots from the nodes of vine where they come into contact the soil. Previous work by Ngome *et al*. (2012) indicated that mucuna has the potential to improve soil fertility, moisture retention and suppress weeds in maize fields. The roots from this plant release allelopathic and toxic phenolic substances known as levodopa, L-3, 4-dihydroxyphenylalanine (L-DOPA) in the soil which control weeds and nematodes in maize (Blanchart *et al.*, 2006; Golisz *et al.*, 2011; Ceballos *et al.*, 2012). The uses of mucuna and cowpea have shown to delay weed seed germination by releasing phytotoxic substances in the soil (Adler *et al.*, 2007).

The mucuna seed contains chemical substances such as phenolics, tannins, lectins and cyanides, widely used in human medicine (McIntyre, *et al.*, 2001; Gurumoorthi *et al.*, 2008; Ceballos *et al.*, 2012). The seed contains high nutritional value crude protein (31-35%), making it a suitable raw material in livestock feed formulation (Tuleun *et al.*, 2009; Mugendi *et al.*, 2010). Mucuna has been reported to fix up to 150 kg N/ha, in addition to producing 35 tons of organic matter (OM) per year (Ojo, 2001; Kaizzi *et al.*, 2006).

2.2.2 Cowpea (*Vigna unguiculata*)

Cowpea is an herbaceous annual legume grown mainly in the savannah regions of the tropics and subtropics in Africa, Asia, and South America (Plate 2.4). The crop belongs to the family Leguminoceae/Fabaceae sub family Papilionaceae. It is believed to have originated in West Africa then spread to the rest of the world (Ba *et al.*, 2004). There are about 27 *Vigna* species but only two species of Vigna are cultivated. These species are *Vigna unguiculata* and *Vigna spontanea* (Zannau *et al.,* 2008). Cowpea is a fast growing plant and the erect type grows to an average height of 40 cm and the prostrate (trailing-climbing type) with other support species can grow up to 1.5m (Mangani and Kuchinda, 2009).

Plate 2.4: Cowpea plant at vegetative growth stage

The leaves are alternating trifoliate per given petiole and eaten as vegetable. The flowers are borne in multiple racemes which are self pollinated the average pods pod length is 15 cm (Plate 2.5).

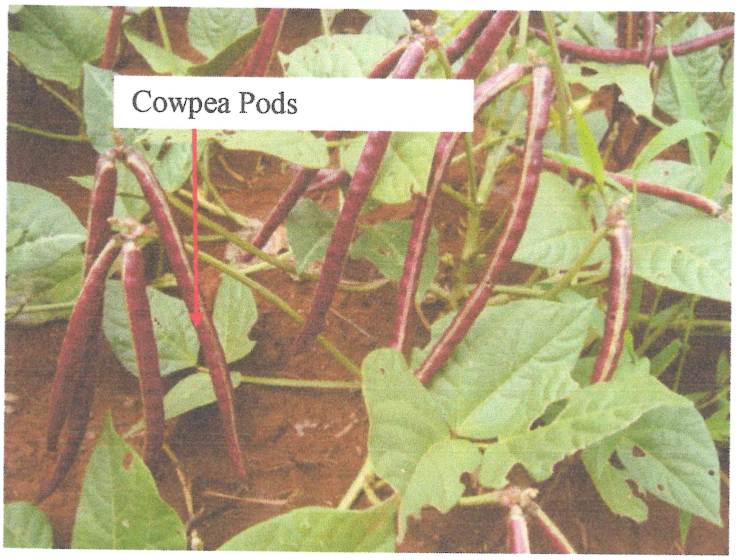


Plate 2. 5: Cowpea plant at reproduction stage

The seed colour range from white, cream and brown depending on variety (Plate 2.6).

Plate 2. 6 : Cowpea seeds

Cowpea roots occupy the topsoil 10-40 cm but the taproot can grow up to 1 m long in the soil profile. It is adapted to a wide range of soils and soil conditions. It is also tolerant to high temperatures though perform well in wet soil conditions (Matsui and Singh, 2003). It releases allelopathic chemical in the soil which suppress many weed species (Adler *et al.*, 2007). When the top vegetative part of the cowpea plant is cut or mowed down, there is plant re-growth and considerable mulch layer formed on the soil surface. Cowpea has been reported to fix up to 100 kg of N per year (Martins *et al.*, 2003) and 3.4 to 4.5 tonnes/ha of organic matter (Jeranyama *et al.*, 2000) in the soil.

2.2.3 Dolichos (*Lablab purpureus*)

Dolichos is a species in the Fabaceae family and a native of Africa (Maass *et al.*, 2005). The legume does well in a wide range of climatic and environmental conditions (Naeem *et al.*, 2009). This species is cultivated in the tropics as a food or fodder crop (Plate 2.7). The plant is a vigorous climber and with support it can grow up to 6m long. The tap root can penetrate up to 1m deep depending on soil type. Dolichos is a vigorous creeping and climbing herbaceous annual plant that is indeterminate. The stem is a vine with many trifoliate leaves per stem making it appear thick in appearance and a good ground cover.

Plate 2. 7 : Dolichos plant at reproduction stage

The inflorescence has different colours ranging from white, blue to a purple hue. Dolichos produces pods of different colours depending on variety. The average size of the pods is 7cm long with 4-6 seeds per pod (Plate 2.8).

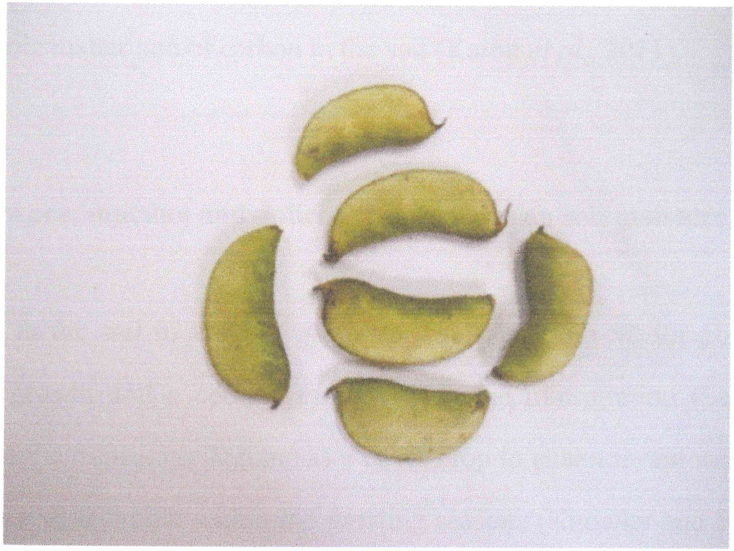


Plate 2. 8 : Dolichos Pods

The colour of the seeds varies from white, cream, brown, dark brown and black depending on cultivar (Plate 2.9).

Plate 2. 9 : Dolichos seeds

In Kenya, some communities, especially those living in central region consume dolichos, popularly known as "Njahi". Dolichos seed has high crude protein 25% and can also be used in animal feed formulation (Njunie *et al.*, 2004). The dolichos plant is vegetative in nature; it increases of organic matter and of carbon in the soil (Karhu *et al.*, 2011).

2.3 Effects of cowpea, mucuna and dolichos cover crops on soil moisture and root distribution

Water is present in the soil in form of moisture which is a solvent for plant nutrients and essential for its growth and a cooling effect during the transpiration (Seneviratne *et al.*, 2010). Farmers in the tropics use legume as a cover crop to enhance rain water conservation, and soil moisture redistribution within the growing seasons (Knowler and Bradshaw, 2007). The biomass from the legumes on the soil surface acts as mulching material, lowering moisture loss from the soil and also reduces soil temperature fluctuations (Abera *et al.*, 2012). The potential for soil water storage and the recharging of aquifers can be improved through use of legume cover crop (Thierfelder and Wall, 2009).

Roots of a given plant play crucial role in water and nutrient uptake and plant physical anchorage in the soil (Kamimura *et al.*, 2014). Understanding the root growth pattern aids in determination of appropriate management practices such as precision irrigation in order to avoid leaching of nutrients beyond the root zone. The orange fibrous roots are concentrated in the topsoil (0-30 cm profile) where they tap soil water and plant nutrients in wider area as compared to the tap root (Prior *et al.*, 2012). Orange fibrous root growth is integrated into bunches of roots, the highest concentrations in the topsoil. Morgan *et al.* (2007) in his study showed that citrus trees develop dense fibrous roots at the topsoil but more in soil profiles with high moisture content. The root penetration and distribution in the soil profile vary with soil type and the degree of soil compaction. The tap root penetrates compacted soils better than fibrous roots and this influences their distribution in the soil profile (Chen and Weils, 2010). A study by Saha *et al.* (2008) on maize-mucuna intercrop showed that root distribution decreased with soil depth. The biomass from cover crop influences soil aggregates and macro pore and hence improving root spreading in the soil (Arredondo and Johnson, 2009; Karuku *et al.*, 2014). Different legumes have different capacities in growth characteristics, ground cover and root distribution in the soil profile (Mulinge *et al.,* 2017).

2.4 Effects of mucuna, cowpea and dolichos cover crops on soil pH, plant nutrients and leaf chlorophyll,

Soil fertility and plant nutrition are two closely related subjects that emphasize the forms and availability of nutrients in soils, their uptake by roots, movement and utilization within plants. Soil fertility refers to the ability of a given soil to supply essential nutrients required by plants (Vanlauwe *et al.*, 2010).

Human activities and poor farming systems contribute to the deterioration of soil resulting to decline in crop production potential (Yates *et al.*, 2011). Most of the small-scale farmers are resource poor cannot afford inorganic fertilizers even with government fertilizer subsidies (Jaetzold *et al.,* 2012). Mucuna, cowpea and dolichos can be an alternative method of soil nutrient regeneration compared to the traditional fallow systems (Nielsen and Vigil, 2010). The soil organic matter from legumes can enhance water retention hence reducing soil bulk density which contributes to reduce soil penetration by roots (Blanco-Canqui *et al.*, 2011;

Ward *et al*., 2012). Continuous use of legumes accumulates plant biomass and plant nutrients in the soil and hence, reduced use of chemicals fertilizers (Homma *et al*., 2012).

Crop productivity should have options of soil fertility management technologies since no single method is complete (Vanlauwe *et al*., 2010). Moreover, use of nitrogen fertilizers increases soil acidification leading to aluminium toxicity thus reducing utilization of accumulated organic matter (Vieira *et al.,* 2009). Legume cover crops reduce challenges arising from the chemical fertilizers and make plant nutrients more available to crops (Hoorman *et al*., 2009). Green manures can significantly enhance the accumulation of nutrients and their availability to plant growth (Karuku *et al.,* 2014).

In the coastal lowlands of Kenya, few farmers keep livestock thus farmyard manure is limited (Saha *et al*., 2008; Ngome *et al*. 2012). The permanent soil cover improves soil aggregate stability and organic matter accumulation (Schipanski and Drinkwater, 2012). Cover crops contribute to adsorption of nutrients in the soil profile making them available for enhanced plant growth (Sainju and Singh, 2008). The total nitrogen and organic carbon recovery from legumes in the soil depends on the type of legume (Fornara and Tilman, 2008).

Mucuna and dolichos produces significant nitrogen and phosphorus in the soil during the decomposition of their vegetative parts if grown over a longer period (Mubiru and Coyne, 2009). Odhiambo, (2011) in his study observed that mucuna, cowpea and dolichos when used as intercrop increased maize yield by 19% as compared to plots without legume in Limpopo. A study by Njarui and Mureithi (2010) on legume fallow of mucuna in Eastern Kenya observed that there was increased nitrogen and phosphorous and maize yield when compared to natural fallows. In a study conducted in Nigeria, Vanlauwe *et al*. (2010) reported that the use of mucuna increased the availability of phosphorus in the soil. Nitrogen-fixing legume crops increases nitrogen and this changes the Carbon-Nitrogen ratio and also reduces soil pH, this effect in the soil can slow the availability of some plant nutrients. The drop in soil pH is due to nitrification of mineralised residue nitrogen causing soil pH decrease (Xu *et al.*, 2007, Wang *et al.*, 2013). The use of Nitrogen fertilisation increases soil acidification and this leads to Al toxicity in the soil, this causes a reduction in the utilization of the accumulated organic matter in soils by the plant (Vieira *et al.*, 2009). The overall effect on soil pH after addition of plant residues would therefore depend on the extent of each of these processes under given conditions.

Leaf chlorophyll content provides valuable information about physiological status of plants. Nitrogen is an essential component and a key molecule in proteins, nucleic acids and chlorophyll in a leaf of a plant. Soil nitrogen among other nutrients is a key determinant of chlorophyll content of plants (Liu *et al.*, 2008). Kalaji *et al.* (2014) study on the effect of the amount of chlorophyll on photosynthesis based on the soil nutrients. He further observed that photosynthesis slowed with plant nutrient deficiencies. The use of the selected legumes will increase plant nutrients in the soil making them available to the orange tree.

2.5 Effect of dolichos, mucuna and cowpea cover crops on orange yield and fruit quality

Many growers consistently rank plant growth, yield and quality as the most important factors in fruit production (Yildiz *et al.*, 2013). The decline in fruit quality has adversely affected the marketing chain of harvested orange fruits and this has impacted negatively on farmers' income (Miyata *et al.*, 2009; Evans *et al.*, 2012). The crop yield and quality improve with nutrient improvement in the soil. The amount of water and nutrient uptake by orange tree, contributes to the fruit development, fruit weight gain and fruit rind thickness (Treeby *et al.*, 2007). Soil moisture is an important factor in any fruit production. When a legume cover crop is used, soil moisture is maintained close to field capacity with minimum fluctuation, fruit yield and improved fruit quality are realized. Karuku (2014) observed the use of crotolaria, mucuna and vetch improved the soil moisture in maize crop.

The use of legume cover crops in management of soil adds plant nutrients such as N, P, K and organic matter to the soil (Kaspar and Singer, 2011). Potassium improves sugar content in fruits and also is important in fruit shelf life (Lester *et al.*, 2010). The juice brix content is an indication of the orange fruit acid-sugar ratio which is simply referred as taste in terms of sweetness (Liu *et al.*, 2012). Fruit juice tends to decline under water stress during fruit development but total sugar in the juice is higher than when soils are moist (Garcia-Tejero *et al.*, 2010; Ladanyia and Ladaniya, 2010). Gattuso *et al.* (2007) found that the increase in soil nutritional supply as a result of using a legume cover crop, improves fruit quality and Flavonoid Composition of citrus juices. The rind firmness, thickness, tensile strength protects the fruit from punctures and water loss. The increase in moisture in the soil as a result of using cover crops influences the fruit rind size (Treeby *et al.*, 2007; Suarez *et al.*, 2010). The development of uniform orange fruit colour during ripening improves the value of the fruit but it is slowed down when night temperatures are above 25°C and above 30°C day temperatures (Singh and Reddy, 2006).

CHAPTER THREE

EFFECTS OF COVER CROPS ON SOIL MOISTURE AND ORANGE ROOT DISTRIBUTION IN ORANGE ORCHARD

Abstract

Inadequate quality-water is a major hindrance to crop production in arid and semi-arid areas of Kenya. Soil moisture influences crop root system growth, shape, structure, physiological function, nutrient uptake as well as root-shoot ratio, plant growth and resulting yields. In coastal region of Kenya, orange yield and fruit quality vary with space and time due to poor soil management and unreliable rainfall with poor distribution patterns. A field study was conducted at KALRO-Matuga, Ganda and Vitengeni locations within the coastal region of Kenya from May 2012 to April 2015. This study evaluated effects of three leguminous cover crops on soil moisture retention and orange feeder root distribution at two soil depths. There were four treatments; mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), dolichos (*Lablab purpureus*) cover crops and a fallow as the control. The experiment was laidout in a randomized complete block design (RCBD) where the treatments were replicated four times within four blocks in an existing grafted Valencia orange orchard. Data collected included particle soil size distribution (PSD), soil moisture content and orange root dry matter density. The data was subjected to the analysis of variance (ANOVA) using R statistical analysis version 3.3.2. Mean separation was done using the least significant difference (LSD) at 5% level of significance. The results of this study show that the effect of legume cover crops varied with treatment, site and year. The use of mucuna, dolichos and cowpea legume cover crops increased soil moisture retention and orange tree root distribution. The mucuna cover crop treated plots recorded the highest soil moisture content in top and sub-soils. Similarly, mucuna treated plots were recorded to have the highest orange feeder root distribution in the topsoil and sub-soil. Mucuna treated plots recorded an increase in SMC by 41.1%, 40.1% and 38.6% at the topsoil and by 26.9%, 24% and 23.8% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded an increase in SMC by

36.5%, 35.5% and 33% in the topsoil and by 21.3%, 17.3% and 19.6% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea treated plots recorded an increase in SMC by 24.9%, 21.3% and 19.9% in the topsoil for Vitengeni, KALRO-Matuga and Ganda respectively. Mucuna treated plots recorded an increase in orange root density by 15.8%, 22% and 31.5% in topsoil and by 23.7%, 24.1% and 45% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded an increase in orange root density by 13.2%, 17% and 20.2% in the topsoil and by 21.1%, 21.5% and 27.5% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. The increase in orange root density in the sub-soils for Ganda, Vitengeni and KALRO-Matuga due to cowpea was not significant. From the outcome of this study, mucuna and dolichos legume cover crop are recommended for use as cover crops in orange tree orchards as they are useful in improving soil moisture retention and orange tree root distribution. Further studies are, therefore, recommended to evaluate the long term (> 3years) effects of the cover crops on soil moisture and orange tree root distribution.

Introduction

The root system plays an important role in physical tree support (Dupuy *et al.*, 2005), and water and plant nutrient uptake (Silber *et al.*, 2003). Root distribution and growth within the soil profile is influenced by age of tree, soil type and soil moisture content (Alves, 2012; Karuku *et al.*, 2014). Root distribution and growth within the soil profile is influenced by age of tree, soil type and soil moisture content (Alves, 2012; Karuku *et al.*, 2014). The distribution of feeder roots within the soil profile increases the rate of water and nutrient uptake (Dalal and Thakur, 2011). Planting density and time of inter-cropping mucuna and maize crop influences root length density (Saha *et al.*, 2008). The orange root systems contains dense feeder roots within the topsoil (10 to 30 cm) which expands radically with time as the tree grows and decreases with soil depth (Morgan *et al.*, 2007). Studies conducted in Florida on citrus root distribution have shown that has a potential to have extensive roots under less dense soils (Obreza and Schumann, 2010; Rewald *et al.*, 2011).

Soil moisture status affects crop root growth, shape, structure, physiological function, water uptake characteristics as well as root-shoot ratio (Comas *et al.*, 2013). The moisture within the soil profile increases nutrient availability to the roots (Arredondo and Johnson, 2009) leading to establishment of a healthy root system and good positioning of lateral roots (Bellini *et al.*, 2014). The amount of moisture in the soil influences plants root growth (Karuku *et al.*, 2014). However, according to Monti and Zatta (2009), the amount of water and solute uptake by a plant is dependent on the root distribution within the soil profile.

The surface biomass from legume cover crop improves water infiltration rates resulting to a deep percolation thus reducing soil erosion run-off in sloppy cultivated lands (Kahimba *et al.*, 2008; Daigh *et al.*, 2014). Legumes have been reported to influence surface soil temperature and evaporation within the plant root zone, leading to improved nutrient and water management (Kahimba *et al.*, 2008; Karuku, *et al.*, 2014). The biomass accumulated from legumes form mulch on the soil surface which increases soil water recharging and water storage capacity in the soil. Root growth and distribution are influenced by the increase in soil moisture which is a result of using legume cover crop. Organic matter from legume cover crop also reduces soil compaction, increase water infiltration and water-holding capacity of the soil (Karhu *et al.*, 2011). The coastal region of Kenya experiences erratic rains, hence supplemental irrigation is necessary. Majority of the smallholder farmers who rely on rains for crop production are resource poor, leading to poor orange tree yields (Jaetzold *et al.*, 2012). Although a lot of work on the effects of legume cover crop on annual crops has been documented, limited research has been reported on their effects on perennial crop such as oranges. There is need for alternative soil and water management technologies to improve water and nutrient uptake by orange trees during low rainfall periods. This study, therefore, sought to evaluate the effect of legume cover crop on soil moisture content and root distribution of orange variety Valencia in coastal lowland of Kenya.

MATERIALS AND METHODS

3.2.1 Description of Study Sites

The experiment was established at Kenya Agricultural and Livestock Research Organization-Matuga (KALRO-Matuga), Ganda location in Kwale County and Vitengeni location in Kilifi County, in the coastal region of Kenya from May 2012 to April 2015 (Figure 3.1).

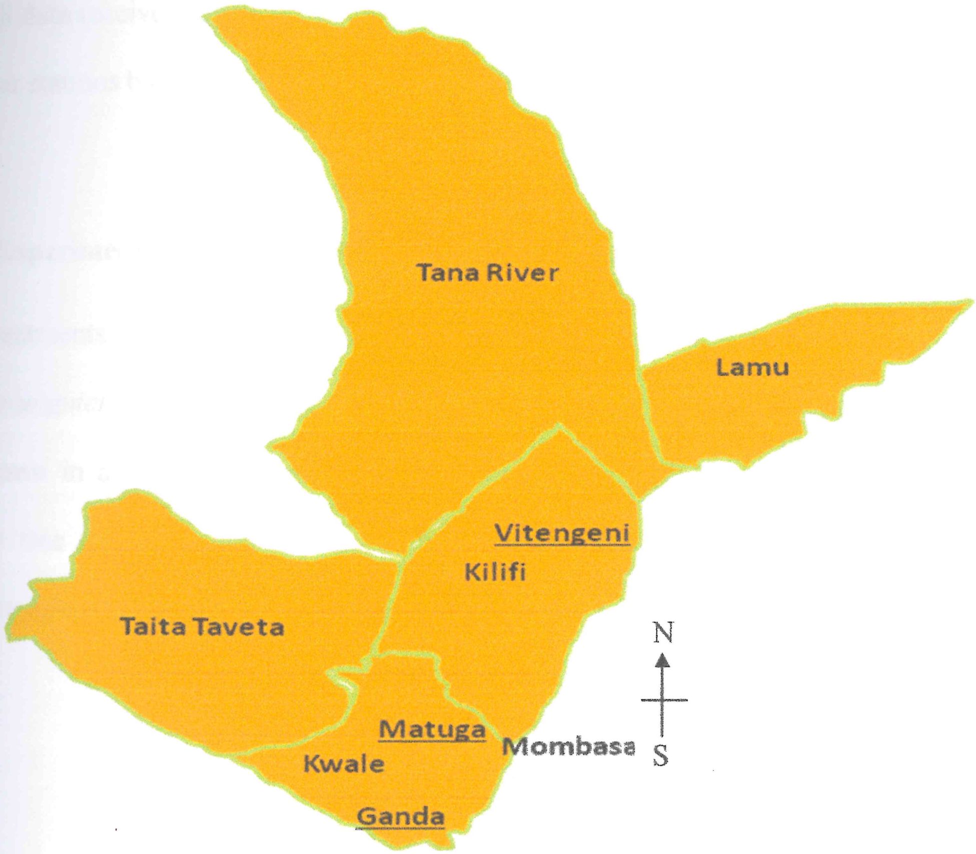


Figure 3. 1: Geographical location of coastal Kenya showing the experimental sites KALRO-Matuga, Ganda and Vitengeni

The fieldwork was superimposed on existing on-farm orange orchards in two locations (Ganda and Vitengeni) and on-station at KALRO-Matuga. Research sites were selected depending on most common grown orange variety (Valencia) in the region, orchard size, recommended tree spacing (6m by 6m) and the tree history. Orange trees selected for the study were within tree age of 15-20 years. It is important to have trees of closer age because root growth increases with tree age (Morgan *et al.*, 2007; Borja *et al.*, 2008). The study sites are located between latitudes 1° and 4° South and longitudes 38° and 41° East, with an annual rainfall of 900 mm and temperature of 29°C during the day and 25°C during the night. KALRO-Matuga and Ganda sites fall within the Coastal Lowland zone three (CL3) while Vitengeni site is within the Coastal Lowland zone four (CL4) of Kenya. The Coastal Lowland zones indicate the production potential in terms of the amount of rainfall received. The Coastal Lowland three CL3 receives relatively higher rainfall as compared to CL4. The rainfall data received in the three sites during the study period was collected from the nearest weather stations but was not for analysis purpose (Appendix 1).

3.2.2 Experimental design, layout and crop husbandry

The treatments included dolichos (*Lablab purpureus),* mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), and a control plot (fallow of natural vegetation). The experiment was laid down in a randomized complete block design (RCBD) four blocks where a line of orange tree formed a block. The treatments were randomly applied in each block and replicated four times in the four blocks making a total of 16 experimental units per site (Plate 3.1).

Plate 3. 1 : A view of orange tree line/block

Each site had four blocks and one orange tree represented an experimental unit/plot in the layout. A tree was left (orange tree guard which were not part of the experiment) on each side of where treatments were applied such orange tree act as a guard tree i.e. within and between the blocks of the treated plots (Figure 3.2). This is because the legume cover crop especially mucuna and dolichos can grow beyond the 3m radius of the orange tree/plot and this can create a treatment overlaps hence there was need for guard trees.

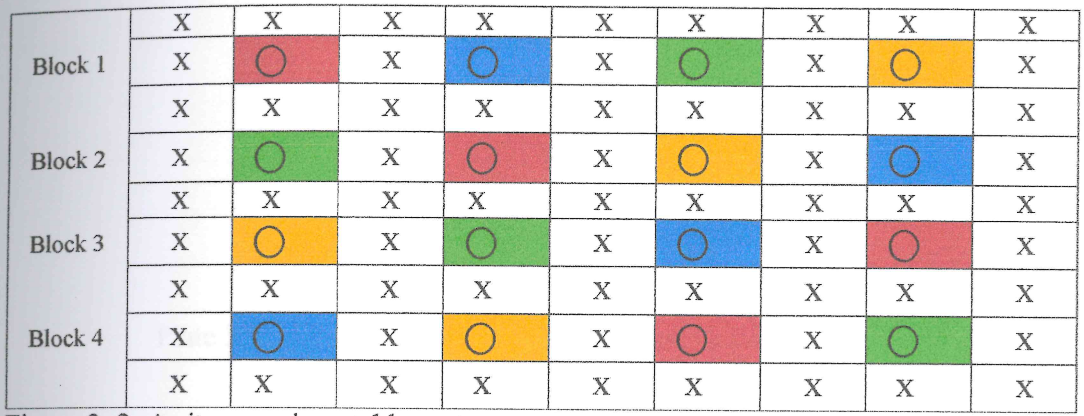
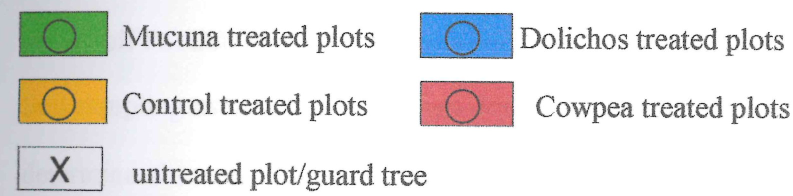


Figure 3. 2: A site experimental layout



The legume cover crop were planted two seeds per hole at a spacing of 60 x 30 cm under the orange canopy within a radius of 3m from the orange tree trunk (Plate 3.2).

There was no addition of fertilizer, manure or chemical pest control on the experimental unit during the study period in all the study sites. Since mucuna and dolichos are climbers, any twining on the orange tree by the climbers was brought down in every two weeks. The cover crop was left to grow to their fullest potential but within a 3 m radius before slashing and spread them evenly within the plot before planting the next cover crop.

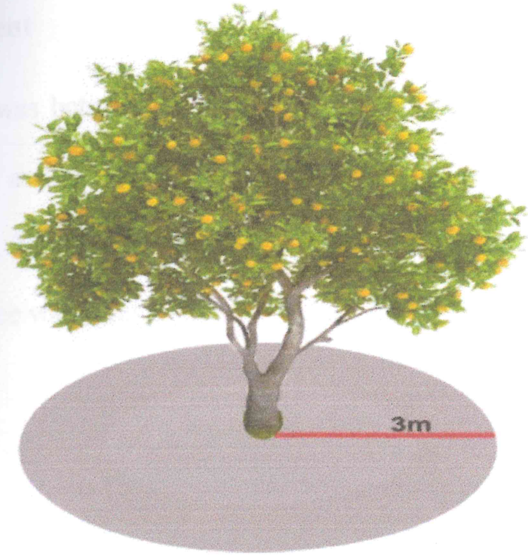


Plate 3. 2 : Site experimental unit planting area within the 3m radius

3.2.3 Soil Particle Distribution

Soil sampling using a soil auger was done before applying the treatments in all the blocks to determine the soil texture. Two soil samples from topsoil (0-20 cm) and then two soil samples from sub-soil (20-40 cm) soil depths. The sampling points were randomly picked by walking in a zigzag maner within a block. In every site, there were four blocks making a total of 16 samples per site from the four blocks. A total of 48 soil samples from the three sites well labelled based on site; soil depth and block were analyzed at National Agricultural Research Laboratory in Nairobi. Soil particle size distribution was determined using the hydrometer method as described by Okalebo *et al.* (2002). The outcome of the analysis on soil particle distribution per site was grouped based on the standard textural classes of soil

3.2.4 Soil moisture content

The soil sampling zone was between 2m and 3m radius from the orange trees trunk (Plate 3.3), at topsoil (0-20 cm) and sub-soil (20-40 cm) soil depths where 80% of the feeder roots are found (Morgan *et al.*, 2007). During rain seasons, soil sampling was done ten days after the rains when most of free water has drained to determine soil moisture retention.

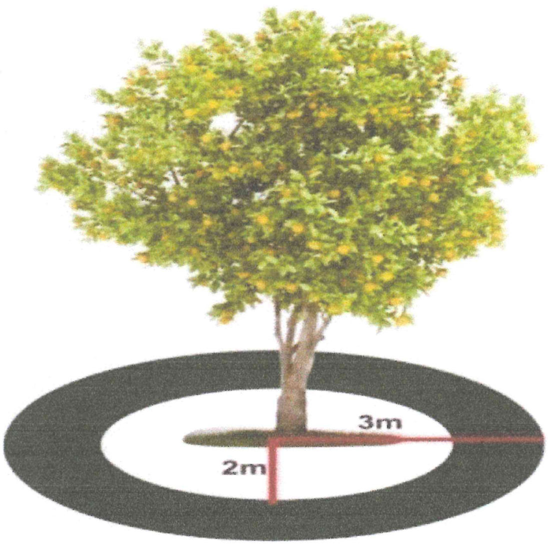


Plate 3. 3 : Soil sampling zone between 2 and 3m radius from the trunk

The first soil sampling using a 6 cm width soil auger was done when the legume cover crop had started covering the soil 4 weeks after planting then once every month for aperiod of 36 months. In order to reduce error due to possible field variation other than that of treatment, in each orange tree, three soil sampling points were randomly picked by walking in a zigzag maner. The three replicate samples obtained from each tree/treatment were mixed to form a representative soil sample (composite sample) per given tree, treatment and soil depth. Soil sampling was done from the four blocks with the four treatments (Dolichos, Mucuna, Cowpea and control), (with three replicates) and 2 soil depths. In each given sampling, a total of 32 composite soil samples from the four treatments were obtained from each site. These soil samples were immediately transported to the laboratory for analysis. The soil moisture content for each sample was determined using gravimetric method as described by Reynolds (1970).

A 50g working sample taken from each composite soil sample per given treatment was weighed using an electronic weighing balance (Model PM 200, Mettler Instrument Limited, Switzerland) before placing it in a pre-weighed brown paper bag. Total weight of soil and paper bag was determined before oven drying at 105°C for 48hrs. Thereafter oven dried soil samples were weighed. The percentage soil moisture content on dry-weight basis (θ_{dw}) in each sample was calculated using the following formula:

$$\theta_{dw} = \frac{\text{weight of moist soil} - \text{weight of oven dried soil}}{\text{Weight of oven dried soil}} \times 100$$

Volumetric water content was then calculated using the following formula:

$$\theta_v = \frac{\rho_b \times \theta_{dw}}{\rho_w}$$

Where θ_v is volume of moisture content, ρ_b is soil bulk density and ρ_w is the density of water, usually taken as 1g cm^{-3}.

3.2.5 Orange root distribution

The soil sampling process to dertermine orange root density was similar to the one explained above however these were new samples taken using a serrated soil auger from each orange tree. The root density from the soil core is an indication of root distribution in the soil profile. This sampling zone was 2m and 3m radii (Plate 3.3) from orange trees trunk where 80% of the orange feeder roots are found (Morgan *et al.*, 2007). Soil cores with orange roots were sampled from the top and sub-soil using a cylindrical soil auger with serrated cutting edge which is different from the above soil auger. The internal diameter of the cylindrical soil auger was 7 cm core diameter and height 15 cm (Plate 3.4). The composite sample from each experimental unit and soil depth containing both root and soil were placed in labelled sampling bags then taken to the laboratory for the determination of orange root dry matter density.

Plate 3. 4: Part of root sampling soil auger with serrated cutting edge.

To loosen the roots from the soil in each sample, hand stirring was done and the mixture carefully passed through a double sieve with 4mm aperture (Plate 3.5) in order to ensure all roots from the soil were captured. The roots from the sieves were placed in smooth metallic bowl with clean water in order to clean them further. Root colour was used to distinguish orange roots which are brownish from other roots. The water from the cleaned roots was removed through decantation and the cleaned roots placed on blotting paper to remove excess water.

Plate 3. 5: A 4mm aperture sieve for root-soil separation

Orange feeder root distribution was determined using the dry root density method as previously described by Van Noordwicjk *et al.* (1985). The extracted roots per sample were weighed to determine fresh weight using an electronic weighing balance. To ensure adequate oven drying the root sample, enclosed in a kaki paper bag, was oven-dried at 105°C for 48hrs and then reweighed.

Dry root densities (DR_d) (in kg m^{-3}) for each sample were determined by dividing the weight of the extracted and dried root mass (DM_d) by the volume of the soil. The volume V (m^3) was calculated from the soil core radius of 0.035 m and length of 0.15 m

$$DR_d = \frac{DM_d}{V}$$

3.2.6 Data analysis

Data on soil moisture content and orange root density was first tested for normality and homogeneity of variances using Shapiro wilk test. The data was further subjected to the analysis of variance (ANOVA) using the procedures of R statistical analysis software version 3.3.2 (R- Core team, 2015). Mean separation was done using the least significant difference (LSD) at 5% level of significance. A regression on soil moisture content for the two soil depths was performed to establish the relationship between soil depth and soil moisture.

RESULTS

3.3.1 Particle Size Distribution of Soils from KALRO-Matuga, Vitengeni and Ganda

The three site soils based on textural classes of soil, Vitengeni soil was sandy clay loam (SCL) while KALRO-Matuga loamy sand (LS) and Ganda sandy soil (S) (Appendix 3.0).

3.3.2 Effect of legume cover crop and site on topsoil soil moisture content in orange orchards.

The results of analysis of variance showed that there was significant interaction between treatment and site ($F = 3.332$; $P < 0.030$) on the level of soil moisture in the topsoil (Appendix 3.1a).

The site Vitengeni was found to have the highest level of soil moisture retention when compared with the other sites. The site Ganda was found to have the lowest level of soil moisture retention when compared with the other sites. With each site, soil moisture was highest in legume mucuna but lowest in cowpea (Table 3.2a). Mucuna treated plots recorded an increase in soil moisture by 41.1%, 40.1% and 38.6% for Vitengeni, KALRO-Matuga and Ganda respectively at the topsoil. Dolichos treated plots recorded an increase in soil moisture by 36.5%, 35.5% and 33% for Vitengeni, KALRO-Matuga and Ganda respectively in the topsoil. Cowpea treated plots recorded an increase in SMC by 24.9%, 21.3% and 19.9% for Vitengeni, KALRO-Matuga and Ganda respectively in the topsoil.

Table 3.1a: Effect of legume cover crop and site on percent soil moisture content of topsoil (0-20cm) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni (Topsoil)	KALRO-Matuga (Topsoil)	Ganda (Topsoil)
Dolichos	5.98b	5.61b	5.48b
Mucuna	6.18a	5.80a	5.71a
Cowpea	5.47c	5.02c	4.94b
Control	4.38d	4.14d	4.12c
LSD $(P \leq 0.05)$	0.19	0.16	0.18
CV %	11.86	10.46	13.49
Pr >F	0.0025	0.0158	0.0425

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

3.3.3 Effect of legume cover crop and site on sub-soil (20-40 cm) soil moisture content in orange orchards.

There was a significant interaction between treatment and site ($F= 2.479$; $P< 0.024$) on the level of soil moisture in the sub-soil (Appendix 3.1b).

The site Vitengeni was found to have the highest level of soil moisture retention when compared with the other sites. The site Ganda was found to have the lowest level of soil moisture retention when compared with the other sites. With each site, soil moisture was highest in legume mucuna but lowest in cowpea (Table 3.2b). Mucuna treated plots recorded an increase in soil moisture by 26.9%, 24% and 23.8% for Vitengeni, KALRO-Matuga and Ganda respectively in the sub-soils. Dolichos treated plots recorded an increase in soil moisture by 21.3%, 17.3% and 19.6% for Vitengeni, KALRO-Matuga and Ganda respectively in the sub-soils. The increase in soil moisture on cowpea treated plots for Vitengeni, KALRO-Matuga and Ganda respectively in the sub-soils was not significantly different.

Table 3.1b: Effect of legume cover crop and site on percent soil moisture content of sub-soil (20-40cm) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni (sub-soil)	KALRO-Matuga (sub-soil)	Ganda (sub-soil)
Dolichos	5.63b	5.48b	5.18b
Mucuna	5.89a	5.79a	5.36a
Cowpea	4.81c	4.75c	4.62c
Control	4.64c	4.67c	4.53c
LSD $(P \leq 0.05)$	0.21	0.19	0.16
CV %	13.02	11.89	15.62
Pr >F	0.0357	0.0215	0.0412

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

3.3.4 Effect of cover crops and site on topsoil (0-20 cm) orange root distribution in orange orchards

The results of the analysis of variance showed that there was significant interaction between treatment and site (F= 2.651; P< 0.034) on the level of orange root density in the topsoil (Appendix 3.2a).

The site Ganda was found to have the highest level of orange root density when compared with the other sites. The site Vitengeni was found to have the lowest level of orange root density when compared with the other sites. Orange root density was highest in legume mucuna but lowest in cowpea in all the sites (Table 3.4a). Mucuna treated plots recorded an increase in orange root density by 15.8%, 22.0% and 31.5% for Vitengeni, KALRO-Matuga and Ganda respectively in topsoil. Dolichos treated plots recorded an increase in orange root density by 13.2%, 17.0% and 20.2% for Vitengeni, KALRO-Matuga and Ganda respectively in topsoil. Cowpea treated plots recorded an increase in orange root density in topsoil by 9.7% for Ganda.

Table 3. 2a: Effect of legume cover crops and site on topsoil (0-20 cm) orange root density (kg m^{-3}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni (Topsoil)	KALRO-Matuga (Topsoil)	Ganda (Topsoil)
Dolichos	0.129a	0.138a	0.149b
Mucuna	0.132a	0.144a	0.163a
Cowpea	0.122b	0.126b	0.136c
Control	0.114b	0.118b	0.124d
LSD ($P \leq 0.05$)	0.013	0.010	0.011
CV %	16.942	13.984	18.431
Pr >F	0.0185	0.0271	0.0325

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

3.3.5 Effect of cover crops and site on subsoil (20-40 cm) orange root distribution in orange orchards

The results of analysis of variance showed that there was significant interaction between treatment and site (F= 4.121; P< 0.041) on the level of orange root density in the subsoil (Appendix 3.2b).

The site Ganda was found to have the highest level of orange root density when compared with the other sites. The site Vitengeni, was found to have the lowest level of orange root density when compared with the other sites. With each site, orange root density was highest in legume mucuna but lowest in cowpea (Table 3.4b). Mucuna treated plots recorded an increase in orange root density by 23.7%, 24.1% and 45% for Vitengeni, KALRO-Matuga and Ganda respectively in the sub-soils. Dolichos treated plots recorded an increase in orange root density by 21.1%, 21.5% and 27.5% for Vitengeni, KALRO-Matuga and Ganda respectively in the sub-soils. Cowpea treated plots had no significant increase of orange root density in the sub-soils for Vitengeni, KALRO-Matuga and Ganda.

Table 3.2b: Effect of legume cover crops and site on sub-soil (20-40cm) orange root density (kg m-3) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni (Sub-soil)	KALRO-Matuga (Sub-soil)	Ganda (Sub-soil)
Dolichos	0.092a	0.096a	0.102b
Mucuna	0.094a	0.098a	0.116a
Cowpea	0.079b	0.081b	0.089c
Control	0.076b	0.079b	0.080c
LSD $(P \leq 0.05)$	0.011	0.014	0.012
CV %	16.602	14.718	18.273
Pr >F	0.0461	0.0382	0.0194

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

3.3.6 Effect of cover crops and year on topsoil (0-20 cm) orange root distribution in orange orchards

The results of the analysis of variance showed that there was significant interaction between treatment and year ($F= 3.907$; $P < 0.045$) on the level of orange root density in the topsoil (Appendix 3.2a).

The year 2014 was found to have the highest level of orange root density when compared with the other years. The year 2012 was found to have the lowest level of orange root density when compared with the other years. Orange root density was highest in legume mucuna but lowest in cowpea in all the years (Table 3.5a). Mucuna treated plots recorded an increase in orange root density by 33.7%, 36.4% and 37.5% for year 2012, 2013 and 2014 respectively in the topsoil. Dolichos treated plots recorded an increase in orange root density by 21.2%, 31.8% and 33.3% for year 2012, 2013 and 2014 respectively in the topsoil. Cowpea treated plots recorded an increase in orange root density by 7.7%, 17.8% and 25.7% for year 2012, 2013 and 2014 respectively in the topsoil.

Table 3.3a: Effect of legume cover crops and year on topsoil (0-20cm) orange root density (kg m-3) in orange orchards with time

	Year		
Treatment	2012 (Topsoil)	2013 (Topsoil)	2014 (Topsoil)
Dolichos	0.126ab	0.170a	0.192a
Mucuna	0.139a	0.176a	0.198a
Cowpea	0.107b	0.152ab	0.181a
Control	0.104b	0.129b	0.144b
LSD $(P \leq 0.05)$	0.029	0.026	0.021
CV %	12.712	10.851	11.068
Pr >F	0.0418	0.0326	0.0209

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

3.3.7 Effect of cover crops and year on sub-soil (20-40 cm) orange root distribution in orange orchards

The results of analysis of variance showed that there was significant interaction between treatment and year ($F= 3.477$; $P < 0.043$) on the level of orange root density in the subsoil (Appendix 3.2b).

The year 2014 was found to have the highest level of orange root density when compared with the other years. The year 2012, was found to have the lowest level of orange root density when compared with the other years. Orange root density was highest in legume dolichos but lowest in cowpea in all the three years (Table 3.5b). Mucuna treated plots recorded an increase in orange root density by 18.3%, 29.5% and 36.6% for 2012, 2013 and 2014 respectively in the sub-soils. Dolichos treated plots recorded an increase in orange root density by 16.9%, 26.9% and 30.7% for year 2012, 2013 and 2014 respectively in the sub-soils. Cowpea treated plots recorded an increase in orange root density by 4.2%, 20.5% and 26.7% for year 2012, 2013 and 2014 respectively in the sub-soils.

Table 3. 3b: Effect of legume cover crops and year on sub-soil (20-40cm) orange root density (kg m-3) in orange orchards with time

	Year		
Treatment	2012 (Sub-soil)	2013 (Sub-soil)	2014 (Sub-soil)
Dolichos	0.083a	0.099a	0.132a
Mucuna	0.084a	0.101a	0.138a
Cowpea	0.074a	0.094ab	0.128a
Control	0.071a	0.078b	0.101b
LSD $(P \leq 0.05)$	0.016	0.018	0.012
CV %	21.423	17.852	19.327
Pr >F	0.5484	0.0361	0.0218

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

DISCUSSIONS

3.4.1 Discussion on the effects of cover crops on soil moisture in orange orchards

Vitengeni site with sandy clay loam soil recorded the highest soil moisture retention compared to KALRO-Matuga with loamy sand in both topsoil and sub-soil. Ganda site with sandy soil texture recorded the lowest soil moisture retention in both topsoil and sub-soil. The significant increase in soil moisture content observed in this study because of using legume cover crops is due to their ability to increase water infiltration. Thierfelder and wall, (2009) observed that cover crops reduced water run-off and evaporation from the soil surfaces and allow more water infiltration. There will be an increase in soil moisture in the soil due to the increased water infiltration. Hoorman (2009) observed that storage of soil moisture improved with the use of cover crops. The use of cover crops also reduced water evaporation from the soil surface. Swella *et al.* (2015) demonstrated that soil water retention in farming systems using cover crops is higher as compared to bare soil surface. Cover crop reduced surface water loss from the soil through increased ground coverage and the amount of biomass they release into the soil during their lifetime (Ward *et al.,* 2012). In this study soil moisture in the soil varied with the type of cover crop. Mucuna legume cover crop recorded the highest soil moisture content in both topsoil and sub-soil while cowpea recorded the lowest soil moisture content. These could be associated to a given legume ability to cover the ground and the amount of biomass the legume adds to the soil over a given period. Ramroudi *et al.*, (2013) observed an increase soil water holding capacity and the recharging of soil water from rainfall because of using legume cover crop with time. Legumes have shown to increase infiltration of water into the soil in conservation agriculture Thierfelder and wall, (2009) however, in the study there was no comparison done on different legumes. In this study, mucuna gave the highest soil moisture retension while cowpea gave the lowest compared to the control. Acording to Abayomi *et al.* (2001) found that mucuna provides larger coverage when compared to other legume species including dolichos.

3.4.2 Discussion on the effects of cover crops on orange root distribution in orange orchards

The result indicates that different legume cover crops have different capacities in influencing the increase of orange root density in the soil. There was an increase in feeder root density over the three year study period (2012-2014) in both topsoil and sub-soil because of using different legume cover crop. Mucuna recorded the highest increase in root density compared to dolichos and cowpea. The amount of roots and their distribution in the soil increase organic matter after their life time enhancing soil resistance to erosion (Williams *et al.*, 2013). The high root density in the sub-soil as compared to topsoil could be as a result of increased soil moisture in the sub-soil. The increase in root density in the soil profile was attributed to abundance in mulching effect as a result of the cover cropping. The upper soil profile allows free air movement and root growth compared to lower depths, where oxygen and root growth is restricted due to soil compaction (Outoukarte *et al.*, 2010). The continuous use of cover cropping system was observed contribute to increase root distribution in the subsoil due to the reduction of soil bulk density. Homma *et al.* (2012) observed increased soil porosity and hence enhanced root penetration and growth because of using legumes in compacted soils. The legumesRoot distribution and growth capability often depends on the type of roots and their ability to penetrate the soil profile (Bellini *et al.*, 2014). However the observed root growth as a result of mucuna also variaed with site where Ganda with sandy soils recorded the highest roots growth.

Conclusions and Recommendations

The results of this study show that the effect of legume cover crops varied with site. The use of mucuna, dolichos and cowpea legume cover crops increased soil moisture retention and orange tree root distribution. The mucuna cover crop treated plots recorded the highest soil moisture content in top and sub-soils. Similarly, mucuna treated plots were recorded to have the highest orange feeder root distribution in the topsoil and sub-soil. Among mucuna, dolichos and cowpea cover crops, cowpea recorded the lowest moisture content and root distribution in both top and subsoil. There are few studies that have tested effect of individual legumes on water retention and infilatration. It will be necessary specific test in future studies to determine the role of Mucuna and other legumes on water retention, water use and infiltration. Legume cover cropping system is a viable farming system that can aid in improving soil moisture in orange orchards and enhance orange root distribution in the soil profile. It can be concluded that mucuna, cowpea and dolichos cover crops improved soil moisture in orange production. Mucuna and dolichos cover crops improved root distribution in orange production. Cowpea improvement on orange root distribution varied with soil texture and soil depth.

From the outcome of this study, mucuna and dolichos legume cover crop are recommended for use as cover crops in orange tree orchards in the coastal lowlands as they are useful in improving soil moisture retention and orange tree root distribution. The adoption of these findings and recommendation to the farmers and their socio-economic impact also need to be established. Since orange trees are a perennial crop, further studies are, therefore, recommended to evaluate the long term (> 3years) effects of the cover crops on soil moisture and orange tree root distribution under different agro-ecological zones.

CHAPTER FOUR

EFFECTS OF LEGUME COVER CROPS ON SOIL PH, PLANT NUTRIENTS AND LEAF CHLOROPHYLL IN ORANGE ORCHARD

Abstract

The soil nutrients and their availability to the plant influences crop growth and production. The use of legume cover crop as a way of plant nutrient management system on orange has not been documented. A field study was established at KALRO-Matuga, Ganda and Vitengeni located within the coastal lowlands of Kenya in May 2012 to April 2015. The study evaluated the effects of three leguminous cover crops on soil pH, plant nutrients and leaf chlorophyll in orange orchard. There were four treatments; mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), dolichos (*Lablab purpureus*) cover crops and a fallow as the control. The experiment was laidout in a randomized complete block design (RCBD) where the treatments were replicated four times within four blocks in an existing grafted Valencia orange orchard. The three legumes were planted under the orange tree within a radius of 3m. Soil was sampled for topsoil (0-20 cm) and sub-soil (20-40 cm). The data collected included soil pH, organic carbon (g kg^{-1}), nitrogen (g kg^{-1}), total phosphorus (mg kg^{-1}), total potassium (mg kg^{-1}) and leaf chlorophyll. Data was first tested for normality and homogeneity and further subjected to the analysis of variance (ANOVA) using the procedures of R statistical analysis software version 3.3.2 (R- Core team, 2015). The effect of mucuna, cowpea and dolichos legume cover crop on plant nutrients on the soil and orange leaf chlorophyll varied with site, years, and increased with time. Mucuna treated orange trees recorded the highest increase in nitrogen in the topsoil and sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea recorded the second highest increase in nitrogen in the topsoil and sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos recorded the lowest in nitrogen increase in the topsoil and sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Mucuna treated orange trees recorded the higest increase in organic carbon in the topsoil and sub-soils for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos

recorded second highest increase in organic carbon in the topsoil and sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea treated orange trees recorded the lowest in organic carbon increase in the topsoil and sub-soils for KALRO-Matuga, Vitengeni and Ganda respectively. Mucuna treated orange trees recorded the highest increase in soil phosphorous in the topsoil and sub-soils for KALRO-Matuga, Vitengeni and Ganda respectively. Cowpea recorded the second highest increase in soil phosphorous in the topsoil and sub-soils for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos recorded the lowest increase in soil phosphorous in the topsoil and in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively compared to the control. Mucuna, cowpea and dolichos increase soil potassium by 28.7%, 25.3% and 12.6% in the topsoil and by 23.1%, 20.2% and 10.5% in the sub-soil respectevly. Mucuna and dolichos increased leaf chlorophyll content by 8.8%, 16.4% and 21.2% in year 2012, 2013 and 2014 respectively. Dolichos increased leaf chlorophyll content by 12.2% and 16.4% in year 2013 and 2014 respectively. Cowpea increased leaf chlorophyll content by 11.2% in in year 2014. From the results of this study, it is observed that mucuna, cowpea and dolichos cover crops are effective in improving the N, OC, P and K contents in the soil and orange leaf chlorophyll. Among the three cover crops, mucuna gave the highest increase and is recommended as a cover crop for orange production in the coastal lowlands

Introduction

Land degradation, due to poor farming methods, is a major problem in sub-Saharan Africa and this leads to a decrease in agricultural productivity (Blanco and Lal, 2009, Fairhurst, 2012). There is need for an integrated soil fertility management (ISFM) as a means of reversing the nutrient deficiencies in citrus orchards in Kenya (Srivastava and Singh, 2009; Vanlauwe *et al.*, 2015). Integration of leguminous cover crops into existing cropping systems is a potential solution to this problem. When these crops are planted as either cover or intercrop, they influence soil chemical and biological properties leading to improved soil fertility and crop productivity (Odhiambo, 2011; Manzeke *et al.* 2012). The maintenance and improvement of soil properties is achieved through provision of ground cover, reduction in soil erosion, regulation of soil temperature, enhancement of soil organic matter and microbial activity (Wasike *et al.*, 2009).

Availability of soil nutrients for plant uptake is usually dictated by soil moisture and physiochemical properties such as pH, cation exchange capacity (CEC), anion exchange capacity (AEC), amount of soil organic matter and base cations (Cavagnaro, 2016). Cover crops have also been reported to increase the quantity of available phosphorus and nitrogen in soils (Takeda *et al.*, 2009; Dube *et al.*, 2014). Nitrogen accumulation in the soil may occur through biological nitrogen fixation or recycling leading to the increased availability to plants (Mulvaney *et al.*, 2009; Wasike *et al.*, 2009). The influence of legume cover crop on soil nitrogen and organic matter accumulation varies with time and type of legume used (Wang *et al.*, 2010; Odhiambo, 2011).

Although there are several species of tropical legumes, few have been studied for their potential as cover crops (Wu *et al.*, 2011). Legumes widely studied as cover crops include wing bean (*Psophocarpus palustris*), mucuna, cowpea, dolichos, clover (*Trifolium spp*) and vetch (*Vicia spp*) (Yeganehpoor *et al*., 2015). Mucuna has been reported to increase maize yield in a maize-mucuna intercropping systems (Saha *et al*. 2008; Mugwe *et al*. 2009; Ngome *et al*., 2012). Soil fertility enhancement when dolichos cover crop is used as a cover crop was reported by Tittonell *et al*. (2012). A positive effect of cowpea, vetch and clover cover crops on soil fertility management has been reported by Karuma *et al*. (2011) and Yeganehpoor *et al*. (2015). Although studies on the effects of legume cover crop on soil fertility, water management, and annual crop yield have been carried out in Kenya (Saha *et al*. 2008; Mugwe *et al*. 2009; Ngome *et al*. 2012; Karuku, 2014), few have been conducted on perennial crops. This study evaluated the effects of dolichos, mucuna and cowpea legume cover crop on soil nutrients and orange leaf chlorophyll content. It will be interesting to know if increase in plant nutrient more so nitrogen in the soil could have any influence on orange leaf chlorophyll.

MATERIALS AND METHODS

4.1.1 Study site, experimental layout and agronomic practices

The study was conducted at Ganda, Vitengeni and Kenya Agricultural and Livestock Research Organization (KALRO) Matuga locations within the coastal lowland region of Kenya from May 2012 to April 2015. The fieldwork was superimposed on existing on-farm orange orchards in two locations (Ganda and Vitengeni) and on-station at KALRO-Matuga. Treatments included mucuna, cowpea, dolichos cover crops and a control (without legume cover crop). The experimental design was a randomized complete block design (RCBD), with each treatment replicated four times. The four treatments applied on existing orange trees where an orange tree formed a plot. The site, experimental layout and agronomic practices as previously described in section 3.3.1 of chapter three of this thesis.

4.1.2 Soil sampling, preparation and analysis

The soil samples were taken within 2m and 3m radii from the orange trees trunk at topsoil (0-20 cm) and sub-soil (20-40 cm) soil depths using a 6cm size soil auger. Majority of the feeder roots of a tree are found at the far end of the main roots (Morgan *et al*., 2007). Initial soil samples were taken from the both top and sub-soil depths before applying the treatments to determine the soil nutrient level. In order to reduce errors due to possible variations, in each orange tree three soil sampling points were randomly picked by walking in a zigzag within the 2m and 3m radii. Each sample was air-dried, ground and passed through a 2 mm sieve to obtain a uniform particle size. Soil pH was measured in 1:2.5 soils to liquid ratio in 0.01 M $CaCl_2$ and analyzed according to the procedure described by Okalebo *et al*. (2002). Available P, K and Ca were analyzed and determined according to procedures described by Mehlich (1984). Organic carbon (g kg^{-1}), total Nitrogen (g kg^{-1}) and particle size distribution were determined according to procedure described by Okalebo *et al*. (2002). Available trace element Iron (Fe) was determined using Atomic Absorption Spectrophotometer (AAS).

4.1.3 Orange leaf chlorophyll content

Orange leaf chlorophyll content was determined by using a chlorophyll meter as described by (Rodriguez and Miller, 2000). At each samplying, ten orange mature leaves exposed to the light from the cannopy were randomly selected from each tree and inserted one at a time in a chlorophyll meter (Model: SPAD-502Plus, Hangzhou Technology co.ltd, China). The use of hand held chlorophyll meter is a non-distructive method because the orange leaves are not removed fom the tree. The average reading of the ten leaves is automated by the machine recorded to form a sample (Plate 4.1). Orange leaf chlorophyll content was measured during day time when there is light twice a month in 36months making a total of 72 samples.

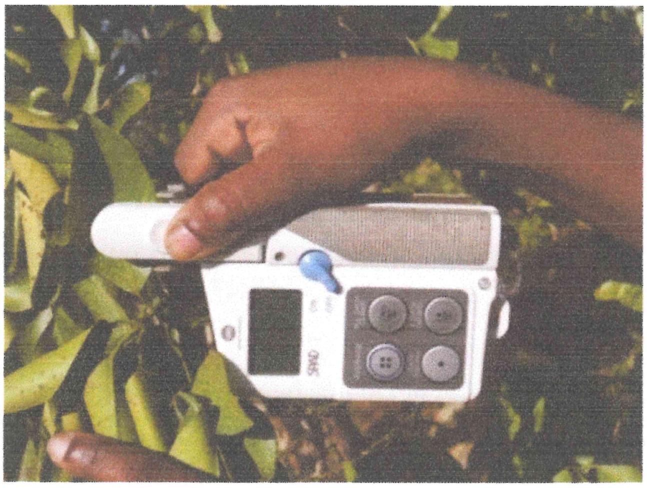


Plate 4. 1: Leaf Chlorophyll content measurement using a chlorophyll meter

4.1.4 Data analysis

Data obtained data on nitrogen, organic carbon, phosphorous, potassium, soil pH and leaf chlorophyll tested for outliers and checked for normality and homogeneity of variances using Shapiro wilk test. The data was further subjected to the analysis of variance (ANOVA) using the procedures of R statistical analysis software version 3.3.2 (R- Core team, 2015). Mean separation was done using the least significant difference (LSD) at 5% level of significance.

RESULTS

4.2.1 Initial Chemical and Physical Properties of Soil at Vitengeni, KALRO-Matuga and Ganda

Initial chemical and physical properties of the soils from three study sites are presented in (Table 4.1). Soil pH ranged between 6.14 from top and sub-soils at the commencement of the experiment. The soil pH range from slight acidic to very slight acidic based on the general guidelines given by Okalebo *et al.* (2002). Soils from Ganda had low amounts of exchangeable P (< 15mg kg^{-1}), in all the sites, total nitrogen (N) and total organic carbon (OC) was very low (< 0.2g kg^{-1}) and (<0.7g kg^{-1}), respectively. Based on the rating set by Landon (1991), the P, N and OC in the plough layer of the soils in Ganda were low and inadequate for supporting optimum crop yields. The average Ca and Fe in the soil from all the sites and soil depths ranged from Ca, 1.2-2.0 mg kg^{-1} and Fe5.16-9.58 based on Mehlich (1984) rating Ca< 2.0 mg kg^{-1} and Fe< 10.0 mg kg^{-1} is considered low. According to Mehlich (1984) classification, zinc, copper and manganese levels were adequate in the soils from all the three sites.

Table 4. 1: Initial levels of plant nutrient and soil pH in top and sub-soil from Vitengeni, KALRO-Matuga and Ganda

	Vitengeni		KALRO-Matuga		Ganda	
Soil Property	TS	SS	TS	SS	TS	SS
Soil pH (H_2O)	6.56	6.44	6.43	6.42	6.41	6.40
Nitrogen (g kg^{-1})	0.60	0.50	0.40	0.50	0.40	0.40
Carbon (g kg^{-1})	6.60	5.00	3.20	5.10	3.20	3.00
Phosphorous (mg kg^{-1})	19.00	17.00	12.00	16.00	12.00	11.00
Potassium (mg kg^{-1})	0.36	0.13	0.08	0.12	0.08	0.09
Calcium (mg kg^{-1})	2.00	1.20	1.60	1.80	1.60	1.40
Iron (mg kg^{-1})	9.58	8.94	5.99	5.16	5.99	5.75
Magnesium (mg kg^{-1})	1.28	0.56	0.51	0.52	0.51	0.44
Sodium (mg kg^{-1})	0.12	0.12	0.08	0.12	0.08	0.07

TS= Topsoil (0-20 cm); SS= Sub-soil (20-40 cm)

4.2.2 Effects of legume cover crop and site on topsoil nitrogen level in orange orchards at Vitengeni, KALRO-Matuga and Ganda

The results showed significant interaction between treatment and site (F= 2.99; P< 0.04) on nitrogen in the topsoil (Appendix 4.1a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of nitrogen in the topsoil varied with site (Table 4.2a). The site Ganda was found to have the highest percentage increase in soil nitrogen when compared with the other sites. The site Vitengeni was found to have the lowest level of nitrogen when compared with the other sites. With each site, nitrogen was highest in legume mucuna but lowest in dolichos. Mucuna treated plots recorded an increase in nitrogen by 27.7%, 29.2% and 33.3% in the topsoil for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea treated plots recorded an increase in nitrogen by 16.6%, 18.1% and 25.5% in the topsoil for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded an increase in nitrogen by 10.6%, 12.5% and 13.7% in the topsoil for Vitengeni, KALRO-Matuga and Ganda respectively.

Table 4. 2a: Effects of legume cover crop and site on topsoil (0-20 cm) nitrogen (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	0.73b	0.81b	0.58b
Mucuna	0.84a	0.93a	0.68a
Cowpea	0.77ab	0.85b	0.64ab
Control	0.66c	0.72c	0.51c
LSD $_{(P \leq 0.05)}$	0.062	0.072	0.065
CV%	12.45	17.53	15.90
Pr >F	0.016	0.022	0.016

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.3 Effects of legume cover crop and site on sub-soil nitrogen level in orange orchards at Vitengeni, KALRO-Matuga and Ganda

There was a significant interaction between treatment and site (F= 7.62; P< 0.05) on nitrogen in the sub-soil (Appendix 4.1b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of nitrogen in the sub-soil varied with site (Table 4.2b). The site KALRO-Matuga was found to have the highest level of soil nitrogen when compared with the other sites. The site Ganda was found to have the lowest level of soil nitrogen when compared with the other sites. With each site, nitrogen was highest in legume mucuna but lowest in dolichos. Mucuna treated plots recorded an increase in nitrogen by 17.2%, 21.3% and 24.5% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded an increase in nitrogen by 16.9%, 9.8% and 10.2% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea treated plots recorded an increase in nitrogen by 12.1%, 14.8% and 16.3% in the sub-soils for Vitengeni, KALRO-Matuga and Ganda respectively.

Table 4.2b: Effects of legume cover crop and site on sub-soil (20-40 cm) nitrogen ($g\ kg^{-1}$) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	0.62b	0.67b	0.54b
Mucuna	0.68a	0.74a	0.61a
Cowpea	0.65a	0.70ab	0.57b
Control	0.58c	0.61c	0.56c
LSD $(P \leq 0.05)$	0.031	0.041	0.038
CV%	21.31	20.58	21.80
Pr >F	0.037	0.046	0.021

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.4 Effects of legume cover crop and year on topsoil nitrogen level in orange orchards at Vitengeni, KALRO-Matuga and Ganda

There was a significant interaction between treatment and year (F= 4.33; $P < 0.006$) on nitrogen in the topsoil (Appendix 4.1a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of nitrogen in the topsoil varied with year (Table 4.3a). The year 2014 was found to have the highest level of soil nitrogen in the topsoil when compared with year 2012 and 2013. The year 2012, was found to have the lowest level of nitrogen when compared with the other years. Nitrogen was highest in legume mucuna but lowest in dolichos in the topsoil. Mucuna treated plots recorded an increase in nitrogen by 11.5%, 18.3% and 27.4% in the topsoil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in nitrogen by 3.3%, 13.3% and 19.4% in the topsoil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in nitrogen by 1.6%, 5.0% and 9.7% in the topsoil for the year 2012, 2013 and 2014 respectively.

Table 4.3a: Effects of legume cover crop and year on topsoil (0-20 cm) nitrogen (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	0.62b	0.63b	0.68c
Mucuna	0.68a	0.71a	0.79a
Cowpea	0.63b	0.68a	0.74b
Control	0.61b	0.60b	0.62d
$LSD_{(P \leq 0.05)}$	0.046	0.049	0.047
CV%	11.45	14.06	13.00
Pr >F	0.561	0.019	0.008

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.5 Effects of legume cover crop and year on sub-soil nitrogen level in orange orchards at Vitengeni, KALRO-Matuga and Ganda

There was a significant interaction between cover crop and year (F= 3.38; P< 0.004) on nitrogen in the sub-soil (Appendix 4.1b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of nitrogen in the sub-soil varied with year (Table 4.3b). The year 2014 was found to have the highest level of soil nitrogen in the sub-soil when compared with the other years. The year 2012, was found to have the lowest level of nitrogen when compared with the other years. Nitrogen was highest in legume mucuna but lowest in dolichos in the sub-soil. Mucuna treated plots recorded an increase in nitrogen by 10.0%, 19.0% and 25.8% in the sub-soil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in nitrogen by 6.0%, 13.7% and 23.5% in the sub-soil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in nitrogen by 4.0%, 7.8% and 15.7% in the sub-soil for the year 2012, 2013 and 2014 respectively.

Table 4.3b: Effects of legume cover crop and year on sub-soil (20-40cm) nitrogen (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	0.52a	0.55b	0.59b
Mucuna	0.55a	0.61a	0.67a
Cowpea	0.53a	0.58ab	0.63b
Control	0.50a	0.51c	0.51c
$LSD_{(P \leq 0.05)}$	0.054	0.038	0.059
CV%	16.31	17.49	15.22
Pr >F	0.051	0.040	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.6 Effects of legume cover crop and site on topsoil organic carbon level in orange orchards.

There was significant interaction of treatment and site (F= 2.57; P< 0.002) on organic carbon in the topsoil (Appendix 4.2a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of organic carbon in the topsoil varied with site (Table 4.4a). The site KALRO-Matuga was found to have the highest level of soil organic carbon when compared with Vitengeni and Ganda. The site Ganda was found to have the lowest level of organic carbon when compared with KALRO-Matuga and Vitengeni. With each site, organic carbon was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded an increase in organic carbon by 32.2%, 29.3% and 25.8% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos treated plots recorded an increase in organic carbon by 22.7%, 18.5% and 19.6% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively. Cowpea treated plots recorded an increase in organic carbon by 16.0%, 13.3% and 8.3% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively.

Table 4.4a: Effects of legume cover crop and site on topsoil (0-20 cm) organic carbon (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	6.40b	6.82b	6.35a
Mucuna	6.98a	7.35a	6.68a
Cowpea	6.12b	6.45b	5.75b
Control	5.40d	5.56c	5.31c
LSD $_{(P \leq 0.05)}$	0.416	0.424	0.392
CV%	16.45	11.65	18.29
Pr >F	0.022	0.019	0.016

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.7 Effects of legume cover crop and site on sub-soil organic carbon level in orange orchards.

There was a significant interaction of treatment and site (F= 2.87; P< 0.04) on soil organic carbon in the sub-soil (Appendix 4.2b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of organic carbon in the sub-soil varied with site (Table 4.4b). The site KALRO-Matuga was found to have the highest increase in soil organic carbon when compared with Ganda and Vitengeni. The site Vitengeni was found to have the lowest level of soil organic carbon increase when compared with KALRO-Matuga and Ganda. With each site, soil organic carbon was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded an increase in organic carbon in the soil by 29.9%, 26.7%and 21.3% in the sub-soil for KALRO-Matuga, Ganda and Vitengeni respectively. Dolichos treated plots recorded an increase in organic carbon in the soil by 19.9%, 19.7% and 13.8% in the sub-soil for KALRO-Matuga, Ganda and Vitengeni respectively. Cowpea treated plots recorded an increase in organic carbon in the soil by 14.8%, 11.1% and 6.5% in the sub-soil for KALRO-Matuga, Ganda and Vitengeni respectively.

Table 4.4b: Effects of legume cover crop and site on sub-soil (20-40 cm) organic carbon (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	5.62ab	6.14b	4.62a
Mucuna	5.99a	6.65a	4.89a
Cowpea	5.26bc	5.88bc	4.29b
Control	4.94c	5.12c	3.86c
LSD $_{(P \leq 0.05)}$	0.396	0.497	0.398
CV%	18.30	14.91	21.23
Pr >F	0.002	0.028	0.004

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.8 Effects of legume cover crop and year on topsoil organic carbon level in orange orchards.

There was a significant interaction of treatment and year (F= 4.70; P< 0.004) on organic carbon in the topsoil (Appendix 4.2a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of soil organic carbon in the topsoil varied with year (Table 4.5a). The year 2014 was found to have the highest soil organic carbon in the topsoil. The year 2012 was found to have the lowest level of soil organic carbon in the topsoil. Soil organic carbon was highest in legume mucuna but lowest in cowpea in the topsoil. Mucuna treated plots recorded an increase in soil organic carbon by 8.7%, 16.6% and 21.8% in the topsoil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in soil organic carbon by 6.4%, 12.2% and 18.8% in the topsoil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in soil organic carbon by 4.6%, 6.8% and 13.5% in the topsoil for the year 2012, 2013 and 2014 respectively.

Table 4.5a: Effects of legume cover crop and year on topsoil (0-20 cm) organic carbon (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	5.51ab	5.88b	6.26b
Mucuna	5.63a	6.11a	6.42a
Cowpea	5.42b	5.59c	5.98c
Control	5.18b	5.24d	5.27d
LSD $(P \leq 0.05)$	0.134	0.141	0.136
CV%	21.18	17.46	16.58
Pr >F	0.049	0.007	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.9 Effects of legume cover crop and year on sub-soil organic carbon level in orange orchards.

There was a significant interaction of treatment and year ($F= 4.67$; $P< 0.02$) on soil organic carbon in the sub-soil (Appendix 4.2b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of organic carbon in the sub-soil varied with year (Table 4.5b). The year 2014 was found to have the highest level of soil organic carbon in the sub-soil when compared with year 2012 and 2013. The year 2012, was found to have the lowest level of organic carbon when compared with the other years. Organic carbon was highest in legume mucuna but lowest in cowpea in the sub-soil. Mucuna treated plots recorded an increase in soil organic carbon by 2.3%, 13.0% and 18.6% in the sub-soil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in soil organic carbon by 1.4%, 8.3% and 13.4% in the sub-soil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in soil organic carbon by 1.0%, 3.1% and 7.3% in the sub-soil for the year 2012, 2013 and 2014 respectively.

Table 4.5b: Effects of legume cover crop and year on sub-soil (20-40 cm) organic carbon (g kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	4.28a	4.58b	4.82b
Mucuna	4.31a	4.78a	5.04a
Cowpea	4.26a	4.36c	4.56c
Control	4.22a	4.23c	4.25d
LSD $(P \leq 0.05)$	0.124	0.156	0.172
CV%	24.76	22.87	18.47
Pr >F	0.094	0.021	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.10 Effects of legume cover crop and site on topsoil phosphorus level in orange orchards

The results of analysis of variance showed a significant interaction between treatment and site (F= 3.06; P< 0.005) on soil phosphorous in the top soil (Appendix 4.3a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of phosphorous in the topsoil varied with site (Table 4.6a). The site KALRO-Matuga was found to have the highest level of soil phosphorous when compared with Vitengeni and Ganda sites. The site Ganda was found to have the lowest level of soil phosphorous when compared with the other sites. With each site, soil phosphorous was highest in legume mucuna but lowest in dolichos. Legume mucuna treated plots recorded an increase in soil phosphorous by 20.3%, 18.8% and 18.2% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively. Cowpea treated plots recorded an increase in soil phosphorous by 17.5%, 17.2% and 14.7% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos treated plots recorded an increase in soil phosphorous by 12.0%, 10.0% and 4.6% in the topsoil for KALRO-Matuga, Vitengeni and Ganda respectively.

Table 4.6a: Effects of legume cover crop and site on topsoil (0-20 cm) phosphorus (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	19.64b	21.43a	13.56b
Mucuna	21.83a	23.02a	15.33a
Cowpea	21.01a	22.48a	14.88ab
Control	17.92b	19.14b	12.97b
LSD $_{(P \leq 05)}$	1.83	2.12	1.96
CV%	18.16	14.82	19.34
Pr >F	0.043	0.027	0.048

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.11 Effects of legume cover crop and site on sub-soil phosphorus in orange orchards

There was a significant interaction between treatment and site ($F= 4.54$; $P< 0.005$) on soil phosphorus in the sub-soil (Appendix 4.3b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of phosphorous in the sub-soil varied with site (Table 4.6b). The site KALRO-Matuga was found to have the highest level of soil phosphorus when compared with Vitengeni and Ganda sites. The site Ganda was found to have the lowest level of soil phosphorus when compared with the other sites. With each site, soil phosphorus was highest in legume mucuna but lowest in dolichos. Mucuna treated plots recorded an increase in soil phosphorus by 14.8%, 10.2% and 11.5% in the sub-soil for KALRO-Matuga, Vitengeni and Ganda respectively. Cowpea treated plots recorded an increase in soil phosphorus by 11.8%, 6.2% and 4.6% in the sub-soil for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos treated plots recorded an increase in soil phosphorus by 8.3%, 2.2% and 1.9% in the sub-soil for KALRO-Matuga, Vitengeni and Ganda respectively. Legume mucuna was found to have significant increase in soil phosphorus in the sub-soil of Ganda site.

Table 4.6b: Effects of legume cover crop and site on sub-soil (20-40 cm) phosphorus (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Site		
	Vitengeni	KALRO-Matuga	Ganda
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	16.09bc	17.59a	13.12b
Mucuna	17.34a	18.65a	14.36a
Cowpea	16.72ab	18.16a	13.47b
Control	15.74c	16 .24b	12.88b
LSD $_{(P \leq 05)}$	1.22	1.58	1.41
CV%	23.16	16.93	21.41
Pr >F	0.045	0.037	0.586

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.12 Effects of legume cover crop and year on topsoil phosphorus level in orange orchards

There was a significant interaction between treatment and year (F= 3.51; P< 0.003) on soil phosphorous in the topsoil (Appendix 4.3a).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of phosphorous in the topsoil varied with year (Table 4.7a). The amount soil phosphorous increased with years where year 2014 was found to have the highest soil phosphorous in the topsoil. The year 2012 was found to have the lowest level of soil phosphorous in the topsoil. Soil phosphorous was highest in legume mucuna but lowest in dolichos in the topsoil. Mucuna treated plots recorded an increase in soil phosphorous by 9.7%, 14.8% and 22.3% in the topsoil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in soil phosphorous by 7.4%, 12.9% and 14.8% in the topsoil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in soil phosphorous by 5.2%, 5.3% and 7.4% in the topsoil for the year 2012, 2013 and 2014 respectively.

Table 4.7a: Effects of legume cover crop and year on topsoil (0-20 cm) extractable phosphorous (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Topsoil)	(Topsoil)	(Topsoil)
Dolichos	18.14ab	18.18b	18.38c
Mucuna	18.92a	19.81a	20.92a
Cowpea	18.53ab	19.48a	19.64b
Control	17.25b	17.26b	17.11d
LSD$_{(P \leq 0.05)}$	1.35	1.28	1.24
CV%	18.58	19.74	16.95
Pr >F	0.689	0.036	0.016

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.13 Effects of legume cover crop and year on sub-soil phosphorus level in orange orchards

There was a significant interaction between treatment and year (F= 2.84; P< 0.01) on phosphorous in the sub-soil (Appendix 4.3b).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of soil phosphorous in the sub-soil varied with year (Table 4.7b). The year 2014 was found to have the highest level of soil phosphorous in the sub-soil when compared with year 2012 and 2013. The year 2012, was found to have the lowest level of soil phosphorous when compared with the other years. Soil phosphorous was highest in legume mucuna but lowest in legume dolichos in the sub-soil. Mucuna treated plots recorded an increase in soil phosphorous by 5.1%, 11.1% and 13.0% in the sub-soil for the year 2012, 2013 and 2014 respectively. Dolichos treated plots recorded an increase in soil phosphorous by 2.3%, 3.1% and 6.6% in the sub-soil for the year 2012, 2013 and 2014 respectively. Cowpea treated plots recorded an increase in soil phosphorous by 3.5%, 6.9% and 8.2% in the sub-soil for the year 2012, 2013 and 2014 respectively.

Table 4.7b: Effects of legume cover crop and year on sub-soil (20-40 cm) extractable phosphorous (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

	Year		
	2012	2013	2014
Treatment	(Sub-soil)	(Sub-soil)	(Sub-soil)
Dolichos	13.78a	14.47a	14.64a
Mucuna	14.18a	15.26a	15.51a
Cowpea	13.96a	14.66a	14.85a
Control	13.49a	13.72b	13.73b
$LSD_{(P \leq 0.05)}$	1.54	1.48	1.63
CV%	21.64	20.68	18.79
Pr >F	0.867	0.041	0.031

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.14 Effects of legume cover crop on topsoil potassium level in orange orchards

Effect of mucuna, dolichos and cowpea legume cover crop significantly ($F= 3.46$; $P< 0.041$) increased potassium (K) content in the topsoil (Appendix 4.4a).

Legume mucuna was found to have the highest level of potassium in the topsoil when compared dolichos and cowpea (Table 4.8a). Dolichos was found to have the lowest level of soil potassium when compared with the other legumes. Mucuna, cowpea and dolichos increase soil K by 28.7%, 25.3% and 12.6% respectevly in the topsoil compared to the control.

Table 4.8a: Effects of legume cover crop on topsoil (0-20 cm) potassium (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

Treatment	Potassium (mg kg^{-1}) Topsoil (0-20 cm)
Dolichos	0.196ab
Mucuna	0.224a
Cowpea	0.218a
Control	0.174b
LSD ($P \leq 0.05$)	0.041
CV%	36.53
Pr >F	0.0414

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.15 Effects of legume cover crop on sub-soil potassium level in orange orchards

Effect of mucuna and cowpea legume cover crop significantly ($F= 2.23$; $P< 0.05$) increased potassium content in the sub-soil (Appendix 4.4b).

Legume mucuna was found to have the highest level of potassium in the topsoil when compared dolichos and cowpea (Table 4.8b). Dolichos treated plots were found to have the lowest level of soil potassium in the sub-soil when compared with the other legumes. Mucuna, cowpea and dolichos increase soil potassium in the sub-soil by 23.1%, 20.2% and 10.5% respectively compared to the control.

Table 4.8b: Effects of legume cover crop on subsoil (20-40 cm) potassium (mg kg^{-1}) in orange orchards at Vitengeni, KALRO-Matuga and Ganda

Treatment	Potassium (mg kg^{-1}) Sub-soil (20-40 cm)
Dolichos	0.148b
Mucuna	0.165a
Cowpea	0.161a
Control	0.134b
LSD $(P \leq 0.05)$	0.025
CV%	21.02
Pr >F	0.0497

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.16 Effects of legume cover crop on topsoil soil pH level in orange orchards

The results of analysis of the variance showed effects due to site difference (F= 3.68; P< 0.05) at topsoil on soil pH (Appendix 4.5a).

The site Vitengeni was found to have the highest level of soil pH when compared with KALRO-Matuga and Ganda sites. The site Ganda was found to have the lowest level of soil pH when compared with the other sites.There was no significant difference in soil pH between KALRO-Matuga, Ganda and the control (Table 4.9).

Table 4.9: Effects of site on topsoil (0-20 cm) soil pH level in orange orchards at Vitengeni, KALRO-Matuga and Ganda

Site	Soil pH Topsoil (0-20 cm)
Vitengeni	6.56a
Matuga	6.43b
Ganda	6.41b
LSD $(P \leq 0.05)$	0.036
CV %	2.938
Pr >F	0.0464

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.17 Effects of legume cover crop and site on orange leaf chlorophyll content in orange orchards

The analysis of variance showed that there was a significant interaction between treatment and site ($F= 3.40$; $P< 0.04$) on orange leaf chlorophyll (Appendix 4.6).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange leaf chlorophyll varied with site (Table 4.10a). The site KALRO-Matuga was found to have the highest level of orange leaf chlorophyll when compared with Vitengeni and Ganda. The site Ganda was found to have the lowest level of orange leaf chlorophyll when compared with KALRO-Matuga and Vitengeni. With each site, orange leaf chlorophyll was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded an increase in orange leaf chlorophyll by 29.1%, 24.5% and 21.8% for KALRO-Matuga, Vitengeni and Ganda respectively. Dolichos treated plots recorded an increase in orange leaf chlorophyll by 17.8%, 12.5% and 10.2% for KALRO-Matuga, Vitengeni and Ganda respectively. Cowpea treated plots recorded an increase in orange leaf chlorophyll by 13.0%, 6.7% and 5.8% for KALRO-Matuga, Vitengeni and Ganda respectively.

Table 4.10a: Effects of legume cover crop and site on orange leaf chlorophyll content at Vitengeni, KALRO-Matuga and Ganda

Treatment	Site		
	Vitengeni	KALRO-Matuga	Ganda
Dolichos	72.71b	77.85b	69.13a
Mucuna	80.46a	85.32a	73.41a
Cowpea	68.97bc	74.70b	66.37a
Control	64.65c	66.09c	62.76b
LSD (P ≤ 0.05)	6.24	5.63	3.48
CV%	5.61	4.82	5.89
Pr >F	0.002	0.001	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

4.2.18 Effects of legume cover crop and year on orange leaf chlorophyll

There was a significant interaction between treatment and year ($F= 2.23$; $P< 0.003$) on orange leaf chlorophyll (Appendix 4.6).

Effect of mucuna, cowpea and dolichos on orange leaf chlorophyll content significantly ($P\leq 0.05$) increased with year (Table 4.10b).

The year 2014 was found to have the highest level of orange leaf chlorophyll content when compared with other years. The year 2012 was found to have the lowest level of orange leaf chlorophyll content when compared with the other years. Orange leaf chlorophyll was highest in legume mucuna but lowest in cowpea.

Mucuna increased leaf chlorophyll content by 8.8%, 16.4% and 21.2% in year 2012, 2013 and 2014 respectively. Dolichos increased leaf chlorophyll content by 12.2% and 16.4% in year 2013 and 2014 respectively. Cowpea increased leaf chlorophyll content by 11.2% in year 2014.

Table 4.10b: Effects of legume cover crop and year on orange leaf chlorophyll content at Vitengeni, KALRO-Matuga and Ganda

Treatment	Year		
	2012	2013	2014
Dolichos	69.0b	73.8a	78.6a
Mucuna	72.8a	76.9a	81.2a
Cowpea	68.4b	69.2b	74.5b
Control	66.9b	65.8b	67.0c
$LSD_{(P \leq 0.05)}$	2.81	3.68	3.43
CV%	2.9	8.2	9.6
Pr >F	0.009	0.001	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

DISCUSSIONS

4.3.1 Discussion on effects of legume cover crops on soil nitrogen level

The sites varied in terms of soil type, the initial soil nutrients and amount of rainfall, and this could have contributed to the site and treatment interaction effects. Ganda site soil type is sandy; KALRO-Matuga soils are loamy sand, while Vitengeni soils are sandy clay loam (Apendix 3.0). Each site received different rainfall (Appendix 1) which could have influenced observed results interaction effects of site and mucuna recorded the highest increase in nitrogen at Ganda site in both top and sub-soil. Ganda site recorded the highest nitrogen increase in the topsoil and yet the initial nitrogen level was lower than Vitengeni but equal to KALRO-Matuga (Table 4.1). The difference in soil type from the three sites is likely to have influenced the accumulation of plant nutrients in the soil and this affects their availability to plants. Dejene (2014) observed that the type of soil influences the level of plant nutrients in the soil. Abera *et al.* (2012) observed that the type of soil and legume influence the nitrogen fixation in the soil. Rondon *et al.* (2007) observed that high soil pH reduce N fixation by the legumes. Legumes fix nitrogen in their root nodules using rhizobial bacteria and the more the roots the more the nodules hence the more the nitrogen fixed and released to the soil profile. Hoorman (2009) showed that legume cover crop can fix nitrogen using rhizobial bacteria up to 60–170 kg of N per hectare per year. This study shows that the different legume cover crops have different capacities in fixing of nitrogen in the soil. Abera *et al.* (2012) observed that the amount of nitrogen fixed in the soil varied with type of legume. Mucuna legume cover crop recorded the highest soil nitrogen in both topsoil and sub-soil. Dolichos recorded the lowest increase in soil nitrogen across the sites. The use of legume cover crops, over the years increased soil nitrogen. There was an increase in soil nitrogen over the study period (2012—2014) in both topsoil and sub-soil because of using different legume cover crop. The continuous use of legume cover crop could have contributed to the increase in soil nitrogen over time. The third year (2014) recorded the highest soil nitrogen while the first year (2012) recorded the least in both topsoil and sun-soil.

4.3.2 Discussion on effects of legume cover crops on soil organic carbon level

The three sites soil type varied where Ganda site soil is sandy, KALRO-Matuga soil is loamy sand, while Vitengeni soil is sandy clay loam (Table 3.1 of section 3.3.1 of this thesis). Average rainfall varied with year and site which could have influenced their decomposition rate and hence the observed site variation organic carbon accumulation in the soil (Appendix 1). The rate of organic matter decomposition and duration is influenced by the amount of moisture in the soil which in turn is also influenced by the the type of soil (Cherr *et al.* 2006). The ability of mucuna to accumulate organic carbon in the soil compared to the other legumes is probably due its massive vegetative growth. Legumes residue material decomposing in the soil increase the C/N ratio and this affects the proportion taken up by plants (Carvalho *et al.*, 2014).

The significance increase over the years in levels of organic carbon by mucuna, cowpea and dolichos could be as a result of plant residue slow decomposition. Dead roots also contribute to increase in organic carbon within the sub-soil. The difference in time and soil depth on mean soil organic carbon could be attributed to slow decomposition of plant debris in the topsoil. The topsoil had the highest increase in carbon as compared to the sub-soil. Hoorman (2009) stated that the increase in organic matter in the soil, the decomposition activities by the microbial in the soil increases. The rate of plant residue decomposition varies from one legume to the other. Cherr *et al.* (2006) reported that woody legumes decomposition and biomass mineralization is slowed due to structure of stem and dry matter portioning.

The year 2014 recorded the highest organic carbon increase while the first year (2012) recorded the lowest in topsoil. The continuous use of legume cover crop could have contributed to the increase in organic carbon in topsoil.

4.3.3 Discussion on effects of legume cover crops on soil phosphorous level

The three sites have varied soil type where Ganda site soil is decribed as sandy, KALRO-Matuga soil is loamy sand, while Vitengeni soil is sandy clay loam (Table 3.1 of section 3.3.1 of this thesis). Alamgir and Marschner, (2013) study on broad bean (*Vicia faba)*, chick pea (*Cicer arietinum)* and white lupin (*Lupin albus)* legumes observed an increase in soil phosphorous. Bedada *et al.* (2014) argued that when organic matter is incorporated in the soil, there is an increase in soil phosphorous concentration in soil surface layers. Mucuna recorded the highest increase in soil phosphorous in both topsoil and sub-soil. The results agree with Marschner *et al.*, (2011) who indicated that the increase of phosphorous by mucuna attributed to the ability of this crop to access available forms of phosphorous. Vanlauwe *et al.* (2000) reported that the use of mucuna and crotalaria (*Crotalaria Juncea)* legume cover crop increased phosphorus in soil.

The slow increase in soil P in the soil attributed to the slow rate of decomposition of vegetative materials from cover crops. The year variation is due to phosphorous being a structural constituent in hard tissues in plants leading to slow decomposition rate and slow release phosphorous in the soil (Alamgir *et al.*, 2012). Alamgir *et al.* (2012) study on structural constituent of phosphorous in plants indicated that phosphorous is found in hard tissues such as stems and roots leading to low decomposition rate and slow release to the soil.

4.3.4 Discussion on effects of legume cover crops on potassium level

The increase of potassium in the soil is the ability of mucuna to release more residual potassium to the upper soil layers from decomposing vegetative material (Imoro *et al.* 2013). This cover crop builds up organic matter and improves soil properties and microbial activity increase mineralization and release of potassium (Feichtinger *et al*, 2004). Saha *et al.* (2008) argued that when mucuna is intercropped with maize, the potassium level of this crop increases leading to increased maize yields. It is possible to argue that mucuna and cowpea legume cover crop under orange orchards have a similar mechanism in increasing potassium in both top and sub-soils and hence improve fruit quality.

4.3.5 Discussion on effects of legume cover crops on soil pH level

Soil pH influences the uptake of soil nutrients by plant and makes them unavailable to the plants. There was a significant difference on site soil pH and this could have influenced the uptake of plant nutrients by the orange tree and hence influenced the orange yield and fruit qualities in chapter five of this thesis. The effect legumes on soil properties as a slow process which required at least five years to having a significant effect on soil pH (Zeng *et al.*, 2011; Yuan and Xu. 2011). This could explain why the use of mucuna, cowpea and dolichos had no significant effect on soil pH in this study period. There was no significant difference because of using legume cover crops

(Table 4.1 and 4.9) the Soil pH influence the nutrient absorption by the plant roots and this affects the uptake by plants (Zeng et al., 2011)

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4.3.6 Discussion on effects of legume cover crops on orange leaf chlorophyll

The result from the interaction showed that the source of chlorophyll content variation was not only due to the cover crops but site and year also contributed. The sites varied in soil types and the initial levels of plant nutrients and this contributed to site variations (Table 3.1 section 3.3.1; Table 4.1 of this thesis). The amount of rainfall varied with sites hence this influenced the uptake of plant nutrients (Appendix 1). The effect of mucuna, cowpea and dolichos legume cover crop on orange leaf chlorophyll varied with year. Nutrients dissolve in soil water then taken up by plants, and this influences the biosynthesis of chlorophyll as well as systematic metabolism in plants. Biljana and Markovi (2009) reported that nitrogen being a structural component of chlorophyll in leaves determined by the amount of this element in soil. Mucuna legume cover crop significantly increased orange leaf chlorophyll content from year 2012 to year 2014. Dolichos legume cover crop significantly increased orange leaf chlorophyll content from year 2013 to year 2014. Cowpea legume cover crop significantly increased in orange leaf chlorophyll content on the year 2014. The highest level of orange leaf chlorophyll was during the year 2014 and the lowest in in year 2012. This increase orange leaf chlorophyll content with time was due to the accumulated and decomposed organic matter and increased nutrients in the soil. Plant remains take time to decompose hence the observed delayed increase because of using the legume cover crops.

The amount of soil nitrogen is a key determinant of leaf chlorophyll content (Liu, 2008). When a legume cover crop incorporated in soil, nitrogen mineralized within weeks and months (Ngome *et al.* 2011). Sulok *et al.* (2014) observed that leaves of plants with higher nitrogen are usually dark green and tend to have high chlorophyll content. Concentration of chlorophyll in leaves reported to influence rate of photosynthesis (Ndukwe *et al.*, 2011). The use of mucuna, cowpea and dolichos legume cover crop influenced orange tree nutrition and subsequent orange leaf chlorophyll content. Results from this study support those of Tabaldi *et al.* (2012) who observed increase of leaf chlorophyll when cover crops used in production of Madagascar dragon tree (*Serjania marginata*).

Conclusion and Recommendations

Results of this study demonstrated that mucuna legume cover crops increases soil organic carbon, nitrogen, potassium, phosphorus content in the soil and orange leaf chlorophyll content. The effect of mucuna, cowpea and dolichos on plant nutrients, orange leaf chlorophyll varied spatially, and temporary. Mucuna was found to have the highest increase in nitrogen, organic carbon, phosphorous and potassium in both top and sub-soils and orange leaf chlorophyll content. The overall ranking of the cover crops on the bases of soil nutrients was as follows: Nitrogen = mucuna > cowpea >dolichos, Organic carbon = mucuna > dolichos > cowpea, Phophorous = mucuna > cowpea > dolichos, Potassium = mucuna > cowpea > dolichos, Orange leaf chlorophyll = mucuna > dolichos > cowpea.

From the results, I have concluded that all the three legumes (mucuna, dolichos and cowpea) contribute to improvement of nutrients in top and sub-soils subsequently increasing orange leaf chlorophyll. Mucuna legume cover crop however gave the best results in improving plant nutrients and orange leaf chlorophyll. It can be confirmed that mucuna, dolichos and cowpea contributed to an increase of N, OC, P and K in the soil; mucuna = 464kg ha^{-1} N, 3,184kg ha^{-1} OC, 10.2kg ha^{-1} P and 0.12kg ha^{-1} K respectively in the soil. Dolichos = 232kg ha^{-1} N, 2,336kg ha^{-1} OC, 3.8kg ha^{-1} P and 0.05kg K respectively in the soil. Cowpea = 312kg ha^{-1} N, 1,608kg ha^{-1} OC, 6.8kg ha^{-1} P and 0.1kg ha^{-1} K respectively in the soil. Mucuna is herby recommend to be used by farmers as a cover crop in orange orchards in the coastal lowland of Kenya for it can supply plant nutrients in orange orchards. Farmers thus have the option of growing oranges under natural fallow or with mucuna as a cover crop. Further research is however, recommended to evaluate the long term effects (> 3years) of the cover crops in citrus orchard faming systems in different Agro-ecological zones, soil types and seasons.

CHAPTER FIVE:

EFFECTS OF LEGUME COVER CROPS ON ORANGE (*Citus sinensis*) YIELD AND FRUIT QUALITY

Abstract

Fruit crop production and quality are influenced by soil physical, biochemical characteristics and production practices. Recent reports show that orange yield and fruit quality is declining in Kenya's coastal lowlands. Smallholder citrus growers require an efficientand sustainable production system which enhances orange yield and fruit quality. A study conducted to evaluate the effect of three legume cover crops mucuna cowpea and dolichos on orange fruit yield and quality. The study was conducted at Ganda and KALRO-Matuga in Kwale County and Vitengeni, in Kilifi County, from May 2012 to April 2015. There were four treatments; mucuna (*Mucuna pruriens*), cowpea (*Vigna unguiculata*), dolichos (*Lablab purpureus*) cover crops and a fallow as the control. The experiment was laidout in a randomized complete block design (RCBD) where the treatments were replicated four times within four blocks in an existing grafted Valencia orange orchard. Fruit yield was determined by counting the number of fruits, average weight and diameter of fruit. Fruit quality was determined by measuring juice content, the peel thickness and fruit sugar/acid ratio (Brix). The data on fruit number, fruit weight, fruit diameter, fruit juice and fruit brix subjected to analysis (ANOVA) as described in section 3.2.6 of chapter 3 of this thesis. The mean separation was done using the least significant difference (LSD) at 5% level of significance.

The results from the study showed that there was interaction between treatments and sites hence the effects of the legume cover crops varied with site. Orange fruit number increased by 15.8%, 7.4% and 6.4% for Vitengeni, KALRO-Matuga and Ganda respectively due to mucuna and 15.4% for Vitengeni due to dolichos. Mucuna increased orange fruit weight by 12.4%, 10.5% and 7.6% for Ganda, KALRO-Matuga and Vitengeni respectively. Orange fruit weight increased by 8.8%, 7.8% and 7.2% for Ganda, KALRO-Matuga and Vitengeni respectively due to dolichos and 6.0% for Ganda due to cowpea. The orange fruit diameter

increased by 8.1%, 5.5% and 5.1% for Ganda, KALRO-Matuga and Vitengeni respectively due to mucuna. Dolichos and cowpea increased orange fruit diameter for Ganda by 4.9% and 4.2% respectively. Mucuna increased orange fruit juice by 7.2%, 5.5% and 4.8% for Ganda, KALRO-Matuga and Vitengeni respectively and 4.6% and 3.4% for Ganda and KALRO-Matuga due to dolichos. Orange fruit brix increased by 5.8%, 5.1% and 4.2% for Vitengeni, KALRO-Matuga and Ganda respectively due to mucuna. Cowpea increased orange fruit brix by 4.6%, 3.8% and 3.2% for Vitengeni, KALRO-Matuga and Ganda respectively. Orange fruit brix increased by 3.3% and 3.1% for Vitengeni and KALRO-Matuga respectively due to dolichos. The use of mucuna, dolichos and cowpea did not have significant effect on orange fruit rind thickness. It was concluded that mucuna and dolichos are cover crops could be incorporated in orange farming systems because of their impact on orange yields and fruit quality. Further research to evaluate the long term (>3years) effect of the cover crops under different agro-ecological zones is recommended.

Introduction

Citrus (*Citrus* spp.) fruits are the 7th most important fruit in both production and consumption in Kenya (Kilalo *et al.*, 2009; HCD, 2015). They are important sources of income to the resource-poor farmers, employment in rural areas and human nourishment. The main citrus species grown in Kenya are sweet oranges (*Citrus sinensis*), lemons (*Citrus limon*), limes (*Citrus latifolia*), tangerines (*Citrus tangerina*) and grapefruit (*Citrus paradisi*) (HCD, 2015). Orange crop occupies 13% of the total area under fruit production in coastal Kenya (HCDA, 2013). Orange fruit production has been declining over the decades with little effort being put in place to reverse the trend. Orange yields of 8-12 tons per hectare have been reported while the potential is 20 tons/ha under well managed orchards (Ouma, 2008). Srivastava and Singh, (2016) reported that one of the major cause of fruit production decline is low soil fertility which is associated with inadequate fertilizer use. Additionally, poor agronomic practices have contributed to low orange production (Ouma *et al.*, 2010; Socio-economic Atlas Kenya, 2014). The erratic rainfall which is poorly distributed affect orange production especially dry spells during the fruiting periods.

The use of legume cover crops is an economically feasible and ecologically sustainable practice that plays an important role in the recovery of soil fertility (Nzokou *et al.*, 2011). Abdel-Aziz *et al.* (2008) found that the potassium content in Valencia orange leaves increased as a result of using legume cover crops. According to Dian-Ming *et al.* (2011), cover crops enhance the retention of organic soil carbon and nitrogen as well as soil aggregation and biological balance in orchard management practices. The legume cover crop plays a major role in the provision or maintenance of soil phosphorus, potassium and calcium that are essential in fruit development, seed formation and fruit quality (Bedada *et al.*, 2014). Legume cover crops produce vegetative material which decomposition in the soil, release nutrients which support plant growth and enhanced fruit yield (Aseri *et al.*, 2008). Shamseldin *et al.* (2010) reported that rhizobacteria decompose soil biomass, releasing substantial nitrogen and other plant nutrients that can improve fruit yield. Gattuso *et al.* (2007) showed that the increase in nutritional supply from the soil as a result of using legume cover crop, improves the fruit quality and flavonoid composition of citrus juices. Legume cover crops reported to be more beneficial than grass cover crops because they improve soil nitrogen through biological nitrogen fixation (BNF) (Fisher and Davies, 2010). The leguminous cover crop residues also provide residual soil N for the succeeding seasons (Teasdale *et al.*, 2007).

Although there are several tropical legume species, only a few studied for their potential as cover crops (Saha *et al.*, 2002). For example, Ngome *et al.* (2011) and Carvalho *et al.* (2014) found that mucuna improved soil nitrogen and carbon stock in the soil while Mwangi *et al.*, (2015) reported a significant reduction in weed population and improved maize yields. Swella *et al.* (2015) demonstrated that soil water retention in farming systems using cover crops is higher as compared to bare soil surface. Unfortunately, there is limited information on the effects of cover crops on fruit crop growth and productivity in Kenya. This study conducted to evaluate the effect of cover crops on orange tree yield and fruit quality in the coastal lowlands of Kenya.

MATERIALS AND METHODS

5.2.1 Experimental sites, design and crop husbandry

The study was conducted at Ganda and Kenya Agricultural and Livestock Research Organization (KALRO)-Matuga in Kwale County and Vitengeni in Kilifi County, within the coastal lowlands of Kenya from May 2012 to April 2015. The fieldwork superimposed on existing on-farm orange orchards in two locations (Ganda and Vitengeni) and on-station at KALRO-Matuga. The experimental design was a randomized complete block design (RCBD) four blocks with each treatment replicated four times. The site details, layout and agronomic practices carried out as outlined in section 3.3.1 of chapter three of this thesis.

5.2.2 Data collection

Data collected included (i) weather data: rainfall, temperature and relative humidity from the nearest weather stations, (ii) orange fruit yield: fruit number and fruit weight(g) based on the orange fruiting seasons and (iii) fruit quality: juice content (ml), fruit diameter (mm), brix (%) and fruit rind thickness(mm) based on the orange fruiting seasons.

Weather data collected from Ramisi, KALRO-Matuga and Vitengeni meteorological weather stations from January 2012 to April 2015. The selection of weather stations was based on closeness to each of the experimental site. Data on fruit number was determined by counting the total number of fruits harvested per tree per given fruiting season. There are two orange fruiting seasons per physical year fruit data collected in a total of six fruiting seasons. Fruit weight (g) was determined by selecting 10 fully mature oranges from different branches of each plot and weighed using electronic balance (Model PM 200, Mettler Instrument Limited, Switzerland). The average weight per fruit was determined by dividing total weight of fruits selected with ten. Fruits for fruit weight determination were sampled six times in every fruiting season making a total of 36 samples per experimental unit. Fruit diameter (mm) was determined by randomly selecting 10 mature orange fruits from different branches of each experimental unit per site per season. The fruit size (equatorial diameter) measured using venire calipers as described by (Morgan *et al*, 2005). Fruits for fruit size determination were sampled six times in every fruiting season making a total of 36 samples per plot in three years. Fruit juice (ml) was determined by randomly selecting 5 fully mature fruits from different branches in each experimental unit. The juice extracted from the fruit by cutting at the equatorial into two halves and squeezing juice using a juice extractor. The juice was then passed through a 2mm sieve size and measured using a measuring cylinder. Fruits for juice determination were sampled in every fruiting season making a total of 36 samples per experimental unit. Orange juice brix (%) was determined by selecting randomly five (5) fully mature fruits from different branches in each ploy. The fruits were cut at the equatorial and two drops of fruit juice placed on a refractometer sensor (Plate 5.1). Fruits for brix determination were sampled six times in every fruiting season making a total of 36 samples per plot.The brix was measured and determined using a calibrated brix refractometer (Model; RHB 0-90 with three scales, Grand index solution Enterprise Ltd, Hong Kong, China) as described by Kimball (2012).

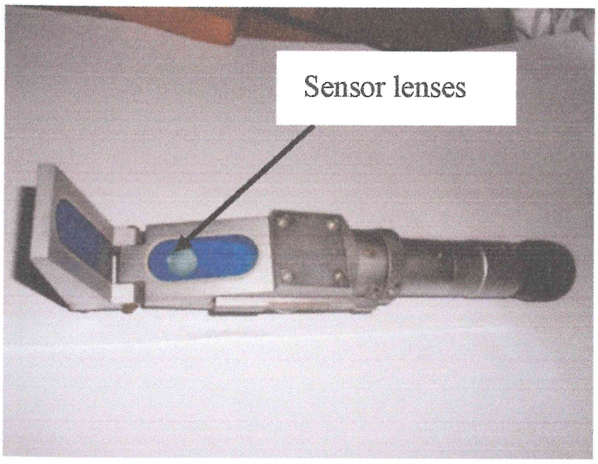

Plate 5. 1: Open Refractometer exposing the sensor lenses

The refractometer was held and viewed in a bright light background to read the direct fruit brix reading of orange juice (Plate 5.2).

Plate 5. 2: Refractometer taking brix reading

The fruit rind thickness (mm) was determined by randomly selecting five mature oranges from trees under the different treatments. Fruits rind thickness determinations were sampled six times in every fruiting season making a total of 36 samples per tree. Rind thickness was measured using procedures described by Bain (1958). The fruit was cut transversely in two halves (Plate 5.3). The pulp was removed to expose the fruit rind then the rind thickness measured using a vanier calipers.

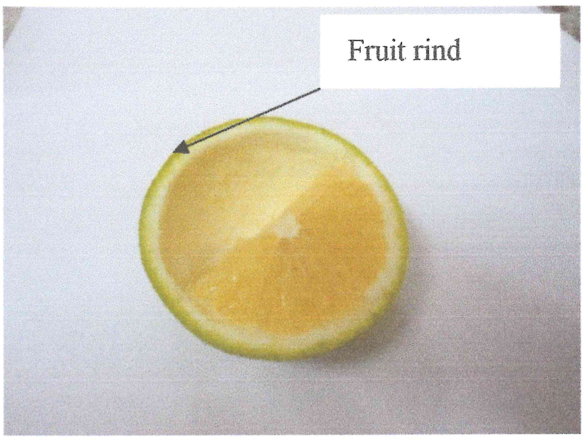

Plate 5. 3: Cut orange fruit exposing the internal part and rind

5.2.3 Data analysis

The data obtained on fruit number, fruit weight, fruit diameter, orange juice and fruit brix were first checked for outliers, normality and homogeneity of variance prior to statistical analysis. Data on fruits were found to meet the assumption for ANOVA and were not transformed before analysis with ANOVA at ($P<0.05$) using procedures of R statistical analysis software version 3.3.2 (R Core team, 2015). Mean separation was done using least significant difference (LSD) at 5% level of significance.

RESULTS

5.3.1 Weather data and the study sites

The weather data from meteorological stations nearest to the study site, Ramisi, KALRO-Matuga and Vitengeni during orange fruiting cycles May 2012 to April 2015 period (Table 5.1). The amount of moisture in the soil and its availability to a crop is an important factor in fruit production and yield. The ambient temperature influences fruit development and colour change at maturity. The first orange fruiting cycle is from April to September, which coincides with May—August long rains. The second fruiting cycle is October to March coinciding with short rains October—December.

The average rainfall for Vitengeni during the six fruiting cycles was 328.5 mm, with mean monthly maximum and minimum temperature of 29.2°C and 24.8°C, respectively. KALRO-Matuga had an average rainfall of 363.4mm during the six fruiting cycles was 363.4mm with a mean monthly maximum and minimum temperature of 28°C and 24.3°C. The average rainfall for Ganda during the six fruiting cycles was 470.6mm, with a mean monthly maximum and minimum temperature of 27.67°C and 23.5°C.

The three-year period mean relative humidity for Ganda, KALRO-Matuga and Vitengeni sites was 85.2%, 84.6% and 80.7%, respectively. The detail monthly rainfall distribution during the study period is as in (Appendix 1).

Table 5.1: Mean rainfall and temperature for Ganda, KALRO-Matuga and Vitengeni in six orange fruiting seasons

		Ganda			KALRO-Matuga			Vitengeni		
		R/fall	Temp (°C)		R/fall	Temp (°C)		R/fall	Temp (°C)	
Year	F/Season	(mm)	max	min	(mm)	max	min	(mm)	max	min
2012:S/1	May-Sep	367	27	23	352.8	27	23	273	29	24
2012:S/2	Oct-Mar	236	28	24	105.8	29	25	368.4	30	25
2013:S/3	May-Sep	479.3	27	23	475.5	28	24	360.6	29	25
2013:S/4	Oct-Mar	297	29	25	77.5	29	26	169.4	30	26
2014:S/5	May-Sep	733.6	27	22	754.1	27	23	407.9	28	24
2014:S/6	Oct-Mar	352	28	24	344.1	28	25	391.7	29	25
Mean		410.8	27.7	23.5	351.6	28	24.3	328.5	29.2	24.8

S= Seasons (May-September fruiting); S= Seasons (October-March fruiting); R/fall= Rainfall; Temp=Temperature; F=Fruiting

5.3.2 Effects of legume cover crop and site on the number of orange fruit

The analysis of the variance showed that there was a significant interaction between treatment and site ($F= 3.74; P<0.01$) on orange fruit number (Appendix 5.1).

Effect of mucuna and dolichos legume cover crops on the increased fruit number at Vitengeni compared to the other sites (Table 5.2). The site Vitengeni was found to have the highest level of orange fruit number when compared with KALRO-Matuga and Ganda. The site Ganda was found to have the lowest level of orange fruit number when compared with KALRO-Matuga and Vitengeni. With each site, orange fruit number was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded an increase in orange fruit number by 15.8%, 7.4% and 6.4% for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded an increase in orange fruit number by 15.4% for Vitengeni. Contrary to mucuna and dolichos, cowpea treated plots recorded a comparable but insignificant increase in orange fruit number for Vitengeni, KALRO-Matuga and Ganda.

Table 5.2: Effects of legume cover crop and site on the number of orange fruits at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni	KALRO-Matuga	Ganda
Dolichos	503a	418b	321b
Mucuna	505a	434a	332a
Cowpea	462b	407b	315b
Control	436b	404b	312b
LSD $(P \leq 0.05)$	19.9	16.5	8.3
CV%	19.9	23.65	17.52
Pr >F	0.024	0.057	0.094

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

5.3.3 Effects of legume cover crop and site on orange fruit weight

The analysis of variance showed that there was a significant interaction between treatment and site (F= 3.32; P<0.05) on orange fruit weight (Appendix 5.2).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit weight varied with site (Table 5.2). The site Ganda was found to have the highest orange fruit weight when compared with Vitengeni and KALRO-Matuga. The site Vitengeni was found to have the lowest orange fruit weight when compared with KALRO-Matuga and Ganda. With each site, orange fruit weight was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded a significant increase in orange fruit weight by 12.4%, 10.5% and 7.6% for Ganda, KALRO-Matuga and Vitengeni respectively. Dolichos treated plots recorded a significant increase in orange fruit weight by 8.8%, 7.8% and 7.2% for Ganda, KALRO-Matuga and Vitengeni respectively. Cowpea treated plots recorded an increase in orange fruit weight by 6.0%, 2.9% and 2.5% for Ganda, KALRO-Matuga and Vitengeni respectively. As opposed to mucuna and dolichos, cowpea treated plots increased a comparable orange fruit weight for KALRO-Matuga and Vitengeni which was not significantly different.

Table 5.3: Effects of legume cover crop and site on orange fruit weight (g) at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni	KALRO-Matuga	Ganda
Dolichos	251.7a	261.8a	275.7b
Mucuna	252.6a	268.3a	284.4a
Cowpea	240.6b	249.6b	268.8c
Control	234.7b	242.9b	253.5d
LSD $(P \leq 0.05)$	7.36	9.13	8.01
CV%	9.08	7.34	7.85
Pr >F	0.039	0.042	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

5.3.4 Effects of legume cover crop and season on orange fruit weight

The analysis of variance showed that there was a significant interaction between treatment and season ($F= 2.77$; $P<0.03$) on orange fruit weight (Appendix 5.2).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit weight varied with seasons (Table 5.4). The season six was found to have the highest orange fruit weight when compared with other season. Season one was found to have the lowest orange fruit weight when compared with the other seasons. Season four recorded low fruit weight compared to season three. Orange fruit weight was highest in legume mucuna but lowest in cowpea. Mucuna increased orange fruit weight by 5.5%, 7.5%, 7.8%, 7.3%, 9.8% and 11.7% in seasons 1, 2, 3, 4, 5 and 6 respectively. Dolichos increased orange fruit weight by 3.8%, 5.3%, 7.1%, 6.5%, 8.1% and 9.0% in seasons 1, 2, 3, 4, 5 and 6 respectively. Cowpea increased orange fruit weight by 2.9%, 4.7%, 5.9%, 5.3%, 9.5% and 8.2% in seasons 1, 2, 3, 4, 5 and 6 respectively.

Table 5.4: Effects of cover crop and season on orange fruit weight (g) at Vitengeni, KALRO-Matuga and Ganda

	2012		2013		2014	
Treatment	S/ 1	S/ 2	S/ 3	S/ 4	S/ 5	S/ 6
Dolichos	251.6a	254.0b	259.9a	256.7a	264.6a	265.5a
Mucuna	255.7a	259.4a	261.6a	258.6a	268.8a	272.1a
Cowpea	249.3a	252.5b	257.0b	253.8b	263.2a	263.6a
Control	242.3a	241.2b	242.7b	241.0b	244.8b	243.6b
LSD $(P \leq 0.05)$	14.83	17.51	16.46	14.26	16.78	18.67
CV %	10.35	11.40	9.81	9.84	11.48	12.32
Pr >F	0.279	0.046	0.041	0.012	0.008	0.018

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.
S/=Season

5.3.5 Effects of legume cover crop and site on orange fruit diameter

The analysis of the variance showed that there was a significant interaction between treatment and site (F= 4.25; P<0.04) on orange fruit diameter (Appendix 5.3).

Effect of mucuna, dolichos and cowpea legume cover crops on orange fruit diameter varied with site (Table 5.5). The site Ganda was found to have the highest orange fruit diameter when compared with Vitengeni and KALRO-Matuga. The site Vitengeni was found to have the lowest orange fruit diameter when compared with KALRO-Matuga and Ganda. With each site, orange fruit diameter was highest in legume mucuna but lowest in cowpea. Mucuna treated plots recorded a significant increase in orange fruit diameter by 8.1%, 5.5% and 5.1% for Ganda, KALRO-Matuga and Vitengeni respectively. Dolichos and cowpea treated plots recorded a significant increase in orange fruit diameter by 4.9% and 4.2 respectively for Ganda. As opposed to mucuna, dolichos and cowpea treated plots increased a comparable but insignificant orange fruit diameter for KALRO-Matuga and Vitengeni.

Table 5.5: Effects of legume cover crop and site on orange fruit diameter (mm) at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni	KALRO-Matuga	Ganda
Dolichos	67.3b	69.2b	72.6b
Mucuna	69.5a	71.3a	74.8a
Cowpea	67.0b	68.9b	72.1b
Control	66.1b	67.4b	69.2c
LSD $(P \leq 0.05)$	2.03	2.12	2.06
CV%	5.41	4.86	5.62
Pr >F	0.041	0.044	0.026

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

5.3.6 Effects of legume cover crop and site on orange fruit juice

The analysis of variance showed a significant interaction between treatment and site (F= 3.81; P<0.002) on orange fruit juice (Appendix 5.4).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit juice varied with site (Table 5.6). The site Ganda was found to have the highest orange fruit juice when compared with Vitengeni and KALRO-Matuga. The site Vitengeni was found to have the lowest orange fruit juice when compared with KALRO-Matuga and Ganda. With each site, orange fruit juice was highest in legume mucuna but lowest in cowpea. Mucuna significant increased orange fruit juice by 7.2%, 5.5% and 4.8% for Ganda, KALRO-Matuga and Vitengeni respectively. Orange fruit juice significant increased by 4.6% and 3.4% for Ganda and KALRO-Matuga respectively due to dolichos.

Table 5.6: Effects of legume cover crop and site on orange fruit juice (ml) at Vitengeni, KALRO-Matuga and Ganda

	Site		
Treatment	Vitengeni	KALRO-Matuga	Ganda
Dolichos	87.6b	94.5b	96.4b
Mucuna	90.2a	96.4a	98.8a
Cowpea	86.7b	92.8c	93.7c
Control	86.1b	91.4c	92.2c
LSD $(P \leq 0.05)$	1.89	1.74	1.91
CV%	12.89	13.17	10.61
Pr >F	0.004	0.012	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$. NS = Not Significant at $P \leq 0.05$.

5.3.7 Effects of legume cover crop and season on orange fruit juice

The analysis of variance showed a significant interaction between treatment and season ($F = 3.18$; $P < 0.03$) on orange fruit juice (Appendix 5.4).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit juice varied with seasons (Table 5.7). The season six was found to have the highest orange fruit juice when compared with other seasons. Season one was found to have the lowest orange fruit juice when compared with the other seasons. Orange fruit juice was highest in legume mucuna but lowest in cowpea. Mucuna increased orange fruit juice by 3.6%, 4.9%, 5.9%, 6.1%, 7.5% and 8.6% in seasons 1, 2, 3, 4, 5 and 6 respectively. Dolichos increased orange fruit juice by 1.5%, 3.1%, 4.6%, 4.7%, 6.0% and 6.8% in seasons 1, 2, 3, 4, 5 and 6 respectively. Cowpea increased orange fruit juice by 1.2%, 2.5%, 3.6%, 3.7%, 4.1% and 4.9% in seasons 1, 2, 3, 4, 5 and 6 respectively.

The interaction effect of mucuna with season significantly increased the orange fruit juice in the 1st to 6th fruiting season. Interaction effect of dolichos with season significantly increased orange fruit juice in the 2nd to 6th fruiting season. The interaction effect of cowpea with season increased orange fruit juice in the 3rd to 6th fruiting season.

Table 5.7: Effects of legume cover crop and season on orange fruit juice (ml) at Vitengeni, KALRO-Matuga and Ganda

	Year					
	2012		2013		2014	
Treatment	S 1	S 2	S 3	S 4	S 5	S 6
Dolichos	90.0b	90.8ab	93.7a	91.3a	94.8a	95.8b
Mucuna	91.9a	92.4a	94.9a	92.5a	96.1a	97.4a
Cowpea	89.8b	90.3b	92.8a	90.4a	93.1b	94.1c
Control	88.7b	88.1b	89.6b	87.2b	89.4c	89.7d
LSD $(P \leq 0.05)$	1.68	2.11	2.24	2.18	1.51	1.36
CV%	6.41	7.62	8.64	10.92	8.98	7.29
Pr >F	0.049	0.057	0.037	0.031	0.028	0.023

Means within the column followed by same letter are not significantly different at $P \leq 0.05$. S =Season

5.3.8 Effects of legume cover crop and site on orange fruit brix

The results of analysis of variance showed a significant interaction between treatment and site (F= 3.37; P<0.007) on fruit brix (Appendix 5.5).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit brix varied with site (Table 5.8). The site Vitengeni was found to have the highest fruit brix when compared with KALRO-Matuga and Ganda. The site Ganda was found to have the lowest orange fruit brix when compared with KALRO-Matuga and Vitengeni. With each site, orange fruit brix was highest in legume mucuna but lowest in dolichos. Mucuna treated plots significantly increased orange fruit brix by 5.8%, 5.1% and 4.2% for Vitengeni, KALRO-Matuga and Ganda respectively. Cowpea treated plots significantly increased orange fruit brix by 4.6%, 3.8% and 3.2% for Vitengeni, KALRO-Matuga and Ganda respectively. Dolichos treated plots recorded a significant increase in orange fruit brix by 3.3% and 3.1% for Vitengeni and KALRO-Matuga respectively.

Table 5.8: Effects of legume cover crop and site on orange fruit brix (%)at Vitengeni, KALRO-Matuga and Ganda

Treatment	Site		
	Vitengeni	KALRO-Matuga	Ganda
Dolichos	46.69c	46.55c	45.64c
Mucuna	47.84a	47.43a	46.57a
Cowpea	47.18b	46.87b	46.12b
Control	45.21d	45.15d	44.68c
LSD $(P \leq 0.05)$	0.29	0.30	0.21
CV%	4.97	4.42	5.42
Pr >F	0.0072	0.002	0.016

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.

5.3.9 Effects of legume cover crop and season on orange fruit brix

The results of analysis of variance showed a significant interaction between treatment and season ($F= 2.27$; $P< 0.003$) on fruit brix (Appendix 5.5).

Effect of mucuna, dolichos and cowpea legume cover crops on the level of orange fruit brix varied with seasons (Table 5.9). The season six was found to have the highest orange fruit brix when compared with other seasons. Season one was found to have the lowest orange fruit brix when compared with the other seasons. Orange fruit brix was highest in legume mucuna but lowest in dolichos. The orange brix (fruit sweetness) level increase as a result of using legume cover crops. Mucuna significantly increased orange fruit brix by 0.9%, 1.5%, 2.0%, 3.0%, 3.7% and 4.1% from 1st season to 6th season respectively. Cowpea significantly increased orange fruit brix by 1.4%, 1.7%, 2.1%, 2.4% and 2.9% from 2nd season to 6th season respectively. Dolichos significantly increased orange fruit brix by 0.9%, 1.2%, 1.9% and 2.2% from 3rd season to 6th season respectively.

Table 5.9: Effects of legume cover crop and season on orange fruit brix (%) at Vitengeni, KALRO-Matuga and Ganda

Treatment	Year					
	2012		2013		2014	
	S 1	S 2	S 3	S 4	S 5	S 6
Dolichos	46.00b	46.05b	46.43c	46.55c	46.86c	46.96
Mucuna	46.39a	46.70a	46.92a	47.34a	47.68a	47.82a
Cowpea	46.01b	46.67a	46.78b	46.95b	47.08b	47.26b
Control	45.99b	46.01b	46.00d	45.98d	45.97d	45.95d
LSD $(P \leq 0.05)$	0.029	0.044	0.062	0.034	0.052	0.064
CV%	0.961	0.856	1.462	1.063	1.479	1.569
Pr >F	0.032	0.001	0.034	0.001	0.001	0.001

Means within the column followed by same letter are not significantly different at $P \leq 0.05$.
S =Season

DISCUSSIONS

5.4.1 Discussion on the effect of cover crops on orange fruit number

The sites varied in terms of agro-ecological zones, amount of rainfall received (Table 5.1) and distribution and also varied with soil type hence different soil moisture retention. The improved moisture in the soil due to cover crops could have influenced the increase in number of orange fruits could support.

The significant increase of fruit numbers on cover crop could be attributed to the ability of dolichos and mucuna legume cover crop to improve soil water holding capacities leading to improved fruit set (Morgan *et al.*, 2010). Abdel-Aziz *et al.* (2008) reported an increase in fruit set orange tree vegetative growth and fruit yield with reduced fruit drop as a result of increased soil moisture due to cover cropping. Abayomi *et al.*, (2001) reported that mucuna and dolichos covered the ground shortly after germination and are efficient in biomass production and mulching of soil.

5.4.2 Discussion on effects of legume cover crops on orange fruit weight

The sites varied in terms of soil type and rainfall received and this could have contributed to the site effects. Each site has different soil type and received different amount of rainfall which could have influenced the site variation, orange tree water uptake and orange fruit water accumulation. The biomass when on the soil surface acts as mulching material, lowering soil temperature fluctuations and moisture loss through evaporation (Abera *et al.*, 2012). The increase in fruit weight because of legume cover crop could have been attributed to improved soil nutritional status, soil water holding capacities fruit nutritional tree support. Swella *et al.* (2015) demonstrated that soil water retention in farming systems using cover crops is higher as compared to bare soil surface.

The sixth season recorded the highest increase in orange fruit weight while the first season recorded the least orange fruit weight gain. Season 4 recorded the low fruit weight as compared to season 3, the said season 4 received lowest rainfall across the sites as compared to other seasons. It can be argued that the weight gain over the season is a clear indication of nutritional and moisture increase in the soil due to cover cropping. Fruit trees require plant nutrients and water to support the fruit development and expansion. The legume cover crop increased soil moisture retention based on type of legume and this may have also influenced fruit weight gain. Treeby *et al.* (2007) argued that the amount of water in soil dictated orange tree growth and fruit development. According to Kallsen and Sanden (2011), weather conditions influence citrus tree vegetative growth, flowering, fruit formation and fruit quality. Additionally, Ripoll *et al.* (2014), reported that water influences nutrient uptake by fruits trees thus influencing fruit quality and quantity. The increased fruit weight recorded during the 2014 (5th and 6th season) may have been attributed to accumulation of plant nutrients in the soil over time because of legume cover crop. According to Mubiru and Coyne (2009), Wu *et al.* (2011), Ngome *et al.*, (2011) and Carvalho *et al.* (2014) legume cover crop contributed to the increase of plant nutrients in the soil through biological and chemical processes.

5.4.3 Discussion on effects of legume cover crops on orange fruit diameter

The use of legume cover crop may have increased organic matter in the soil and improve water infiltration and recharging of soil water from rainfall. The reduced surface evaporation due to cover crops improves water storage in the soil. Thierfelder and Wall, (2009) reported that the use of cover crop as a water conservation technique which reduces the runoff. According to Ceballos *et al.* (2012), mucuna establishes a good ground cover which helps in biomass accumulation, soil moisture retention, leading to improved orange fruit development. Karuku *et al.* (2014) study observed a decline in fruit size and yield as a result of soil water deficit during fruit development.

The effect of mucuna, dolichos and cowpea cover crops on orange fruit diameter was significantly influenced by season and site. Each site has different soil type and the amount of rainfall received different from season to season. The site and season differences could have influenced the growth and development of the orange fruit (Table 5.1). Treeby *et al.* (2007) argued that the amount of water in soil dictated orange tree growth and fruit development.

5.4.4 Discussion on effects of legume cover crops on orange fruit juice

Ganda site whose soil is sandy received highest rainfall and was found to have the highest orange fruit juice when compared with KALRO-Matuga and Vitengeni. The site Vitengeni whose soil is sandy loam received the lowest rainfall and was found to have the lowest orange fruit juice. The site differed in terms of soil and rainfall received, this contributed to the interaction effects of treatment and site. The different type of legume cover crops differed in their effects ti orange fruit juice. Mucuna treated plots had the highest orange fruit juice across the sites while cowpea had the lowest orange fruit juice.

5.4.5 Discussion on effects of legume cover crops on orange fruit brix

The amount of rainfall received by each site was different and this could have influenced the level of brix accumulation by the orange fruit. Ganda received the highest amount of rainfall of 410.8mm during the fruiting period and has the lowest orange fruit brix. Vitengeni received lowest amount of rainfall 328.5mm during the fruiting periods but recorded the highest orange fruit brix (Table 5.1). It can be argued that the more the soil moisture, the more the juice but the less the fruit brix. Barry and Castle, (2004) showed that there is fruit sucrose hydrolysis on well watered trees. Barry *et al.*, (2003) argued that the sugar accumulation in citrus fruit was influenced by plant water relations. The results on increase in fruit brix correspond with the observed increase in potassium by legume cover crops mucuna and cowpea. Gattuso *et al.* (2007) found that the nutritional supply from the soil especially potassium, improves the sugar composition of citrus fruits.

The fifth and sixth seasons of year three (2014) recorded the highest increase in orange fruit brix while the first and second seasons of year one (2012) recorded the least amount of orange fruit brix. The increase in fruit brix over the three years may have been attributed to the use of cover crops. It can be argued that the fruit brix gain over the seasons is a clear indication of increase in plant nutrients in the soil. Fruit trees require plant nutrients and water to support the fruit development and brix. The observed results agree with Garcia *et al.* (2010) who reported that low irrigated citrus influence the fruit soluble solids composition in the juice. Although season 4 recorded low rainfall in all the sites, the fruit brix increased despite low moisture level. The results agree with Gattuso *et al.* (2007) who reported that water stressed tree reduces citrus fruit juice but increases the total sugar (brix) in the juice. Ladaniya and Ladaniya (2010) indicated that the soluble solid in fruit juice is a factor of the available water in the fruits.

The fifth and sixth seasons recorded the highest increase in orange fruit juice while the first and second seasons recorded the least amount of orange fruit juice. The increased fruit juice recorded over time may have been attributed to accumulation of legume cover crop residues in the soil. It can be argued that the juice gain over the season is a clear indication of moisture increase in the soil. Swella *et al.* (2015) demonstrated that soil water retention in farming systems using cover crops is higher as compared to surfaces without cover crops. Fruit trees require plant nutrients and water to support the fruit development and juice content. The legume cover crop increased soil moisture retention based on type of legume and this may have also influenced the amount of fruit juice. Hoorman (2009) observed that storage of soil moisture improved with the use of cover crops. There are more rains during long rains compared to short rains (Table 5.1). According to Garcia *et al.* (2010); Ladanyia and Landaniya (2010) and Gattuso *et al.* (2007), low moisture in the soil leading to water stress reduces citrus fruit juice.

Conclusions and Recommendations

The results of this study showed that the use of legume cover crops significantly increased orange tree yield and improved fruit quality compared to the control. Mucuna and dolichos cover crop contributed to the increase in fruit number across the sites. The use of mucuna contributed to high increase in orange fruit weight across the sites and seasons. Dolichos and mucuna increased the orange fruit diameter across the sites. Cowpea, mucuna and dolichos increased the juice in orange fruits across the sites and seasons. The fruit brix increased as a result of using mucuna, cowpea and dolichos across the sites and seasons. Mucuna cover crop recorded the highest increase in orange fruit number, fruit weight, fruit diameter and fruit brix while cowpea had the least increase compared to the control. Cowpea recorded the highest increase in fruit juice while dolichos recorded the least increase compared to the control. The control plots recorded the lowest in all the parameters under evaluation. It can, therefore, be concluded that mucuna and dolichos cover crops contribute to increased production and improved fruit quality. From the outcome of this study, mucuna and dolichos legume cover crops are recommended for use in orange tree orchards. The adoption of these findings by farmers can aid in improving soil fertility management and orange productivity in the coastal lowlands of Kenya. Further studies are however, suggested to evaluate the long term (> 3years) effect of the different cover crops on orange tree yield and fruit quality under different agro-ecological zones.

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General conclusion

Orange is among the important fruit crop grown mostly by small-scale farmers in the coastal lowlands of Kenya. The fruit yield and quality of orange is continuously declining due to challenges of low soil nutrient content (Chapter 1, section 1.1). Majority of the farmers grow their orange trees as a pure stand. Legume cover crops can protect and improve soil productivity through the addition of organic mass decomposition and nitrogen fixation from roots hence a cheap source of organic matter, N, P, K. The results of this study show that use of legume cover crops improved soil moisture storage and retention levels, enhanced orange feeder root distribution in orange trees. Mucuna cover crop formed thick foliage ground cover and produced more organic matter on the soil surface as compared to dolichos and cowpea (Appendix 2.1 and 2.4). The soil moisture and root distribution varied with soil depth, soil type and the type of cover crop. Soil moisture and root density decreased with soil depth and vice versa. There was more water retention within the topsoil (0-20 cm) compared to sub-soil (20-40 cm) as a result of using cover cropping system.

The selection of the tropical legumes was based on adaptability, growth characteristics including the economical uses like vegetable, seed and fodder when harvested. Dolichos and cowpea are mainly grown as food crop but they can also be used as animal fodder. Mucuna is mainly grown as a fodder crop the seed has several challenges when it comes to human consumption because of its chemical content.

Data on the following parameters were gathered in the process of identifying the most appropriate legume cover crop in orange crop production:

(a) Soil moisture

(b) Root distribution density

(c) Soil pH

(d) Soil plant nutrient content

(e) Orange leaf chlorophyll content

(f) Fruit yield

(g) Fruit quality

Mucuna had the highest soil moisture and root density enhancement as observed from results. Increase in soil moisture and feeder root distribution could have been due to accumulation of soil organic matter, enhanced soil porosity, water infiltration and improved soil microclimate. It was observed that root distribution density increased within soil zones with high moisture. It can therefore be concluded from the results that mucuna and dolichos are viable cover crops that can aid in improving orange soil moisture and enhance orange root distribution.

The influence of the legume cover crops on soil properties varied whereby fruit juice brix increased when mucuna was used as a cover crop. This legume also showed high increase in potassium in the soil (Chapter 4, section 4.3.5). Potassium has many roles in plant and fruit development. This nutrient translocates water into the cell of a developing fruit and also is responsible for the total soluble solutes. Chlorophyll level in leaves is one of the key parameters and indicator of crop productivity potential. The orange leaf chlorophyll content varied with different cover crops, a clear indicator of their different potential in increasing orange fruit productivity (Chapter 4, in section 4.3.9). Soil pH level can influence uptake of some plant nutrients from the soil and reduce their availability to plants. The results show that there was no significant effect on soil pH as a result of using legume cover crops (Chapter 4, section 4.3.8).

Fruit yield and quality could be associated with high soil moisture retention and soil nutrient level as result of using cover crops (Chapter 3 and 4).

coastal region of Kenya has a diverse cropping systems hence need for proper soil agement through the use of legumes by small-scale farmers. The use of these tropical ımes cover crops can generally be applied to citrus as well as other crops grown in the on as improved fallows (shortened rest periods).

ults of this study indicate that use of legume cover crop may provide a cost –effective and alternative strategy for soil fertility improvement, soil moisture conservation and weed nagement in small-holder orange farms. The study also demonstrates the potential of er crops in orange production. The use of legume cover crop in the preservation of soil ility for crop production has been proved to be a more sustainable farming system when npared to the use of inorganic fertilizers (Olson *et al.*, 2010). It can be concluded that cuna is the best cover crop among that can aid in improving orange production in the ıstal lowlands of Kenya. The overall ranking of the three legume species evaluated in this dy in terms of:

(a) Soil moisture retention improvement and increase in orange root distribution; mucuna > dolichos > cowpea

(b) Soil plant nutrients improvement and orange leaf chlorophyll content increase; mucuna > cowpea > dolichos

(c) Orange yield increase and fruit quality improvement; mucuna > dolichos > cowpea

2 General recommendations

ased on the above conclusions, it can therefore be recommended that legume cover crops ould be used to improve soil and water conservation, addition of plant nutrients and nprove orange productivity in the coastal lowlands of Kenya.

he results of this study on the use of legume cover crop should be used to develop orange uit production management plans for the lowlands region of Kenya. Legume cover crops ill allow farmers to reduce input costs, reduce environmental risk and increase orange production. Farmers could be advised to use legume cover crop in tree farming systems to save on labour costs incurred in the orchard field maintenance. Production packages should be developed and easy access of seed to the farmers established. Institutions dealing with agricultural research and extension services should facilitate farmers in cover crop seed bulking production. With persistence and creativity, cover cropping can provide many benefits at minimum input cost. The adaptability of this technology among the small-scale farmers and the long term impact of cover cropping system in orange production also should be established.

6.3 Suggested areas for further research

The following study areas can be suggested from this study;

- There is need to undertake research to ascertain the effects of long term (more than the three years) use of cover cropping system in orange production.
- It is important to test more types of legumes to find out the most appropriate interms of different agro-ecological zones and socio-economic factors.
- There is need to test nutrient content within orange fruit or leaf of orange trees to ascertain the actual nutrient taken up by the crop.

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ENDICES

Appendix 1.1: Rainfall data for the study sites

No. 6A (Rev 7/70) KENYA METEOROLOGICAL DEPARTMENT

ndix 1.2: Ganda rainfall observation at for the year January 2012- April, 2015

ıisi Rainfall (mm) 2km From the site													
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL	MEAN
0	0	7.3	66.1	128	78.2	68	45.6	25.5	51	73.4	110.5	654.1	54.6
0	0	1	3	10	6	4	3	3	4	6	12	52	
1	0	112.4	223	203	97.5	32.2	53.4	93.2	64.1	131	51.4	1062.2	114
1	0	6	8	10	4	2	3	5	3	6	3	51	
0	11.4	49	134.3	374.1	173	116	36.2	34.3	76.1	102	163.1	1264.5	129
0	2	5	6	13	7	6	3	2	3	6	6	59	
0	24	27	134									993.6	
0	4	6	11										

ndix 1.3: KALRO-Matuga rainfall observation at for the year January 2012- April 2015

LRO-Matuga Rainfall (mm) 200m From site													
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL	MEAN
0	0	31.5	37.5	170	9	17	70	87.9	61.8	15	29	528.6	44.1
0	0	4	2	11	2	2	2	7	5	3	1	39	
0	18.8	77.7	107	225	35.8	0	0	215	58.7	0	0	738.1	61.5
0	2	6	5	5	2	0	0	4	3	0	0	27	
0	0	94.5	60.8	270	203	118.5	38.8	123.8	186.5	69.5	88.1	1253.9	110
0	0	6	4	9	5	6	3	6	5	2	2	48	
0	8.5	40	113									840.2	
0	1	5	7										

ppendix 1.4: Vitengeni rainfall observation at for the year January 2012- April 2015
'itengeni Rainfall (mm) 1km From the site

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL	MEAN
2012	0	0	0	22.8	97.7	39.5	21.6	91	23.2	160	154	54.9	664.1	55.3
Days	0	0	0	1	5	4	4	4	2	5	8	4	37	
2013	0	0	16	6.4	224	55.9	22	23.7	35.2	35.2	25.4	109	552.4	46.0
Days	0	0	3	2	10	8	4	3	4	4	4	7	49	
2014	0	0	48.9	62	234	58.1	46.5	35.1	34.2	130	143	119	910.5	75.9
Days	0	0	8	7	10	7	3	4	3	6	8	8	64	
2015	0	0	26	78									709.0	
Days	0	0	2	4										

ource: Kenya Meteorological Department Field Stations

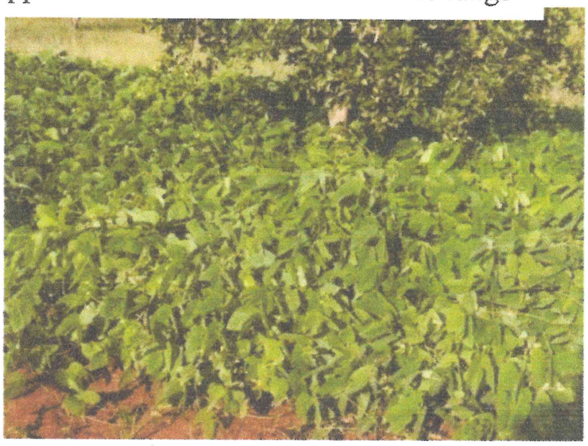
ppendix 2.1: Orange tree planted with cover crop at different growth stages

Appendix 2.2 Mucuna at full ground cover

Appendix 2.3: Mucuna at aging stage

Appendix 2.4: Mucuna cover at a distance

Appendix 2.5: Mucuna cover at close range



endix 3. 0: Soil textural properties for Vitengeni, KALRO-Matuga and Ganda

	Vitengeni	KALRO-Matuga	Ganda
	Proportion (%)	Proportion (%)	Proportion (%)
ınd	65	84	91
ay	26	14	6
ilt	9	2	3
ture	**SCL**	**LS**	**S**

= Particle Size Distribution; SCL=sandy clay loam; LS=loamy sand; S= sandy soil

oisture and Root Distribution Analysis of Variance for Vitengeni, KALRO-a and Ganda

lix 3.1a: Effect of legume cover crops on soil moisture at 0-20cm soil depth

of variation	df	SS	MS	F value	Pr(>F)
	3	1.1	0.35	0.198	0.8971
ent	3	75.3	25.10	13.073	0.0014 ***
	2	21.0	10.48	5.469	0.0514
	2	240.2	120.08	62.542	0.0532
ent x site	6	3.6	0.59	3.332	0.0302 *
ent x year	6	6.6	1.11	6.620	0.0651
year	4	30.3	7.575	4.231	0.8454
ent x site x year	12	14.3	1.19	0.665	0.7855
als	393	702.4	1.79		

dix 3.1b: Effect of legume cover crops on soil moisture at 20-40cm soil depth

e of variation	df	SS	MS	F value	Pr(>F)
	3	2.7	0.90	0.509	0.6764
ment	3	140.1	46.69	24.691	0.0026 **
	2	16.6	8.30	4.393	0.0698
	2	163.9	81.95	43.265	0.0767
ment x site	6	5.1	0.85	2.479	0.0241 *
ment x year	6	9.6	1.61	3.910	0.4887
x year	4	33.1	8.27	4.702	0.5872
tment x site x year	12	14.2	1.18	0.670	0.7811
duals	393	693.5	1.76		

ificance different. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 3.2a: Effect of legume cover crops on orange root density at 0-20cm soil depth

Source of variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0309	0.0103	2.759	0.0426 *
Treatment	3	0.0918	0.0306	8.869	0.0028 **
Site	2	0.0056	0.0028	0.762	0.0635
Year	2	0.0712	0.0356	9.519	0.0405 *
Treatment x site	6	0.0342	0.0057	2.651	0.0337 *
Ttreatment x year	6	0.0809	0.0135	3.907	0.0449 *
Site x year	4	0.0304	0.0076	2.200	0.0695 .
Treatment x site x year	12	0.0631	0.0053	1.524	0.1158
Residuals	249	0.8589	0.0035		

Significance different. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 3.2b: Effect of legume cover crops on orange root density at 20-40cm soil depth

Source of variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0576	0.0192	4.583	0.0538.
Treatment	3	0.0261	0.0087	3.076	0.0461 *
Site	2	0.0311	0.0156	3.702	0.0608
Year	2	0.0488	0.0244	5.809	0.0365 *
Treatment x site	6	0.0282	0.0047	4.121	0.0405 *
Treatment x year	6	0.0873	0.0146	3.477	0.0426 *
Site x year	4	0.0132	0.0033	0.789	0.5332
Treatment x site x year	12	0.1140	0.0095	2.270	0.0954
Residuals	249	1.0423	0.0042		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ndix 4.1: Soil Nutrient, Soil pH and orange leaf Analysis of Variance tables for ophyll

ndix 4.1a: Effects of legume cover crops nitrogen in 0-20 cm soil depth

rce of Variation	df	SS	MS	F value	Pr(>F)
:k	3	0.0005	0.0001	1.773	0.1568
ıtment	3	0.0015	0.0005	5.518	0.0028 **
	2	0.0010	0.0005	5.611	0.0682 .
r	2	0.0039	0.0019	21.778	0.0345 *
ıtment x site	6	0.0012	0.0002	2.985	0.0444 *
ıtment x year	6	0.0025	0.0004	4.325	0.0056 **
x year	4	0.0005	0.0001	1.353	0.2554
ıtment x site x year	12	0.0008	0.0001	0.671	0.7756
duals	104	0.0102	0.0001		

ificance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ndix 4.1b: Effect of legume cover crops on nitrogen in 20-40 cm soil depth

ce of Variation	df	SS	MS	F value	Pr(>F)
:k	3	0.0006	0.0002	1.478	0.2249
tment	3	0.0006	0.0002	3.602	0.0441 *
	2	0.0013	0.0063	4.846	0.0582 .
r	2	0.0042	0.0021	16.231	0.0213 *
tment x site	6	0.0005	0.0001	7.623	0.0477 *
tment x year	6	0.0026	0.0004	3.380	0.0044 **
x year	4	0.0011	0.0003	2.034	0.0949
tment x site x year	12	0.0004	0.0003	0.261	0.9937
duals	104	0.0135	0.00013		

ificance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 ppendix 4.2a: Effect of legume cover crops organic carbon in 0-20 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0586	0.0195	1.541	0.20851
Treatment	3	0.0682	0.0227	1.790	0.00024 ***
Site	2	0.3151	0.1575	12.406	0.04074 *
Year	2	0.1260	0.0630	4.290	0.01495 *
Treatment x site	6	0.1951	0.0325	2.565	0.00234 **
Treatment x year	6	0.0530	0.0088	4.696	0.00345 **
Site x year	4	0.0639	0.0160	1.260	0.29060
Treatment x site x year	12	0.0450	0.0037	0.295	0.9889
Residuals	104	1.3186	0.0127		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.2b: Effect of legume cover crops on organic carbon in 20-40cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.146	0.049	5.113	0.02243 *
Treatment	3	0.332	0.111	11.649	0.00571 **
Site	2	0.142	0.071	7.474	0.04652 *
Year	2	0.056	0.028	2.947	0.52344
Treatment x site	6	0.049	0.008	2.865	0.03681 *
Treatment x year	6	0.266	0.044	4.666	0.02341 *
Site x year	4	0.049	0.012	1.274	0.28510
Treatment x site x year	12	0.048	0.004	0.419	0.95311
Residuals	104	0.9908	0.0095		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ppendix 4.3a: Effect of legume cover crops on soil phosphorous in 0-20 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	68.8	22.9	1.452	0.0569
Treatment	3	137.9	45.9	2.909	0.0186 *
Site	2	102.4	51.2	3.241	0.0365 *
Year	2	719.0	359.5	22.753	0.0215 *
Treatment x site	6	195.2	32.5	3.059	0.0053 **
Treatment x year	6	333.4	55.6	3.510	0.0033 **
Site x year	4	80.0	20.0	1.264	0.2890
Treatment x site x year	12	112.5	9.4	0.592	0.8439
Residuals	104	1 646.4	15.8		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.3b: Effect of legume cover crops on soil phosphorous in 20-40 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	82.9	27.62	3.251	0.0748
Treatment	3	72.5	24.17	2.843	0.0437 *
Site	2	153.2	76.62	9.012	0.0045 **
Year	2	268.7	134.35	15.805	0.0382 *
Treatment x site	6	231.3	38.55	4.537	0.0045 **
Treatment x year	6	144.7	24.12	2.838	0.0134 *
Site x year	4	17.0	4.25	0.500	0.7357
Treatment x site x year	12	53.9	4.49	0.529	0.8919
Residuals	104	883.7	8.50		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.4a: Effect of legume cover crops on soil potassium in 0-20 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0175	0.0058	1.495	0.2203
Treatment	3	0.0408	0.0135	3.462	0.0414 *
Site	2	0.0303	0.0152	3.885	0.6721
Year	2	0.0407	0.0204	5.231	0.8635
Treatment x site	6	0.0613	0.0102	2.624	0.0508 .
Treatment x year	6	0.0423	0.0071	1.808	0.0555 .
Site x year	4	0.0566	0.0142	3.637	0.0582
Treatment x site x y	12	0.0564	0.0047	1.207	0.2879
Residuals	104	0.4050	0.0039		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.4b: Effect of legume cover crops on soil potassium in 20-40 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0052	0.0017	0.474	0.7014
Treatment	3	0.0244	0.0081	2.234	0.0487 *
Site	2	0.0366	0.1831	5.027	0.2168
Year	2	0.0320	0.0161	4.396	0.6516
Treatment x site	6	0.0575	0.0096	2.633	0.0504 .
Treatment x year	6	0.0413	0.0069	1.891	0.0963 .
Site x year	4	0.0424	0.0106	2.912	0.0604 .
Treatment x site x year	12	0.0377	0.0031	0.863	0.58646
Residuals	104	0.3785	0.0036		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

Appendix 4.5a: Effect of legume cover crops on soil pH level in 0-20 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.439	0.146	3.658	0.9463
Treatment	3	0.769	0.256	6.424	0.0592 .
Site	2	0.136	0.068	3.677	0.0464 *
Year	2	0.055	0.028	0.690	0.5039
Treatment x site	6	0.621	0.103	2.591	0.0622 .
Treatment x year	6	0.013	0.002	0.056	0.9993
Site x year	4	0.001	0.000	0.007	0.9998
Treatment x site x year	12	0.007	0.001	0.014	1.0000
Residuals	104	4.151	0.040		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.5b: Effect of legume cover crops on soil pH level in 20-40 cm soil depth

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	1.145	0.382	6.434	0.0705 .
Treatment	3	0.863	0.288	4.850	0.0634 .
Site	2	2.884	1.442	24.441	0.0563 .
Year	2	0.032	0.016	0.268	0.7652
Treatment x site	6	0.370	0.062	1.045	0.5358
Treatment x year	6	0.013	0.002	0.037	0.9997
Site x year	4	0.002	0.001	0.009	0.9998
Treatment x site x year	12	0.013	0.001	0.019	1.0000
Residuals	104	6.169	0.059		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4.6: Effect of legume cover crops on orange leaf chlorophyll

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	5	1.7	0.215	0.88592
Treatment	3	2269	756.3	95.738	0.00165 **
Season	5	744	148.8	18.835	0.00264 **
Site	2	123	61.5	7.785	0.03271 *
Treatment x site	6	161	26.8	3.394	0.04323 *
Treatment x season	15	1070	71.3	2.230	0.00268 **
Season x site	10	120	12.0	1.519	0.18592
Treatment x season x site	30	311	10.4	1.313	0.13837
Residuals	211	1665	7.9		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.1: Analysis of Variance tables for orange tree yield and fruit quality

Appendix 5.1: Effect of legume cover crops on orange fruit number

Source of Variation	df	ss	ms	F value	Pr(>F)
Block	3	2340	7798	1.378	0.2514
Treatment	3	1452	4838	8.548	0.0352 *
Season	5	6388	1278	2.257	0.0502
Site	2	2654	1327	23.443	0.0277 *
Treatment x site	6	5912	9853	3.741	0.0138 *
Treatment xseason	15	1001	6674	1.179	0.0905
Season x site	10	1872	1872	0.331	0.9726
Treatment x season x site	30	6588	2196	0.388	0.9991
Residuals	211	1194	5660		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.2: Effect of legume cover crops on orange fruit weight

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	1012	3372	6.548	0.05121 .
Treatment	3	1273	4242	8.238	0.04510 *
Season	5	1046	2091	4.059	0.00154 **
Site	2	2978	1489	2.891	0.00231 **
Treatment x site	6	1026	1709	3.319	0.04564 *
Treatment x season	15	5950	397	2.770	0.03091 *
Season x site	10	3658	366	0.710	0.71451
Treatment x season x site	30	5397	180	0.349	0.99946
Residuals	211	1087	515		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.3: Effect of legume cover crops on orange fruit diameter

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.38	0.128	0.538	0.65650
Treatment	3	3.23	1.077	4.543	0.04103 *
Season	5	12.46	2.492	6.515	0.14088
Site	2	14.36	7.180	10.295	0.04216 *
Treatment x site	6	6.04	1.007	4.246	0.03546 *
Ttreatment x season	15	3.39	0.226	0.953	0.50694
Season x site	10	22.54	2.254	9.511	0.06456
Treatment x season x site	30	5.44	0.181	0.764	0.80798
Residuals	211	50.03	0.237		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.4: Effect of legume cover crops on orange fruit juice

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	272	91	0.736	0.531591
Treatment	3	7136	2378	19.339	0.066682
Season	5	1011	202	3.644	0.029434 *
Site	2	5814	2907	23.634	0.035616 *
Treatment x site	6	2811	469	3.808	0.001263 **
Treatment x season	15	2175	145	3.179	0.029287 *
Season x site	10	2436	244	1.980	0.056811 .
Treatment x season x site	30	4276	143	1.159	0.270568
Residuals	211	2596	123		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.5: Effect of legume cover crops on orange brix

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	2.07	0.689	4.849	0.05277 .
Treatment	3	16.06	5.353	37.271	0.00257 **
Season	5	5.10	1.020	7.183	0.03576 *
site	2	6.17	3.085	21.725	0.01638 *
Treatment x site	6	1.17	0.195	3.369	0.00721 **
Treatment x season	15	4.41	0.294	2.270	0.00323 **
Season x site	10	3.57	0.357	2.509	0.22840
Treatment x season x site	30	5.76	0.192	1.352	0.11519
Residuals	211	30.00	0.142		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5.6: Effect of legume cover crops on orange fruit Rind

Source of Variation	df	SS	MS	F value	Pr(>F)
Block	3	0.0009	0.0004	1.756	0.15661
Treatment	3	0.0336	0.0112	64.539	0.25722
Season	5	0.0186	0.0037	3.448	0.04186 *
Site	2	0.0161	0.0081	6.445	0.95629
Treatment x site	6	0.0035	0.0006	3.345	0.63661
Treatment x season	15	0.0047	0.0003	1.785	0.06831 .
Season:site	10	0.0110	0.0011	6.358	0.58853
Treatment x season x site	30	0.0085	0.0003	1.628	0.07630 .
Residuals	211	0.0366	0.0002		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1