ENHANCING PERFORMANCE OF MAIZE-COWPEA BASED CROPPING SYSTEMS IN COASTAL LOWLAND KENYA THROUGH STRESS RESILIENT VARIETIES AND SOIL MOISTURE CONSERVATION PRACTICES

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DECLARATION

I hereby declare that this is my original work and has not been presented in this or any other University for the award of a degree.

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DEDICATION

I dedicate this thesis to my beloved wife Patience Mulaa Ndiso, and my five beautiful daughters Grace Dhahabu Birya, Faith Karembo Birya, Mercy Kanze Birya, Tabitha Haluwa Birya and Hope Faida Birya, for the patience, support and encouragement they gave me while pursuing the Doctor of Philosophy in Agronomy.

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GENERAL ABSTRACT

Coastal lowland region of Kenya is prone to drought hence enhancing productivity of maize-cowpea based cropping systems requires deployment of stress resilient varieties and agronomic practices that enhance moisture retention. Studies were conducted on-farm at Tezo location and on-station at Pwani University and Kenya Agricultural and Livestock Research Organization Mtwapa, coastal lowland Kenya, in the short rains and long rains of 2011 and 2012. The objectives were: (i) To identify cowpea varieties most preferred by coastal farmers through participatory variety selection; (ii) To determine the influence of drought stress on canopy temperature, chlorophyll content, growth and yield of local and improved cowpea varieties; (iii) To determine the effect of variety and insecticide application on pest damage and growth and yield of local and improved cowpea varieties (iv) To determine the effect of intercropping maize and cowpea on soil moisture content, canopy temperature, chlorophyll content, growth and yield of the component crops; (v) To determine the effect of cowpea crop residue management on soil moisture content, canopy temperature, chlorophyll content, growth and yield of intercropped maize and cowpea; (vi) To determine the effect of different farmyard manure levels on soil moisture content, canopy temperature, chlorophyll content, growth and yield of intercropped maize and cowpea; (vii) To determine the effect of varying N-fertilizer application on soil moisture content, canopy temperature, chlorophyll content, growth and yield of intercropped maize and cowpea in coastal lowland Kenya. All the experiments were laid out in randomized complete block design and replicated three times. In all the experiments, data collected were subjected to analysis of variance using SAS and means separated using the least significant difference (LSD) at p=0.05. In the first objective, participatory cowpea varietal evaluation of 11 cowpea varieties was conducted using criteria developed by farmers. Farmers' cowpea selection criteria before

flowering and at podding were high grain yield, drought tolerance, early maturity, ease of harvesting and leafiness. Kutambaa, KVU 27-1 and Nyeupe were rated top varieties at these stages. Farmers' selection criteria at maturity and after harvest included grain yield, color, taste and cooking duration. KVU 419, Kaima koko and Nyeupe were rated top varieties at these stages. In the second objective, the 11 cowpea varieties were subjected to no water stress, water stress during the vegetative stage and water stress during flowering. Water stress imposed at vegetative growth stage and flowering reduced cowpea growth attributes (plant height, shoot dry matter, and leaf number), ground cover and chlorophyll content, but increased canopy temperature, time to anthesis, harvest index, grain yield and yield components (pod weight, number of pods, grains per pod and grain weight) for most varieties. In the third objective, 11 cowpea varieties were either sprayed with an insecticide or not sprayed. Pest damage levels at vegetative, flowering, podding and maturity stages were over 50% in all varieties. Insecticide application reduced pod damage and insect pest damage at vegetative, flowering and podding stages. Insecticide application reduced grain yield by a range of 11.6% (Nyekundu) to 662.5% (Macho). In the fourth objective, cowpea variety Nyeupe was either intercropped with maize variety DH04 or maize variety Lamu. Sole crops of both maize varieties and cowpea variety Nyeupe were also evaluated. Sole cowpea plots and maize-cowpea intercrop plots had higher moisture content than sole maize plots. Intercropping reduced chlorophyll content, weed biomass, growth attributes, yield and yield components of maize and cowpea, but increased canopy temperature and cowpea nodule numbers. In the fifth objective, two intercrop systems (Lamu-cowpea and DHO4-cowpea) and three crop residue management options (no residue, surface mulch and crop residue incorporation) were evaluated. Application of crop residues (incorporated or mulched) increased soil moisture content and chlorophyll content, growth attributes, yield and yield components of cowpea and maize, but reduced canopy temperature and

cowpea nodule number. Crop residue incorporation outperformed surface mulching in most plant attributes. In the sixth objective, DH04-cowpea and Lamu-cowpea intercrops were subjected to three farmyard manure levels (0, 2.5 and 5.0 t/ha). Farmyard manure application increased soil moisture content and groundcover, chlorophyll content, growth parameters, yield and yield components of maize plants; however, it reduced canopy temperature and all cowpea plant attributes. DH04-cowpea intercrop outperformed Lamu-cowpea intercrop in most plant attributes. In the seventh objective, DH04-cowpea and Lamu-cowpea intercrops were subjected to three inorganic N-fertilizer levels (0, 30 and 60 kg N/ha). Application of N-fertilizer increased maize chlorophyll content, growth attributes, yield and yield components; however, it reduced these plant attributes canopy temperature and cowpea nodulation. Performance of maize under DH04-cowpea intercrop was higher than under Lamu-cowpea intercrop.

Cowpea varieties most preferred by coastal farmers were KVU 419, Nyeupe, KVU 27-1 and Kutambaa. Water stress reduced cowpea growth, but enhanced grain yield and yield components. None of the 11 varieties was resistant to insect pests, but varied in the response to insecticide application. Intercropping cowpea with either DH04 maize variety or Lamu maize variety was more productive than sole cropping. Surface mulching and crop residue incorporation conserved moisture and enhanced crop performance, with the latter being more beneficial. Farmyard manure application enhanced soil moisture retention and yield performance of maize in maize-cowpea-intercrop but decreased cowpea performance. Application of N-fertilizer reduced cowpea growth and yield but increased these attributes in maize. Crop residue use and applications of farmyard manure and inorganic N-fertilizers decreased canopy temperature. It is advisable for farmers in coastal lowland Kenya to adopt stress resilient varieties and integrate crop residue, farmyard manure and inorganic N-fertilizers in maize-cowpea intercrop systems.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Maize (*Zea mays* L.) is one of the most important cereal crops in the world, extensively grown in irrigated and rain-fed areas (Irshad *et al*., 2002). Generally it ranks third among cereal crops, after wheat and rice. Maize is the most important food crop in coastal lowlands of Kenya, a region which experiences persistent maize crop failures and low yields. The coastal region has an average maize grain yield of 0.5 – 1.0 t ha^{-1}, compared to the national average of 1.5 t ha^{-1} (Duflo *et al*., 2008). In 2009, farmers in coastal Kenya produced 1,194,118 bags of 90 kg maize from a total land area of 115,675 ha, giving an average yield of 0.9 t ha^{-1}. Consequently, about 1.8 million people in the coastal region are food insecure and requires assistance throughout the year (MoA, 2010). The major factors limiting maize yields in the coastal region are soil moisture stress, low soil fertility, and rapid growth of weeds (Saha, 2007). The soil moisture stress is due to low and erratic rainfall (700 – 1000 mm per year) that comes in two seasons (Jaetzold *et al.*, 2012). Also, the soils are sandy and have very low water retention capacity; hence, crops grown on them often suffer drought stress (Adcock *et al*., 2006). Further, the soils are characterized by low organic matter and are deficient in major nutrients, especially nitrogen (Ndiso *et al*., 2012). The moisture stress and low soil fertility problems are exacerbated by rapid growth of weeds due to the hot-humid climate of the region (Saha, 2007). According to Gethi (2002), maize grain is subject to infestation by a complex of pests and diseases consisting primarily of insects, mites and fungi. These contribute to substantial post harvest losses. The total grain loss due to pest infestation in maize is estimated at 57% (Grisley, 1997). The crop losses due to pest infestation of maize and legumes are expected to be higher in the coastal region than other parts of Kenya due to the humid climatic conditions of the region.

In the coastal region of Kenya over 90% of smallholder farmers intercrop or relay crop maize and cowpea (Vigna unguiculata) during the long rains season (Obong'o *et al*., 1993). Cowpea is used for both food and forage (Singh, 2002) and its relatively high protein content makes it an important supplement in the diet of many African people (Bressani, 1985) who consume cereals that are high in carbohydrates but low in protein (Kamara *et al*., 2007). Cowpea is frequently intercropped with cereals, where it contributes to the maintenance of soil fertility (Vanlauwe *et al*., 2007). By incorporating cowpea into the cropping systems, farmers in the region have for long utilized biologically fixed nitrogen to maintain soil fertility (Saha, 2007). The ability of legumes to fix nitrogen through symbiosis with species of rhizobia gives them special value in low input agriculture (Massion-Boivin *et al*., 2009). Some cowpea varieties are drought tolerant and yield well in dry environments (Cattivelli et al., 2008). They have deep root systems that stabilize the soil and enable absorption of water from lower layers of the soil. They also form an effective canopy cover that conserves moisture and can fix up 49.8 kg N ha^{-1} (Hagan *et al*., 2010). However, little is known about the genetic and symbiotic diversity of these bacteria in distinct ecosystems (Gulmaraes *et al*. 2012). Therefore, when cowpea varieties for the region are identified, they are ideal for coastal lowland Kenya where the soils are fragile and droughts are prevalent. Most farmers are aware of the ability of legumes to improve soil fertility and suppress weeds, hence they have for long relied on intercropping or relay cropping cereals with legumes (Saha, 2007). Intercropping maize with cowpea is a common practice in coastal Kenya. Maize-cowpea intercrop has been used to reduce populations of notorious weeds such as nut grass (*Cyperus rotundus*) (Makoi and Ndakidemi, 2011).

1.2 Problem Statement

Maize yields in the coastal region of Kenya are low, ranging from 0.5 t ha^{-1} to 1.0 t ha^{-1} compared to the potential of >3.0 t ha^{-1} (Wekesa *et al*., 2003). Maize production in coastal lowland Kenya is based on a low-input system in which organic and inorganic fertilizers are rarely used. The low maize yields are mostly due to poor soil fertility and low, erratic rainfall. The soils are low in organic matter, resulting in poor infiltration rates and low water holding capacity. Nitrogen is the most limiting nutrient in the region (Ndiso *et al*., 2012). Small holder farmers cannot afford the costly fertilizers. The current cropping systems do not favor improvement in crop yields; build up of organic matter, efficient utilization of soil water, and suppression of weeds. Cowpea has the potential to improve soil fertility through nitrogen fixation when integrated into maize-based cropping systems. However, the cowpea genotypes currently grown in coastal Kenya are unimproved, low yielding and their levels of tolerance to drought and insect pest had not been established. Moderate to heavy stress has been reported to reduce cowpea yield by 42.6 to 98.4% (Abayomi and Abidoye, 2009). A Kenyan report indicates losses of up to 80% occur on indigenous cowpea varieties as a result of pod borer attack (Okeyo-Owuor *et al*., 1983). In addition, most farmers grow local landraces of maize and cowpea rather than improved varieties which have been bred for drought tolerance and insect resistance (Wekesa *et al*., 2003)

1.3 Justification

The best starting point in developing new pro-poor agriculture is the system that farmers have developed and/or inherited over the centuries (Chambers, 1983). Most of the farmers (over 70%) in the coastal region of Kenya grow local coastal maize landraces (LCML) despite the various improved varieties which have been released for growing in the region (Wekesa et al., 2003). However, some of the LCMLs such as Lamu maize variety can perform as well as the improved varieties under drought (Ndiso *et al*., 2012) and low input conditions. Cowpea, the most important grain legume in coastal Kenya, is mainly grown as an intercrop or relay crop with maize (Njunie *et al.,* 2007). As a cover crop, cowpea has the ability to conserve moisture (Ghanbari *et al*., 2010) and improve soil fertility through nitrogen fixation (Giller, 2001). Intercropping combined with competitive maize cultivars can reduce weed infestation (Gomez *et al.*, 2007). One of the component crops in an intercropping system may act as a buffer or barrier against the spread of insect pests and pathogens (Seran and Brintha, 2010). Intercropping with legumes has been rated by farmers in coastal Kenya as one of the most effective and most commonly used method for improving soil fertility (Mureithi *et al.*, 1996). There is need to enhance productivity of maize-cowpea based cropping system in coastal Kenya region, which is characterized by persistent crop failures due to low soil moisture availability and low soil fertility. Improving the region's maize-cowpea intercropping system by utilizing the existing resources may be the best option for improving land productivity and food security in the coastal region of Kenya. The strategy of intercropping high yielding, drought tolerant and insect resistant cowpea and maize varieties in coastal lowland Kenya will enhance efficient use of soil moisture leading to increased productivity. The main elements studied were screening of local landraces of cowpea for drought tolerance and resistance to insect pest infestation; intercropping of selected maize and cowpea varieties; moisture retention enhancement by integrating cowpea crop residue, farmyard manure and inorganic fertilizer are in maize-cowpea intercropping systems.

1.4 Objectives

1.4.1 Main objective

To enhance the performance of the maize-cowpea based cropping system in coastal lowland Kenya through stress resilient varieties and soil moisture conservation practices.

1.4.2 Specific objectives

1. To identify cowpea varieties preferred by coastal farmers through participatory variety selection

2. To determine the influence of drought stress on canopy temperature, growth and yield of local and improved cowpea varieties in coastal lowland Kenya.

3. To establish the effect of variety and insecticide application on pest damage, growth and yield of local and improved cowpea varieties in coastal lowland Kenya.

4. To assess the effect of intercropping maize and cowpea on soil moisture content, canopy temperature, growth and yield of the component crops in coastal lowland Kenya.

5. To evaluate the effect of cowpea crop residue management on soil moisture content, canopy temperature, growth and yield of intercropped maize and cowpea in coastal lowland Kenya.

6. To determine the effect of different farmyard manure levels on soil moisture content, canopy temperature, growth and yield of intercropped maize and cowpea in coastal lowland Kenya.

7. To establish the effect of varying N-fertilizer application levels on soil moisture content, canopy temperature, growth and yield of intercropped maize and cowpea in coastal lowland Kenya.

1.5 Hypotheses

1. There are some cowpea varieties which are preferred by farmers in coastal Kenya.

2. Existing cowpea varieties in coastal Kenya are tolerant to drought stress.

3. Existing cowpea varieties in coastal Kenya are resistant to insect-pest infestation.

4. Intercropping increases soil moisture content, canopy temperature, growth and yield performance of maize and cowpea component crops.

5. Integration of cowpea crop residue in maize-cowpea intercropping systems increases soil moisture content, canopy temperature, growth and yield performance of intercropped maize and cowpea.

6. Application of farmyard manure improves moisture retention, canopy temperature, growth and yield performance of maize-cowpea intercrops

7. Application of N-fertilizer increases soil moisture retention, canopy temperature, growth and yield performance of maize-cowpea intercrops.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The challenge of identifying management options that would maximize productivity of compatible crops in traditional systems is the major concern of agricultural production in the tropics (Connor *et al*., 2011). Semi-arid tropics are characterized by limited land use options, poor crop management practices and poverty (Swift, 1996). In most of these areas the natural resource base (soil and ground water) is becoming depleted through compaction, erosion, salinization, net nutrient export, and diminishing water supply (Cassman, 1999). The arid and semi-arid lands (ASALs) make up 80% of Kenya's land area (Huho *et al.,* 2009). In the coastal region of Kenya only the 10 mile coastal strip is in coastal lowland zone three (CL 3 coconut cassava zone) (Jaetzold *et al*., 2012), while the rest of the region is semi-arid land, characterized by low moisture availability as a result of insufficient and erratic rainfall (Wekesa *et al*., 2003). Most of the soils are sandy, highly drained and are low in organic matter. Water infiltrates easily and passes rapidly through the rooting zone. Thus crops grown on them tend to suffer from drought (Waaijenberg, 1994). In the coastal region of Kenya four factors which greatly influence crop yields are low soil moisture availability, low soil fertility, weed competition and insect pest-infestation.

2.2 Low soil moisture

Climate change, as a result of global warming, is considered to be ongoing (Seinfeld and Pandis, 2012), and this is expected to result in a long-term trend towards higher temperatures, greater evapotranspiration, and increased incidence of drought. These trends, coupled with an expansion of cropping into marginal areas, are generating increasingly drought–prone maize production environments (Eakin and Wehbe, 2009). Drought is a widespread phenomenon across large areas of sub-Saharan Africa, with an estimated 22% of mid-altitude/subtropical, and 25% of lowland tropical maize growing regions affected annually by inadequate water supply during the growing season (Heisey and Edmeades, 1999). Water is one of the major physical constraints to crop production in semi-arid areas, hence there is need to use it efficiently (Passioura, 2006). Moisture stress affects crop plants at all growth stages, but its effect on maize grain yield is less severe when it occurs at vegetative stages than when it occurs at the tasselling and silking stages. Drought stress occurring at grain filling can reduce the final size and weight of maize kernels (Castiglioni *et al.,* 2008). However, as the kernels mature the stress-induced yield reduction declines (Guoth *et al.,* 2008). The grain yield potential of dry land maize is closely related to the annual precipitation (Rockstrom *et al.,* 2010). Drought stress is a major climatic factor limiting the production of maize in the tropics (Ortiz *et al*., 2008). Globally, average maize grain yields are estimated to be 2.0 – 3.0 t ha^{-1} in moisture stress environments and 4.0 – 6.0 t ha^{-1} under favorable moisture conditions (Bouman *et al.,* 2007).

Agronomic interventions that aim at maximizing water availability at key growth stages are important (Qadir and Drechse, 2011). According to Richards (1985), farmers in semi-arid lands respond to ecological, environmental and socio-economic changes by flexible and dynamic management strategies. The need for more water-efficient crop management practices may be one of the strongest incentives for adopting a cropping system in ASAL areas (Mertz *et al*., 2009). Increasing soil water storage and reducing losses from evaporation by using surface mulches and by planting shelter belts is critical in improving the water use efficiency of a cropping system (Triplett and Dick, 2008). In a situation of reducing rainfall, studies on efficiency of water use (WU) by component intercropping systems are important (Chirwa *et al.,* 2007). The actual water use and microclimate of intercropping systems have apparently received less attention than their agronomic manipulation (Connor *et al*., 2011). The mean annual rainfall along the Kenyan coast ranges from 500-900 mm at the North

Coast to 1000-1500 mm in the wetter areas south of Mombasa (UNEP, 1998). Rainfall occurs during two distinct periods; the long rains between March and May and short rains usually between October and December (Mutai and Ward, 2000). The efficient use of the limited soil moisture in the region is therefore a crucial factor for future increases in crop production, which should come primarily from increased grain yield per unit area of land (Rosenzweig and Tubiello, 2007). Identification and incorporation of drought tolerant maize and cowpea varieties into the intercropping systems will enhance productivity of the cropping systems in the coastal lowland region.

2.3 Low soil fertility

Declining soil fertility and high fertilizer costs are major limitations to crop production in smallholder farms in Kenya (Vanlauwe *et al.,* 2007). Among the major nutrients, nitrogen, (N) is the most limiting and rarely do soils in the tropics have enough of this nutrient to produce high and sustainable yields (Muthuri *et al.,* 2014). The lack of adequate amounts of nitrogen in most soils of coastal Kenya limits the farmers' goals of increasing yield per unit area. Rebuilding soil fertility in traditional agricultural systems has in the past been achieved throlugh long-duration fallow periods (Foley, 2009). However, with increased human population and land pressure, long fallow periods are no longer feasible (Alika *et al.,* 2005).

The quantity of nitrogen needed for agriculture is projected to continue increasing up to the year 2030 (Popp *et al.,* 2010) and this would lead to greater environmental degradation. Reduced dependence on fertilizer nitrogen and adoption of farming practices that favour the more economically viable and environmentally prudent nitrogen fixation will benefit both agriculture and the environment (Singh *et al.,* 2013). There are several options which are available to manage nitrogen in farmers' fields. Chemical fertilizers are often considered to be an immediate answer to current nutrient deficiencies in soils (Otieno *et al*., 2009).

Unfortunately, commercial nitrogen fertilizers are expensive and out of reach of most smallholder farmers. As a result, cheaper sources of nitrogen need to be sought if yields are to be sustained and food security attained. Nitrogen requirement of legumes can be met by both mineral N assimilation and symbiotic N_2-fixation (Gan *et al*., 2008). On-farm nutrient sources such as crop residues, compost manures, and household wastes, have commonly been used by farmers in the management of soil fertility (Tittonelli *et al*., 2005). Low soil productivity limits food production in the farms such that the genetic potentials of various crop varieties grown in the country have not been fully realized. The nutrient status at coastal region can be classified as N and S deficient (KARI, 1994). The poor, exhausted soils are the main problem in the coastal region. Low maize yields are achieved even after application of N and P fertilizers because micronutrients are lacking hence other modern measures of recycling nutrients are necessary (Jaetzold *et al.*, 2012).

2.4 Pest infestation

Cowpea is an important grain legume in many parts of the world (Takim and Uddin, 2010), and is regarded as an integral part of traditional cropping systems throughout Africa (Isubikalu *et al.*, 2000). It has the potential to increase incomes of both farmers and traders (Owolade *et al.*, 2004). However, the crop is attacked by a spectrum of pest species (Isubikalu *et al*., 2000). It is thus considered too risky an investment by many growers because of the numerous pest problems associated with it (Remison, 1997). The major pests of cowpea in the humid tropics are weeds (Ayeni, 1992) and insects (Jackai and Adalla, 1997). Weeds and insects often coexist and reduce crop yields in agricultural systems. In addition to the individual effects that insects and weeds have on crops, these two types of pests and their management practices can interact and impact on crop production (Takim and Uddin, 2010). The hot-humid climate of the coastal region favours rapid growth of weeds such as *Cyperus rotundus* (Saha, 2007) and insects such as pod borer (Wekesa *et al*., 2003).

2.4.1 Weed infestation

Weeds constitute a major limiting factor to cowpea production (Okafor and Adegbite, 1991). Weeds reduce yields by about 12% annually in the United States of America (Pimentel, 1991). Tijani-Eniola (2001) reported that weed could cause yield losses ranging from 50 to 80% in Nigeria. Crop losses by weeds could be aggravated by delay in weeding or inability to weed throughout the entire crop growth period (Takim and Uddin, 2010). However, studies of threshold levels of weeds have shown that complete weed elimination is not essential for high yield (Sangakkara, 1999), probably because the crop also competes strongly with weeds. In addition, to their repressive effects owing to competition, weeds also act as reservoirs or alternate hosts for insects, diseases and nematodes (Jackai and Adalla, 1997). Weeds reduce crop yields and quality by competing for nutrients and water.

Weeds may decrease the value and productivity of land, reduce harvesting and processing efficiency, increase cost and labor for control measures, and restrict flow of water to reservoirs, canals, and ditches (Takim and Uddin, 2010). The soil weed seed reservoir is the major source of weed infestation in most tilled agricultural soils (Altieri and Liebman, 1988). The number, types and distribution of weed seeds in the reservoir are determined by the field’s location and cropping history, edaphic characteristics such as moisture holding capacity, past weed control practices (Janiya and Mood, 1989) tillage, land preparation methods and weed seed dormancy (Zimdahl *et al*., 1988). The hot-humid climate of the coastal region favours rapid weed growth (Saha, 2007). The most harmful weed competition occurs during the first three to six weeks after sowing (Gacheru *et al*., 1993). To reduce this competition, farmers in the region carry out several weeding operations during each cropping season (Mureithi *et al*., 1996). According to Saha (2007), a farmer might be required to weed at least three times in a single maize crop in a wet year.

The smallholder farmers in the coastal region of Kenya do not use planted fallows between cropping seasons; neither do they maintain their farms weed-free (Saha, 2007). Weeds therefore grow in abundance and produce a lot of seeds during this period, thus increasing the seed load on the soil surface (Mureithi *et al*., 1996). The weed seeds get mixed with soil during land preparation for the following season. Weed seeds germinate and the new weeds grow very fast after the rains start (Gacheru *et al*., 1993). If a farmer is not quick enough, planting of food crops is done when weed seedlings have already emerged and this leads to early crop-weed competition (Saha, 2007). The farmer is, therefore, forced to start weeding as soon as the crops emerge. Labor for weeding is usually provided by the family members, mostly women (Mureithi *et al*., 1996). Hand weeding is so slow an operation that maize in one part of a field may be destroyed by weeds while the farmer is trying to complete weeding in another portion (Gacheru *et al.,* 1993). The result of this differential weed control is a reduction in the average crop yield. Crop losses by weeds could be aggravated by delay in weeding or inability to weed throughout the entire crop growth period (Takim and Uddin, 2010). Farmers in this region have also used cowpea for smothering problematic weeds such as nut grass (Obong'o *et al.*, 1993; Saha *et al.*, 1993).

2.4.2 Insect pest infestation

Insect pest damage cowpea from seedling emergence to storage (Karungi *et al.,* 2000) and accounts for a 13% annual reduction in yields in United States agricultural systems (Pimentel, 1991). Losses from insects include defoliation of leaf tissue, removal of fluid from phloem and xylem systems, mining of parenchyma tissue, formation of galls, or blemishing the harvested fruit or vegetable (Schoonhoven *et al.,* 1998). Insect pests' attacks often lead to total cowpea grain yield loss (Singh and Allen, 1980), such that the crop yield cannot exceed 400 kg per hectare without the application of insecticides. The poor yield of cowpea is partly attributed to a series of insect pests and diseases, the most devastating being *Maruca vitrata*

(Spotted pod borer) which attacks the flowers and bores through the pods (van Cotthem, 2007). Other insects include *Helicoverpa armigera* (Gram pod borer) and *Melanogromyza* spp (leaf miner fly) which cause grain yield losses of up to 60 % (Amatobi, 1994).

Cowpeas are susceptible to infestation by Bruchidae especially those belonging to the genus *Callosobruchus* (Idoko and Adesina, 2012). Another bruchid, *Bruchidius atrolineatus* (Pic), damages cowpea seeds in the field and to a limited extent in storage (Kabeh and Lale, 2008). All the species belonging to the genus *Callosobruchus* are oligophagus pests attacking a number of grain legumes in the family Leguminosae (Haines, 1991). However, *C. maculates* is the most dominant species in storage (Jackai and Daoust, 1986). Because these pests commence infestation in the field, it is possible to mitigate infestation by embarking on pre-harvest interventions aimed at reducing the level of initial infestation (Kabeh and Lale, 2008). The integration of host plant resistance and intercropping has been found to be very effective in reducing field infestation (Lale and Sastawa, 2000).

Generally, cowpea farmers do not spray their crops with insecticides. Insect control is left to chance and providence. This attitude promotes control through natural enemies (Kamara *et al*., 2007). Despite the high potential for cowpea production in many areas, insect pests are a serious constraint. In Kenya, seed yield losses due to insect pests were first reported to be between 26 and 63% and were attributed mainly to the pod borer (Amatobi, 1994). Synthetic pesticides recommended for use in cowpea can effectively control *M. vitrata* in the field, yet farmers do not spray their cowpea with pesticides. Apart from the environmental and health concerns, there are also socio-economic implications that make the use of chemical pesticides problematic. Among these are the low level of farmers' education, lack of capital, high prices of pesticides, lack of input market and low access to recommended pesticides (van Cotthem, 2007). According to Takim and Uddin (2010), in addition to the individual effects that insects and weeds have on crops, these two types of pests and their management practices can interact and impact on crop production. Weeds reduce crop yields and quality by competing for nutrients and water. They may also decrease the value and productivity of land, reduce harvesting and processing efficiency, increase cost and labor for control measures, and restrict flow of water to reservoirs, canals and ditches (Smith and Hill, 1990). Therefore, future goals in multiple cropping researches should include increasing the infrastructural support to farmers and, in particular, providing insect pest forecasts which can allow more flexibility in cropping designs, and also creating better adapted, insect pest and disease resistant crop varieties (Perrin, 1977).

2.5 Intercropping

Intercropping, a multiple cropping system, has been practiced traditionally by small-scale farmers in the tropics. In particular, cereal and legume intercropping is recognized as a common cropping system throughout tropical developing countries (Ofori and Stern, 1987). Typically, cereal crops such as maize (*Zea mays* L.), millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) are dominant crop/plant species whereas legume crops such as beans (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* L.), groundnut (*Arachis hypogaea* L.), pigeonpea (*Cajanus cajan* L.) and soybean *(Glycine max* L.) are the associated plant species. Intercropping systems have been reported to be more productive than sole crops grown on the same land (Kiari *et al*., 2011). Farmers in coastal lowland Kenya are aware of the declining fertility and have used cereal-legume cropping systems to improve soil fertility over time. In a previous, study it was observed that a cereal crop following a legume performed better than that grown on land that had no legume (Mureithi *et al*., 1996). This observation was in agreement with results from the Fertilizer Use Recommendation Project (FURP) carried out in Kilifi, Kwale and Lamu counties of the Coastal region of Kenya. These results showed that maize yields in unfertilized plots were 600 kg ha^{-1} higher per year in a maize-cowpea relay cropping sequence than in a cropping sequence without cowpea (FURP, 1994). Intercropping and relay cropping with legumes have been rated by farmers in the coastal region as among the most effective and most commonly used methods of improving soil fertility (Mureithi *et al*., 1996). Legumes have been demonstrated to have great potential for improving soil fertility at relatively low cost compared to inorganic fertilizers (Hudgens, 1996).

2.5.1. Effect of intercropping on pest infestation

A cropping system that reduces initial weed infestation is likely to allow for a reduction in the number of weeding operations in a maize crop (Gacheru *et al.,* 1993). Intercropping combined with competitive maize cultivars can reduce weed infestation (Gomez *et al.,* 2007). Adoption of such a cropping system will allow farmers have free time early in the season. The cropping system would therefore improve the use of human labor resource and also preserve soil structure because of the reduced soil disturbance (Mureithi *et al.,* 1996). The farmer may, therefore, save a few man-hours of labour (Gacheru *et al.,* 1993). It is generally believed that one component crop in an intercropping system may act as a buffer or a barrier against the spread of pests and pathogens (Oso and Falade, 2010). Raheja (1973) reported that the damage by sorghum ear fly (*Calocoris angustatus*) in sorghum–pigeon pea intercrop was considerably less than that in sole sorghum. However, such interactions are not always beneficial. Bhatnagar and Davies (1981) found that in sorghum–pigeon pea intercrop, pod damage to the pigeon pea component by pod borer (*Helicoverpa armigera*) was more than in sole cropped pigeon pea.

2.5.2. Effect of intercropping on resource use

In intercropping systems, two or more crops grow simultaneously on the same field such that the period of overlap is long enough to include the vegetative stage (Gomes and Gomez, 1983). In many parts of Africa, the most successful intercropping systems are mixtures of species that are both temporally and spatially diverse (Francis, 1994). These systems are quite useful in agriculture since they can enhance soil fertility, out-compete weeds, and provide a varied supply of food and income to the farm family (Beets, 1990). The use of crops that are adapted to intercropping stress and optimum planting dates, crop densities, and spatial organization can contribute to yield increases. Intercropping systems make better use of available resources because the different crop species occupy slightly different niches (Willey, 1979; Dusa and Stan, 2013).

According to Francis (1994) a careful consideration of resource use by crop mixtures can help in understanding how to manage their components and design new and more environmentally sound systems. Such an evaluation would also help in designing more efficient resource use intercropping systems (Dusa and Stan, 2013). Intercropping systems have, for long, been discounted as backward and detrimental to real progress in agriculture (Francis, 1994). However, these systems gained more recognition (Rao and Mathuva, 2000) as potential contributors to substantial and sustainable increases in future food production (Tsubo *et al.,* 2003). Crop mixtures are known to exploit a wider range of soil strata than do monocultures that have relatively uniform root structure and rooting habit/depth (Francis, 1994). The crops in a mixture may also have different nutrient requirements over time, and thus complement each other in the uptake and use of soil nutrients. Grain leguminous -cereal mixed intercrops are better at exploiting natural resources than the sole crops of different plant species (Hauggaard-Nielsen *et al.,* 2006). This is because grain leguminous plants can cover their nitrogen demand from atmospheric N_2 fixation and therefore in intercropping with cereals compete less for soil mineral N (Dusa and Stan, 2013). According to Eskandari (2012) intercropping increases soil moisture content, canopy temperature and maize chlorophyll content but reduced these parameters in cowpea. Maximizing advantages of intercropping is therefore a matter of maximizing the degree of complementarities between the components and minimizing inter-species competition (Willey, 1979).

Adoption of an intercropping system is a primary and direct way of increasing diversity of an agro-ecosystem that allows interaction between the individuals of the different crops and varieties (Yancey, 1994). It can add temporal diversity through the sequential planting of different crops during the same season (Mohammed, 2012). Several methods have been used to assess the benefit of intercropping depending on the need. However, one of the most important tools for evaluating an intercropping system is the land equivalent ratio (LER). Providing that all other things are equal, LER is a measure of the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate monocultures (Yancey, 1994). Land equivalent ratio thus allows going beyond a description of the pattern of diversity into an analysis of the advantages of intercropping (Kurata, 1986). It measures the levels of intercrop interference going on in a cropping system. Theoretically, if the agro- ecological characteristics of each crop in a mixture are exactly the same the total LER should be 1.0 and the partial LERs should be 0.5 for each. However, Kutrata, (1986) stated that a LER value of 1.0 indicates no difference in yield between the intercrop and the collections of monocultures and any value greater than 1.0 indicates advantage for intercrop. In contrast LER of less than 1.0 indicates an advantage for intercropping. Land equivalent ratio of 1.2, for example, indicates that the area planted to monoculture would need to be 20% greater than the area planted to intercrop for the two to produce the combined yield (Mohamed *et al.*, 2011).

2.6 Effects of variety and spray application on growth and yield of cowpea

Generally, small holder farmers growing cowpea in coastal lowland region leave cowpea protection to chance or nature leading to low grain yield (Karungi *et al.*, 2000). Insect pests are considered to be largely responsible for this as their attack can result in up to 90 - 100% yield reduction (Jackai and Daoust, 1986). The low cowpea yield obtained from such farmers' fields suggests that natural control by itself cannot afford enough protection as to enhance profitable commercial production (Jackai and Singh, 1983). The use of varieties that are resistant to attack by insect pests is one of the most promising alternative control measures since it is economically and environmentally safe (Tamo *et al.*, 1997). However, despite concerted efforts by many institutions over the last two decades to develop varieties with resistance to the cowpea insect pest complex, resistant varieties are still unavailable to farmers. Chemical control using synthetic insecticides therefore remains the most popular control tactic especially when these pests have exceeded the economic injury level (Jackai *et al.*, 2001). Dzemo *et al.,* (2010) reported that insect pest control insecticide spray led to increased number of cowpea pods per plant, pod weight, number of seeds per pod, seed weight, and grain yield. However, excessive use of chemical insecticides is hazardous to humans and the environment, and often leads to the elimination of ecologically beneficial insects as well as the development of resistance by insect pests (Ekesi, 1999). Furthermore, chemical insecticides are not affordable to a majority of small holder farmers (Bottenberg, 1995).

2.7 Effects of crop residue mulch on soil characteristics and crop performance

Arable farming with the retention of crop residues as mulch has made a significant advent in the USA, comprising more than 35% of the cropped land since the mid 1990s (CTIC, 2000). This system is revolutionary since over the centuries agriculture has traditionally emphasized the opposite, i.e. the need for a clean seedbed without crop residues. Many farmers in developing countries still rely on pre-plant burning of vegetative debris for seed bed preparation just like farmers in developed countries in the past (Erenstein, 2002). The reliance on organic residues from the previous crop distinguishes crop residue mulch (CRM) from other forms of mulching (Erenstein, 1999). It is strategically located at the soil-atmosphere interface, whereby it affects: (i) soil conservation; (ii) soil ecology; (iii) and crop yields.

Crop residue mulch effectively halts soil erosion by providing a protective layer to the soil surface (Kinama *et al*., 2007), increasing resistance against overland flow and enhancing soil surface aggregate stability and permeability through its combined physical and biological effects (van Donk *et al.*, 2010). The resulting reduction in soil erosion is impressive and has been repeatedly observed both in temperate and tropical environments (Moldenhauer *et al.*, 1994). Erosion declines asymptotically to zero as soil cover increases. A near complete soil cover can conceivably almost eliminate soil erosion (Lal *et al*., 1990; Moldenhauer *et al.*, 1994).

The presence of crop residue mulch at the soil-atmosphere interface alters the entire soil ecology (Carsky *et al*., 1998). Crop residue mulch has a profound water conservation effect: the very process that conserves the soil also implies more infiltration of rain water and less runoff and more water retention in the soil profile (Moldenhauer *et al.*, 1994; van Donk *et al*., 2010). The presence of the mulch also reduces soil temperature oscillations and reduces evaporation losses (Erenstein, 2002; Kinama *et al*., 2005). Crop residue mulch has profound effect on soil fertility. Tropical soils typically have a low inherent fertility, where plant available nutrients and organic matter are concentrated in the top soil. The conservation effect of mulch helps maintain this in situ, whereas the mulch itself typically adds organic matter to the low stock of soil organic carbon a key component for sustainable and productive use of soils (Pieri, 1989). Crop residue mulch favours the activity of soil biota by providing a readily available food source and creating a more favourable soil habitat (Carsky *et al.*, 1998). In turn, the activity of soil biota contributes to improved soil physical and chemical properties.

The growth of plants is primarily a function of: (i) defining conditions (carbon dioxide; radiation; temperature; crop attributes); (ii) limiting conditions (water and nutrients); (iii) and reducing conditions (weeds, pests, diseases and pollutants) (Rabbinge and van Ittersum, 1994). By changing the soil ecology, CRM affects a number of these biophysical conditions (Unger, 1990). The marginal yield effect will depend on the extent these changes influence the constraint(s) for crop growth. This makes the yield effect of CRM crop-specific (Howeler *et al.,* 1993), site-specific and somewhat difficult to disentangle in view of the numerous interactions (Lal *et al.,* 1990). The organic matter contributed by CRM can have different short-term yield implications typically hinging on the quality of the organic matter as reflected by the C: N ratio. Crop residue mulch also affects the incidence of crop weeds, pests and diseases. However, the yield effect is uncertain as many weeds, pests and diseases respond uniquely to the CRM-induced alterations in the crop-soil ecosystem (Erenstein, 2002). Mulch also shields the soil surface against solar radiation, thereby buffering soil temperature fluctuations. This may lead to soil temperature stress in the warmer environments while at the same time slowing the necessary warming up of the soil in cooler environments (Lal *et al*., 1990). According to Turmel *et al*., (2015) reduction in soil moisture under mulching was attributed to reduction in soil temperature as a result of reduced moisture loss in the soil profile through evaporation. According to Shafi *et al*., (2010) improvement in soil organic matter due to incorporation of crop residues into the soil was 11.05%. Incorporation of residues in soil enhanced the grain yield by 8.93% when compared with the treatment of residues removal (Shafi *et al*., 2007). Kouyate *et al*., (2000) also reported increases in cereal grain and stover yields by 37 and 49% respectively, when crop residues were incorporated compared with control treatment (no residues incorporation).

2.8 Effects of farmyard manure and inorganic N-fertillizer on crop growth and yield

According to Mehdizaheh *et al.,* (2013) the need to adopt eco-friendly agricultural practices for sustainable food production is of interest globally. Due to the high poverty rate among the rural population, agricultural input subsidies apart from being an instrument of promoting agricultural growth can also be seen as a social protection instrument of ensuring access to inputs, and access and availability of food to vulnerable groups (Dorward *et al.* 2006). The cost of inorganic fertilizers is increasing enormously to an extent that they are out of reach for resource poor farmers. Farmyard manure application has been a noble and traditional practice of maintaining soil health and fertility. The use of organic fertilizers such as farmyard manure, results in higher growth, yield and quality of crops (Mehdizadeh *et al.,* 2013). Farmyard manure (FYM) enhances soil organic matter, humus content, soil water holding capacity, infiltration rate, aeration, porosity, moisture conservation, cation exchange capacity, and water stable aggregates, while decreasing bulk density (Benbi *et al.,* 1998). It contains macro-nutrients, essential micro nutrients, many vitamins, growth promoting factors like indole acetic acid (IAA), giberelic acid (GA) and beneficial microorganisms (Sreenivasa, *et al,* 2010). It has been proved to improve crop growth by improving the soil's physical, chemical and biological properties (Mehmood *et al*., 1997). It is also has an advantage over other organic manures like green manure in terms of having a shorter breakdown period for decomposition (Chupora, 1995). Organic manures can improve soil – water - plant relations through modifying bulk density, total porosity, soil water relation and, consequently, increasing plant growth and water use efficiency (Obi and Ebo, 1995). Nileemas and Sreenivasa, (2011) stated that application of liquid organic manure promotes biological activity in soil and enhances nutrients availability. Awad *et al.,* (2002) stated that organic manure contains high levels of relatively available nutrients elements, which are essentially required for plant growth. Sustainability in agro-ecosystems involves environmentallyfriendly techniques based on biological and non-chemical methods (Bonato and Ridray, 2007). Agricultural production is confronted with the challenges of identifying management options that will maximize productivity of compatible crops in a traditional cropping system (Gobeze *et al.,* 2005). Farmers in Kenya have for long recognized the role of intercropping not only as an insurance against crop failure but also as a convenient strategy for meeting dietary needs. They have incorporated intercropping into the traditional system (Gachene and Makau, 2000). Legume crops have been considered suitable for use in intercropping systems with other crops because they can improve soil fertility through root nitrogen fixation and crop residues (Wanjekeche *et al.*, 2000).

Quality of soil N is a major factor limiting plant production in many agricultural systems and may be improved through the use of legumes and inorganic fertilizer N (Omokanye *et al.,* 2014). Inorganic sources of nitrogen are very expensive and their losses are more as compared to organic sources (Stewart *et al*., 2005). Usually the crop uses 30 to 50% of inorganic nitrogen fertilizer applied, the rest is lost by volatilization, denitrification or leaching as nitrate to the ground water (Stewart *et al*., 2005). When nitrogen fertilizer is added to the field, intercropped legumes use the inorganic nitrogen instead of fixing nitrogen from the air and thus compete with maize for nitrogen (Rehman *et al.,* 2010). However, when nitrogen fertilizer is not applied intercropped legume will fix most of their nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi *et al.,* 2007). Among the plant nutrients, nitrogen deficiency is one of the major limiting factors for cereals (Shah *et al.,* 2003), hence fertilizer nitrogen application is an essential input for crop productivity in most areas of the world (Amanullah *et al.,* 2009). According to Elbashier *et al.,* (2012) N-fertilizer application reduced canopy temperature of wheat plants.

CHAPTER THREE: PARTICIPATORY COWPEA VARIETAL SELECTION IN KILIFI COUNTY OF KENYA

3.1 Abstract

Many released crop varieties in Kenya are often not adopted by farmers because of limited farmer participation in the breeding process. This study was carried out to identify farmer preferred cowpea varieties in coastal lowland Kenya. Four improved (K80, KVU 27-1, KVU – 419 and M66) and seven local cowpea (Khaki, Macho, Kaima koko, Nyeupe, Nyekundu, Kutambaa and Mwandato) varieties were evaluated on-farm in randomized complete blocks. Thirty nine farmers (30 female and 9 male) from three farmer groups in Kilifi participated in the establishment and evaluation of cowpea varieties using their own selection criteria. The varieties were evaluated at flowering, podding, maturity and post harvest stages. Farmers' cowpea selection criteria before flowering and at podding were high grain yield, drought tolerance, early maturity, ease of harvesting and leafiness. Kutambaa, KVU 27-1 and Nyeupe were rated top varieties at these stages. Farmers' selection criteria at maturity and after harvest included grain yield, color, taste and cooking duration. KVU 419, Kaima koko and Nyeupe were rated top varieties at these stages. Grain yield varied from 3.3 t ha^{-1} (KVU 419) to 0.48 t ha^{-1} (Kaima koko). The results of this study have demonstrated that plant breeders integrate color, taste and cooking time as key traits in cowpea improvement programmes. Integration of KUV 419, Nyeupe, KVU 27-1 and Kutambaa cowpea varieties into the maize-based system is likely to improve cowpea productivity in Kilifi County, Kenya.

3.2 Introduction

Plant breeding and agricultural promotion programs continue to be patterned after those in western industrialized countries, emphasizing the use of modern innovations that practice the development of high yielding varieties that perform well in environments that are stabilized through the use of irrigation, fertilizers, pesticides and other inputs (Nkongolo *et al.*, 2008). Perhaps the most significant realization at the beginning of the 21st century is the fact that the areas in the developing world, characterized by traditional/subsistence agriculture, remain poorly served by the top-down transfer-of-technology approach, due to its bias in favor of modern scientific knowledge and its neglect of local participation and traditional knowledge (Miguel, 2002). Single genotypes have been widely promoted, to be grown in pure stands regardless of the system in which the crop is currently being grown or the availability of risk reducing inputs (Nkongolo *et al*., 2008). This could be the reason why many promising crop varieties coming out of national agricultural research institutes and universities are often not taken up by farmers. For example, despite the availability of improved maize varieties farmers still grow coastal maize landraces in coastal lowland Kenya (Ndiso *et al*., 2012). According to Girma *et al*., (2005), the disconnect that has been there between the crop varieties which have been released by plant breeders for a particular region and what the farmers in that region grow raised two major challenges. First new varieties can be disappointing to farmers in case undesirable traits go undetected during the breeding process. Second, breeders discard many crosses and varieties during the selection process because of traits considered undesirable. However, these traits may actually be of interest to farmers, thus indicating the communication gap between breeders and farmers (Kamara *et al.*, 1996).

The top-down transfer-of-technology approach as a strategy in promoting agricultural programs has not produced the desired results of sustainable and increased crop yields. It has also failed to make use of the significant agricultural biodiversity available and its potential to address food security concerns and issues in the region (Nkongolo *et al*., 2008). The most effective way to ensure adoption of improved cultivars is involving farmers in the process of development. Participatory varietal selection has shown success in identifying an increased number of preferred varieties by farmers in a shorter time than the conventional system, in accelerating their dissemination and increasing cultivar diversity (Weltzien *et al.,* 2003).

Denevan (1995) reported that complex farming systems, adapted to the local conditions, have helped small scale farmers to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. According to Nkongolo *et al.,* (2008) a small farmer deals with a variable environment and has multiple production objectives that will affect his or her choice of crops and selection of genotypes. Next to yield, which in formal breeding programmes is by far the most important objective, yield stability, adaptation to production techniques and conditions, and various consumption purposes are selected for. This range of objectives often results in the use of a large number of varieties by individual farmers and the use of genetically heterogeneous varieties. Farmers need adaptation to the local and variable water and soil conditions in combination with a variety of characteristics related to labour and food availability, intercropping and weed competition (Almekinders *et al*., 1994). Consumption objectives include culinary and cultural preferences regarding taste, color, consistence, size, cooking time, processing quality and suitability for preparation of traditional dishes or drinks. Consumption criteria also include secondary uses, such as leaves of sweet potato, cowpea and cassava as vegetable or animal feed (Almekinders *et al.,* 1994). Cowpea is the most important grain legume in coastal Kenya, mainly grown as an intercrop with maize (Njunie *et al.,* 2007; MoA, 2010). There are many cowpea varieties with potential for high yields, tolerance to drought and resistance to insects in the region but have not been evaluated by farmers. The current study was carried out to identify cowpea varieties most preferred by coastal farmers and consumers through participatory variety selection.

3.3 Materials and Methods

3.3.1 Experimental site

The participatory varietal selection study was carried out on-farm at Majaoni in Tezo location, Kilifi County which is 68 km north of Mombasa. It lies between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. The region receives an average annual rainfall of 600–1100 mm that comes in two seasons (Sombroek *et al.,* 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time (Saha, 2007). Mean monthly minimum and maximum temperatures are about 22^0C and 30^0C, respectively, and the mean relative humidity is 80% (Jaetzold *et al*., 2012). According to Sombroek *et al.*, (1982) the soils in coastal lowland Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen), are prone to leaching, and have a pH ranging between 5 and 7 (Mureithi *et al.,* 1995).

3.3.2 Experimental design, treatments and crop husbandry

Needs of farmers were assessed using the participatory rural appraisal technique to set goals and identify farmer's preferences and perceptions on ideotype cowpea cultivar (Adu-Dapaah *et al*., 2007). Farmers who participated and evaluated the cowpea varieties were representative of the area. The participant farmers were selected based on their indigenous knowledge (Nkongolo *et al.*, 2008) and from the most active farmer groups growing maize and cowpea in the region. The farmer groups were identified through the County Director of Agriculture's office in Kilifi. Participants in the participatory varietal selection were drawn from Lamukani, Dziuzeni and Sife moyo farmer groups, all in Bahari Division, Kilifi County. The farmer groups were briefed by the researcher on what was involved in varietal selection exercise. Only farmers from each group who accepted to take part in the study were involved in participatory variety selection. Traits preferred by farmers and consumers were identified and prioritized for both men and women. Cowpea varieties were established and evaluated in one of the farmer group's field in Tezo location based on yield performance and farmers' selection criteria, according to Adu-Dapaah *et al*., (2007). The test varieties included the most popular local varieties and improved varieties which are recommended for the region. Cowpea varieties were laid out in a randomized complete block design (RCBD) and replicated three times.

The cowpea varieties evaluated were (plate 3.1 - 3.11): (i). KVU 419 (improved variety from KALRO Katumani); (ii). Khaki (local variety); (iii). K80 (improved variety for the coastal region); (iv). Macho (local variety); (v). Kaima-koko (local variety); (vi). Nyeupe (local variety); (vii). KVU 27-1 (improved variety from Katumani); (viii). Nyekundu (local variety); (ix). M 66 (improved variety from Katumani); (x). Kutambaa (local variety); and (xi). Mwandato (local variety). Each variety was grown in a 5 m x 5 m plot size. The plant spacing was 60 cm by 30 cm with two seeds per hill. Land was ploughed using a tractor and the farmers participated in the leveling and planting. There were two weedings: three and seven weeks after planting, respectively. Insect pests were controlled by spraying with a pesticide (pestox ® 100 EC) two weeks after planting then fortnightly up to podding stage. Pestox insecticide, whose active ingredient is cypermethrin, is a synthetic pyrethroid that belongs to a group of insecticides used widely as industrial and agricultural pesticides (Chibuike and Parker, 2010).

Thirteen (13) farmers (10 female and 3 male) from each farmer group participated in the exercise. The farmers participated in land preparation, crop establishment, weeding, pest control and harvesting. Evaluation was done before flowering and at podding, maturity and post-harvest stages. The female and male farmers and consumers were assisted to develop selection criteria independently and then jointly. At every evaluation time all farmers were given voting cards. Males were given red cards while the females were given green cards. All the farmers were given a voting card to pick the variety which was best for a certain trait, before choosing the second best and so on. After harvest, all the varieties were cooked in pots before the organoleptic test. During cooking, the water boiled in the pot first before the cowpeas were placed in. The time taken from when the cowpeas were put in the boiling water to when they were ready for eating was recorded. Farmers and consumers were later allowed to taste all the varieties and rank them in order of decreasing palatability. Cooked cowpea samples were scored by semi-trained sensory panel using a modified version of quantitative descriptive analysis (QDA) since standards were not provided (Tomlins *et al.,* 2005). The sensory panel, which consisted of ten (10) panelists, was conducted at one of the farmer's homes near the farmer group field where the evaluation was conducted (Tumlins *et al.,* 2007). The languages used during the sensory testing were Kiswahili (national language) and Giriama (local language). The panelists had been screened for familiarity with the cowpea dish and ability to determine differences between cowpea dishes from different cowpea varieties. Sensory attributes evaluated were color and taste.

Plate 3.1: KVU 419 cowpea variety

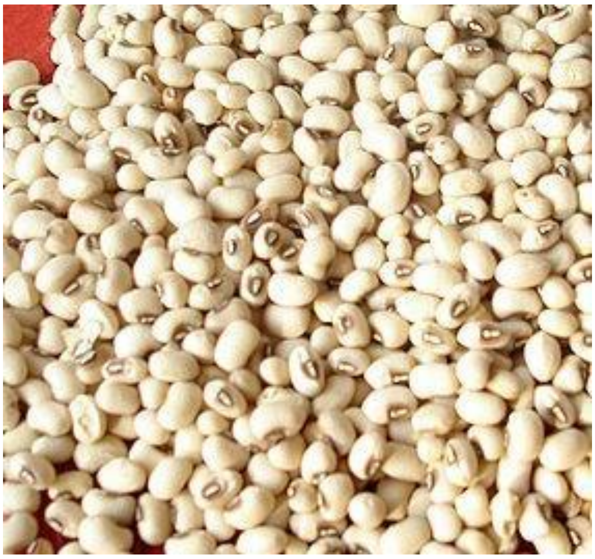

Plate 3.2: Nyeupe cowpea variety

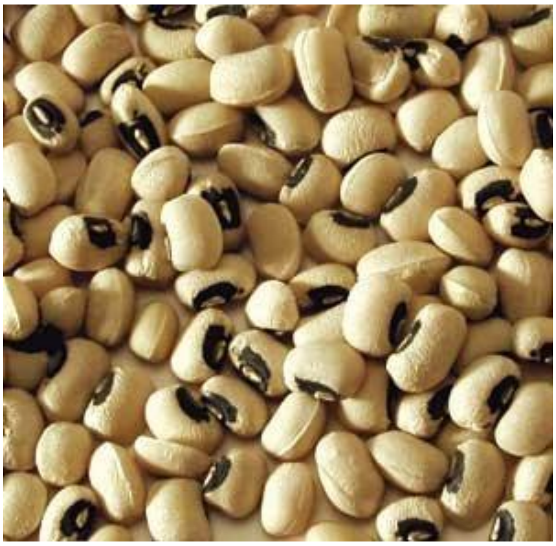

Plate 3.3: Macho cowpea variety

Plate 3.4: Kaima koko cowpea variety

Plate 3.5: Khaki cowpea variety

Plate 3.6: K80 cowpea variety

Plate 3.7: Kuhambala cowpea variety

Plate 3.8: M66 cowpea variety

Plate 3.9: Mwandato cowpea variety

Plate 3.10: KVU 27-1 cowpea variety

Plate 3.11: Nyekundu cowpea variety

3.3.3 Data collection

Data were collected before flowering, at podding, maturity and post harvest stages. Before flowering and at podding the farmers evaluated the varieties on the basis of grain yield (pod load), drought tolerance (based on leaf senescence), time to maturity, and ease of harvesting (plants with large pods were considered easy to harvest). At maturity and post harvest stages the farmers evaluated the varieties based on grain color, grain yield (in terms of kg per plot), taste (organoleptic test after cooking) and cooking time (time taken to cook in boiling water). Each trait was scored on a scale of 1 to 5 (1 = very poor, 2 = poor, 3 = average, 4 = good and 5 = very good) for each variety (Girma *et al*., 2005).

3.3.4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$.

3.4 Results

3.4.1 Farmers' rating of cowpea varieties before flowering and at podding stages

The male farmers' selection criteria in order of decreasing preference were early maturity, high grain yield, drought tolerance, ease of harvesting and leafiness (Table 3.1). The female farmers' selection criteria in order of decreasing preference were high grain yield, drought tolerance, pest and disease resistance, ease of harvesting and leafiness. Both men and women ranked ease of harvesting and leafiness fourth and fifth, respectively. Early maturity was a top priority for the men but it did not feature in the women's criteria, while pest and disease resistance featured in the women criteria as a priority but not in the men selection criteria. Farmers' collective selection criteria knocked out the female farmers' criteria of pest and disease resistance and reorganized the male farmers' criteria by considering the female farmers' priority criteria of high grain yield and drought tolerance. Most of the traits in the farmers' selection criteria, such as high grain yield, drought tolerance and early maturity, were similar with the traits considered by plant breeders. The farmers' selection criteria differed with those of plant breeders in that the former included traits such as ease of harvesting and leafiness (Table 3.1).

Table 3.1: Male and female farmers' criteria for selecting cowpea varieties and the most preferred traits

	Criteria		
Ranking	Men	Women	Men and Women
1	Early maturity	High grain yield	High grain yield
2	High grain yield	Drought tolerance	Drought tolerance
3	Drought tolerance	Pest and disease resistance	Early maturity
4	Ease of harvesting	Ease of harvesting	Ease of harvesting
5	Leafiness	Leafiness	Leafiness

In Table 3.2, male farmers rated M66 to be earliest maturing cowpea variety followed by KVU 27-1 and Kutambaa. The female farmers rated KVU 27-1 and Kutambaa the best for that trait followed by Nyekundu. Kutambaa was rated the highest yielder by both male and female farmers, but male farmers also ranked Kaima koko as the highest yielder.

Table 3.2: Farmers' rating of cowpea varieties before flowering and at podding stages

Cowpea variety	Early maturity		High yield		Drought tolerance		Ease of harvesting		Mean score
	Men	Women	Men	Women	Men	Women	Men	Women	
KVU - 419	4	4	2	5	3	5	3	3	3.6
Khaki	3	5	2	5	2	5	1	5	3.5
K80	4	5	2	5	4	3	3	5	3.9
Macho	5	5	2	5	5	5	5	5	4.6
Kaima- koko	5	4	1	3	3	3	3	5	3.4
Nyeupe	4	5	4	2	2	3	3	1	3.0
KVU 27-1	2	1	2	4	3	1	2	3	2.3
Nyekundu	5	2	5	2	5	4	5	3	3.9
M 66	1	4	4	5	3	3	5	5	3.8
Kutambaa	2	1	1	1	1	3	3	3	1.9
Mwandato	5	3	5	2	5	2	5	2	3.6

*Overall Scores: (1 – 5) Scales; 1 = Very good, 2 = Good, 3 = Average, 4 = Below average and 5 = Poor

The female farmers rated KVU 27-1 as drought tolerant while male farmers rated Kutambaa as drought tolerant. Khaki variety was rated the best in terms of ease of harvesting by male farmers while female farmers ranked Nyeupe as the best in this attribute. The mean scores in Table 3.2 indicate that the best varieties were Kutambaa, KVU 27-1 and Nyeupe with mean scores of 1.9, 2.3 and 3.0, respectively.

3.4.2 Farmers' rating of cowpea varieties at maturity and post harvest stages

The variety selection criteria used by farmers at maturity and post harvest stages were grain color, taste, grain yield and cooking time (Table 3.3).

Table 3.3: Farmers' rating of cowpea varieties at post harvest stage

Cowpea variety	Colour (score)	Grain yield (score)	Taste (score)	Cooking duration (minutes)	Cooking (score)	Mean score	Actual grain yield (t/ha)
KVU - 419	2	1	5	39	2	2.5	3.30
Khaki	5	5	5	29	1	4.0	1.40
K80	5	5	5	40	3	4.5	0.90
Macho	3	2	1	63	5	2.8	2.66
Kaima- koko	5	5	3	55	5	4.5	0.48
Nyeupe	1	5	2	52	5	3.3	1.04
KVU 27-1	4	4	5	55	5	4.5	1.70
Nyekundu	5	5	2	57	5	4.3	1.68
M 66	5	3	5	47	4	4.3	1.80
Kutambaa	5	5	4	55	5	4.8	1.20
Mwandato	5	5	5	82	5	5.0	1.06

*Scores scales: (1 – 5); 1 = Very good, 2 = Good, 3 = Average, 4 = Below average and 5 = Poor; cooking duration was the time the cowpea variety took to be ready for eating while cooking score was the score based on the time taken to be ready for eating

Unlike most plant breeding programmes, farmers considered taste and cooking time as key criteria in cowpea variety selection. Male and female farmers had the same scores for each of the varieties evaluated. Farmers identified Nyeupe as having the best color, KVU 419 as the highest grain yielder, Macho as tastiest and Khaki as the fastest cooking (Table 3.3). Across the selection criteria, the most preferred cowpea varieties were KVU 419, Macho and Nyeupe with mean scores of 2.5, 2.8 and 3.3, respectively.

3.4.3 Overall ranking of the cowpea varieties

Farmers' overall evaluation before flowering, at podding, maturity and after harvest ranked KVU 419, Nyeupe, KVU 27-1 and Kutambaa as the most preferred varieties with mean scores of 3.1, 3.2, 3.4 and 3.4 respectively (Table 3.4). Improved varieties K80, M66 and local varieties Nyekundu, and Kaima koko were ranked below average.

Table 3.4: Farmers' overall rating of the cowpea varieties

Cowpea variety	Mean scores		Mean scores
	Flowering and podding stages	Maturity and post harvest stages	
KVU - 419	3.6	2.5	3.1
Khaki	3.5	4.0	3.8
K80	3.9	4.5	4.2
Macho	4.6	2.8	3.7
Kaima- koko	3.4	4.5	4.0
Nyeupe	3.0	3.3	3.2
KVU 27-1	2.3	4.5	3.4
Nyekundu	3.9	4.3	4.1
M 66	3.8	4.3	4.1
Kutambaa	1.9	4.8	3.4
Mwandato	3.6	5.0	4.3

**Scores scales: (1 – 5): 1 = Very good, 2 = Good, 3 = Average, 4 = Below average and 5 = Poor; Note: ranking dependent on the stage of evaluation*

3.5 Discussion

From the study the farmers' most preferred trait was grain yield. Similar observations were made by Adu-Dapaah *et al.*, (2004) and Truong *et al.*, (2007) who reported that high grain yield was ranked top because all the farmers who participated in the evaluation used cowpea mostly for grain production. Women were also concerned about storage quality and this is reflected in the fact that they considered resistance to diseases and insect pests as very important criteria. This is because women have more knowledge of cooking, food processing, preservation and storage (Nkongolo *et al*., 2008). Although most of the variety selection criteria for men and women were similar, the slight variation is an indication that male and female farmers have particular preferences for certain traits. They have different preferences because they are related to the food chain in different ways, and often at different times and places. Franworth and Jiggins (2003) argued that men and women play different roles and responsibilities within the household, in farming, and in society, yet the operational implications are often obscured, by gender bias and ignorance on the part of plant breeders.

Farmers differed from researchers by considering grain color, ease of harvesting, taste and cooking time as key variety selection criteria. According to Halleegoah *et al*., (2005), farmer's selection criteria are based on market needs. This shows the significance of involving farmers and consumers in varietal selection to complement plant breeders' selection processes; thereby enhancing adoption and diffusion of any recommended variety (Adu-Dapaah *et al.*, 2004). At podding stage the farmers selected the high yielding varieties based on pod load. The number of pods per plant has been reported to be the main yield component with direct effects on cowpea grain yield (Almeida *et al.*, 2014).

The low broad sense heritability for pod load implies that the trait is influenced by environmental effects (Singh and Narayanan, 2000). The varieties which both male and female farmers selected at podding stage were not the ones they selected at maturity and post harvest stages. The overall rating identified four cowpea varieties namely KVU 419, Nyeupe, KVU 27-1 and Kutambaa based on the farmers' most preferred traits of early maturity, pod load, drought tolerance, ease of harvesting, grain color, grain yield, taste and cooking time. From the findings of this study farmers may be inclined to integrate KVU 419, Nyeupe, KVU 27-1 and Kutambaa cowpea varieties in their maize-cowpea intercropping system because they participated in the selection process. The recommended cowpea varieties in the region K80 and M66 were rated below average and this could partly explain why many farmers have not fully adopted these varieties. This study reinforces the suggestions of Adu-Dapaah *et al.*, (2007) that farmer's participation in varietal selection improves crop development and adoption.

3.6 Conclusion

The farmers' most preferred cowpea traits were early maturity, pod load, drought tolerance, ease of harvesting, grain color, grain yield, taste and cooking time. The four most preferred cowpea varieties were KVU 419, Nyeupe, KVU 27-1 and Kutambaa. The farmers' most preferred cowpea traits differed with those of plant breeders in that farmers' considered traits such as colour, taste, cooking duration and ease of harvesting. Therefore, plant breeders should consider these traits in their cowpea breeding programmes.

CHAPTER FOUR: EFFECT OF DROUGHT STRESS ON CANOPY TEMPERATURE, GROWTH AND YIELD PERFORMANCE OF COWPEA VARIETIES

4.1 Abstract

Cowpea (*Vigna unguiculata* (L) Walp) is adapted to dry regions. However, many of its cultivars are damaged by drought especially during reproductive development. Field trials were conducted during the dry seasons of 2011 and 2012 at Pwani University to evaluate the influence of drought stress on the growth and yield performance of cowpea. The experiments were laid out in a randomized complete block design with a split plot arrangement of treatments and replicated three times. Water stress level was assigned to the main plot while the cowpea variety was assigned to the sub-plot. The treatments comprised three water stress levels (no water stress, water stress at vegetative stage and water stress at flowering stage) and 11 cowpea varieties: KVU 419, Khaki, K80, Macho, Kaima koko, Nyeupe, KVU 27-1, Nyekundu, M66, Kutambaa and Mwandato. The data collected included: ground cover, canopy temperature, chlorophyll content, leaf number, days to anthesis, shoot dry matter at maturity, pods per plant, grains per pod, 100-grain weight and grain yield. Data collected were subjected to analysis of variance using SAS statistical package and means compared using the least significant difference (LSD) test, at $p = 0.05$. Water stress imposed at vegetative growth stage and flowering reduced cowpea growth attributes (plant height, shoot dry matter, and leaf number), ground cover and chlorophyll content, but increased canopy temperature, time to anthesis, harvest index, grain yield and yield components (pod weight, number of pods, grains per pod and grain weight) for most varieties.Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days, respectively. For most plant attributes measured, the response to soil moisture stress was dependent on the cowpea variety.

4.2 Introduction

Cowpea (*Vigna unguiculata* (L) Walp) is an important food legume and multipurpose crop (Sanginga *et al.,* 2002). With its high protein content of 25 % (Quin, 1997), cowpea may be regarded as a very nutritious food legume for many ethnic communities who use it in their diets (Dadson *et al*., 2005). All the plant parts that are used for food are nutritious, providing proteins, vitamins and minerals (Abebe *et al*., 2005). The crop is grown throughout the tropical and subtropical areas of the world, where rainfall resources are characteristically low (300 – 600 mm) and variable (Fussell *et al.,* 1991). Generally, cowpea is better adapted to drought, high temperatures and other biotic stresses than most other crops (Onuh and Donald, 2009). It grows well in a wide range of soil textures, from well drained heavy clays to sandy soils, and grows best in slightly alkaline soils (pH 5.5 – 6.5). Cowpea naturally grows under wide and extreme moisture conditions and, once established, it is fairly drought tolerant (Gaiser and Graef, 2001). It is often grown under rain-fed agriculture in areas receiving at least 600 mm annual rainfall.

Many cultivars of cowpea are, however, damaged by drought and high temperatures, especially during reproductive development (Abdelshakoor and Faisal, 2010). According to Ahmed *et al.,* (1992), the combination of high temperature, drought and long hours of day can slow down or inhibit floral bud development, resulting in few flowers being produced and substantially reduced cowpea productivity. Abayomi and Abidoye (2009) reported that cowpea yield reduction ranged from 63% to 98.4% under severe water stress, 42.6% to 65.8% under moderate water stress and 9.5% to 47.2% under mild water stress. Under water deficit conditions, as is often the case in the semi-arid zones, the flowering period is cut short and the seed matures earlier. Moreover, the formation of new floral nodes and flowers are delayed and/or aborted, thus leading to low productivity (Turk and Hall, 1980). In addition, cowpea is also sensitive to drought at different stages of growth (Abdelshakoor and Faisal, 2010).

Cowpea response to drought stress varies with variety, economic portion of the crop, stage of growth when stress is imposed and the duration of the stress. Earlier studies indicated that cowpea could maintain seed yield when subjected to drought at vegetative stage, provided subsequent conditions were conducive for flowering and pod set (Singh *et al.,* 1997). Akyeampong (1986) showed that the crop is highly sensitive to water deficits during flowering and pod filling stages. It has been reported by Marino *et al*., (2007), that water stress has a significant adverse effect on the growth and biological nitrogen fixation of cowpea. Hsiao and Xu (2000) reported that a decrease in soil water potential can markedly affect root hair and retard nodule growth and nitrogen fixation.

Stability in yields of agronomically acceptable cultivars is generally regarded as the ultimate goal in cowpea improvement (Oghiakhe *et al*., 1995). One way to obtain this is to identify genotypes with adequate levels of resistance to drought, heat and other stresses. There is need for cowpea cultivars, which are more tolerant to water deficit or more efficient in water use (Anyia and Herzog, 2004). However, progress in breeding cultivars for dry environments has been slow (Hall *et al*., 1997). Cowpea possesses high yield plasticity under diverse environments, and could alleviate the economic hardships of farmers in case of severe drought and heat (Dadson *et al.,* 2005). The objective of the study was to determine the influence of drought stress on canopy temperature, growth and yield of cowpea varieties in coastal lowland Kenya.

4.3 Materials and Methods

4.3.1 Study site

The study was carried out on-station at Pwani University (PU) in coastal lowland (CL) Kenya; located at 60 km north of Mombasa, between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. The region receives an average annual rainfall of 600–1100 mm that comes in two seasons (Sombroek et al., 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time (Saha, 2007). Mean monthly minimum and maximum temperatures are about 22^oC and 30^oC, respectively, and the mean relative humidity is 80% (Jaetzold and Schmidt, 2012). According to Sombroek *et al.*, (1982), the soils in coastal lowland Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen) and prone to leaching, and have a pH ranging between 5 and 7 (Mureithi *et al.*, 1995). The study was conducted during dry seasons of 2011 and 2012. The soils were analysed for pH and macronutrients (Appendix 1).

4.3.2 Experimental design, treatments and crop husbandry

The experiment was laid out in a randomized complete block design (RCBD), with a split-plot arrangement of treatments and replicated three times. The main plots consisted of the water stress level while the sub plots consisted of the cowpea varieties. The water stress levels were: well watered (maintained at field capacity), water stress at vegetative stage and water stress at flowering stage. The sub-plots consisted of seven local and four improved varieties: (i). KVU 419 (improved variety from KALRO Katumani); (ii). Khaki (local variety); (iii). K80 (improved variety for the region); (iv). Macho (local variety); (v). Kaima-koko (local variety); (vi). Nyeupe (local variety); (vii). KVU 27-1 (improved variety from

KALRO Katumani); (viii). Nyekundu (local variety); (ix). M 66 (improved variety from Katumani); (x). Kuhambala (local variety); and (xi). Mwandato (local variety). The plant spacing was 60 cm x 30 cm with two seeds per hill, no fertilizer was applied. Weeding was done twice; the first and second weedings were done on the second and fifth week after planting respectively.

Water stress was imposed at vegetative and flowering stages. For the vegetative stage, irrigation was stopped six weeks after planting the late maturing cowpea varieties (Nyeupe, Kutambaa and Mwandato) and three weeks after planting the early maturing varieties (KVU 419, Khaki, K80, Macho, Kaima koko, KVU 27-1, Nyekundu and M66). Water stress was imposed for two weeks. For water stress at flowering stage, the irrigation was stopped eight weeks after planting the late maturing varieties and five weeks after planting the early maturing varieties. The water stress was imposed for two weeks when flowering was 50 %. The early maturing varieties were planted three weeks after planting the late maturing varieties to synchronize flowering for the drought to be imposed at the same time (Ndiso *et al.*, 2012). Drip irrigation was applied after every 12 hours for three hours to ensure that soil moisture was maintained at close to field capacity.

4.3.3 Data collection

The data collected included chlorophyll content, days to anthesis, grains per pod, number of leaves, percent ground cover, canopy temperature, number of pods per plant, 100-grain weight, pod weight, dry matter and grain yield. Chlorophyll content was measured using a chlorophyll meter before flowering stage. A leaf was selected, put in the leaf chamber of a chlorophyll meter (model SPAD 502 plus chlorophyll meter) and readings recorded on the screen. Number of days to anthesis was calculated by counting the number of days from planting to 50% flowering. The number of grains per pod was determined by counting the number of grains in each pod at harvest. Ten pods were sampled from each of the ten plants sampled in each plot. Leaf number was determined by counting the number of leaves fortnightly after emergence to flowering stage. Percent ground cover was measured in the net plot (5.76 m^2) at vegetative stage using the string and dot method as described by Sarrantonia (1991). A string measuring 10 m length was marked with ink every 15 cm and stretched across both diagonals of the plot. The number of marks lying over or under a living plant part were counted and recorded. Percent ground cover was calculated as:

$$\%\ \text{Ground cover} = \frac{\text{Number of marks over or under plant part}}{\text{Total number of marks across plot diagonals}}\ \text{x}100$$

Canopy temperature was taken in the middle part of the crop canopy using a canopy temperature meter prior to flowering stage. The number of pods per plant was determined from 10 plants in each plot at harvesting time. Weight of 100 grains was determined by weighing 100 grains of the harvested grains in each plot. Pod weight was determined by weighing 10 pods selected from the 10 plants sampled in each plot at harvest time. Total dry matter was determined by uprooting whole plants (together with the pods) at maturity, oven drying and weighing. Grain yield was taken after harvest from the middle part of the drip lines leaving five hills from each end. The area from which the plants were harvested for grain yield determination was 6.4 m^2. Harvest index was calculated as the weight of harvested grain as a percentage of the total above ground biomass (Blaser, 2009)

4.3.4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$. Linear regression analyses between grain yield and chlorophyll content, canopy temperature, days to anthesis, number of leaves, % ground cover, pods per plant, 100-grain weight, pod weight, and total dry matter were conducted.

4.4 Results

4.4.1 Effect of water stress at vegetative and flowering growth stages on cowpea percent ground cover and number of leaves per plant

Water stress level, cowpea variety and their interaction significantly affected percent ground cover and leaf number (Table 4.1). Water stress at both vegetative and flowering stages significantly reduced the percent ground cover and leaf number in most cowpea varieties except Macho, Nyeupe and Mwandato. Plants subjected to water stress during flowering had higher percent ground cover and leaf number than plants subjected to water stress during the vegetative stage for all varieties except Kaima koko, M66 and KVU 27-1. Under no water stress, Kutambaa had significantly the highest percent ground cover (99.4%) followed by Mwandoto (85.8%) and Nyeupe (83.6%), while M66 had significantly the lowest percent ground cover (49.2%). Percent ground cover varied from 49.2% (M66) to 99.4% (Kutambaa), 29.6% (Khaki) to 95.2% (Nyeupe) and 40.3% (M66) to 99.4% (Nyeupe) under no water stress, stress at vegetative and flowering stages respectively. Percent ground cover reduction due to water stress ranged from 2.3% to 46.4% at vegetative stage and 6.29% and 37.0% at flowering. Under no stress, Kutambaa had significantly the highest leaf number while Mwandato and Nyeupe had significantly the highest leaf number under water stress imposed during vegetative and flowering stages. Number of leaves per plant ranged from 62 (M66) to 134 (Kutambaa) under no stress, 34 (Khaki) to 128 (Nyeupe) under stress at vegetative stage and 49.3 (M66) to 134 (Nyeupe) under stress at flowering.

Table 4.1 Effect of water stress at vegetative and flowering stages on percent ground cover and number of leaves per plant of cowpea

Cowpea variety (V)	Ground cover (%)				Number of leaves per plant			
	Water stress (WS)			V- mean	Water stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	65.4	39.4	43.6	49.5	85.3	48.0	54.0	62.4
Khaki	55.2	29.6	49.2	44.7	70.7	34.0	62.0	55.6
K 80	58.4	39.4	46.4	48.1	75.3	48.0	58.0	60.4
Macho	57.4	56.1	63.8	59.1	74.0	72.0	83.0	73.3
Kaima-koko	73.6	52.6	46.4	57.5	97.0	67.0	58.0	74.0
Nyeupe	83.6	95.2	99.4	92.7	111.3	128.0	134.0	124.4
KVU 27 – 1	51.9	47.8	48.7	49.5	66.0	60.0	61.3	62.4
Nyekundu	65.9	47.8	55.2	56.3	86.0	60.0	70.7	72.2
M 66	49.2	46.4	40.3	45.3	62.0	58.0	49.3	56.4
Kutambaa	99.4	58.9	66.6	75.0	134.0	76.0	87.0	99.0
Mwandato	85.8	94.5	98.0	92.8	114.7	127.0	132.0	124.6
WS-mean	67.8	55.3	59.8		88.8	70.7	77.2	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.0001				0.0001			
p-value VxWS)	0.0001				0.0001			
$LSD_{0.05}$ V	1.5				2.16			
$LSD_{0.05}$ WS	1.0				1.13			
$LSD_{0.05}$ V x WS	2.6				3.7			
CV (%)	2.6				2.9			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

4.4.2 Effect of water stress at vegetative and flowering stages on cowpea chlorophyll content and canopy temperature

Water stress significantly reduced chlorophyll content of cowpea while the main effects of variety and the interaction between cowpea variety and water stress had no effect on this parameter (Table 4.2). Cowpea plants subjected to water stress during the vegetative stage had lower chlorophyll content than non-water stressed plants and plants subjected to water stress during flowering. Water stress during flowering had no effect on chlorophyll content. There were significant differences in canopy temperature due to water stress and the interaction between water stress and cowpea variety (Table 4.2). Cowpea variety main effect on canopy temperature was not significant. Water stress at vegetative stage significantly increased canopy temperature in Khaki, Kaima koko, and Mwandato but significantly reduced canopy temperature in Macho and Nyekundu. Water stress at flowering increased canopy temperature in K80, M66, Kutambaa and Mwandato. Canopy temperature varied from 20.70^{o}C (Mwandato) to 25.23^{o}C (Macho) under no stress, 20.20^{o}C (Kutambaa) to 24.83^{o}C (Kaima-koko) under water stress imposed at vegetative stage and 22.77^{o}C (KVU 27-1) to 25.60^{o}C (K80) under stress imposed at flowering stage.

Table 4.2: Effect of water stress at vegetative and flowering growth stages on cowpea chlorophyll content and canopy temperature

Cowpea variety (V)	Chlorophyll content index				Canopy temperature (^{o}C)			
	Water stress (WS)			V- mean	Water stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	54.70	46.43	50.00	50.38	22.67	23.10	23.17	22.98
Khaki	53.37	51.47	56.23	53.69	21.97	24.43	22.93	23.11
K 80	54.43	50.67	50.13	51.74	22.53	23.50	25.60	23.87
Macho	56.13	46.23	55.67	52.68	25.23	21.50	23.27	23.33
Kaima-koko	51.20	47.00	50.77	49.66	22.47	24.83	23.23	23.51
Nyeupe	53.77	51.17	52.23	52.39	22.30	23.10	23.77	23.06
KVU 27 – 1	53.87	48.67	53.63	52.06	22.53	24.37	22.77	23.22
Nyekundu	52.13	45.27	49.53	48.98	24.96	20.47	23.03	22.82
M 66	53.23	46.20	50.20	49.88	21.63	22.33	24.67	22.87
Kutambaa	54.47	48.73	52.47	51.89	20.97	20.20	25.37	22.17
Mwandato	50.77	47.47	54.07	50.77	20.70	23.20	23.83	22.58
WS-mean	53.46	48.12	52.27		22.54	22.82	23.79	
p-value (V)	0.264				0.561			
p-value (WS)	0.0001				0.007			
p-value VxWS)	0.856				0.0003			
$LSD_{0.05}$ V	Ns				Ns			
$LSD_{0.05}$ WS	1.91				0.72			
$LSD_{0.05}$ V x WS	Ns				2.39			
CV (%)	7.56				6.35			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

4.4.3 Effect of water stress at vegetative stage and flowering on cowpea number of days to anthesis

Cowpea variety and water stress had significant effects on the number of days to anthesis (Table 4.3), but their interaction had no significant effect on this attribute. Water stress at vegetative and flowering stages significantly increased the number of days to anthesis. There was no significant difference between water stress at vegetative and at flowering stage in the number of days to anthesis.

Table 4.3: Effect of water stress at vegetative and flowering growth stages on cowpea number of days to anthesis

Cowpea variety (V)	Number of days to anthesis			
	Water stress (WS)			V- mean
	Nws	Vws	Fws	
KVU 419	42.67	43.00	48.0	44.56
Khaki	44.67	47.33	46.00	46.00
K 80	44.67	45.67	48.00	46.11
Macho	46.67	49.67	48.67	48.33
Kaima-koko	47.67	48.33	49.00	48.33
Nyeupe	58.33	59.67	58.33	58.78
KVU 27 – 1	44.67	46.00	47.00	45.89
Nyekundu	40.00	44.33	44.67	43.00
M 66	42.67	45.67	42.67	43.67
Kutambaa	61.00	62.33	70.00	64.44
Mwandato	63.00	70.33	67.33	66.89
WS-mean	48.70	51.10	51.80	
p-value (V)	0.0001			
p-value (WS)	0.0001			
p-value VxWS)	0.086			
$LSD_{0.05}$ V	2.51			
$LSD_{0.05}$ WS	1.31			
$LSD_{0.05}$ V x WS	Ns			
CV (%)	5.27			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

Mwandato had significantly the highest number of days to anthesis while KVU 419, Nyekundu and M66 had significantly lower number of days to anthesis than most of the varieties. Kutambaa had a lower number of days to anthesis than all varieties except Mwandato. The number of days to anthesis varied from 44.3 (Nyekundu) to 70.3 (Mwandato). Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days respectively.

4.4.4 Effect of water stress at vegetative and flowering growth stages on cowpea number of pods per plant and grains per pod

Cowpea variety, water stress and the interaction between cowpea variety and water stress significantly affected the number of pods per plant (Table 4.4). Water stress at vegetative and flowering stages significantly increased the number of pods per plant in cowpea varieties. The number of pods per plant varied from 4.3 (Kutambaa) to 10.3 (M66) under no water stress, 6.3 (Mwandato) to 11 (K80) under water stress at vegetative stage and 7.3 (Mwandato) to 12.3 (Macho) under water stress at flowering. Water stress increased the number of pods per plant by 5 and 5.7 at vegetative and flowering stages respectively. Plants subjected to water stress during flowering stages had higher number of pods per plant than water stress at vegetative stage. The varieties which had significantly higher number of pods per plant under water stress at flowering stage were Macho, Nyeupe and M66. Cowpea varieties, water stress and their interactions had no significant effect on the number of cowpea grains per pod (Table 4.4). The average number of grains per pod for plants under no water stress, water stress at vegetative stage and water stress at flowering was 13.8, 14.2 and 13.8, respectively. Number of grains per pod varied from 11.7 (Nyeupe) to 15.7 (Kaima Koko), 13.0 (Macho) to 15.3 (KVU 419), and 12.7 (Nyeupe and M66) to 16.0 (Khaki) under no stress, stress at vegetative stage and stress at flowering, respectively.

Table 4.4: Effect of water stress at vegetative and flowering growth stages on number of pods per plant and grains per pod of cowpea

Cowpea variety (V)	Number of pods per plant				Number of grains per pod			
	Water stress (WS)			V- mean	Water stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	10.0	9.0	10.0	9.7	13.7	15.3	14.3	14.4
Khaki	7.3	10.7	9.0	9.0	15.3	15.0	16.0	15.4
K 80	9.0	11.0	7.7	9.2	14.7	15.0	14.0	14.6
Macho	10.0	10.0	12.3	10.8	12.3	13.0	13.7	13.0
Kaima-koko	9.0	10.0	9.3	9.4	15.7	14.3	13.0	14.3
Nyeupe	6.0	8.0	11.7	8.6	11.7	13.3	12.7	12.6
KVU 27 – 1	8.0	9.0	8.7	8.6	12.0	14.7	14.7	13.8
Nyekundu	10.0	10.0	9.3	9.8	15.0	13.0	14.3	14.1
M 66	10.3	10.7	11.7	10.8	15.3	14.0	12.7	14.0
Kutambaa	4.3	9.3	8.7	7.4	14.0	14.0	13.0	13.7
Mwandato	5.3	6.3	7.3	6.3	12.3	15.0	13.3	13.6
WS-mean	8.1	9.5	9.6		14.0	14.2	13.8	
p-value (V)	0.0001				0.141			
p-value (WS)	0.0003				0.549			
p-value VxWS)	0.006				0.625			
$LSD_{0.05}$ V	1.46				Ns			
$LSD_{0.05}$ WS	0.76				Ns			
$LSD_{0.05}$ V x WS	2.39				Ns			
CV (%)	17.0				13.4			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

4.4.5 Effect of water stress at vegetative and flowering growth stages on cowpea 100-grain weight and pod weight

Cowpea variety, water stress and interaction between cowpea variety and water stress significantly affected cowpea 100-grain weight (Table 4.5). Water stress at vegetative and flowering stages significantly reduced 100-grain weight of cowpea varieties. Plants subjected to water stress during flowering stages had a lower 100-grain weight than water stress at vegetative stage. Weight of 100-grains varied from 12.9 g (Nyekundu) to 19.3 g (Nyeupe), 12.0 g (Nyekundu) to 18.9 g (Nyeupe) and 11.7 g (Nyekundu) to 18.6 g (Nyeupe) under no water stress, stress at vegetative and flowering stages, respectively. Variety Nyeupe had significantly higher 100-grain weight than other varieties under all water stress levels. Variety and interaction between variety and water stress significantly reduced cowpea pod weight (Table 4.5). Main effects of water stress levels had no significant effect on cowpea pod weight.

Table 4.5: Effect of water stress at vegetative and flowering growth stages on cowpea 100-grain weight and pod weight (t/ha)

Cowpea variety (V)	100-grain weight (g)				Pod weight (t/ha)			
	Water stress (WS)			V- mean	Water stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	13.6	13.1	12.7	13.1	11. 67	6.07	6.97	8.23
Khaki	13.6	13.1	12.8	13.2	9.50	3.97	8.17	7.21
K 80	13.5	13.4	13.3	13.4	10.17	6.07	7.57	7.93
Macho	16.4	15.8	15.6	15.9	10.00	9.70	11.33	10.34
Kaima-koko	13.5	13.5	12.9	13.3	13.43	8.90	7.57	9.97
Nyeupe	19.3	18.9	18.6	18.9	15.60	18.07	19.00	17.56
KVU 27 – 1	18.0	17.3	16.4	17.2	8.80	7.90	8.10	8.27
Nyekundu	12.9	12.0	11.7	12.2	11.77	7.90	9.47	9.71
M 66	14.6	14.4	13.5	14.2	8.17	7.57	6.27	7.33
Kutambaa	14.9	14.1	12.3	13.8	19.00	10.27	11.93	13.73
Mwandato	13.7	13.3	13.1	13.4	16.10	17.93	18.70	17.58
WS-mean	14.9	14.5	13.9		12.20	9.49	10.46	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.0001				0.0001			
p-value VxWS)	0.0001				0.0001			
$LSD_{0.05}$ V	0.09				0.32			
$LSD_{0.05}$ WS	0.05				0.17			
$LSD_{0.05}$ V x WS	0.16				0.56			
CV (%)	0.65				3.21			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

Water stress at vegetative stage significantly increased pod weight of Nyeupe and Mwandato and reduced pod weight of Khaki but had no effect on other varieties. Water stress at flowering significantly increased pod weight of Nyeupe and Mwandato and significantly reduced pod weight of KVU 419 and Kaima koko; but had no effect on the rest of the varieties. Under no water stress, KVU 419 and Mwandato had significantly higher and lower pod weight, respectively, than most varieties. Under water stress at vegetative stage, Mwandato and KVU 27-1 had significantly lower and higher pod weight, respectively, than most varieties. Nyeupe and Mwandato had significantly higher and lower pod weight, respectively, than most varieties under stress at flowering stage.

4.4.6 Effect of water stress at vegetative and flowering growth stages on cowpea above ground dry matter at maturity and grain yield

Variety, water stress and interaction between variety and water stress significantly affected cowpea shoot dry matter and grain yield (Table 4.6). Water stress at vegetative and flowering stages significantly lowered the shoot dry matter in cowpea varieties by 56.2% and 36.2% respectively. At vegetative stage the reduction in shoot dry matter ranged from 26.4% in Macho to 86.8% in Mwandato, while, at flowering stage it ranged from 15.3% in KUV 27-1 to 78.3% in Mwandato. At vegetative stage Nyeupe and Mwandato had higher dry matter reduction of 76.3% and 86.8%, respectively while at flowering stage Mwandato had the highest reduction of 78.3% in shoot dry matter. Water stress at vegetative stage significantly increased grain yield in KVU 27, Nyekundu, Kaima Koko, K80 and M66 by 121.1, 102.2, 55.8, 52.8 and 52.4% respectively; but it significantly reduced grain yield in Nyeupe by 44.0%. Water stress at flowering significantly increased grain yield in Nyekundu and Kutambaa by 53.3 and 119.6%, respectively, but had no significant effect on grain yield in the rest of the varieties. KVU 419 had significantly higher grain yield than Kutambaa, Mwandato and Khaki under no stress but its yield was not significantly different from the rest of the varieties. Under water stress at vegetative stage, KVU 27-1, Nyekundu and Kaima koko had significantly higher grain yield than most of the other varieties. Under water stress at flowering, no major differences were noted among the varieties except that Mwandato had significantly lower grain yield than most varieties while Nyeupe had higher grain yield than

Mwandato, KVU 419 and Khaki. Average grain yield across all water stress levels varied from 0.5 t/ha (Mwandato) to 1.40 t/ha (Nyekundu)

Table 4.6: Effect of water stress at vegetative and flowering growth stages on cowpea above ground dry matter yield at maturity and grain yield

Cowpea variety (V)	Dry matter yield (t/ha)				Grain yield (t/ha)			
	Water stress (WS)			V- mean	Water stress (WS)			V- mean
	Nws	Vws	Fws		Nws	Vws	Fws	
KVU 419	20.49	11.67	14.92	15.69	1.34	1.25	1.04	1.21
Khaki	22.67	9.50	12.56	14.91	0.68	0.90	1.03	0.87
K 80	22.41	10.20	16.25	16.29	0.89	1.36	1.23	1.16
Macho	9.18	10.00	12.48	10.55	1.09	0.89	1.41	1.13
Kaima-koko	19.78	13.40	16.27	16.48	1.13	1.76	1.23	1.37
Nyeupe	15.60	3.60	8.11	9.10	1.16	0.65	1.54	1.12
KVU 27 – 1	25.19	8.80	14.44	16.14	0.90	1.99	1.17	1.35
Nyekundu	23.54	11.70	14.89	16.71	0.92	1.86	1.41	1.40
M 66	21.33	8.20	18.06	15.86	1.05	1.60	1.12	1.26
Kutambaa	19.00	7.21	10.34	12.18	0.56	0.74	1.23	0.84
Mwandato	16.00	2.12	3.48	7.20	0.48	0.38	0.65	0.50
WS-mean	19.86	8.69	12.67		0.93	1.22	1.19	
p-value (V)	0.0001				0.0001			
p-value (WS)	0.136				0.0002			
p-value VxWS)	0.0003				0.0001			
$LSD_{0.05}$ V	0.41				0.27			
$LSD_{0.05}$ WS	Ns				0.14			
$LSD_{0.05}$ V x WS	0.70				0.47			
CV (%)	27.17				26.02			

WS –Water stress, Nws – No water stress, Vws – Vegetative water stress and Fws – Flowering water stress

4.4.7 Effects of water stress at vegetative and flowering growth stages on cowpea harvest index

Cowpea variety, water stress and the interaction between cowpea variety and water stress significantly affected the harvest index (Table 4.7). Water stress at vegetative stage significantly increased harvest indices of all cowpea varieties except Macho, Nyeupe and Kutambaa. Water stress at flowering enhanced cowpea harvest indices for only K80, Kaima-koko, Nyekundu, and Kutambaa varieties. Mwandato had significantly the highest harvest indices under all the stress levels. Under water stress at vegetative stage, Kutambaa and Nyeupe had significantly the highest indices than all other varieties. Harvest indices varied from 2.93% (Mwandato) to 12.8% (M66) under no stress, 2.13% (Mwandato) to 25.3% under stress at vegetative stage and 3.47% (Mwandato) to 18% (M66) at flowering.

Table 4.7: Effects of water stress at vegetative and flowering growth stages on cowpea harvest index

Cowpea variety (V)	**Harvest index (%)**			
	Control (no stress)	**Vegetative stage**	**Flowering stage**	**V-mean**
KVU 419	11.53	20.53	14.87	15.64
Khaki	7.13	22.77	12.70	14.20
K 80	8.70	22.53	16.27	15.83
Macho	10.93	9.23	12.40	10.85
Kaima-koko	8.37	19.70	16.27	14.78
Nyeupe	7.43	3.57	8.13	6.38
KVU 27 – 1	10.20	25.30	14.90	16.80
Nyekundu	7.80	23.70	14.93	15.48
M 66	12.87	21.17	18.00	17.35
Kutambaa	2.97	7.20	10.33	6.83
Mwandato	2.93	2.13	3.47	2.84
WS-Means	8.26	16.17	12.93	
p-value (V)	0.0001			
p-value (WS)	0.0001			
p-value VxWS)	0.0001			
$LSD_{0.05}$ V	3.52			
$LSD_{0.05}$ WS	1.84			
$LSD_{0.05}$ V x WS	6.10			
CV (%)	30.0			

4.4.8 Linear regression relationships between grain yield and other cowpea crop traits

Linear regression relationships between grain yield and chlorophyll content, days to anthesis, leaf number, ground cover and dry matter were negative (Figure 4.1 to 4.5). In contrast, linear regression relationships between grain yield and canopy temperature, pods per plant, 100-grain weight and pod weight were positive (Figure 4.6 to 4.9).

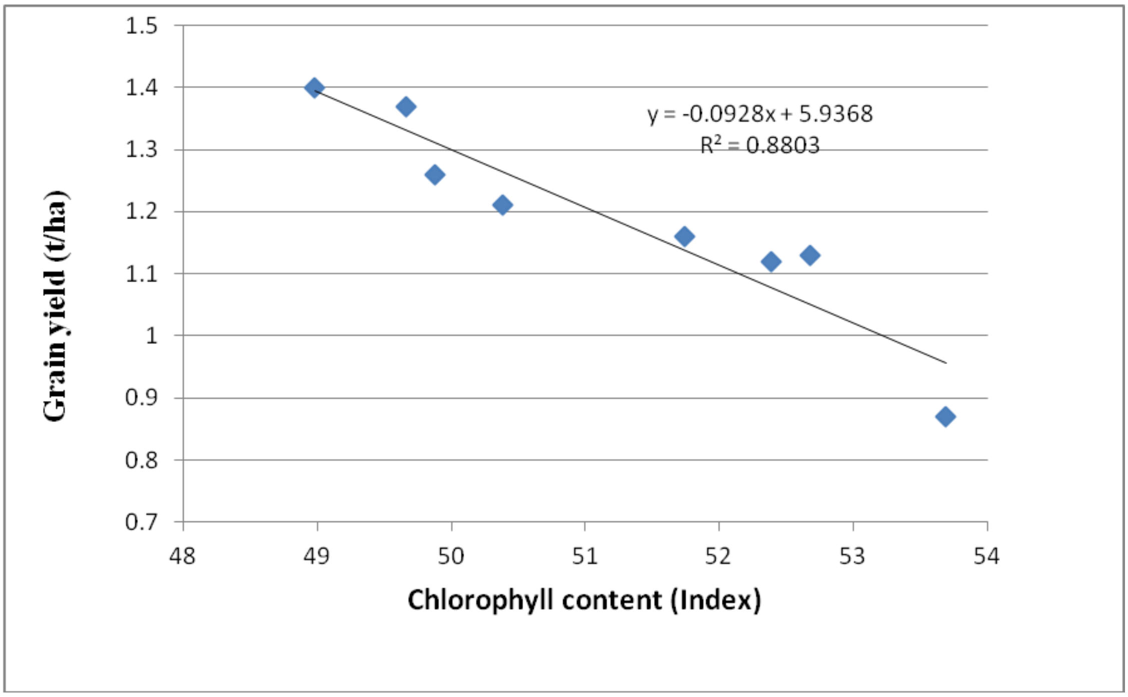

Figure 4.1 Linear regression relationship between grain yield and chlorophyll content index of cowpea

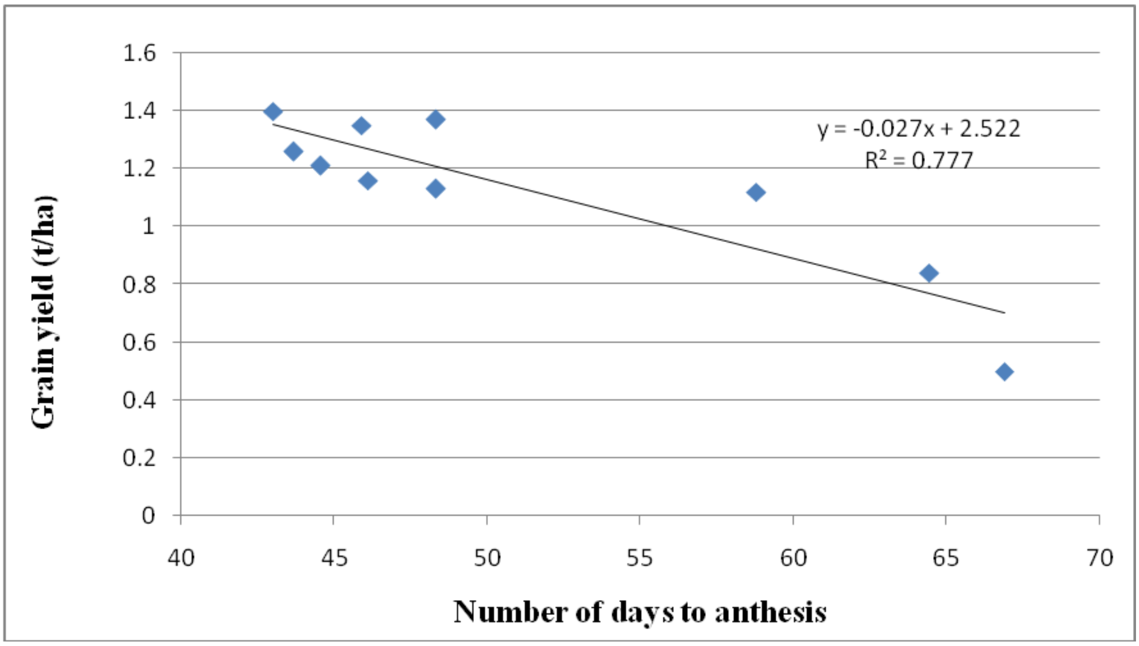

Figure 4.2 Linear regression relationship between grain yield and days to anthesis of cowpea

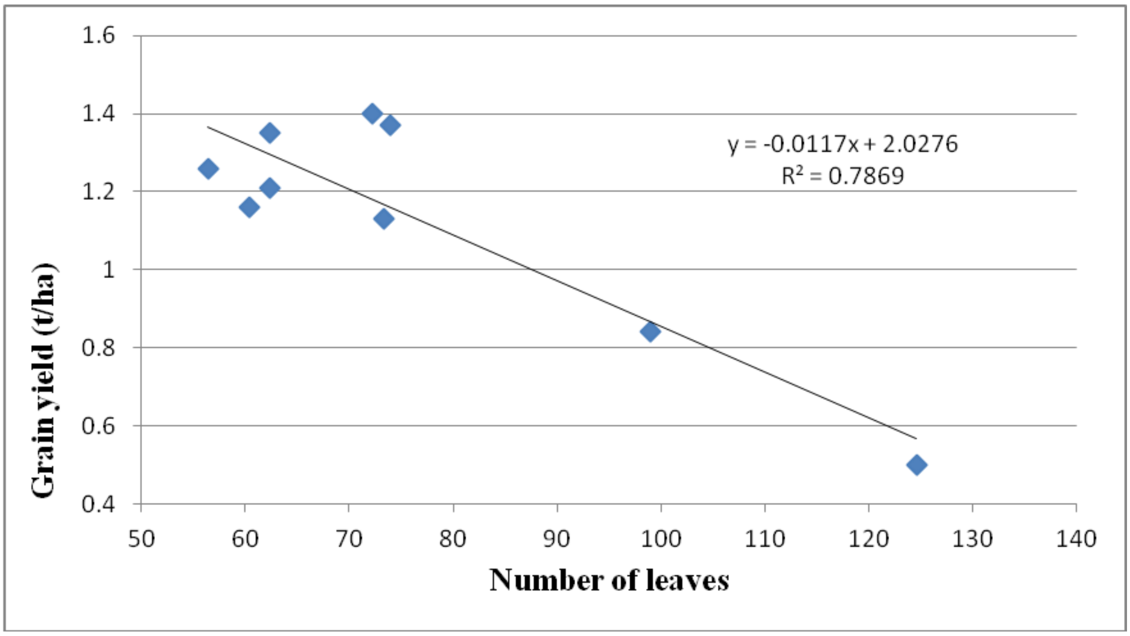

Figure 4.3 Linear regression relationship between grain yield and number of leaves of cowpea

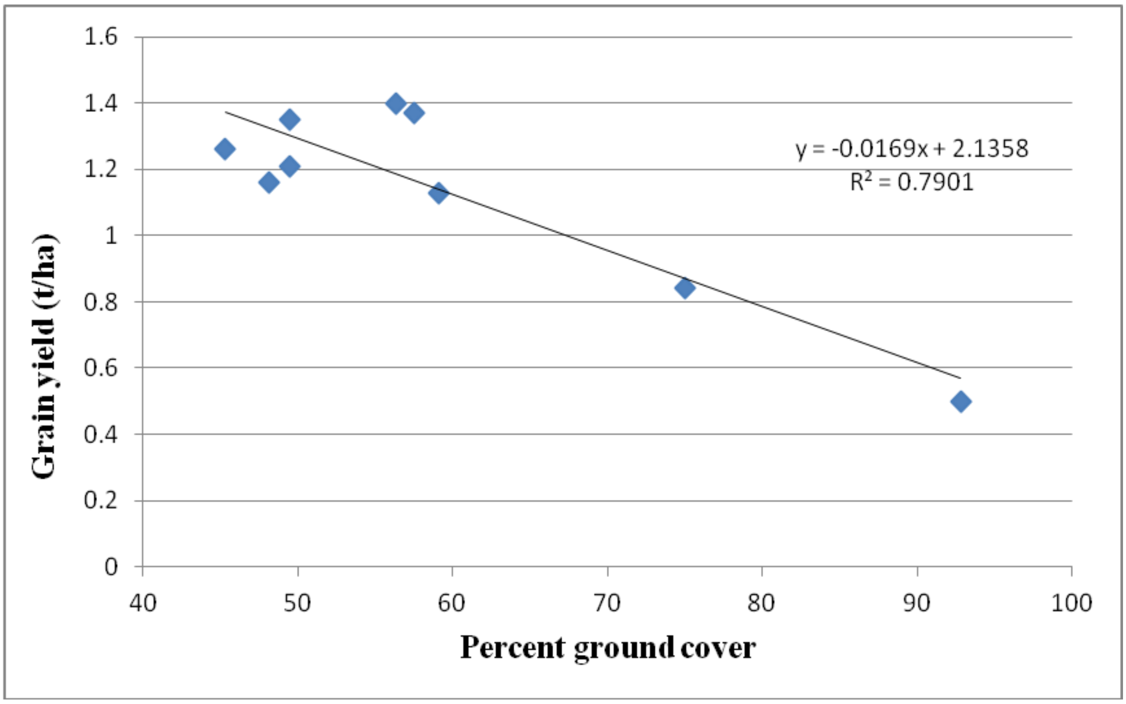

Figure 4.4 Linear regression relationship between grain yield and percent ground cover of cowpea

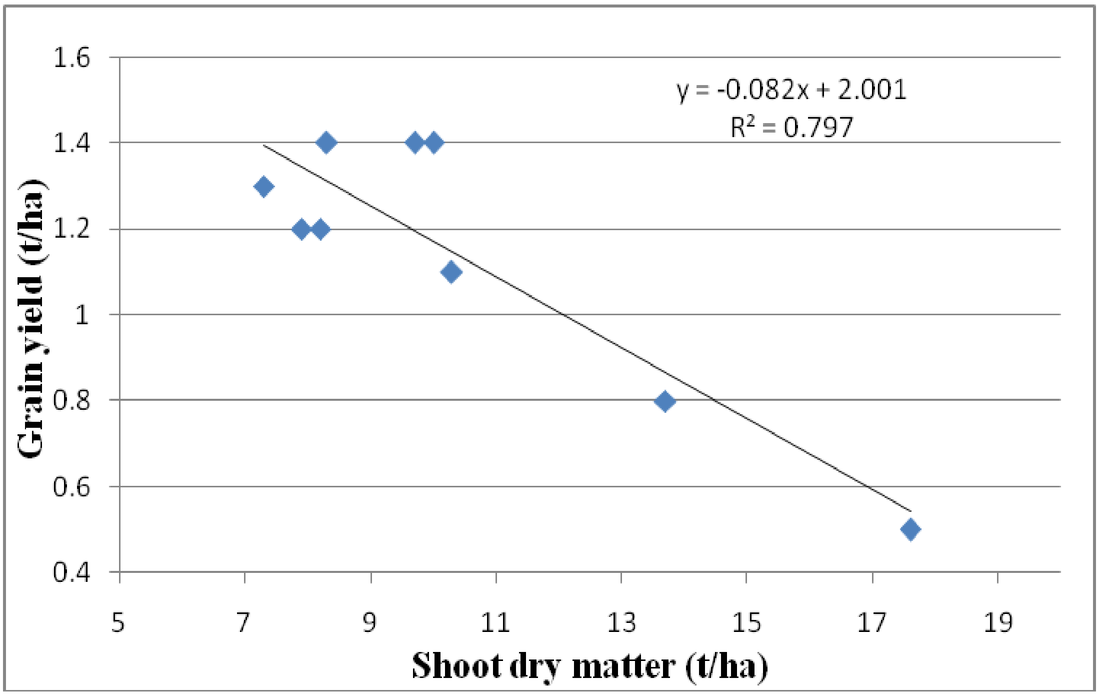

Figure 4.5 Linear regression relationship between grain yield and dry matter of cowpea

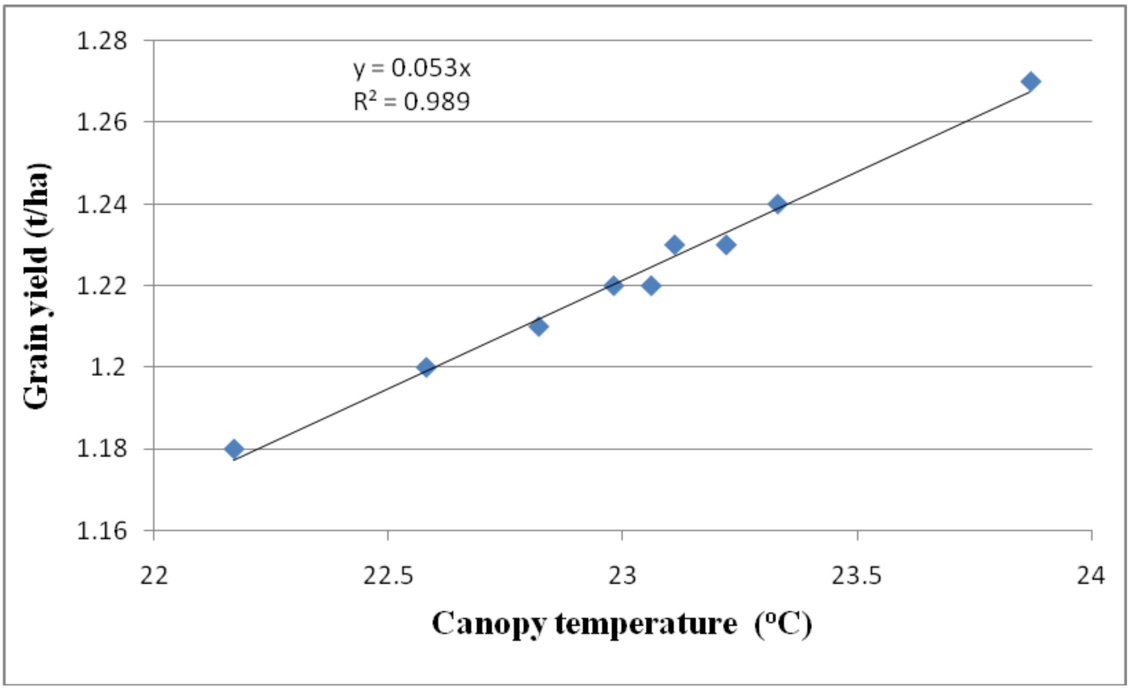

Figure 4.6 Linear regression relationship between grain yield and canopy temperature of cowpea

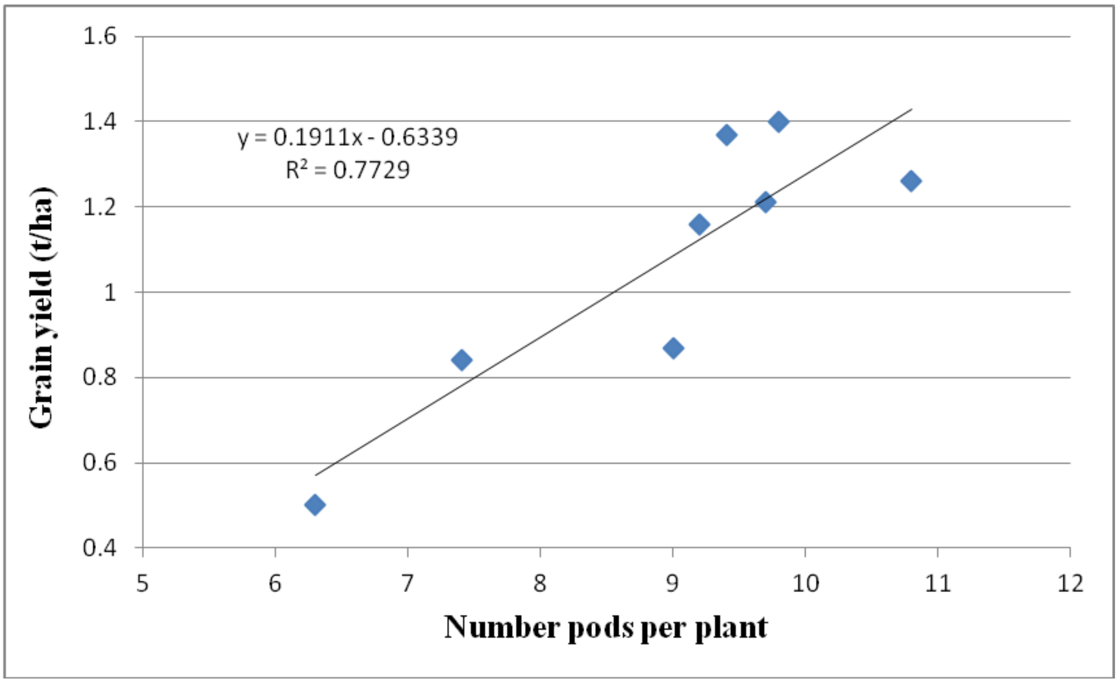

Figure 4.7 Linear regression relationship between grain yield and number of pods per plant of cowpea

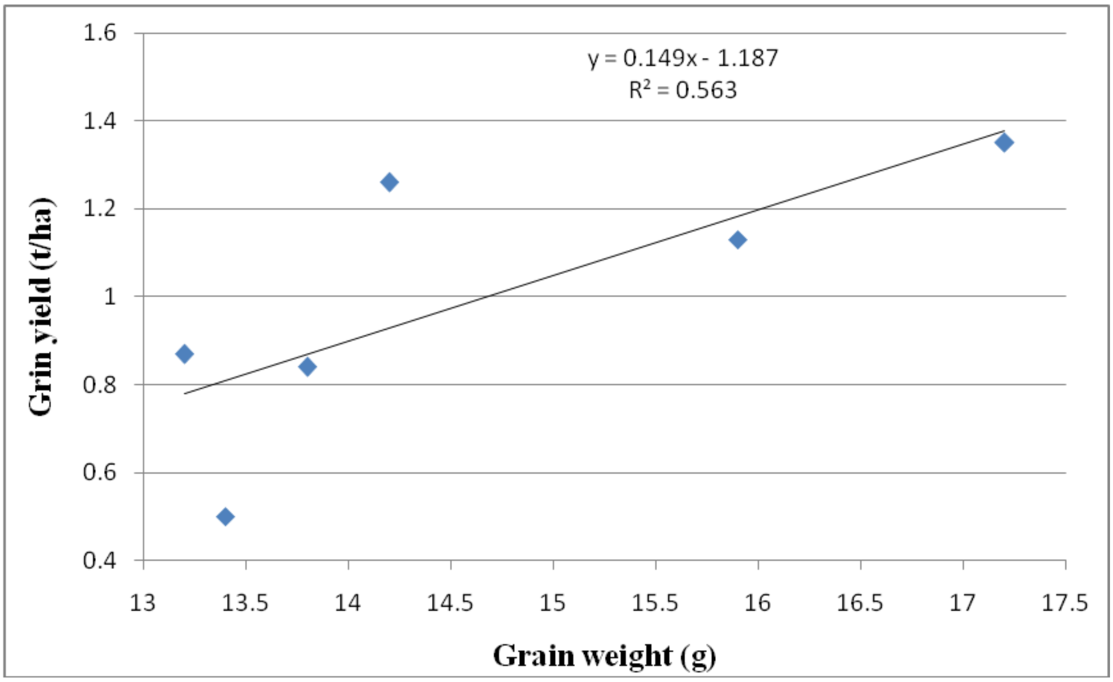

Figure 4.8 Linear regression relationship between grain yield and 100-grain weight (g) of cowpea

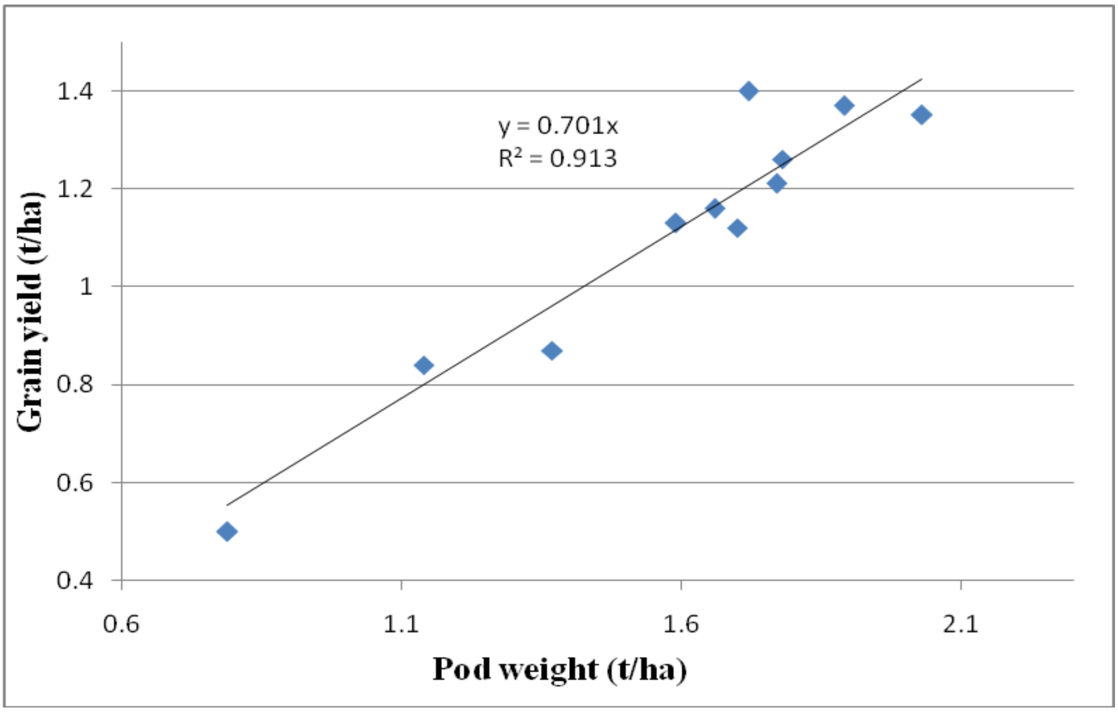

Figure 4.9 Linear regression relationship between pod weight (t/ha) and grain yield of cowpea

4.5 Discussion

4.5.1 Effects of variety and water stress on cowpea chlorophyll content, canopy temperature and time to anthesis

Water stress at vegetative stage significantly reduced cowpea chlorophyll content. This observation has been reported in previous studies. Hayatu and Mukhtar, (2010) reported 100% reduction in the chlorophyll content of cowpea genotypes under both moderate and severe water stress. Chlorophyll content is among the morphological, biochemical and physiological traits for drought screening in cowpea (Souza, *et al.* 2004). In the current study, the response to drought in terms of chlorophyll content was, however, not dependent on the cowpea variety. Chlorophyll content could not therefore be used to identify drought tolerant cowpea varieties. Water stress during flowering had no effect on chlorophyll content.

Water stress significantly increased canopy temperature for varieties such as Khaki and Kaima-koko but reduced the canopy temperature of Macho and Nyekundu. Hamidou *et al.*,

(2007) reported that water stress significantly increased canopy temperature of cowpea plants. They attributed this to the fact that cowpea plants closed their stomata to avoid dehydration thereby leading to an increase in canopy temperature. Stomata closure is the first responsive event of plants to water deficiency (Lisar *et al.*, 2012). There was a positive linear relationship between canopy temperature and grain yield, suggesting that stomatal closure resulted in increased water use efficiency. Hall *et al.*, (1997) reported that stomata closure under water stress resulted in increased water use efficiency (WUE). Canopy temperatures of Nyeupe and Macho decreased when water stress was imposed suggesting that they did not depend on stomata adjustment as a strategy to deal with water stress. Water stress at vegetative and flowering stages increased time to anthesis by 4 and 7 days, respectively. Abayomi and Abidoye, (2009) reported that the onset of and dates to full flowering of cowpea were significantly delayed under high moisture stress. The interaction between variety and water stress did not affect the time to anthesis.

4.5.2 Effects of water stress on cowpea leaf number, percent ground cover and shoot dry matter yield at maturity

Water stress caused reduction in cowpea leaf number, percent ground cover and dry matter yield at maturity. Reduction in leaf production and/or increase in leaf senescence and abscission due to water stress have been reported in previous studies (Abidoye, 2004). Okon (2013) and Samson and Helmut (2007) reported that post-flowering water stress reduced the cowpea total dry matter. Reduction in leaf and plant growth has been attributed to decrease in cellular expansion resulting from a decrease in plant water content (Abayomi and Abidoye, 2009), reduction in leaf formation and increased abscission of lower leaves (Waseem et *al*., 2011). The reduction in growth parameters under water stress conditions could also be attributed to decline in photosynthesis (Chaves *et al.*, 2009). The effects of water stress on leaf number, percent ground cover and dry matter yield were dependent on cowpea genotypes (Hayatu and Mukhtar, 2010).

4.5.3. Effects of water stress on harvest index, grain yield and yield components

Water stress at both vegetative and flowering stages significantly increased the number of pods per plant, pod weight, grain yield and harvest index for some varieties. Earlier studies indicated that cowpea could maintain seed yield when water stress was subjected at vegetative stage provided subsequent conditions were conducive for flowering and pod set (Singh *et al.*, 1997). However, Akyeampong (1986) showed that cowpea is highly sensitive to water deficits during flowering and pod filling stages which lead to reduced grain yields. In the current study, there was a positive linear regression relationship between grain yield and number of pods per plant, 100-grain weight and pod weight. Grain yield in cowpea is determined by the product of the number of pods per plant that reach maturity, the average number of grains per pod and 100-grain weight (Akyeampong, 1985). Under water stress conditions, cowpea closes their stomata to avoid dehydration (Hamidou *et al.,* 2007). This reduces water loss (Souza *et al.* 2004) and increases water use efficiency (WUE) (Hall, *et al.* 1997). Cowpea varieties with high pod weight under water stress conditions could be making use of the additional photosynthetic capacity of their pods (Ahmed and Suliman, 2010). Dadson *et al*., (2005) reported that water stress increased cowpea harvest index. Most of the varieties in the current study apparently responded to water stress by partitioning more photosynthates to the grain relative to the shoot, thus leading to grain yield increases. This suggests that short-term moderate drought stress during vegetative growth and flowering enhances grain yield of some cowpea varieties but reduces shoot growth. Cowpea varieties which were superior in yield and high harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419. Under no water stress, the cowpea varieties which had high harvest indices were M66, KVU 419, Macho and KVU 27-1.

4.6 Conclusion

Water stress imposed at vegetative and flowering reduced growth parameters and chlorophyll content, but enhanced grain yield and yield components of some varieties. The impact of water stress on growth is dependent on the cowpea variety. Moderate stress may be beneficial if cowpea is grown for grain production but not if grown for vegetable production. Cowpea varieties which were superior in yield and high harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419.

CHAPTER FIVE: EFFECTS OF VARIETY AND INSECTICIDE SPRAY APPLICATION ON PEST DAMAGE AND YIELD OF COWPEA

5.1 Abstract

Cowpea (*Vigna unguiculata* (L)) Walp) has the potential to increase food security in coastal lowland. However, it is often attacked by a spectrum of pest species hence its production is considered too risky an enterprise by many growers. Field studies were at Pwani University farm under irrigation to evaluate the effects of variety and insecticide spray application on the pest damage and yield of cowpea. The trial was designed as a randomized complete block design with a split plot arrangement, replicated three times. The main plots were two pest management levels (no insecticide spray and insecticide spray) while the sub-plots included 11 local and improved cowpea varieties. Data collected included: insect pest damage at pre-flowering, flowering, podding and maturity stages, number of pods per plant, number of grains per pod, 100-grain weight and grain yield. Data collected were subjected to analysis of variance using the SAS statistical package. Insecticide application reduced pest damage at pre-flowering, flowering and podding by 23.5%, 20.6% and 52.3%, respectively. Pod borer damage was 49.9% lower in sprayed than unsprayed plots. Insecticide application significantly increased cowpea grain yield, with the increase ranging from 11.6% in Nyekundu to 662.5% in Macho. Varieties such as KVU 419, Macho, Kaima koko and Nyeupe had lower pod borer damage than K80, Mwandato and Nyekundu which had the highest damage under no insecticide spray. All the cowpea varieties evaluated were similarly affected by insect pests, indicating that application of an insecticide is necessary for sustainable cowpea production. Insecticide spray at podding stage is more critical than at pre-flowering and flowering stages.

5.2 Introduction

Cowpea (*Vigna unguiculata* (L)) Walp) is the most important grain legume in many parts of the world (Takim and Uddin, 2010) and its production is regarded as an integral part of the traditional cropping system throughout Africa (Isubikalu *et al.,* 2000). It is mostly grown as an intercrop with maize and is preferred by farmers because of its role in maintaining soil fertility through nitrogen-fixation (Asiwe *et al.,* 2009), and its nutritive value as fodder for livestock (Dzemo *et al*., 2010). The causes of low yields in cowpea production include insect pests, diseases, parasitic weeds, drought and low soil fertility; however, insect pests constitute the major constraint (Karungi *et al.,* 2000). The crop is attacked by a spectrum of pest species (Isubikalu *et al*., 2000). Cowpea production is therefore considered too risky an enterprise by many growers because of the numerous pest problems associated with it (Egho, 2010; Isubikalu *et al.,* 2000).

Over 130 species of insect pests have been recorded on cowpea and they attack virtually every part of the crop including the roots, leaves, flowers and pods (Singh and Jackai, 1985). Different insect pests specialize on different parts of a cowpea plant and, in the worst cases, these pests overlap in their incidence and damage. It is not unusual to find four or more pests on the crop at the same time (Singh and Jackai, 1985). Insect pests which severely damage cowpea during all growth stages are the cowpea aphids (*Aphis craccivora* Koch), foliage beetles (*Ootheca sp, Medythia spp*), the flower bud thrips (*Megalurothrips sjostedti Trybom*), the legume pod borer (*Maruca vitrata Fabricius*) and the sucking bug complex, of which *Clavigralla spp, Anoplocnemis spp, Riptortus spp, Mirperus spp, Nezara viridula Fab and Aspavia armigera* L. are the most important and prevalent (Egho, 2010; Jackai and Adalla, 1997).

The most important pre-flowering pests are *Ootheca mutabilis* and *Zonocerus variegates* but the most damaging of all pests are those that occur during flowering and podding stages. They include flower thrips dominated by *Megalurothrips sjostedi*, the legume pod borer *Maruca vitrata; Clavigralla tomentosicollis* and a complex of pod sucking bugs. The legume pod borer, *Maruca vitrata*, is a tropical pest of legume crops, particularly cowpeas (Jackai, 1995). Without control measures, its infestation rate can reach 80% and cause seed damage rates of up to 50% (Dreyer *et al*., 1994). Pod borers are important pests of the reproductive structures of cowpea with early feeding leading to flower bud and flower abortions, hence poor pod set (Tamo *et al.,* 1997). Insect pests are considered to be largely responsible for up to 90 – 100 % yield reduction (Jackai and Daoust, 1986). In Africa, average cowpea yields vary dramatically from 0.05 to 0.55 t ha^{-1} (Cisse *et al*., 1995), due to insect pests which damage cowpea from seedling emergence to storage (Karungi *et al.,* 2000). Losses from insects are associated with defoliation of root or leaf tissue, removal of fluid from phloem and xylem systems, mining of parenchyma tissue, formation of galls, or blemishing the harvested fruit or vegetable (Schoonhoven *et al*., 1998).

The insect pests that reduce cowpea yield to zero are those that attack the flowering and the podding stages (Fisher *et al*., 1987). A cowpea grain yield loss of 45 – 52% was recorded in Northern Nigeria during flowering stages, followed by 21 – 26% loss during pod formation, 7 – 9% loss during the pre-flowering and 2 – 3% loss in the establishment stage (Raheja, 1976). According to Jackai *et al*., (1985), it is not feasible to grow cowpea commercially without the use of insecticide sprays. In Kenya a report indicates grain yield losses of up to 80% in indigenous cowpea varieties as a result of pod borer attack (Okeyo-Owuor *et al*., 1983). Generally, peasant farmers growing cowpea in the region leave cowpea protection to chance or nature. The low yield obtained from such farmers' fields suggests that natural control by itself cannot afford enough protection to enhance profitable commercial production (Jackai and Sign, 1983). Dzemo *et al.*, (2010) reported that insect pest control insecticide sprays led to increased number of cowpea pods per plant, pod weight, number of seeds per pod, seed weight, and grain yield. The use of varieties that are resistant to attack by insect pests is one of the most promising alternative control measures. This strategy is economically and environmentally safe and can easily be integrated with other control measures (Alabi *et al.,* 2003). The objective of this study was to evaluate the effects of variety and insecticide spray application on pest damage and yield of cowpea.

5.3 Materials and Methods

5.3.1 Study site

The study was carried out at Pwani University (PU) in coastal lowland (CL) Kenya. This site is located 60 km north of Mombasa between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. Mean monthly minimum and maximum temperatures are about 22^0C and 30^0C, respectively, and the mean relative humidity is 80% (Jaetzold and Schmidt, 2012). The area receives an average annual rainfall of 600–1100 mm that comes in two seasons (Sombroek *et al.,* 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season, with 75% of the annual rainfall usually received during this time (Saha, 2007). According to Sombroek *et al.,* (1982), the soils in CL Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen), are prone to leaching, and have a pH range of 5 to 7 (Mureithi *et al*., 1995). The study was conducted in the dry season of 2011 and 2012 under drip irrigation.

5.3.2 Experimental design, treatments and crop husbandry

The experimental design was randomized complete block design, with a split-plot arrangement of treatments, replicated three times. Insecticide spray treatments were assigned to the main plots while the cowpea varieties were assigned to the sub-plots. This was done to avoid wind drift. The main plots had two treatments: no insecticide spray and insecticide spray. The insecticide used in spray treatment was *pestox ® 100 EC*. It was sprayed two weeks after planting then fortnightly up to podding stage. Pestox insecticide, whose active ingredient is cypermethrin, is a synthetic pyrethroid that belongs to a group of insecticides used widely as an industrial and agricultural pesticide (Chibuike and Parker, 2010). Cypermethrin, like all synthetic pyrethroids, kills insects by disrupting normal functioning of the nervous system (Sukanya and Doss, 2013). The 11 cowpea varieties tested comprised: (i). KVU 419 (improved variety from Kenya Agricultural and Livestock Research Organization (KALRO)-Katumani); (ii). Khaki (local variety); (iii). K 80 (improved variety for the region); (iv). Macho (local variety); (v). Kaima-koko (local variety); (vi). Nyeupe (local variety); (vii). KVU 27-1 (improved variety from KALRO Katumani); (viii). Nyekundu (local variety); (ix). M 66 (improved variety from KALRO Katumani); (x). Kutambaa (local variety); and (xi). Mwandato (local variety). A drip irrigation system was used to grow the experimental crops. The drip lines were 60 cm apart while the plots were 50 cm apart. Each replication had 11 plots and each plot had two drip lines. Inter-row spacing was 60 cm and within row spacing was 30 cm. Two seeds were planted in each hill. Weeds were controlled manually by hand weeding at two and four weeks after planting respectively. No organic or inorganic fertilizer was applied.

5.3.3 Data collection

Data collected included: insect pest damage at pre-flowering and flowering stages, damage by pod sucking bugs and pod borer, number of pods per plant, number of grains per pod, 100-

grain weight and grain yield. Pest damage was scored at vegetative, flowering, podding and maturity stages. Insect pest damage at vegetative stage (two weeks before flowering) was scored by calculating the percent number of the damaged leaves in relation to the total number of leaves. Pod sucking bugs and pod borer damage were determined by sampling 10 plants and calculating % damaged pods. Damage at all the stages was scored according to Baidoo and Mochiah (2014) using a scale of 1 to 5; with 1 = less that 25% damage; 2 = >25% but < 50%; 3 = 50%, 4 = >50% < 75% and 5 = >75% damage. The number of pods per plant and number of grains per pod were determined from 10 plants per plot by counting at harvesting time. Weight of 100-grains was determined by weighing 100 grains of the harvested grains per plot. Grain yield was determined by harvesting mature plants from an area of 6.4 m^2 in the middle part of the drip lines leaving five hills on each end. Harvested grains were sundried, weighed and grain yield adjusted to 14% moisture content as recommended (Mahapatra *et al.*, 2013)

5.3.4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at p = 0.05. Linear regression analyses between grain yield and the following parameters were performed: pest damage at pre-flowering, pest damage at flowering, number of pods per plant, pod borer damage, number of grains per pod, and 100-grain weight.

5.4 Results

5.4.1 Effects of variety and insecticide spray application on pest damage at pre-flowering and flowering stages

The most common pests at pre-flowering stage were leafhoppers (*Empoasca dolichi*), bean fly (*Ophiomyia phaseoli*), aphids (*Aphis craccivora*), and foliage beetles (*Photinus pyralis,* *Epicauta vittata, Podabrus flavicollis, Osmoderma eremicola* and *Oedemera nobilis).* At flowering stage the pests at pre-flowering stage were joined by the cowpea flower thrips *(Megalurothrips sjostedti*), green vegetable bud (*Nezara viridula*), Brown bean bug (*Riptortus serripes*) and the Legume pod borer (*Maruca testulalis Gayer*). Insecticide application significantly reduced pest damage at pre-flowering and flowering stages, while cowpea variety and interaction between cowpea variety and insecticide application had no significant effect (Table 5.1).

Table 5.1: Effects of variety and insecticide spray application on pest damage at pre-flowering and flowering stages

Cowpea varieties (V)	PDS at pre-flowering stage			PDS at flowering stage		
	Pest management (PM)		V-means	Pest management (PM)		V-means
	NIP	IP		NIP	IP	
KVU 419	4.67	3.67	4.20	4.33	3.33	3.83
Khaki	4.67	3.50	4.10	3.67	3.33	3.50
K 80	4.83	3.50	4.20	4.67	3.67	4.17
Macho	4.67	3.67	4.20	4.67	3.67	4.17
Kaima-koko	4.83	3.67	4.30	4.33	3.67	4.00
Nyeupe	4.17	3.33	3.8	3.67	3.00	3.33
KVU 27 – 1	4.50	3.50	4.00	4.33	3.67	4.00
Nyekundu	4.67	3.33	4.00	4.33	3.67	4.00
M 66	4.50	3.67	4.10	4.00	3.33	3.67
Kutambaa	4.67	3.50	4.00	4.33	3.00	3.67
Mwandato	4.83	3.67	4.30	4.67	3.00	3.83
PM-mean	4.64	3.55		4.27	3.39	
p-value (V)	0.548			0.248		
p-value (PM)	0.0001			0.0001		
p-value (V x PM)	0.967			0.769		
$LSD_{0.05}$ V	Ns			Ns		
$LSD_{0.05}$ PM	0.18			0.28		
$LSD_{0.05}$ V x PM	Ns			Ns		
CV (%)	8.98			14.89		

PDS – Pest damage scores, NIP – No insecticide spray and IP – Insecticide spray

Pest damage at pre-flowering and flowering stages in insecticide sprayed plots was significantly lower than in unsprayed plots by 23.5% and 20.6%, respectively. Pest damage was over 50% in all the varieties at both stages.

5.4.2 Effects of variety and insecticide spray application on pest damage at podding stage and pod borer damage

The most common pests at podding stage were green vegetable bug (*Nezara viridula*), brown bean bug (*Riptortus serripes*) and legume pod borer (*Maruca testulalis* Gayer). Insecticide application had significant effects on pest damage at podding while, variety and the interaction between variety and insecticide spray had no effect (Table 5.2). Pest damage at podding stage was significantly higher in unsprayed plots than in insecticide sprayed plots. Insecticide application reduced pest damage at podding stage by 52.3%. Pod borer damage was significantly affected by insecticide application and the interaction between cowpea variety and insecticide spray application (Table 5.2). Pod borer damage in unsprayed plots was significantly higher than in insecticide sprayed plots for all the varieties. In unsprayed plots, varieties such as K80, Mwandato and Nyekundu had higher pod borer damage than most of the other varieties. Majority of the varieties were not significantly different in pod borer damage in sprayed plots except that KVU 419 and Nyekundu had lower pod damage than K80. Insecticide application reduced pod borer damage by an average of 49.9%. Pod borer damage ranged from 37.5% in Macho and Kaima koko to 66.8% in Nyekundu. Varieties such as KVU 419, Macho, Kaima koko and Nyeupe had low pod borer damage scores under no insecticide spray treatment.

Table 5.2: Effects of variety and insecticide spray application on pest damage at podding stage and pod borer damage scores

Cowpea varieties (V)	PDS at podding stage			Pod borer damage scores		
	Pest management (PM)		V-means	Pest management (PM)		V-means
	NIP	IP		NIP	IP	
KVU 419	4.67	2.33	3.50	2.67	1.33	1.67
Khaki	5.00	2.33	3.70	3.33	1.67	2.00
K 80	4.67	2.33	3.50	4.33	2.33	1.83
Macho	5.00	2.33	3.70	2.67	1.67	2.17
Kaima-koko	5.00	2.67	3.80	2.67	1.67	2.17
Nyeupe	5.00	2.00	3.50	2.33	1.33	1.67
KVU 27 – 1	5.00	2.33	3.70	3.67	1.67	1.83
Nyekundu	4.67	2.33	3.50	4.00	1.33	1.67
M 66	5.00	2.33	3.70	3.33	1.67	2.00
Kutambaa	5.00	2.00	3.50	3.33	1.67	1.67
Mwandato	4.67	2.67	3.70	4.33	2.00	1.67
PM-mean	4.88	2.33		3.33	1.67	1.85
p-value (V)	0.87			0.31		
p-value (PM)	0.0001			0.0001		
p-value (V x PM)	0.48			0.003		
$LSD_{0.05}$ V	Ns			Ns		
$LSD_{0.05}$ PM	0.19			0.23		
$LSD_{0.05}$ V x PM	Ns			0.75		
CV (%)	10.58			24.47		

PDS – Pest damage scores, NIP – No insecticide spray and IP – Insecticide spray

5.4.3 Effects of variety and insecticide spray application on number of cowpea pods per plant and grains per pod

Cowpea variety, insecticide application and interaction between cowpea variety and insecticide application had significant effects on the number of pods per plant (Table 5.3). The number of pods per plant was significantly higher in insecticide sprayed plots than in unsprayed plots for all the varieties tested. The increase in number of pods per plant due to insecticide application ranged from 6.6% in Mwandato to 135.5% in Macho. Under no insecticide spray, Nyekundu had the highest number of pods per plant while under insecticide application Macho had the highest number of pods per plant. Varieties such as Mwandato, K80, Kaima koko and Nyeupe did not respond significantly to insecticide spray application with respect to number of pods per plant. Cowpea variety and insecticide application had significant effects on the number of grains per pod (Table 5.3). The number of grains per pod under sprayed plots was significantly higher than the number of grains per pod under no spray plots. Cowpea varieties with the highest number of grains per pod under no spray plots were M66, K80 and Kutambaa. The varieties with the highest number of grains per pod in sprayed plots were KVU 419, Kaima koko, Khaki, M66 and Nyekundu. Insecticide application increased the number of grains per pod by an average of 102.1%, with a range of 75.0 % (Nyeupe and Kutambaa) to 208.3% (Mwandato).

Table 5.3: Effects of variety and insecticide spray application on the number of cowpea pods per plant and grains per pod

Cowpea varieties (V)	Number of pods per plant			Number of grains per pod		
	Pest management (PM)		V-means	Pest management (PM)		V-means
	NIP	IP		NIP	IP	
KVU 419	4.33	9.00	7.50	7.33	16.00	11.67
Khaki	4.33	7.33	8.50	7.00	15.33	11.17
K 80	6.00	8.00	8.00	8.00	14.67	11.33
Macho	4.67	11.00	7.83	7.00	14.33	10.67
Kaima-koko	6.33	8.00	8.00	7.00	15.67	11.33
Nyeupe	4.00	6.00	6.00	6.67	11.67	9.17
KVU 27 – 1	5.00	8.00	6.50	7.67	14.00	10.83
Nyekundu	8.33	10.67	10.50	7.33	15.00	11.17
M 66	5.33	10.33	8.17	8.33	15.33	11.83
Kutambaa	3.33	5.67	5.67	8.00	14.00	11.00
Mwandato	5.00	5.33	5.33	4.00	12.33	8.17
PM-mean	5.15	8.12	7.50	7.12	14.4	10.76
p-value (V)	0.0001			0.0001		
p-value (PM)	0.0001			0.0001		
p-value (V x PM)	0.0001			0.074		
$LSD_{0.05}$ V	1.45			1.25		
$LSD_{0.05}$ PM	0.62			0.53		
$LSD_{0.05}$ V x PM	2.05			Ns		
CV (%)	16.09			9.92		

PDS – Pest damage scores, NIP – No insecticide spray and IP – Insecticide spray

5.4.4 Effects of variety and insecticide spray application on cowpea 100-grain weight and grain yield

There were significant effects on cowpea 100-grain weight due to cowpea variety, insecticide spray application and their interaction (Table 5.4). The 100-grain weight in sprayed plots was significantly higher than in unsprayed plots. Cowpea varieties with the highest 100-grain weight in unsprayed plots were K80 and Kaima koko. The varieties with the highest 100-grain weight in sprayed plots were Nyeupe and KVU 27-1. Insecticide application increased weight of 100 grains by an average of 41.43%, with a range of range of 2.83% (K80) to 125.76% (Kutambaa).

Table 5.4: Effects of variety and insecticide application on 100-grain weight and grain yield of cowpea

Cowpea varieties (V)	100-grain weight (g)			Grain yield (t/ha)		
	Pest management (PM)		V-means	Pest management (PM)		V-means
	NIP	IP		NIP	IP	
KVU 419	8.87	13.60	12.82	0.88	1.18	1.04
Khaki	9.50	13.60	13.72	0.51	0.71	0.69
K 80	15.07	15.50	14.27	0.44	0.64	1.10
Macho	8.53	16.40	15.80	0.16	1.22	0.70
Kaima-koko	13.50	14.33	14.58	0.18	0.92	0.91
Nyeupe	11.83	19.30	15.60	0.33	1.16	0.74
KVU 27 – 1	12.33	18.00	15.17	0.33	0.74	0.62
Nyekundu	10.40	12.90	14.12	0.69	0.77	0.89
M 66	9.30	14.60	11.95	0.34	1.05	0.67
Kutambaa	6.60	14.90	10.17	0.30	0.68	0.45
Mwandato	12.03	13.70	12.87	0.48	1.05	0.74
PM-mean	10.72	15.17	13.73	0.42	0.92	0.78
p-value (V)	0.0001			0.0001		
p-value (PM)	0.0001			0.0001		
p-value (V x PM)	0.0001			0.0001		
$LSD_{0.05}$ V	1.12			0.08		
$LSD_{0.05}$ PM	0.48			0.04		
$LSD_{0.05}$ V x PM	1.59			0.12		
CV (%)	7.17			9.28		

PDS – Pest damage scores, NIP – No insecticide spray and IP – Insecticide spray

Cowpea variety, insecticide spray application and their interaction significantly affected cowpea grain yield (Table 5.4). Insecticide application significantly increased grain yield of all the varieties except for Nyekundu where there was no effect. Insecticide application increased grain yield by an average of 119.1%, with a range of 11.6% (Nyekundu) to 662.5% (Macho). Variety KVU 419 had the highest grain yield under no spray treatment followed by Nyekundu, while Macho and Kaima koko had the lowest yield under the same treatment. In sprayed plots, Macho, KVU 419 and Nyeupe had the highest grain yield while K80, Kutambaa, Khaki and Nyekundu had the lowest. Grain yield varied from 0.16 t ha^{-1} (Macho) to 0.88 t ha^{-1} (KVU 419) in unsprayed plots and from 0.64 t ha^{-1} (K80) to 1.22 t ha^{-1} (Macho) in insecticide sprayed plots.

5.4.5 The linear regression relationships between grain yield and pest damage, number of pods per plant, number of grains per pod and 100-grain weight.

Linear regression relationship between grain yield and pest damage at pre-flowering and at flowering, respectively, was positive (Figure 5.1 and 5.2). In contrast, the linear regression relationships between grain yield and pod borer damage was negative R^2 =0.524) (Figure 5.3).

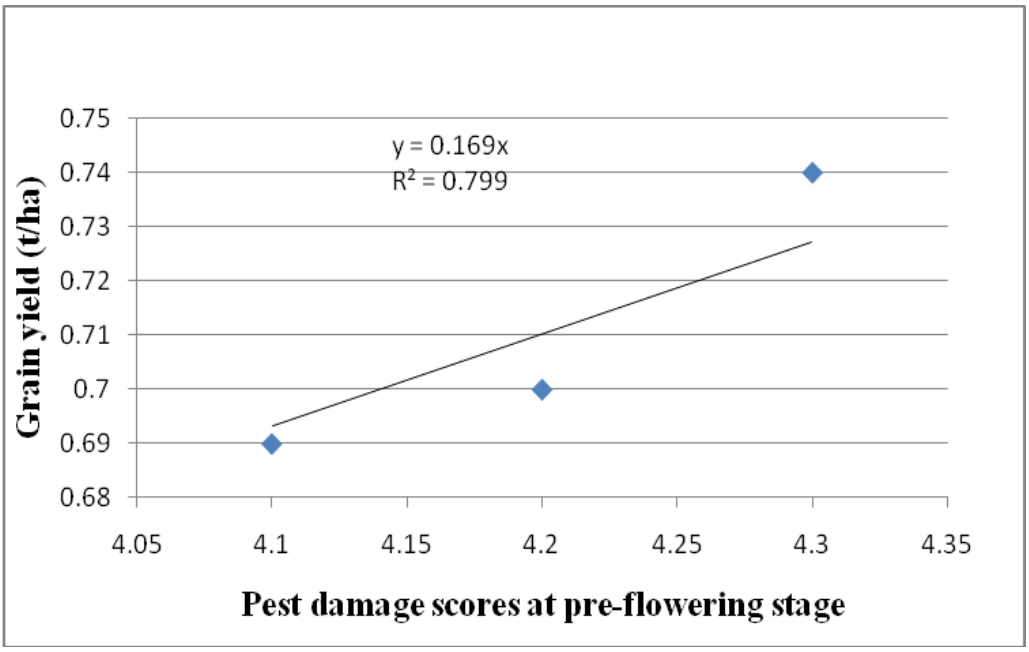

Figure 5.1 Linear regression relationship between grain yield and pest damage score at pre-flowering stage

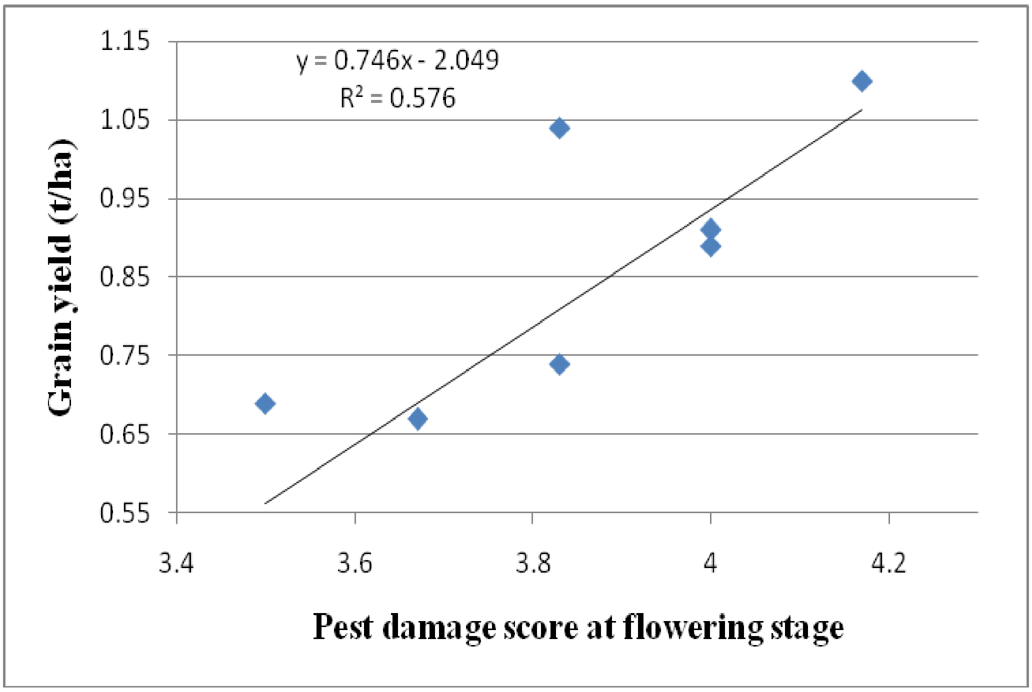

Figure 5.2 Linear regression relationship between grain yield and pest damage score at flowering stage

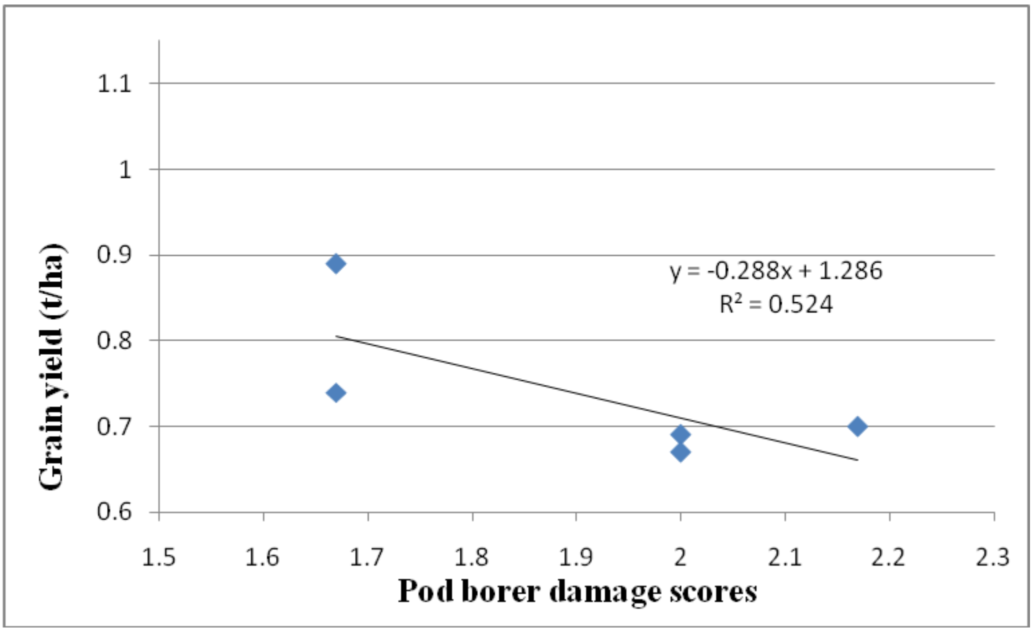

Figure 5.3 Linear regression relationship between grain yield and pod borer damage score

5.5 Discussion

5.5.1 Effects of variety and insecticide spray application on pest damage of cowpea at pre-flowering, flowering and podding stages

The major pests at pre-flowering stage included leafhoppers, bean fly, aphids and foliage beetles. The presence of many insect pest species at pre-flowering stage is a feature of cowpea (Karungi *et al.*, 2000). In the current study, all the varieties tested had more than 50% pest damage. According to Asante *et al*., (2001), losses in foliage attributed to field pests of cowpea ranged from 20% to almost 100%. Insecticide application reduced pest damage at pre-flowering stage by 23.5%. This finding is in agreement with previous reports by Egho (2010) and Isubikalu *et al.*, (2000) who indicated that spraying with an insecticide significantly reduced cowpea pest damage at pre-flowering stage. That there were no differences in pre-flowering pest damage among the varieties suggests that none of the 11 varieties tested was resistant to the pre-flowering pests. Insecticide spray application is therefore an important strategy for reducing pre-flowering insect pests in coastal lowland

Kenya. At flowering stage the major pests were cowpea flower thrips (*Megalurothrips sjostedti*), which joined forces with the pests that were already causing insect damage from the pre-flowering stage. Jackai and Daoust, (1986) reported that the yield of cowpea is low in tropical Africa due to major post flowering pests such as flower bud thrips, *Megalurothrips sjostedti Tryb*. In the current study, insecticide application significantly reduced cowpea pest damage at flowering by 20.6%. Oparaeke *et al.*, (2005) reported that complete crop failure may occur where insecticide protection is not introduced especially for improved, high yielding varieties. All the cowpea varieties tested had more than 50% pest damage and none of them showed resistance to insect damage at flowering. Control of these pests using insecticides or other methods is therefore crucial for sustainable cowpea production.

The major pests at podding stage were the legume pod borer (*Maruca testulalis*) and the pod sucking bugs, particularly the green vegetable bug (*Nezara viridula*), large brown bean bug (*Riptortus serripes*), and small brown bean bug (*Melanacanthus scutellaris*). Karungi *et al.* (2000) and Amatobi (1995) have shown that pod borers and pod sucking bugs are the most important pests of cowpeas. The legume pod borer (*Maruca testulalis)* is the most important lepidopterist cowpea pest and causes severe damage (Singh and Allen, 1980). Insecticide application significantly reduced insect damage at podding by 49.9%, with decreases in damage ranging from 37.5% in Macho and Kaima koko to 66.8% in Nyekundu. Under insecticide spray the insect damage ranged between >25% and <50% for all the varieties. The reduction in pest damage due to insecticide spray was higher at podding stage than at pre-flowering and flowering stages. The finding of the current study indicates that insecticide spray at podding stage is more critical than at pre-flowering and flowering stages. This finding is in agreement with the findings of Egho and Enujeke (2012) who reported significant reduction in pod borer damage in Nigeria when cowpea plants were treated with dimethoate pesticide. In Kenya a report indicates losses of up to 80% occur on indigenous cowpea varieties as a result of pod borer attack (Okeyo-Owuor *et al*., 1983). The observations in the current study imply that application of pesticide is necessary for sustainable cowpea production in the region. There were no varietal differences in pod borer damage for all cowpea varieties evaluated. In contrast, Veerappa (1998) reported significant differences in pod borer damage among 45 cowpea varieties. The author noted that tolerant genotypes had higher phenol and tannin content than the susceptible ones. Phenol compounds are mainly concentrated in the seed coat (Preet and Punia, 2000). Based on seed coat color, the white varieties in the current study were expected to be more suscetiple to pod borer damage than the black, red, and light brown varieties which are associated with high phenol and tannin contents (Morrison *et al*., 1995). This implies that phenol and tannin contents in the pods of the 11 varieties may not have been significantly different. There is need to breed for resistance to cowpea pod borer by introgressing genes from resistant cowpea germplasm into existing high yielding, farmer preferred cowpea varieties.

5.5.2 Effects of variety and insecticide spray application on number of pods per plant, grains per pod, 100-grain weight and grain yield of cowpea

Insecticide application significantly increased the average number of pods per plant, grains per pod, 100-grain weight and grain yield of cowpea by 57.7%, 102.1%**,** 41.43% and 119.1%, respectively. These findings are in agreement with Dzemo *et al*., (2010) who indicated that application of insecticides once at flower budding, early podding and pod filling significantly reduced pod and seed damage, resulting in substantial increase in the number of pods per plant, seeds per pods, seed weight and grain yield. According to Ahmed *et al.*, (2014), insecticide sprays adequately protected cowpea pods from damage by the insect pests, thereby significantly increasing grain yield. The response of grain yield and yield components to insecticide applicaction varied with variety. The percent increase due to spray application ranged from 6.6% (Mwandato) to 135% (Macho) in number of pods per plant, 2.83% (K80) to 125.76% (Kutambaa) in 100-grain weight and 11.6% (Nyekundu) to 662.5% (Macho) in grain yield. This suggests that some varieties were either less affected by pests than others or less responsive to insecticide application. The varieties that showed modest response to insecticide application were Nyekundu (11.6%), KVU 419 (34.1%), Khaki (39.2%) and K80 (45.5%) whereas those that exhibited huge responses were Macho (662.5%), Kaima koko (411.1%), Nyeupe (251.5%) and M66 (208.8%). The cowpea varieties which were highly responsive to insecticide application could be used to stabilize cowpea grain yield in the coastal region of Kenya.

Linear regression relationship between grain yield and pod borer damage was negative while that between grain yield and pest damage (at both pre-flowering and flowering stages) highly positive. The positive linear regression relationship between grain yield and pest damage at pre-flowering and flowering stages observed in this study is in agreement with the findings of Rahman *et al*., (2008) who reported impressive crop grain yields due to 50% defoliation intensity imposed at the flowering stage. This could be attributed to the fact that pest damage at pre-flowering may stimulate compensatory growth in cowpea (Jackai *et al.*, 2001). Many studies on crop growth have concluded that the impact of defoliation on crop yield depends on the extent of insect pest damage (Ibrahim *et al*., 2010). Pest control in cowpea at pre-flowering and flowering stages may not be very critical due to the compensatory growth. Abudulai and Shepard (2001) reported that early pod-fill is the most susceptible stage to damage by pod-sucking bugs in cowpea. The results of these studies suggest that if insecticides must be applied, it would be most effective when it is done at early pod-fill stage. The increase in yield components such as the number of pods per plant, number of grains per pod and 100-grain weight as a result of insecticide spray application contributed to increased grain yield. This is supported by the positive linear regression relationship between these yield components and grain yield. Ceyhan and Aliavci (2005) made a similar observation.

5.6 Conclusion

Insecticide application significantly reduced insect pest damage at pre-flowering, flowering and podding stages resulting in increase in cowpea growth parameters, yield and yield components. All the cowpea varieties evaluated were similarly affected by insect pests. For successful production of cowpea in the region, application of insecticides is necessary. The cowpea varieties which were highly responsive to insecticide application namely Macho, Kaima koko, Nyeupe and M66 could be used to stabilize cowpea grain yield in coastal lowland Kenya.

CHAPTER SIX: EFFECT OF CROPPING SYSTEM ON SOIL MOISTURE CONTENT, CANOPY TEMPERATURE, GROWTH AND YIELD PERFORMANCE OF MAIZE AND COWPEA

6.1 Abstract

Over 90% of small scale farmers in the coastal lowland Kenya intercrop or relay crop maize and cowpea during the long rains season. An experiment was carried out at Pwani University and Kenya Agricultural and Livestock Research Organization-Mtwapa to determine the effects of intercropping on soil moisture, canopy temperature and yield performance of maize-cowpea intercrops in the coastal lowland of Kenya in 2011 and 2012. The trial was laid out in a randomized complete block design and replicated three times. Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield for both maize and cowpea. Cowpea root nodule number, number of pods per plant, number of grains per pod and grain yield, maize ears per plant and stover yield were also determined. Data collected were analyzed using the general linear model (GLM) procedure for analysis of variance using SAS statistical package. Where the F values were significant, means were compared using the least significant difference (LSD) test at $p = 0.05$. Sole cowpea plots and maize-cowpea intercrop plots had higher moisture content than sole maize plots. Intercropping reduced chlorophyll content, weed biomass, growth attributes (leaf number, plant height and ground cover), yield and yield components of maize and cowpea, but increased canopy temperature and cowpea nodule numbers. Land equivalent ratios for Lamu-cowpea and DH04-cowpea intercrops were 1.23 and 1.49, respectively. Intercropping enhanced moisture retention and was more productive than sole cropping.

6.2 Introduction

Maize (*Zea mays* L.), a staple food in Kenya, is produced by mostly small scale farmers who have little capacity to produce it efficiently. The small scale farmers form the largest portion of over 80% of the total Kenyan farmers (Booker, 2010). Cereal-legume intercropping plays an important role in subsistence food production in both developed and developing countries, especially in situations of limited water resources (Dahmardeh *et al*., 2010). It alters the abiotic and biotic features of an agro-ecosystem and could alter the life cycle of pests such as weeds (Banik 2006). A cropping system that reduces weed population may provide a weed suppressive foundation upon which cultural weed control could be laid (Tsubo *et al*., 2005).

Cowpea is frequently intercropped with cereals where it contributes to the maintenance of soil fertility (Carsky *et al.*, 2001). Over 90% of small scale farmers in the coastal lowland of Kenya intercrop or relay maize and cowpea during the long rains season (Saha *et al.*, 1993). The ability of legumes to fix nitrogen through symbiosis with species of rhizobia gives them special value in low input agriculture (Saha *et al.*, 1993; Giller, 2001). By incorporating cowpea into the cropping systems, farmers in the region have for long utilized biologically fixed nitrogen to maintain soil fertility but the yields have not stabilized. The individual crops that constitute an intercrop can differ in their use of resources spatially, temporally, or in form, resulting in overall more complementary and efficient use of resources than when they are grown in sole cropping; thus decreasing the amount available for weeds (Hauggard-Nielsen *et al.*, 2001). For example, when growing pea and barley in intercrops, Hauggard-Nielsen *et al.* (2006) found that there was an increased efficiency in utilizing environmental resources for plant growth and a better competitive ability towards weeds as compared to sole crops. Baumann *et al.* (2000) reported that intercropping increases light interception by the weakly competitive component and can, therefore, shorten the critical period for weed control and reduce growth and fecundity of late-emerging weeds. The apparent increased competitiveness of intercropping systems makes them potentially useful for integration into low in-put farming systems in which options for chemical weed control are reduced or non-existent (Szumigalski and Van Acker, 2005).

The advantages of intercropping over monocropping include soil conservation, lodging resistance, yield increment (Anil *et al.,* 1998) and weed control (Banik *et al.,* 2006). Yields of intercropping are often higher than in sole cropping systems (Lithourgidis *et al.,* 2006) mainly due to resources such as water, light and nutrients that can be utilized more effectively than in sole cropping systems (Li *et al.,* 2006). When two crops are planted together, intra and/or inter specific competition or facilitation between plants may occur (Zhang and Li, 2003). Competition among the mixtures is thought to be a major aspect affecting yield as compared with sole cropping of cereals (Ndakidemi, 2006). Land equivalent ratio has been used to determine the intercropping system advantages (Yilmaz *et al.,* 2008). According to Naresh *et al.,* (2014) reported reduced canopy temperature in maize-wheat intercropping system. In the coastal lowland region of Kenya the growth, canopy temperature, chlorophyll content and yield performance of different maize and cowpea varieties under intercrop systems have not been evaluated. Therefore, the objective of this study was to determine the effect of intercropping on soil moisture content, canopy temperature, chlorophyll content and yield performance of maize-cowpea intercrops in the coastal lowland Kenya.

6.3 Materials and Methods

6.3.1 Study site

The study was carried out at Pwani University (PU) and Kenya Agricultural and Livestock Research Organization (KALRO)-Mtwapa both located in Kilifi County in the coastal region of Kenya. Pwani University is located 60 km north of Mombasa between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. Kenya Agricultural and Livestock Research Organization

(KALRO)-Mtwapa is situated at 30 m above sea level (a.s.l), 39.219^o E and 4.347^o S, 20 km north of Mombasa (Jaetzold *et al.*, 2012). The two sites are situated in coastal lowland zone 4 (CL4). The region receives an average annual rainfall of 600–1100 mm that comes in two seasons (Sombroek *et al.*, 1982). The long rains are received in March/April and continue up to August while the short rains are received in October, November and December. The long rains season is the most important cropping season as it receives 75% of the annual rainfall (Saha, 2007). The sites have mean monthly minimum and maximum temperatures of about 22^{0}C and 30^{0}C, respectively, and mean relative humidity of 80% (Jaetzold *et al.*, 2012). The rainfall, temperature and relative humidity experienced at the Kilifi and Mtwapa sites during the experimental period are shown in appendix 1. According to Sombroek *et al.*, (1982), the soils in coastal lowland Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen), prone to leaching, and have a pH ranging between 5 and 7 (Mureithi *et al.*, 1995). The soil characteristics of Pwani University research farm and KALRO Mtwapa are shown in appendix 2.

6.3.2 Experimental design, treatments and crop husbandary

The experiment was set up in a randomized complete block design with three replications. Treatments consisted of two drought tolerant and insect resistant maize varieties (Lamu and DH04) which were either sole cropped or intercropped with cowpea variety Nyeupe. The experimental plot size was 5 m x 5 m. The spacing for sole maize was 100 cm x 50 cm with two plants per hill, while the spacing for sole cowpea was 60 cm x 30 cm with two plants per hill. For the intercrop, the cowpea was planted in between the maize rows. All the experimental plots were hand weeded at 4 and 8 weeks after planting maize, as recommended in the coastal region (Gacheru *et al*., 1993). Maize stem borer was controlled using Bulldock (0.5 g/kg Beta cyfluthrin) at 2 kg per Ha (or a pinch into the funnel of the plant at knee height stage when there is adequate moisture). Triple superphosphate was applied to sole maize and intercropped maize at planting using the recommended rate of 100 kg ha^{-1} (46 kg P_2O_5 ha^{-1}). The maize was later top-dressed with nitrogen at 30 kg N/ha in form of calcium ammonium nitrate in two splits: 18 kg N ha^{-1} at first weeding and 12 kg N ha^{-1} at top-dressing during the second weeding according to Saha and Muli (2002).

6.3.3 Data collection

Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield for both maize and cowpea. Cowpea root nodule number, numbers of pods per plant, number of grains per pod and grain yield was determined. The methods of data collection for all the aforementioned parameters were as indicated in chapter four. For maize ears per plant and maize stover yield were also determined. To determine the number of nodules per plant, five cowpea plants were dug out with all the roots, dipped in water to remove the soil and root nodules counted. Land equivalent ratios were calculated as indicated in 6.3.3.2.

6.3.3.1 Soil moisture determination

A neutron probe was used to determine the soil moisture level. Access tubes were installed in every experimental plot after land preparation. The tubes were installed up to 100 cm depth so that data could be collected up to 80 cm soil depth. A portion of the tube, about 50 cm long, was left protruding above ground level to allow for the positioning of the neutron probe while taking moisture reading. Moisture data was taken at Kilifi site for two seasons. Since all the parameters measured in the experiments had similar trend at kilifi and at mtwapa sites, it was assumed this must be same for soil moisture content.

Soil moisture content was measured at booting, silking and maturity stages in all the experimental plots. Soil samples were collected within the net-plot area of each plot using a hand auger. Care was taken to avoid collecting samples for previous sampling positions. Soil columns from 20, 40, 60 and 80 cm depth were taken from within the experimental plots and bare ground outside the experimental plots. Each soil column was immediately placed in a pre-weighed moisture can and sealed using an air tight lid. The loaded moisture cans were taken to the laboratory where each was weighed, its lid removed and fitted to the bottom, and then placed in an oven. The soil samples were oven-dried at 105^oC for 48 hours and weighed. Soil moisture content on dry-matter basis (Θ_{dw}) was calculated using the following formula:

$$\Theta_{dw} = \frac{W_{ms} - W_{ds}}{W_{ds}} \; x \; 100$$

Where W_{ms} = Weight of moist soil and W_{ds} = weight of dry soil.

Volumetric moisture content (Θ_v) was then derived using the following

$$\Theta_v = \frac{P_b}{P_w} \; x \; \Theta_{dw}$$

Where P_b is bulk density of the soil, and P_w is the density of water that is usually taken as unit in g cm^3 units. Four extra access tubes were installed within the experimental field for the calibration of the neutron probe. During each day set for soil moisture determination, probe readings (counts) were taken at the specified soil depths using one of the extra four access tubes. At the same time, soil samples were collected from the specified soil depth within 30 cm radius around the access tube and used to determine moisture content using the gravimetric procedure. Just before the start of data collection from the experimental plots, the carrying case was placed on flat ground within the field and the probe placed on the nameplate depression on top of the case. A standard count was then taken. Boart Longyear Company (1995) defined standard count as a measurement of neutrons which have lost significant energy by collision with the hydrogen in the wax in the shield within the body of the carrying case. The standard count, when taken in the same manner each time, provides means of checking the validity of the counting function.

The procedure for taking the standard count was repeated immediately after data collection from the experimental plots. The two readings for the standard counts were then averaged to give the mean standard count. Count ratios were then calculated as ratios of the probe readings for given depths to the corresponding mean standard counts. The moisture content of the soil surrounding the access tube used for probe calibration (determined by the gravimetric method) was then plotted against the count ratios, using the Microsoft Excel program. The regression curve obtained (Figure 6.1) was used to convert the neutron probe data to volumetric moisture content (Θ_v) of the soil.

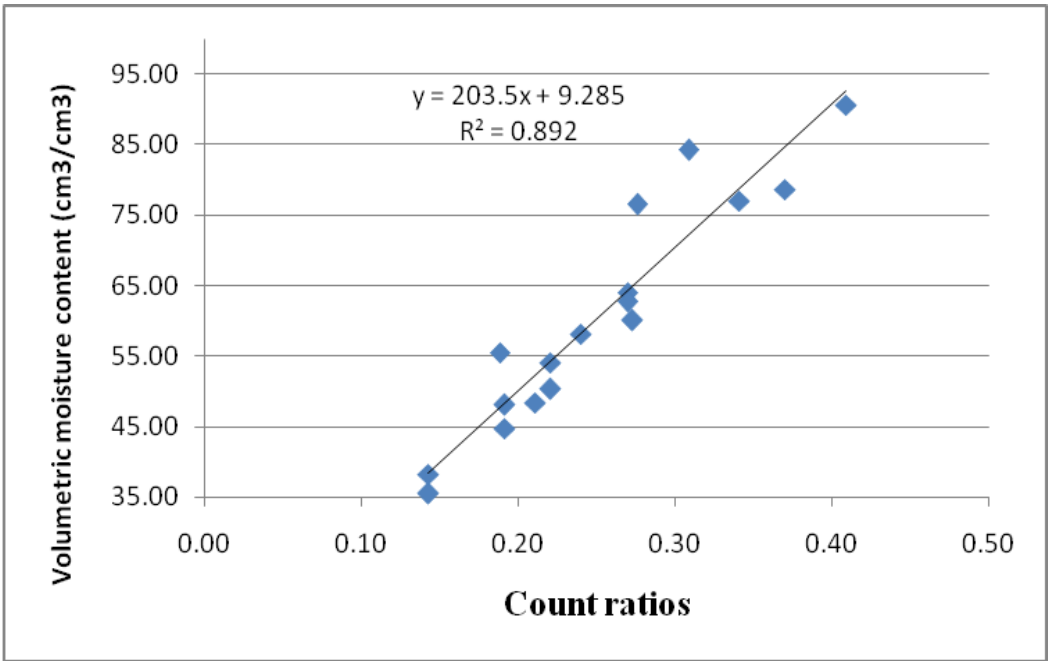

Figure 6.1 Soil moisture calibration curve

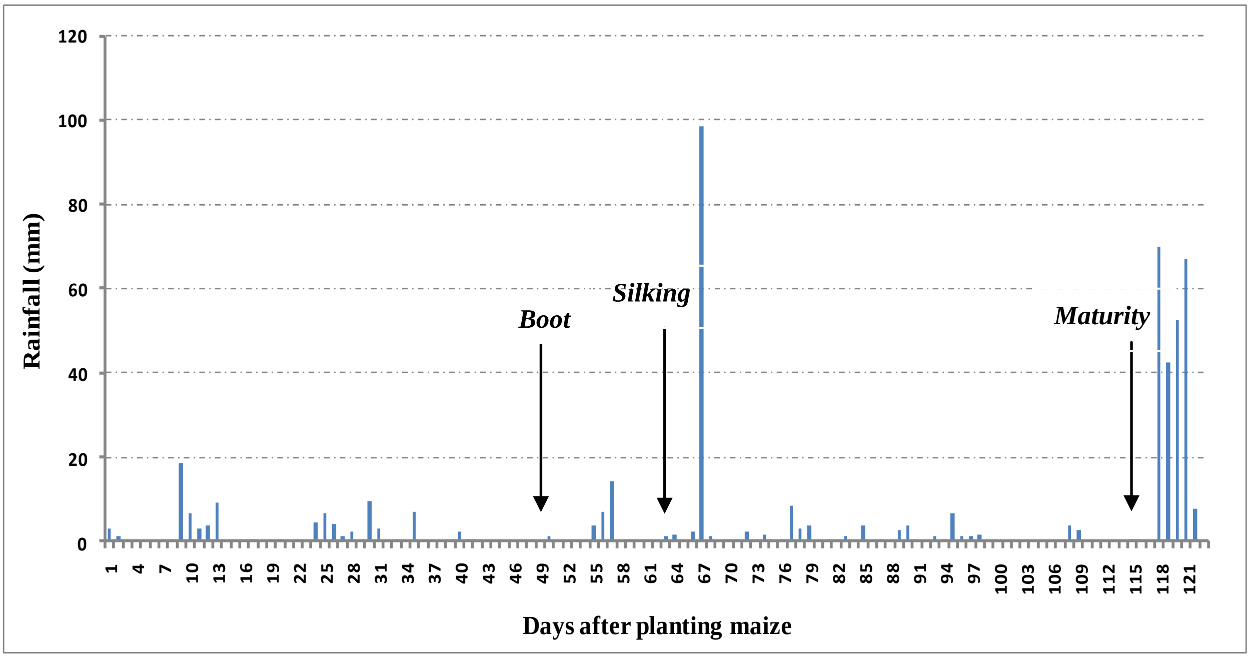

Figure 6.2: Amount of rainfall received during the growth stages. Arrows indicate the time when soil moisture content data was determinedusing a neutron probe

6.3.3.2 Land equivalent ratio

The land equivalent ratios (LER) were determined according to the formula indicated below (Mead and Willey, 1980):

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB}$$

LA and LB are the LERs for the individual crops (maize and cowpea respectively). YA and YB are the individual crop yields in intercropping, where SA and SB are their yields as sole crops.

6.3.4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$.

6.4 Results

6.4.1 Effects of cropping system on soil moisture content

The cropping system had significant effect on soil moisture content at 20, 60 and 80 cm soil depths, but not at 40 cm soil depth (Table 6.1). At 20 cm, sole cowpea plots had higher moisture content than sole maize crop plots and maize-cowpea intercrop plots at maize booting, silking and maturity. Lamu-cowpea intercrop plots had significantly lower moisture content than DH04-cowpea and sole DH04 plots. Sole crops maize had lower moisture content than maize-cowpea intercrops. Sole Lamu maize variety plots had the lowest moisture content compared to other cropping systems.

Table 6.1: Effect of cropping systems on soil moisture content (% per volume)at 20, 40, 60 and 80 cm at different growth stages

Cropping system	Boot	Silk	Maturity	Boot	Silk	Maturity
	20 cm Soil depth			40 cm soil depth		
Sole cowpea	16.54	17.11	15.41	18.77	22.88	22.97
Sole Lamu	12.64	11.58	11.34	16.78	17.51	16.53
Sole DH04	15.55	13.41	13.65	15.86	21.49	20.62
Lamu– cowpea	13.28	12.75	12.38	17.46	19.44	18.98
DH04-cowpea	15.55	14.58	14.42	16.41	23.01	21.9
P-value	0.0001	0.0001	0.0001	0.1515	0.0975	0.1199
$LSD_{0.05}$	0.72	0.62	0.53	NS	NS	NS
CV (%)	2.66	2.37	2.08	7.57	11.64	13.57
	60 cm Soil depth			80 cm soil depth		
Sole cowpea	23.55	28.45	25.49	28.6	29.19	25.51
Sole Lamu	19.76	25.52	27.54	25.51	28.61	29.57
Sole DH04	18.48	19.87	23.35	23.38	25.42	24.36
Lamu – cowpea	23.55	28.33	26.64	27.56	29.52	27.59
DH04-cowpea	22.51	24.66	23.49	26.27	27.18	23.64
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
$LSD_{0.05}$	0.54	0.5	0.48	0.53	0.49	0.51
CV (%)	1.31	1.04	1.01	1.06	0.92	1.04

In most stages, sole crop of maize had higher moisture content than maize cowpea intercrop. At 60 and 80 cm depths, sole cowpea had similar moisture content as Lamu-cowpea intercrop at most growth stages. Lamu-cowpea intercrop plots and sole Lamu plots had higher moisture content than DH04-cowpea intercrop and sole DHO4 plots respectively. Sole cowpea plots had higher moisture than sole maize and DH04-cowpea plots.

6.4.2 Ground cover, weed biomass and canopy temperature

The cropping system had significant effects on crop ground cover, weed biomass and canopy temperature (Table 6.2). Sole cowpea had higher percent ground cover than sole maize crops and Lamu-cowpea intercrop in both sites. In Kilifi, intercrops had higher percent ground cover than sole maize crops while in Mtwapa the converse was the case. Lamu-cowpea intercrop had significantly lower ground cover than DH04-cowpea intercrop in Mtwapa. Ground cover in Kilifi was 40.3% higher than in Mtwapa. Maize–cowpea intercrops and sole cowpea had significantly lower weed biomass than sole maize in both sites. No differences in weed biomass were noted between DHO4-cowpea and Lamu-cowpea intercrops and between DHO4 and Lamu sole crops.

Table 6.2: Effects of cropping systems on ground cover, canopy temperature and weed biomass at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Ground cover (%)		Weed biomass (t/ha)		Canopy temp (o C)	
	Kilifi	Mtwapa	Kilifi	Mtwapa	Kilifi	Mtwapa
Sole cowpea	86	61.03	0.05	0.03	29.67	26.27
Maize var. Lamu-cowpea	77.87	32.87	0.06	0.05	26.50	27.82
Maize var. DH04-cowpea	84.93	34.43	0.08	0.04	28.87	26.44
Sole maize var. Lamu	67.07	46.37	0.15	0.07	24.30	24.33
Sole maize var. DH 04	74.43	58.47	0.13	0.07	26.40	24.31
P-value	0.0001	0.0001	0.0001	0.0001	0.002	0.0001
$LSD_{0.05}$	3.27	0.55	0.02	0.009	1.89	0.58
CV (%)	2.22	0.63	10.91	9.41	3.70	1.20

* DH04 = Dryland Hybrid 04; temp = temperature

Weed biomass in Kilifi was 50% higher than in Mtwapa. Intercropping systems had significantly higher canopy temperatures than sole maize cropping systems in both sites.

Canopy temperature of sole cowpea was not significantly different from canopy temperature of DH04-cowpea intercrop in both sites. In Kilifi, DH04-cowpea intercrop and sole cowpea had higher canopy temperature, than sole maize crops and Lamu–cowpea intercrop. In contrast, Lamu-cowpea intercrop had the highest canopy temperature in Mtwapa. Canopy temperatures in Mtwapa were 4.9% lower than in Kilifi.

6.4.3 Cowpea chlorophyll content and leaf number

Chlorophyll content and leaf number of cowpea were significantly affected by cropping systems (Table 6.3). Cowpea chlorophyll content in Lamu-cowpea intercrop was significantly lower than for sole cowpea and DH04-cowpea intercrop. Cowpea chlorophyll content in Kilifi was 4.8% higher than in Mtwapa. Intercropped cowpea had significantly lower leaf number per plant than sole cowpea in both sites. In Kilifi, DH04-cowpea intercrop system had a higher cowpea leaf number per plant than Lamu-cowpea intercrop system, while the converse was the case for Mtwapa. Cropping systems in Kilifi had 25.6% higher cowpea leaf numbers than in Mtwapa.

Table 6.3: Effects of cropping systems on cowpea chlorophyll content and leaf number at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Chlorophyll content (Index)		Cowpea leaf number/plant	
	Kilifi	Mtwapa	Kilifi	Mtwapa
Sole cowpea	51.60	45.87	65.70	31.47
Maize var. Lamu-cowpea	46.37	46.60	18.90	26.50
Maize var. DH04-cowpea	50.90	48.60	23.60	22.57
P-value	0.01	0.12	0.0001	0.0002
$LSD_{0.05}$	2.63	2.87	2.83	1.47
CV (%)	2.34	2.69	3.46	2.41

* DH04 = Dryland Hybrid 04

6.4.4 Maize chlorophyll content and leaf number

The cropping system significantly affected maize chlorophyll content (Table 6.4). In Kilifi, intercropped maize had significantly higher chlorophyll content than sole maize. However, in Mtwapa intercropped Lamu maize was not significantly different from sole maize. DH04-cowpea intercrop system had higher maize chlorophyll than Lamu-cowpea intercrop system in both sites. Mean maize chlorophyll contents in Kilifi and Mtwapa were similar. The cropping systems had no significant effect on the maize leaf number in Kilifi.

Table 6.4: Effect of cropping system on maize chlorophyll content and leaf number at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Chlorophyll content (Index)		Maize leaf number/plant	
	Kilifi	Mtwapa	Kilifi	Mtwapa
Maize var. Lamu-cowpea	43.50	42.50	12.17	11.73
Maize var. DH04-cowpea	49.30	45.47	11.47	8.63
Sole maize var. Lamu	38.57	43.53	11.07	11.63
Sole maize var. DH 04	42.23	42.03	12.47	8.47
P-value (CPS)	0.0002	0.0721	0.2039	0.0001
$LSD_{0.05}$	2.28	2.66	Ns	0.60
CV (%)	2.63	3.06	6.51	2.95

* DH04 = Dryland Hybrid 04

In contrast, in Mtwapa sole cropped and intercropped maize variety Lamu had higher maize leaf numbers than sole cropped and intercropped maize variety DH04. Kilifi had 14.2% higher maize leaf numbers than Mtwapa.

6.4.5 Plant height of cowpea and maize

Cropping systems significantly reduced plant height of cowpea and maize (Table 6.5). In Kilifi, sole cowpea had significantly higher plant height than intercropped cowpea while Lamu-cowpea intercrop system had the least cowpea plant height. In Mtwapa there was no significant difference between plant height of sole crop cowpea and intercropped cowpea in the DH04-cowpea intercrop system. Plant height in Kilifi was 7.2% higher than in Mtwapa. Plant height in sole crops was significantly higher than in intercrops in both sites. Maize plant height in Lamu-cowpea and DH04-cowpea intercrops was not significantly different in Kilifi. However, in Mtwapa maize variety Lamu intercropped with cowpea was 31.9% taller than maize variety DH04 intercropped with cowpea. Maize plant height in Kilifi was 15.2% higher than in Mtwapa**.**

Table 6.5 Effect of cropping system on plant height of cowpea and maize at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Plant height (cm)		Maize plant height (cm)	
	Kilifi	Mtwapa	Kilifi	Mtwapa
Sole cowpea	40.63	28.60	-	-
Maize var. Lamu-cowpea	24.60	29.93	160.23	157.87
Maize var. DH04-cowpea	29.53	29.43	164.57	107.50
Sole maize var. Lamu	-	-	188.83	199.20
Sole maize var. DH04	-	-	178.77	122.40
P-value	0.0003	0.052	0.001	0.0001
$LSD_{0.05}$	3.05	1.02	9.38	0.85
CV (%)	4.26	1.53	2.71	0.29

* DH04 = Dryland Hybrid 04

6.4.6 Cowpea root nodules number, pods per plant and grains per pod

Intercropping significantly increased the number of cowpea root nodules, number of pods per plant and number of grains per pod in both sites (Table 6.7). Cowpea intercropped with Lamu and DH04 had the highest number of root nodules in Kilifi and Mtwapa respectively. Kilifi had 95% higher number of root nodules than Mtwapa. Cowpea intercropped with DH04 had a higher number of pods per plant than cowpea intercropped with Lamu. The number of pods per plant in Kilifi was 68.9% higher than in Mtwapa. Intercropping significantly increased the number of grains per pod in both sites for Lamu-cowpea but not for DH04-cowpea in Mtwapa (Table 6.7). Cowpea intercropped with Lamu had a higher number of grains per pod than sole cowpea in both sites. In Mtwapa, sole cowpea had higher number of grains per pod than cowpea intercropped with DH04. The number of grains per pod in Kilifi was 67.2% higher than in Mtwapa.

Table 6.6: Effect of cropping system on number of cowpea root nodules, pods per plant and grains per pod at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Root nodules (number)		Pods per plant (number		Grains per pod (number)	
	Kilifi	Mtwapa	Kilifi	Mtwapa	Kilifi	Mtwapa
Sole cowpea	7.67	15.33	7.83	2.9	10.7	3.67
Maize var. Lamu-cowpea	12.03	20.33	8.93	3.4	13.73	5.2
Maize var. DH04-cowpea	10.9	24	14.43	3.4	12.27	3.17
P-value	0.0003	0.0002	0.0001	0.009	0.019	0.0004
$LSD_{0.05}$	0.86	1.51	0.41	0.26	1.69	0.42
CV (%)	3.71	3.35	1.76	3.57	6.11	4.63

* DH04 = Dryland Hybrid 04

6.4.7 Number of ears per plant and 100-grain weight of maize

Numbers of ears per plant and grain weight of maize were significantly affected by cropping system (Table 6.8). Sole crops had a significantly higher number of maize ears per plant (EPP) than intercrops in Kilifi. Cropping systems had no significant effect on EPP in Mtwapa. The number of EPP in Kilifi was 62.7% higher than in Mtwapa.

Table 6.7: Effect of cropping system on number of ears per plant and 100-grain weight of maize at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Maize ears per plant (number)		Maize 100-grain wt (g)	
	Kilifi	Mtwapa	Kilifi	Mtwapa
Maize var. Lamu-cowpea	0.56	0.24	36.53	11.63
Maize var. DH04-cowpea	0.47	0.19	31.43	12.35
Sole maize var. Lamu	0.66	0.22	37.60	13.73
Sole maize var. DH 04	0.67	0.22	37.67	12.94
P-value (CPS)	0.008	0.789	0.046	0.002
$LSD_{0.05}$	0.1	Ns	2.81	0.58
CV (%)	8.59	24.03	3.92	2.28

* DH04 = Dryland Hybrid 04

Maize grain weight was significantly affected by the cropping system (Table 6.8). Weight of 100-grains of intercropped DH04 maize was lower than for sole DH04 and Lamu crop maize at Kilifi. Maize variety Lamu intercropped with cowpea had the lowest maize 100-grain weight. At Mtwapa, intercropped maize had lower 100-grain weight than sole maize. The weight of maize 100-grains in Kilifi was 64.7% higher than in Mtwapa.

6.4.8 Cowpea 100-grain weight and grain yield

Intercropping significantly reduced cowpea 100-grain weight when cowpea was intercropped with maize variety Lamu (Table 6.9). There was no significant difference between sole crop cowpea and cowpea intercropped with DH04 in Kilifi. In Mtwapa, cowpea intercropped with DH04 had the highest 100-grain weight. In Kilifi, cowpea grain weight was 63.1% higher than in Mtwapa. Intercropping system significantly reduced cowpea grain yield by 44 – 46% in Kilifi and 50% in Mtwapa (Table 6.9). Cowpea grain yield for intercrops was not significantly different in both sites. Kilifi had 69% higher cowpea grain yields than in Mtwapa.

Table 6.8: Effect of cropping system on cowpea 100-grain weight and grain yield at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Cowpea 100-grain wt (g)		Cowpea grain yield (t/ha)	
	Kilifi	Mtwapa	Kilifi	Mtwapa
Sole cowpea	13.80	5.02	0.41	0.14
Maize var. Lamu-cowpea	12.71	4.64	0.22	0.07
Maize var. DH04-cowpea	13.74	5.20	0.23	0.07
P-value (CPS)	0.012	0.0001	0.002	0.011
$LSD_{0.05}$	0.60	0.08	0.06	0.04
CV (%)	1.97	0.71	9.01	18.68

* DH04 = Dryland Hybrid 04

6.4.9 Maize stover yield and grain yield

The cropping system significantly reduced maize grain yield and stover yield in both sites (Table 6.10). Intercropped Lamu maize variety had 24 – 31% lower maize grain yield than when sole cropped in both sites. In Kilifi, grain yields of sole DH04, sole Lamu and intercropped DH04 were not significantly different. In Mtwapa sole maize variety DH04 had the highest maize grain yield of 0.89 t/ha. Maize grain yield in Kilifi was 61.4% higher than in Mtwapa. Maize variety DH04 intercropped with cowpea had the lowest maize stover yield in both sites. In Kilifi, maize variety Lamu intercropped with cowpea, sole cropped Lamu and sole cropped DH04 were not significantly different. Intercropping reduced maize stover by 42 – 46% in DH04 and 14% in Lamu.

Table 6.9: Effect of cropping system on maize stover yield and grain yield at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system	Maize grain yield		Maize stover yield	
	Kilifi	Mtwapa	Kilifi	Mtwapa
	-----------------(t/ha)----------------			
Maize var. Lamu-cowpea	1.68	0.63	4.82	1.77
Maize var. DH04-cowpea	2.24	0.86	2.73	1.35
Sole maize var. Lamu	2.45	0.83	4.39	2.05
Sole maize var. DH 04	2.41	0.89	5.04	2.33
P-value	0.001	0.0001	0.017	0.0001
$LSD_{0.05}$	0.26	0.03	0.82	0.03
CV (%)	5.99	2.00	9.66	0.74

* DH04 = Dryland Hybrid 04

In Mtwapa, the cropping system with the highest maize stover yield was sole maize variety DH04 with 2.33 t/ha. Maize stover yield in Kilifi was 59.7% higher than in Mtwapa.

6.4.10 Land equivalent ratio

Land equivalent ratio was not significantly affected by cropping systems at both sites. Land equivalent ratios for Lamu-cowpea intercrop ranged from 1.23 (Mtwapa) to 1.24 (Kilifi) while that for DHO4-cowpea intecrop ranged from 1.47 (Mtwapa) to 1.33 (Kilifi) (Table 6.11).

Table 6.10 Land equivalent ratios of cropping systems in Kilifi and Mtwapa at Kilifi and at Mtwapa sites during July – October 2011/2012 season

g system	Kilifi	Mtwapa
	LER	LER
Lamu - cowpea	1.24	1.23
DH04 - cowpea	1.33	1.47
P-value	0.628	0.198
$LSD_{0.05}$	Ns	Ns
CV (%)	15.18	11.79

LER = Land equivalent ratio

6.5 Discussion

6.5.1 Effect of intercropping on soil moisture content

The study has shown that at 20 cm depth, sole cowpea plots had higher moisture content than sole maize crop plots and maize-cowpea intercrop plots at maize booting, silking and maturity stages. Maize-cowpea intercrop plots had higher soil moisture content than sole maize crop plots. Ghanbari *et al.,* (2010) reported higher soil moisture content in sole cowpea and maize-cowpea intercrop plots than in sole maize plots. This was attributed to the fact that sole cowpea and maize-cowpea intercrops, which had higher groundcover and shading effect than sole maize, reduced water evaporation thereby enhancing moisture conservation. The current results could also be attributed to the fact that maize has higher water requirements than cowpea which is adapted to drought stress (Filho, 2000). A study by Gao *et al*., (2010) indicated that lateral growth of maize and legume roots in the intercropped plots occurred mainly in the top 16–22 cm layer, or just above the plough pan. The soil moisture content below the root levels was not perhaps being transpired hence the increase in soil moisture with increase in soil depth. Lamu-cowpea intercrop and sole Lamu maize plots had lower moisture content than DH04-cowpea intercrop and sole DH04 maize variety plots at 20 cm depth; suggesting that Lamu variety exploited moisture in the top 20 cm better than DHO4 variety. At lower depths (60 and 80 cm), sole DHO4 and DH04-cowpea intercrop crops depleted moisture more than sole cowpea, lamu-cowpea intercrop and sole Lamu crops. This suggests that DH04 maize variety roots exploited moisture in the lower layers of the soil more than Lamu maize variety roots. Rooting depth is positively related to soil exploration and greater acquisition of water from deep strata (Lynch and Wojciechowsk, (2015). Genotypes with greater rooting depth are better able to exploit moisture stored from previous season (Wasson *et al*., 2012). In most case, sole maize crop plots had lower moisture content than maize-cowpea intercops. This could be attributed to the higher ground cover observed under the maize-cowpea intercrop system than in the maize monocrop system. High ground cover reduces water evaporation thereby improving soil moisture retention Ghanbari *et al.,* (2010).

6.5.2 Canopy temperatures

The study demonstrated that maize-cowpea intercrop and sole cowpea canopies had raised temperatures relative to maize sole crop canopies. Choudhary *et al.,* (2012) reported higher canopy temperatures in intercrops and sole cowpea than in sole maize. In this study sole cowpea and intercrops had higher canopy temperatures than sole maize. The higher canopy temperature in sole cowpea than sole maize could be attributed to the fact that maize transpires much more than cowpea hence maize canopies become cooler than cowpea-maize canopies (Belel *et al.,* 2014).

6.5.3 Chlorophyll contents of cowpea and maize

Intercropping significantly reduced cowpea chlorophyll contents in both sites. The findings of this study agreed with the report by Prasanthi and Venkateswaralu (2014) which indicated that sole cropped legumes recorded higher total chlorophyll than intercropped legumes. Under intercropped situation, maize by virtue of its faster and vigorous growth might have dominated and utilized soil resources more efficiently, thereby suppressing cowpea plants.

This could be the reason why cowpea chlorophyll content reduced under intercropping. In this study intercropping increased maize chlorophyll content. The finding is in agreement with the studies by Amini *et al*., (2013) and Prasanthi and Venkateswaralu (2014) who reported that intercropped maize had higher maize chlorophyll content than pure stands. Similarly a report by Dahmardeh *et al.*, (2010) indicated that maize intercropped with cowpea showed increases in the amount of nitrogen, phosphorus and potassium content as compared to sole maize. Increases in N could be attributed to biological nitrogen fixation by the cowpea and potential transfer of nitrogen to the associated maize intercrop (Matusso *et al.*, 2014). In this study, there was an increase in nodulation due to intercropping suggesting increased N-fixation and available N for intercropped maize (Chemining'wa and Nyabundi, 1994).

6.5.4 Ground cover and growth parameters of cowpea and maize

Intercropping maize with cowpea significantly increased percent ground cover relative to sole cropping. Previous studies showed that maize intercropped with cowpea had higher ground cover than sole maize crops (Kariaga, 2004). Intercropping significantly reduced cowpea leaf number and plant height. The reduction in growth parameters is in agreement with the study by Lemlem (2013) who reported that intercropping legumes with maize significantly reduced cowpea growth. This could be attributed to shading of cowpea by the taller maize crop (Iderawumi, 2014). Cowpea was introduced 28 days after planting maize hence it could have faced shading and increased competition from already established maize (Iderawumi, 2014). The study has shown intercropping reduced maize leaf number, plant height and stover yield. Undies *et al.*, (2012) reported that intercropping maize with soybean reduced maize plant height, number of leaves per plant and stover yield were below their sole crop values. This was attributed to competition for resources by component crops. The intercrops had higher percent ground cover at Kilifi than at Mtwapa possibly because there was less competition for moisture (Lemlem, 2013) in Kilifi than in Mtwapa since the former received higher amounts of rainfall than the latter (Appendix 1).

6.5.5 Weed biomass

The study indicates that intercropping resulted in significant percent reduction in weed biomass compared to sole maize crop system in both sites. Eskandari and Kazemi (2011) reported that intercrops were more effective in weed control than sole crops. This could be attributed to weed suppression in intercropping systems through more efficient use of environmental resources by component crops (Poggio, 2005). Under intercropping system light interception and shading due to increased ground cover could be the main reason for reduction of weed biomass (Ghanbari-Bonjar, 2000). The finding that intercropping suppressed weed biomass in this study underscores the importance of intercropping maize and cowpea as one of the weed management strategies in the coastal lowland Kenya. Katsaraware and Manyanhaire (2009) reported reduction in weed biomass under maize-cowpea intercropping system in Zimbabwe. In this study the increase in ground cover could have resulted in weed suppression.

6.5.6 Cowpea root nodule number

The study has shown that intercrops had higher number of root nodules than sole crops in both sites. This finding is in agreement with the findings of Cardoso *et al.,* (2007) and Lemlem (2013) who reported increases in the number of root nodules and nodule weight of legumes under intercrops compared to sole crops. This may be associated with depletion of nitrogen by the more competitive maize since nodulation and nitrogen fixation are enhanced under low N conditions (Chemining'wa and Nyabundi, 1994). Root nodules in Mtwapa were higher than in Kilifi. This could be because Kilifi received a higher amount of rainfall than Mtwapa (Appendix 1) which may have enhanced maize growth causing increased shading of cowpea (Kombiok *et al.*, 2005). Lamu maize variety was taller than DH04 maize variety. This could explain why DH04 -cowpea intercrop had higher number of root nodules than Lamu-cowpea intercrop in Mtwapa. Shading has been known to reduce nodule number (Egbe *et al.*, 2013).

6.5.7 Grain yield and yield components of cowpea and maize

Intercropping significantly reduced cowpea and maize grain yield and yield components. The findings of this study are in agreement with the studies by Takim (2012) and Lemlem (2013) who reported that intercropping legumes with maize significantly reduced cowpea and maize grain yield and yield components. The reduction in cowpea grain weight and grain yield in this study could be attributed to the reduction in cowpea leaf number and plant height under intercropping system. Maize grain yield was higher when DH04 maize variety was intercropped with cowpea than when Lamu maize variety was intercropped with cowpea. This could be attributed to the fact that DH04 maize variety was an improved maize variety, hence may be more efficient in utilization of soil resources. In the current study, DH04 maize appeared to exploit water at lower soil depths better than Lamu maize variety.

Land equivalent rations (LER) for Lamu-cowpea and DH04-cowpea intercrops were 1.24 and 1.33, respectively, in Kilifi and 1.23 and 1.47, respectively, in Mtwapa. This suggests that intercropping maize and cowpea is more efficient and productive in the use of environmental resources for plant growth than growing sole crops of maize and cowpea (Ghanbari *et al.*, 2010; Mead and Willey, 1980). Therefore the two maize-cowpea intercrops are both beneficial and could be used to enhance land productivity in the region. However, DHO4-cowpea intercrop appears more productive than Lamu-cowpea intercrop.

6.6 Conclusion

Intecropping increased soil moisture content at all growth stages in 20, 60 and 80 cm soil depths. Although intercropping significantly reduced yield and yield components of cowpea and maize, intercropped maize-cowpea had higher land productivity than monocropped cowpea and maize respectively. Land productivity of DH04-cowpea intercrop was higher than for Lamu-cowpea intercrop in both sites.

CHAPTER SEVEN: EFFECT OF COWPEA CROP RESIDUE MANAGEMENT ON SOIL MOISTURE CONTENT, CANOPY TEMPERATURE, GROWTH AND YIELD OF MAIZE - COWPEA INTERCROPS

7.1 Abstract

The major limitations to crop production in smallholder farms in Kenya are moisture stress and declining soil fertility. Incorporation of crop residues into the soil or their use as surface mulch has the potential of conserving moisture. A study was carried out at Pwani University and Kenya Agricultural and Livestock Research Organization (KALRO)-Mtwapa in 2011/2012 to determine the effect of cowpea crop residue management on soil moisture content, canopy temperature, growth and yield of maize and cowpea intercrop. The experiment was laid out in a randomized complete block design (RCBD), with a factorial arrangement of treatments and replicated thrice. Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea. Cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize ears per plant and stover yield were also determined. Data was analyzed using the general linear model (GLM) procedure for analysis of variance using SAS statistical package. Where the F values were significant, means were compared using the least significant difference (LSD) test, at p = 0.05. Application of crop residues (incorporated or mulched) increased soil moisture content and chlorophyll content, growth attributes, yield and yield components of cowpea and maize, but reduced canopy temperature and cowpea nodule number. The increase in cowpea and maize grain yield in Kilifi due to incorporation of crop residues into the soil was 111.1% and 440.5%, respectively**.** Crop residue incorporation outperformed surface mulching in most plant attributes.

7.2 Introduction

Water is a major limiting factor for crop production in the tropics, particularly in semi-arid regions (Rowland, 1993). Soil water availability is directly related to environmental factors (including precipitation, evapotranspiration, soil type and topography), but may be influenced by agronomic practices, including irrigation, fallowing and sowing time, or via specific water conservation practices, such as terracing and mulching (Martin *et al.*, 2008). Under semi-arid conditions, surface plant residues play an important role in conservation of soil water through reduced soil evaporation (Thomas 1996). In addition, crop residues as a mulch moderate the temperature fluctuation in the top soil layer (Farahani *et al.,* 1998), enhance the activity of soil microorganisms and fauna (Klocke 1999) and nutrient release, improve water infiltration, and facilitate root development. According to van Donk *et al.,* (2012), retention of crop residues on the soil surface is a key strategy for reducing surface water runoff and erosion. A crop residue enhances water infiltration and protects the soil from sealing and crusting by rainfall (McGuire 2009). A mulch of crop residues may also contribute to the control of weeds by smothering them or through allelopathic effects (Farahani *et al*., 1998).

Africa is not able to feed its ever increasing population due to declining nutrient status of her soils (Omotayo and Chukwuka 2009). For increased food production, nutrient replenishment is necessary (Tilman *et al*., 2002). Nutrients are depleted due to nutrient mining through crop harvests, residue removal (Mugendi *et al.,* 2003), and soil erosion (Muchena *et al.,* 2005), coupled with inadequate external replenishment (Mugendi *et al*., 2010). In Kenya declining soil fertility and high fertilizer costs are major limitations to crop production in smallholder farms in Kenya (Chemining'wa *et al.,* 2004). Water being one of the major physical constraints to crop production in semi-arid areas, there is a need to use it effectively (Rowland, 1993). The water conservation effect of surface residue may potentially increase crop yields in tropical environments (van Donk *et al.,* 2012).

In coastal lowland Kenya over 90% of small scale farmers intercrop or relay crop maize and cowpea during the long rains season (Obong'o *et al*., 1993; Saha *et al.*, 1993). Legumes have great potential for improving soil fertility at relatively low cost compared to inorganic fertilizers. The reliance on organic residues from the previous crop distinguishes crop residue mulch from other forms of mulching. This is because crop residue mulch is strategically located at the soil-atmosphere interface, whereby it affects soil conservation; soil ecology and crop yields (Erenstein, 1999). Hence the need to determine the effects of crop residues on soil moisture content, canopy temperature, chlorophyll content, growth and yield maize-cowpea intercrop.

7.3 Materials and Methods

7.3.1 Study site

The study was carried out at Pwani University (PU), and Kenya Agricultural Research Institute (KARI). Pwani University is located 60 km north of Mombasa between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. Mean monthly minimum and maximum temperatures of about 22^0C and 30^0C, respectively, and mean relative humidity of 80% (Jaetzold *et al*., 2012). The site is located in coastal lowland (CL) Kenya. The region receives an average annual rainfall of 600–1100 mm that occurs in two seasons (Sombroek *et al.,* 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time (Saha, 2007). The rainfall, temperature and relative humidity at the Kilifi and Mtwapa sites are shown in Appendix 1. According to Sombroek *et al.*, (1982), the soils in coastal lowland Kenya are mostly ferralsols. They have low electron cation exchange, total N, organic carbon content are deficient in essential plant nutrients (such as calcium, magnesium, zinc and sodium), prone to leaching, and have a pH 5.6 as shown in appendix 2. The experiment was conducted during the long rains in July - October season in 2012.

7.3.2 Experimental design, treatments and crop husbandry

The experiment was laid out in a randomized complete block design, with a factorial arrangement of treatments and replicated three times. The treatments consisted of two intercrop systems and three cowpea crop residue management options. The intercrop systems were: (a) maize variety Lamu intercropped with cowpea variety Nyeupe and (b) Dryland Hybrid 04 (DH04) intercropped with cowpea variety Nyeupe. The crop residue management options were: (a) control (no residue), (b) crop residue surface mulch and (c) crop residue incorporated into soil. A drought/insect pest resistant cowpea variety Nyeupe was used for intercropping with maize in both cropping systems. Experimental plot size was 5 m x 5 m. Maize spacing was 100 cm x 50 cm giving a population of 20,000 plants per hectare. Cowpea was planted in between the maize with a spacing of 30 cm within the row, two plants per hill, giving a plant population of 66,660 plants/ha. All the cowpeas in the two sites were planted four weeks after the maize to reduce competition (Mureithi *et al.*, 1996). The amount of crop residue applied was 110 g/hill. This was either applied on the soil surface or incorporated into the soil. Weeding was done by hand at two, four and six weeks after planting.

7.3.3 Data collection

Data collected included: soil moisture content, canopy temperature, chlorophyll content, ground cover, leaf number, plant height, grain weight, and grain yield for both maize and cowpea. Cowpea root nodule number, number of pods per plant and number of grains per pod, maize number of ears per plant and maize stover yield were also determined. Moisture content was determined by using a neutron probe. The methods of data collection were similar to those used in chapter six.

7.3.4 Data analysis

Collected data was analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$.

7.4 Results

7.4.1 Soil moisture content

Cropping system and crop residue management significantly affected soil moisture content at 20 and 40 cm soil depth at all maize growth stages; however, cropping system and crop residue management had no significant effect on soil moisture content at 60 and 80 cm soil depth (Table 7.1). At 20 cm soil depth DH04-cowpea intercrop had higher soil moisture content than Lamu-cowpea intercrop, but the converse was true at 40 cm soil depth. Crop residue surface mulching and crop residue incorporation increased moisture content in both cropping systems, but the latter had higher moisture content than the former at most growth stages (Table 7.2).

Table 7.1: Effect of cropping system on moisture content (%) at 20, 40, 60 and 80 cm soil depths at different growth stages in Kilifi

Cropping system	Boot	Silk	Maturity	Boot	Silk	Maturity
	20 cm Soil depth			40 cm soil depth		
Lamu – cowpea	10.76	11.48	6.85	15.20	19.17	13.81
DH04-cowpea	11.60	12.95	8.56	14.16	17.08	12.10
P-value	0.0003	0.0117	0.0363	0.001	0.0003	0.0167
$LSD_{0.05}$	0.35	1.06	1.57	0.53	0.88	1.33
CV (%)	2.96	8.27	19.45	3.46	4.63	9.74
	60 cm Soil depth			80 cm soil depth		
Lamu – cowpea	18.40	21.59	16.76	22.99	26.33	20.01
DH04-cowpea	18.66	21.83	15.05	23.51	25.50	19.98
P-value	0.222	0.834	0.262	0.734	0.579	0.979
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS
CV (%)	2.34	10.90	19.08	13.55	11.89	12.92

NS – Not significant

Table 7.2: Effect of crop residue management on moisture content (%) at 20 and 40 cm soil depth at different growth stages in Kilifi

Crop residue management	20 cm soil depth			40 cm soil depth		
	Boot	Silk	Maturity	Boot	Silk	Maturity
No crop residue	8.96	10.69	7.35	13.02	15.88	10.83
Surface mulch	12.53	11.93	7.67	15.39	18.10	11.26
Crop residue incorp.	12.04	14.03	8.09	15.62	20.41	16.78
P-value (CRM)	0.0001	0.0006	0.7014	0.0001	0.0001	0.0001
P-value (CPS x CRM)	0.024	0.263	0.109	0.009	0.011	0.006
$LSD_{0.05}$ (CRM)	0.43	1.30	NS	0.65	1.08	1.62
$LSD_{0.05}$ (CPS x CRM)	0.539	1.650	2.450	0.828	1.451	2.062
CV (%)	2.96	8.27	19.45	3.46	4.63	9.74

7.4. 2 Ground cover and Canopy temperature

Cropping system, crop residue management and their interaction had significant effects on ground cover and canopy temperature (Table 7.3). Surface mulching and incorporation of crop residue into the soil increased percent ground cover of both cropping systems in both sites. Incorporation of crop residue into the soil had higher ground cover than surface mulching in Mtwapa. Lamu maize intercropped with cowpea had higher ground cover than

DHO4 maize intercropped with cowpea under all the residue management options except under the control (no residue treatment). Average percent ground cover was higher at Kilifi than at Mtwapa by 57.6%.

Table 7.3: Effects of cropping system and crop residue management on percent ground cover and canopy temperature at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Percent ground cover							
Lamu - cowpea	82.23	86.57	87.77	85.52	32.60	39.20	51.30	41.03
DH04 - cowpea	84.40	85.50	85.53	85.14	26.80	28.27	39.10	31.39
CRM-mean	83.32	86.04	86.65		29.70	33.74	45.20	
P-value (CPS)	0.003				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.22				1.00			
$LSD_{0.05}$ CRM	0.27				1.23			
$LSD_{0.05}$ CPS x CRM	0.39				1.84			
CV (%)	2.41				2.64			
	Canopy temperature (^oC)							
Lamu - cowpea	22.87	22.43	22.23	22.51	27.57	26.40	24.77	26.25
DH04 - cowpea	25.30	24.80	24.50	24.87	28.20	27.50	27.33	27.68
CRM-mean	24.09	23.62	23.37		27.89	26.95	26.05	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0004				0.0001			
P-value (CPS x CRM)	0.002				0.0001			
$LSD_{0.05}$ CPS	0.17				0.20			
$LSD_{0.05}$ CRM	0.20				0.24			
$LSD_{0.05}$ CPS x CRM	0.30				0.36			
CV (%)	6.70				6.89			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residue into the soil significantly reduced canopy temperatures in both sites and cropping systems (Table 7.3). Crop residue surface mulch had significantly higher canopy temperature than crop residue incorporation in Lamu-cowpea intercrop at Mtwapa. Lamu maize intercropped with cowpea had a significantly lower canopy temperature than DH04 maize intercropped with cowpea in all residue management options in both sites. Average canopy temperature was 13.8% higher in Mtwapa than in Kilifi.

7.4.3 Chlorophyll contents of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea chlorophyll content at Mtwapa (Table 7.4). At Kilifi only the cropping system had a significant effect on chlorophyll content. Surface mulching and incorporation of crop residue into the soil significantly increased cowpea chlorophyll content in both cropping systems at Mtwapa. Crop residue incorporation had significantly higher chlorophyll content than surface mulch in both cropping systems. Cowpea intercropped with Lamu maize had significantly higher chlorophyll content than cowpea intercropped with DHO4 maize in both cropping systems at both sites. At Kilifi, cowpea intercropped with Lamu maize had significantly lower cowpea chlorophyll content than cowpea intercropped with DHO4 maize. Cropping system, crop residue management and their interactions had significant effect on maize chlorophyll content (Table 7.4). Surface mulching and incorporation of crop residue into the soil significantly increased maize chlorophyll content in Kilifi for both cropping systems. Incorporation of crop residue into the soil had significantly higher maize chlorophyll content than crop surface mulching. DHO4 maize intercropped with cowpea had higher chlorophyll content than Lamu maize intercropped with cowpea under control and surface mulched plots. Average maize chlorophyll content in Mtwapa was 11.1% higher than in Kilifi for both intercrops.

Table 7.4: Effects of cropping system and crop residue management on chlorophyll content of cowpea and maize at Kilifi and at Mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
				Cowpea chlorophyll content (index)				
Lamu - cowpea	48.73	47.67	44.10	46.83	54.73	55.67	56.83	55.74
DH04 - cowpea	49.63	49.47	50.23	49.78	46.43	53.33	54.97	51.58
CRM-mean	49.18	48.57	47.17		50.58	54.50	55.90	
P-value (CPS)	0.026				0.0001			
P-value (CRM)	0.366				0.0001			
P-value (CPS x CRM)	0.181				0.0001			
$LSD_{0.05}$ CPS	2.52				0.26			
$LSD_{0.05}$ CRM	Ns				0.32			
$LSD_{0.05}$ CPS x CRM	Ns				0.47			
CV (%)	4.97				0.46			
				Maize chlorophyll content (index)				
Lamu - cowpea	35.40	38.57	41.53	39.49	44.47	45.50	44.00	44.66
DH04 - cowpea	38.33	40.83	44.50	40.23	40.80	41.57	46.67	43.01
CRM-mean	36.87	39.70	43.02		42.64	43.534	45.34	
P-value (CPS)	0.0001				0.461			
P-value (CRM)	0.0001				0.595			
P-value (CPS x CRM)	0.0001				0.398			
$LSD_{0.05}$ CPS	0.11				Ns			
$LSD_{0.05}$ CRM	0.13				Ns			
$LSD_{0.05}$ CPS x CRM	0.20				Ns			
CV (%)	2.60				10.38			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

7.4.4 Leaf numbers of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea and maize leaf numbers (Table 7.5). Surface mulching and incorporation of crop residue into the soil significantly increased cowpea and maize leaf numbers in both cropping systems and sites. Generally crop residue incorporation had significantly higher cowpea and maize leaf numbers than crop residue surface mulch in both cropping systems. Cowpea intercropped with DHO4 maize variety had significantly higher cowpea leaf number than cowpea intercropped with Lamu maize under the different residue management options.

Table 7.5: Effect of cropping system and crop residue management on leaf number of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea leaf number per plant							
Lamu - cowpea	18.60	19.70	21.67	19.99	18.50	23.43	33.20	25.04
DH04 - cowpea	23.40	25.40	30.40	26.40	23.43	24.37	28.50	25.43
CRM-mean	21.00	22.55	26.04		20.97	23.90	30.85	
P-value (CPS)	0.0001				0.0008			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.17				0.18			
$LSD_{0.05}$ CRM	0.20				0.22			
$LSD_{0.05}$ CPS x CRM	0.30				0.33			
CV (%)	0.68				0.69			
	Maize leaf number per plant							
Lamu - cowpea	10.70	11.57	15.33	12.53	9.20	9.73	10.03	9.65
DH04 - cowpea	11.30	11.50	12.80	11.87	8.60	8.87	8.97	8.81
CRM-mean	11.00	11.54	14.07		8.90	9.30	9.50	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.13				0.08			
$LSD_{0.05}$ CRM	0.16				0.09			
$LSD_{0.05}$ CPS x CRM	0.24				0.14			
CV (%)	1.04				0.79			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Lamu maize intercropped with cowpea had significantly higher maize leaf number than DHO4 maize intercropped with cowpea. Mtwapa had 8.8 % higher average cowpea leaf number than Kilifi. In contrast Kilifi had 24.3% higher average maize leaf number than Mtwapa.

7.4.5 Plant height of cowpea and maize

Cropping system, crop residue management and their interactions had significant effects on cowpea and maize plant heights (Table 7.6).

Table 7.6: Effect of cropping system and crop residue management on plant height (cm) of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea plant height (cm)							
Lamu - cowpea	21.73	23.67	28.8	24.73	31.40	33.67	37.37	34.15
DH04 - cowpea	22.33	25.77	27.13	25.08	28.47	31.20	33.67	31.11
CRM-mean	22.03	24.72	27.97		29.94	32.44	35.52	
P-value (CPS)	0.442				0.0001			
P-value (CRM)	0.011				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	Ns				0.14			
$LSD_{0.05}$ CRM	1.17				0.17			
$LSD_{0.05}$ CPS x CRM	1.76				0.25			
CV (%)	3.67				0.40			
	Maize plant height (cm)							
Lamu - cowpea	168.60	177.50	187.57	177.89	116.20	156.43	187.70	153.44
DH04 - cowpea	140.30	140.50	142.40	141.07	146.10	146.40	149.33	147.28
CRM-mean	154.45	159.00	164.99		131.15	151.42	168.52	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.24				0.13			
$LSD_{0.05}$ CRM	0.28				0.16			
$LSD_{0.05}$ CPS x CRM	0.43				0.24			
CV (%)	0.14				0.08			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residue into the soil significantly increased cowpea plant height in both cropping systems in both sites. Incorporation of crop residues into the soil had higher cowpea plant height than surface mulching in both cropping systems in Mtwapa and in Lamu-cowpea intercrop in Kilifi. Cowpea intercropped with Lamu maize had significantly higher cowpea plant height than cowpea intercropped with DH04 maize under the different, crop residue management options at Mtwapa. Mean cowpea plant height in Mtwapa was 31.0% higher than in Kilifi. Surface mulching and incorporation of crop residues into the soil increased maize plant height in Lamu-cowpea intercrop in both sites and DH04-cowpea intercrop in Mtwapa. Incorporation of crop residue into the soil had higher maize plant height than surface mulching in both cropping systems and sites. Lamu maize intercropped with cowpea had significantly higher plant height than DH04 maize intercropped with cowpea cropping system under all the crop residue management options. The mean maize plant height in Kilifi was 6.1% higher than in Mtwapa.

7.4.6 Cowpea root nodule number

Cropping system, crop residue management and their interactions had significant effect on the number of cowpea root nodules (Table 7.7). Surface mulching and incorporation of crop residue into the soil significantly reduced the number of root nodules in both cropping systems in Mtwapa and DH04–cowpea intercrop at Kilifi. Crop residue incorporation into the soil had a lower number of root nodules than surface mulching in both cropping systems in Mtwapa. Cowpea intercropped with DH04 maize had significantly higher number of cowpea root nodules than cowpea intercropped with Lamu maize under all the crop residue management options in Mtwapa and under control (no residue incorporation and no surface mulch) in Kilifi. Kilifi had 151.6% higher average number of root nodules than Mtwapa.

Table 7.7: Effect of cropping system and crop residue management on number of cowpea root nodules per plant at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
Lamu - cowpea	14.53	12.53	10.30	12.45	6.40	4.60	3.80	4.93
DH04 - cowpea	25.47	13.63	12.17	17.09	9.60	5.70	5.10	6.80
CRM-mean	20.00	13.08	11.24		8.00	5.15	4.45	
P-value (CPS)	0.002				0.0001			
P-value (CRM)	0.008				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	2.43				0.14			
$LSD_{0.05}$ CRM	2.97				0.18			
$LSD_{0.05}$ CPS x CRM	4.45				0.27			
CV (%)	15.65				2.33			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

7.4.7 Pods per plant and grains per pod of cowpea

Cropping system, crop residue management and their interactions had significant effects on cowpea number of pods per plant and grains per pod of cowpea (Table 7.8). Incorporation of crop residue significantly increased the number of pods per plant in both cropping systems in Mtwapa and in Lamu-cowpea intercrop in Kilifi. Surface mulching increased the number of pods per plant only in DH04-cowpea intercrop at Mtwapa. Incorporation of crop residue into the soil had higher number of pods per plant than surface mulching at both sites. Cowpea intercropped with DH04 maize had significantly higher number of pods per plant than cowpea intercropped with Lamu maize under control and surface mulch options. The average number of pods per plant in Kilifi was 183.3% higher than in Mtwapa. Surface mulching increased the number of grains per pod only in Lamu-cowpea intercrop at Kilifi.

Table 7.8: Effect of cropping system and crop residue management on number pods per plant and grains per pod of cowpea at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Number of pods per plant							
Lamu - cowpea	6.50	6.67	8.43	7.20	2.23	2.37	3.10	2.57
DH04 - cowpea	8.36	8.40	9.40	8.72	2.73	3.10	3.33	3.05
CRM-mean	7.43	7.54	8.92		2.48	2.74	3.22	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.01				0.08			
$LSD_{0.05}$ CRM	0.12				0.10			
$LSD_{0.05}$ CPS x CRM	0.17				0.15			
CV (%)	1.14				2.81			
	Number of grains per pod							
Lamu - cowpea	10.67	13.50	13.53	12.57	4.00	4.80	5.50	4.77
DH04 - cowpea	13.33	13.53	14.63	13.83	4.80	5.07	5.33	5.07
CRM-mean	12.00	13.52	14.08		4.40	4.94	5.42	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.26				0.06			
$LSD_{0.05}$ CRM	0.32				0.07			
$LSD_{0.05}$ CPS x CRM	0.40				0.09			
CV (%)	1.87				1.17			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Incorporation of crop residue into the soil significantly increased the number of cowpea grains per pods in both cropping systems and sites. Incorporation of crop residues into the soil had higher number of grains per pod than surface mulching in DH04-cowpea intercrop at Kilifi and Lamu-cowpea at Mtwapa. Cowpea intercropped with DH04 maize had significantly higher number of grains per pod than cowpea intercropped with Lamu maize under control plots in both sites, and crop residue incorporated plots at Kilifi. The average number of pods in Kilifi was 168.3% higher than in Mtwapa.

7.4.8 Ears per plant and 100-grain weight of maize

Cropping system, crop residue management and their interactions had significant effects on the number of ears per plant and 100-grain weight of maize (Table 7.9).

Table 7.9: Effect of cropping system and crop residue management on number ears per plant and 100-grain weight (g) of maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Maize number of ears per plant							
Lamu - cowpea	0.14	0.46	0.53	0.38	0.15	0.17	0.19	0.17
DH04 - cowpea	0.33	0.66	0.88	0.62	0.13	0.24	0.33	0.23
CRM-mean	0.24	0.56	0.705		0.14	0.21	0.26	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.010				0.007			
$LSD_{0.05}$ CRM	0.013				0.009			
$LSD_{0.05}$ CPS x CRM	0.022				0.016			
CV (%)	2.05				3.64			
	Maize 100-grain weight (g)							
Lamu - cowpea	31.60	34.30	35.4	33.77	11.53	12.50	13.50	12.51
DH04 - cowpea	28.37	30.43	31.73	30.18	10.23	11.27	11.27	10.92
CRM-mean	29.99	32.37	33.57		10.88	11.89	12.39	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.007				0.0001			
P-value (CPS x CRM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.32				0.19			
$LSD_{0.05}$ CRM	0.39				0.23			
$LSD_{0.05}$ CPS x CRM	0.58				0.34			
CV (%)	0.95				1.51			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Surface mulching and incorporation of crop residues into the soil significantly increased the number of maize ears per plant and also 100-grain weight. Incorporation of crop residues into the soil had higher number of ears per plant and 100-grain weight than surface mulching in at both sites. DH04 maize variety intercropped with cowpea had significantly higher number of ears per plant and lower 100-grain weight than Lamu maize variety intercropped with cowpea under the different residue management options. Average number of ears per plant and 100-grain weight at Kilifi, were 150% and 172.9% higher than at Mtwapa, respectively.

7.4.9 Cowpea 100-grain weight and grain yield

Cropping system, crop residue management and their interactions had significant effects on cowpea 100-grain weight and grain yield (Table 7.10). Crop residue incorporation into the soil significantly increased percent cowpea 100-grain weight in Lamu-cowpea intercrop in both sites and grain yield both cropping systesm and sites. Surface mulch had no effect on 100-grain weight in both cropping systems at Kilifi, but increased cowpea grain yield in DH04-cowpea intercrop. Incorporation of crop residue into the soil had higher grain weight than surface mulching in Lamu-cowpea intercrop. Cowpea intercropped with Lamu maize had significantly higher cowpea 100-grain weight than cowpea intercropped with DHO4 maize only under crop residue incorporation options at Kilifi. Cowpea intercropped with DH04 maize had significantly higher cowpea grain yield than cowpea intercropped with Lamu maize under all crop residue management options at Kilifi and under crop residue incorporation option at Mtwapa. Kilifi had 179.5% and 111.1% higher average cowpea 100-grain weight and grain yield, respectively, than Mtwapa.

Table 7.10: Effects of cropping system and crop residue management on cowpea 100-grain weight (g) and grain yield (t/ha) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Cowpea 100-grain weight (g)							
Lamu - cowpea	13.64	13.67	17.44	14.92	4.83	5.17	5.23	5.08
DH04 - cowpea	13.35	13.66	14.05	13.69	5.07	5.20	5.20	5.16
CRM-mean	13.50	13.67	15.75		4.95	5.19	5.22	
P-value (CPS)	0.0001				0.101			
P-value (CRM)	0.0001				0.023			
P-value (CPS x CRM)	0.0001				0.002			
$LSD_{0.05}$ CPS	0.29				Ns			
$LSD_{0.05}$ CRM	0.36				0.12			
$LSD_{0.05}$ CPS x CRM	0.54				0.17			
CV (%)	1.95				1.78			
	Cowpea grain yield (t/ha)							
Lamu - cowpea	0.15	0.15	0.26	0.19	0.13	0.13	0.33	0.20
DH04 - cowpea	0.44	0.61	0.66	0.57	0.13	0.13	0.23	0.16
CRM-mean	0.295	0.38	0.46		0.13	0.13	0.28	
P-value (CPS)	0.0001				0.087			
P-value (CRM)	0.0001				0.0001			
P-value (CPS x CRM)	0.001				0.604			
$LSD_{0.05}$ CPS	0.01				Ns			
$LSD_{0.05}$ CRM	0.01				0.01			
$LSD_{0.05}$ CPS x CRM	0.02				Ns			
CV (%)	3.052				4.43			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

7.4.10 Maize stover yield and grain yield

Cropping system, crop residue management and their interactions had significant effects on maize stover yield and grain yield (Table 7.11). Surface mulching and incorporation of crop residue into the soil significantly increased maize stover yield in both cropping systems. Crop residue incorporation had higher stover yield than surface mulching in Lamu-cowpea intercrop. There was no significant difference between surface mulching and incorporation of crop residue into the soil in DH04-cowpea intercrop. In Kilifi, Lamu maize intercropped with cowpea had significantly higher maize stover yield than DH04 maize intercropped with cowpea.

Table 7.11: Effects of cropping system and crop residue management on stover yield (t/ha) and grain yield of maize (t/ha) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	R_0	R_1	R_2	CPS-means	R_0	R_1	R_2	CPS-means
	Maize stover yield (t/ha)							
Lamu - cowpea	4.87	6.67	7.43	6.32	2.43	2.63	2.90	2.65
DH04 - cowpea	3.52	4.79	5.24	4.52	1.27	1.83	1.73	1.61
CRM-mean	4.20	5.73	6.34		1.85	2.23	2.32	
P-value (CPS)	0.022				0.0001			
P-value (CRM)	0.380				0.001			
P-value (CPS x CRM)	0.115				0.0001			
$LSD_{0.05}$ CPS	1.49				0.11			
$LSD_{0.05}$ CRM	Ns				0.14			
$LSD_{0.05}$ CPS x CRM	Ns				0.20			
CV (%)	26.10				4.92			
	Maize grain yield (t/ha)							
Lamu - cowpea	1.52	1.65	2.62	1.93	0.20	0.30	0.43	0.31
DH04 - cowpea	2.22	2.42	2.88	2.51	0.30	0.57	0.71	0.53
CRM-mean	1.87	2.04	2.75		0.25	0.44	0.57	
P-value (CPS)	0.0001				0.0001			
P-value (CRM)	0.003				0.307			
P-value (CPS x CRM)	0.0002				0.0002			
$LSD_{0.05}$ CPS	0.25				0.07			
$LSD_{0.05}$ CRM	0.30				Ns			
$LSD_{0.05}$ CPS x CRM	0.45				0.37			
CV (%)	9.78				18.45			

Crop residue management (CRM) levels: R_0 = No crop residue; R_1 = crop residue on the soil surface; and R_2 = crop residues incorporated into the soil

Incorporation of crop residue into the soil significantly increased maize grain yield in both cropping systems at Kilifi. DHO4 maize intercropped with cowpea had significantly higher maize grain yield than Lamu maize intercropped with cowpea under the control (no-surface mulch + no-crop residue incorporation) and surface mulched plots. On average, DHO4-cowpea intercrop had 30% higher maize grain yield than Lamu-cowpea intercrop. Average maize grain yield in Kilifi was 440.5% higher than at Mtwapa.

7.5 Discussion

7.5.1 Soil moisture content

Crop residue incorporation and surface mulch increased soil moisture content at 20 and 40 cm depths. Thobatsi (2009) reported that soils under maize mulch had higher soil water content than un-mulched soils in maize intercropped with cowpea. Other researchers have also demonstrated that retention of crop residues on the surface enhances water infiltration, protects the soil from sealing and crusting by rainfall, and conserves soil moisture (Thomas, 1996; McGuire, 2009). Crop residue incorporation had higher moisture content than leaving crop residue on the soil surface. Karuku *et al.,* (2014) indicated that crop residue incorporation into the soil optimized the partitioning of the water balance components, increasing moisture storage. In a similar study, Lighourgidis *et al.,* (2006) reported that incorporation of vetch crop residues significantly improved the quantity and frequency of deep water percolation. At 20 cm soil depth DH04-cowpea intercrop had higher soil moisture content than Lamu-cowpea intercrop while the converse was true at 40 cm soil depth. This observation supports a previous finding (see chapter six of this thesis) that suggested that Lamu maize variety exploited moisture in the top 20 cm soil better than DH04 maize variety which in turn exploited moisture better than the former at lower depths.

7.5.2 Chlorophyll content of cowpea and maize

The study has shown that surface mulch and incorporation of crop residue into the soil increased cowpea and maize chlorophyll content. Ramesh and Devasenapathy (2006) reported that mulching enhanced soil moisture gains in cowpea plots which led to favourable plant physiological parameters such as chlorophyll content. Boomsma *et al.* (2009) also reported that mulching increased maize chlorophyll content. These observations were attributed to availability of sufficient soil moisture and N for plants. Mulching enhances plant N-uptake efficiency and improves nutrient preservation over unmulched plots (Zamir *et al*., 2013). Chlorophyll content was higher at Mtwapa than at Kilifi possibly because Mtwapa had higher soil nutrients than the latter (Boomsma *et al.,* 2009).

7.5.3 Canopy temperature

Surface mulch and incorporation of crop residue into the soil significantly reduced canopy temperatures of maize-cowpea intercrops. Turmel *et al*., (2015) attributed the reduction in canopy temperature under mulching to reduction in soil temperature, hence reduced moisture loss in the soil profile through evaporation. Reduction in soil temperature due to mulching was also reported by Kinama, (1997). Availability of moisture in soil ensures continued transpiration and precludes the need for stomatal closure which is a common strategy by plants to reduce moisture loss. Lamu-cowpea intercrop had lower canopy temperature than DH04-cowpea intercrop, suggesting that Lamu maize variety transpired more leading to reduction in temperature. The cropping system canopy temperature averages were higher at Mtwapa than at Kilifi possibly due to water stress conditions, because Mtwapa received lower amount of rainfall than Kilifi (Appendix 1).

7.5.4 Cowpea root nodule number

Surface mulch and incorporation of crop residues into the soil significantly reduced the number of cowpea root nodules per plant in both cropping systems. The findings are in agreement with the study by Ibewiro *et al*., (2001) and Singh *et al*., (2011) who reported significant reduction in the number of root nodules under mulching. The findings in the current study, could be attributed to increased shading of cowpea by maize which increased in growth and ground cover under mulch and crop residue incorporation. Cowpea intercropped with Lamu maize variety had a lower number of root nodules than cowpea intercropped with DH04 maize variety. Kilifi had 151.6% more root nodules than Mtwapa. This could be attributed to the fact that Mtwapa received lower amount of rainfall and had higher soil nutrient content than Kilifi.

7.5.5 Ground cover, growth and yield parameters of cowpea and maize

The study has shown that surface mulch and incorporation of crop residue into the soil increased cowpea and maize ground cover, growth, grain yield and yield components at both sites. Dahmardeh *et al.,* (2010) and Scopel *et al.,* (2004) reported significant increase in leaf number and plant height due to effective water conservation as a result of surface mulching and incorporaton of crop residues into the soil. Salako *et al* (2007) reported increased cowpea and maize ground cover due to application of crop residues. Dahmardeh *et al.,* (2010) and Nyakatawa (1997) reported that mulching increased yield and yield components of cowpea and maize. Mulches intercept raindrops, retard runoff promote infiltration and reduce surface evaporation, thereby enhancing moisture availability for plant uptake (Odhiambo and Bomke, 2001).

Incorporation of crop residues into the soil had significantly higher cowpea and maize ground cover, growth, grain yield and yield components than surface mulch. This may be attributed to decomposition of incorporated crop residues releasing nutrients for crop use and improving the soil physical and chemical properties that affect plant growth (van Donk *et al*., 2012). Crop residues have significant effect on nutrient cycling; soil organic matter and soil organic carbon (van Donk *et al.*, 2012; Pieri, 1989). Yield and yield components of cowpea and maize in Kilifi were significantly higher than in Mtwapa. This could be attributed to the fact that Kilifi received higher amount of rainfall than Mtwapa (Appendix 1).

7.6 Conclusion

Cowpea crop residue mulch and cowpea crop residue incorporation into the soil significantly increased soil moisture content, ground cover, cowpea and maize ground cover, growth and yield parameters, yield components of maize and cowpea, but decreased the canopy temperature. Incorporation of crop residues into the soil had significantly higher growth parameters, yield and yield components of intercrops than surface mulching. The performance of DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop.

CHAPTER EIGHT: EFFECT OF DIFFERENT FARMYARD MANURE LEVELS ON SOIL MOISTURE CONTENT, CANOPY TEMPERATURE, GROWTH AND YIELD OF MAIZE – COWPEA INTERCROPS

8.1 Abstract

The cost of inorganic fertilizers is prohibitively expensive for resource challenged small holder farmers in the coastal lowland Kenya. Use of organic fertilizers has the potential to improve the productivity of maize-cowpea based cropping systems. A study was carried out at Pwani University and Kenya Agricultural and Livestock Research Institute (KALRO) Mtwapa in 2011 and 2012 to determine the effects of farmyard manure levels on soil moisture content, canopy temperature, growth and yield performance of maize-cowpea intercrop. The treatments comprised two cropping systems and three farmyard manure levels. The farmyard manure levels comprised: control (no manure), 2.5 t manure ha^{-1} and 5.0 t manure ha^{-1}. The experiment was laid out in a randomized complete block design, with a factorial arrangement of treatments and replicated three times. Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea. Cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize ears per plant and stover yield were also determined. Data was analyzed using the general linear model (GLM) procedure for analysis of variance using SAS statistical package. Where the F values were significant, means were compared using the least significant difference (LSD) test, at $p = 0.05$. Farmyard manure application increased soil moisture content and groundcover, chlorophyll content, growth parameters, yield and yield components of maize plants; however, it reduced canopy temperature and all cowpea plant attributes. DH04-cowpea intercrop outperformed Lamu-cowpea intercrop in most plant attributes. The performance of DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop.

8.2 Introduction

Maize is the staple food in Kenya, produced by small scale farmers who have limited capacity to produce efficiently (Schroeder *et al*., 2013). Low soil fertility and moisture stress are the major factors limiting maize productivity in the coastal lowland of Kenya (Wekesa *et al.,* 2003). Adoption of inorganic fertilizers in coastal lowlands is low and this has been attributed to high fertilizer costs (Saha *et al.,* 1993). According to Saleem *et al*., (2011) the cost of inorganic fertilizers is prohibitively expensive for resource challenged smallholder farmers. Organic manures such as animal manure, compost and green manure cover crops are suggested alternatives (Nandwa, 1995). According to Tennakoon and Bandara, (2003) both plant materials and animal manure have considerable amounts of plant nutrients. Thus continual applications of these organic manures can not only supply plant nutrients but also enrich agricultural soils. In addition to being important sources of N for crop production, animal manures and compost are beneficial in soils because they can increase the water holding capacity and the cation exchange capacity (Nandwa, 1995). The responses of crops to manure application has been attributed to quantity of manure N already available to the plants, amount of N that becomes available after mineralization during the season, release and availability of P, K, and micronutrients, and improvement of soil structure and permeability (Bocchi and Tano, 1994).

Majority of farmers in the coastal region neither use organic nor inorganic fertilizers. Among the organic sources, farmyard manure is the most important as it contains all the nutrients needed for crop growth including trace elements, albeit in small quantities (Achieng *et al.* 2010). Farmyard manure can be used for crop production as a substitute of chemical fertilizers (Khan *et al.,* 2005; Ayoola *et al.,* 2007). The efficiency of manure utilization by a crop is determined by the method of application, time of incorporation and the rate of decomposition in the soil (Achieng *et al.,* 2010). Despite the importance of farmyard manures as sources of nutrients, their use is limited mainly due to their low and variable nutrient composition and the large quantities needed to provide adequate plant nutrients (Nandwa, 1995). The objective of the study was to determine the effects of farmyard manure levels on soil moisture content, canopy temperature, chlorophyll content, growth and yield of maize-cowpea intercrop.

8.3 Materials and Methods

8.3.1 Study site

The study was carried out at Pwani University and Kenya Agricultural and Livestock Research Organization (KALRO). Pwani University is located 60 km north of Mombasa between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. Mean monthly minimum and maximum temperatures of about 22^0C and 30^0C, respectively, and mean relative humidity of 80% (Jaetzold *et al.,* 2012). The site is in coastal lowland (CL) Kenya. The region receives an average annual rainfall of 600–1100 mm in two seasons (Sombroek *et al.,* 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season and 75% of the annual rainfall is usually received during this time (Saha, 2007). The rainfall, temperature and relative humidity at the Kilifi and Mtwapa sites are shown in Table 6.1. According to Sombroek *et al.,* (1982), the soils in coastal lowland Kenya are mostly ferralsols. They are low in cation exchange capacity, total N organic matter content and essential plant nutrients (such as Calcium, Magnesium, Zinc and Sodium). In addition, they are prone to leaching, and have a pH of 5.6. Soils were analysed for pH, total N, Organic carbon, Phosphorus, potassium, calcium, Magnesium, Manganese, Copper, Iron, Zinc and Sodium (Appendix 2).

8.3.2 Experimental design, treatments and crop husbandry

The study evaluated the effect of intercropping maize with cowpea under different farmyard manure levels in the coastal lowland of Kenya. A randomized complete block design with a factorial arrangement of treatments was used and replicated three times. The treatments comprised two cropping systems and three farmyard manure levels. The cropping systems comprised: Dryland Hybrid 04 (DH04) - cowpea intercrop and Lamu - cowpea intercrop. The farmyard manure levels comprised: control (no manure), 2.5 t manure ha^{-1} and 5.0 t manure ha^{-1}. Cowpea variety Nyeupe, which was among the farmer prefereed, drought/insect pest resistant cowpea, was used for intercropping with maize. Plot size was 5 m x 5 m. Maize plant spacing was 100 cm x 50 cm giving a 20,000 plant population per hectare. Cowpea was planted in between the maize rows with spacing of 30 cm within the row, two plants per hill, giving a plant population of about 66,660 plants/ha. All the cowpeas in the two sites were planted four weeks after the maize was planted to reduce competition (Mureithi *et al.*, 1996). Weeding was done by hand at two, four and six weeks, respectively, after planting.

8.3.3 Data collected

Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea. Cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize number of ears per plant and stover yield were also determined. Data was collected as described in chapter six.

8.3.4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) tests, at p = 0.05.

8.4 Results

8.4.1 Soil moisture content

Cropping systems and farmyard manure (FYM) application had significant effect on soil moisture content at 20, 40 and 60 cm soil depths. Interaction between cropping system and FYM had no significant effect on soil moisture content. In most cases, Lamu-cowpea intercrop plots had significantly lower moisture content than DH04-cowpea intercrop plots at all soil depths and maize growth stages (Table 8.1). Farmyard manure application significantly increased moisture content relative to the control at all stages (Table 8.2). Application of 2.5 t/ha had significantly higher moisture content than application of 5 t/ha.

Table 8.1: Effect of cropping system on soil moisture content (% per volume) at 20, 40, 60 and 80 cm soil depth at all growth stages

Cropping system	20 cm Soil depth			40 cm soil depth		
	Boot	Silk	Maturity	Boot	Silk	Maturity
Lamu – cowpea	7.43	13.52	9.22	13.25	19.52	13.32
DH04-cowpea	9.12	15.43	9.33	14.83	22.19	14.53
P-value	0.0001	0.0001	0.451	0.0001	0.0001	0.0001
$LSD_{0.05}$	0.37	0.39	0.32	0.34	0.22	0.27
CV (%)	4.22	2.57	3.24	2.34	0.99	1.81
	60 cm Soil depth			80 cm soil depth		
Lamu – cowpea	17.02	22.68	17.84	22.48	25.79	22
DH04-cowpea	20.24	23.87	19.59	23.83	25.9	22.25
P-value	0.0001	0.0001	0.0001	0.0001	0.292	0.137
$LSD_{0.05}$	0.31	0.42	0.323	0.319	NS	NS
CV (%)	1.59	1.72	1.64	1.31	0.80	1.50

Table 8.2: Effect of farmyard manure on soil moisture content (% per volume) at 20, 40, 60 and 80 cm soil depth in all growth stages

Farmyard manure	20 cm soil depth			40 cm soil depth		
	Boot	Silk	Maturity	Boot	Silk	Maturity
0 t/ha FYM	7.47	15.47	7.91	13.69	20.02	13.26
2.5 t/ha FYM	8.98	14.45	11.22	14.44	22.57	14.62
5.0 t/ha FYM	8.38	13.51	8.70	13.98	19.98	13.89
P-value	0.0001	0.0001	0.0001	0.0088	0.0001	0.0001
$LSD_{0.05}$	0.45	0.48	0.39	0.42	0.27	0.33
CV (%)	4.22	2.57	3.24	2.33	0.99	1.81
	60 cm soil depth			80 cm soil depth		
0 t/ha FYM	17.32	21.95	17.68	23.31	25.97	22.96
2.5 t/ha FYM	22.05	25.48	22.52	26.54	27.56	24.41
5.0 t/ha FYM	16.52	22.39	15.95	19.61	24.02	19.02
P-value (FYM)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
$LSD_{0.05}$ (FYM)	0.38	0.51	0.40	0.39	0.27	0.43
CV (%)	1.59	1.72	1.64	1.31	0.80	1.50

FYM = Farmyard manure

8.4.2 Ground cover and canopy temperture

Application of farmyard manure and cropping system had significant effects on ground cover and canopy temperature (Table 8.3). Application of farmyard manure significantly increased percent ground cover at Mtwapa, but had no effect at Kilifi. DH04 maize variety intercropped with cowpea had a higher percent ground cover than Lamu maize variety intercropped with cowpea at 0 and 5.0 t/ha farmyard manure application. Application of 5 t/ha farmyard manure had a significantly higher percent ground cover than application of 2.5 t/ha farmyard manure. Average percent increase in ground cover with 2.5 t/ha and 5.0 t/ha farmyard manure application was 56.0% and 63.2%, respectively. Farmyard manure application, cropping system and their interaction significantly affected the canopy temperature at Kilifi (Table 8.3). Farmyard manure application reduced canopy temperature in Lamu-cowpea intercrop but had no effect in DH04-cowpea intercrop. Farmyard manure application rates of 2.5 t/ha and 5.0 t/ha were not significantly different in canopy temperature. The canopy temperatures of the two cropping systems were not significantly different at all farmyard manure levels except at 5.0 t/ha where Lamu-cowpea intercrop had lower canopy temperature than DH04-cowpea intercrop.

Table 8.3: Effects of cropping system and farmyard manure application on percent ground cover and canopy temperature at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS-mean
				Percent ground cover				
Lamu - cowpea	89.23	83.47	82.63	86.11	24.43	41.90	41.87	36.07
DH04 - cowpea	82.93	84.10	82.23	83.09	29.23	41.77	45.70	38.90
Mean-FYM	86.08	83.79	82.43		26.83	41.84	43.79	
P-value (CPS)	0.312				0.035			
P-value (FYM)	0.325				0.0001			
P-value (CPS x FYM)	0.317				0.235			
$LSD_{0.05}$ CPS	Ns				0.87			
$LSD_{0.05}$ FYM	Ns				1.07			
$LSD_{0.05}$ CPS x FYM	Ns				Ns			
CV (%)	4.79				2.14			
				Canopy temperature (^oC)				
Lamu - cowpea	24.43	23.43	22.80	23.55	28.39	28.49	27.86	28.25
DH04 - cowpea	23.70	24.03	23.97	23.90	26.76	29.29	27.29	27.78
Mean-FYM	24.07	23.73	23.39		27.58	28.89	27.58	
P-value (CPS)	0.083				0.007			
P-value (FYM)	0.033				0.69			
P-value (CPS x FYM)	0.004				0.45			
$LSD_{0.05}$ CPS	Ns				0.741			
$LSD_{0.05}$ FYM	0.49				Ns			
$LSD_{0.05}$ CPS x FYM	0.90				Ns			
CV (%)	1.60				2.55			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

8.4.3 Chlorophyll contents of cowpea and maize

Application of farmyard manure, cropping system and their interaction significantly affected cowpea chlorophyll content at Kilifi but not at Mtwapa (Table 8.4). At Kilifi, cowpea chlorophyll content was significantly higher under cowpea intercropped with DHO4 maize than under cowpea intercropped with Lamu maize under control (no farmyard manure) and 5.0 t/ha farmyard manure. At Mtwapa, Lamu-cowpea intercrop had significantly lower canopy temperature than DH04-cowpea intercrop. Application of farmyard manure and the interaction between FYM and cropping system significantly affected maize chlorophyll content at Kilifi (Table 8.4).

Table 8.4: Effects of cropping system and farmyard manure application on chlorophyll content of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS- mean
				Cowpea chlorophyll index				
Lamu - cowpea	51.57	48.70	46.60	48.96	52.93	53.07	52.07	52.69
DH04 - cowpea	54.43	49.27	51.53	51.74	54.40	52.53	55.70	54.21
Mean-FYM	53.00	48.99	49.07		53.67	52.80	53.89	
P-value (CPS)	0.0001				0.015			
P-value (FYM)	0.001				0.241			
P-value (CPS x FYM)	0.001				0.025			
$LSD_{0.05}$ CPS	0.74				1.15			
$LSD_{0.05}$ FYM	0.91				Ns			
$LSD_{0.05}$ CPS x FYM	1.58				0.48			
CV (%)	1.40				2.05			
				Maize chlorophyll index				
Lamu - cowpea	38.60	42.47	45.47	42.18	44.83	43.93	43.73	44.28
DH04 - cowpea	36.40	43.20	44.30	41.30	45.50	43.63	46.37	45.17
Mean-FYM	37.50	42.84	44.89		45.17	43.78	45.05	
P-value (CPS)	0.0001				0.142			
P-value (FYM)	0.0001				0.154			
P-value (CPS x FYM)	Ns				Ns			
$LSD_{0.05}$ CPS	0.08				0.11			
$LSD_{0.05}$ FYM	1.24				Ns			
$LSD_{0.05}$ CPS x FYM	1.86				Ns			
CV (%)	2.32				2.72			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

Farmyard manure treatments had no significant effect on maize chlorophyll content at Mtwapa. Application of FYM significantly increased maize chlorophyll content at Kilifi in both cropping systems. Application of 5.0 t/ha FYM had higher chlorophyll content than application of 2.5 t/ha FYM in Lamu-cowpea intercrop. Cropping systems had no significant effect on maize chlorophyll content at 2.5 t/ha and 5.0 t/ha FYM. Lamu-cowpea intercrop had higher maize chlorophyll content than DH04-cowpea intercrop.

8.4.4 Leaf numbers of cowpea and maize

Application of farmyard manure and the interaction between FYM and cropping system significantly affected cowpea leaf number in both sites (Table 8.5). Farmyard manure application significantly increased cowpea leaf number in both cropping systems at both sites. Application of 2.5 t/ha FYM increased cowpea leaf number in Kilifi and Mtwapa by 5.2% and 55.9%, respectively. Application of 5.0 t/ha of FYM increased cowpea leaf number in Kilifi and Mtwapa by 52.8% and 73.5% respectively. Application of farmyard manure, cropping system and their interaction significantly affected maize leaf number of both cropping systems in both sites (Table 8.5). Farmyard manure application significantly increased maize leaf number in both cropping systems and sites. Application of 2.5 t/ha FYM significantly increased maize leaf number in Lamu-cowpea intercrop system in Kilifi. Generally, Lamu maize variety intercropped with cowpea had significantly higher leaf numbers than DH04 maize variety intercropped with cowpea. The average maize leaf number for Mtwapa was 25.7% lower than for Kilifi.

Table 8.5: Effects of cropping system and farmyard manure application on leaf number of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS- mean
				Cowpea leaf number per plant				
Lamu - cowpea	18.37	19.07	29.53	22.32	11.00	23.47	24.37	19.61
DH04 - cowpea	19.07	20.33	27.67	22.36	21.03	26.47	31.23	26.24
Mean-FYM	18.72	19.70	28.60		16.02	24.97	27.80	
P-value (CPS)	0.0001				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.36				0.52			
$LSD_{0.05}$ FYM	0.04				0.64			
$LSD_{0.05}$ CPS x FYM	0.66				0.95			
CV (%)	1.54				2.15			
				Maize leaf number per plant				
Lamu - cowpea	12.27	13.37	14.03	13.22	8.60	8.87	9.67	9.05
DH04 - cowpea	12.33	12.37	13.27	12.66	7.57	7.73	15.30	7.65
Mean-FYM	12.30	12.87	13.65		8.09	8.30	12.49	
P-value (CPS)	0.009				0.0001			
P-value (FYM)	0.002				0.0001			
P-value (CPS x FYM)	0.004				0.0001			
$LSD_{0.05}$ CPS	0.39				0.22			
$LSD_{0.05}$ FYM	0.48				0.27			
$LSD_{0.05}$ CPS x FYM	0.72				0.41			
CV (%)	2.88				2.20			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

8.4.5 Plant heights of cowpea and maize

Application of farmyard manure, cropping system and their interactions significantly affected cowpea and maize plant height (Table 8.6). Application of 5.0 t/ha farmyard manure significantly increased cowpea plant height relative to the cereal in both cropping systems at both sites. Application of 2.5 t/ha FYM increased cowpea plant height only in Mtwapa. The average plant height at Mtwapa was 37.0% higher than at Kilifi. Application of farmyard manure significantly increased maize plant height in both cropping systems at both sites

(Table 8.6). Farmyard manure application increased maize plant height at Kilifi and at Mtwapa by 8.7% and 14.3%, respectively.

Table 8.6: Effects of cropping system and farmyard manure application on plant height (cm) of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS-mean
				Cowpea plant height (cm)				
Lamu - cowpea	18.37	19.07	29.53	22.32	22.67	29.73	33.70	28.70
DH04 - cowpea	19.90	20.33	27.67	22.63	25.67	36.47	36.50	32.88
Mean-FYM	19.14	19.70	28.60		24.17	33.10	35.10	
P-value (CPS)	0.0001				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0020				0.0001			
$LSD_{0.05}$ CPS	0.54				0.31			
$LSD_{0.05}$ FYM	0.66				0.38			
$LSD_{0.05}$ CPS x FYM	0.98				0.56			
CV (%)	2.24				0.95			
				Maize plant height (cm)				
Lamu - cowpea	155.63	175.50	177.00	169.38	128.77	144.30	160.87	144.65
DH04 - cowpea	146.83	147.77	151.90	148.83	132.87	137.73	138.10	136.23
Mean-FYM	151.23	161.64	164.45		130.82	141.02	149.49	
P-value (CPS)	0.0001				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	1.24				2.28			
$LSD_{0.05}$ FYM	1.52				2.79			
$LSD_{0.05}$ CPS x FYM	2.28				4.17			
CV (%)	0.74				1.54			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

Application of farmyard manure levels of 2.5 t/ha and 5.0 t/ha significantly increased maize plant height in Kilifi by 6.9% and 8.7%, respectively. In Kilifi intercropped maize was significantly taller than intercropped maize in Kilifi. Maize plant height average at Mtwapa was 11.7% lower than at Kilifi.

8.4.6 Cowpea root nodule number

Farmyard manure application, cropping system and their interaction had significant effect on cowpea number of root nodules in Mtwapa. In Kilifi, cropping system and farmyard manure application had no effect on number of nodules (Table 8.7). Application of farmyard manure significantly reduced the number of root nodule of cropping systems at both sites. Farmyard manure application rate of 5.0 t/ha resulted in lower number of nodules per plant than 2.5 t/ha in both cropping system at both sites. Cowpea intercropped with DH04 maize variety had higher number of root nodules than cowpea intercropped with Lamu maize variety. The average number of root nodules at Mtwapa was 34.2% higher than at Kilifi.

Table 8.7: Effects of cropping system and farmyard manure application on number of cowpea root nodules per plant at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS-mean
Lamu - cowpea	11.07	7.60	7.17	8.61	6.10	4.87	4.40	5.12
DH04 - cowpea	14.27	12.83	8.30	11.80	17.50	4.50	2.97	8.32
FYM-mean	12.67	10.22	7.74		11.80	4.69	3.69	
P-value (CPS)	0.673				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	Ns				0.10			
$LSD_{0.05}$ FYM	0.84				0.12			
$LSD_{0.05}$ CPS x FYM	1.25				0.54			
CV (%)	5.48				1.37			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure.

8.4.7 Pods per plant and grain per pod of cowpea

Farmyard manure application, cropping system and their interaction significantly affects the number of cowpea pods per plant and grains per pod in both cropping systems and at both sites (Table 8.8). Application of 5.0 t/ha FYM had higher number of cowpea pods per plant than application of 2.5 t/ha FYM.

Table 8.8: Effects of cropping system and farmyard manure application on number pods per plant and grains per pod of cowpea at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS- mean
				Cowpea number of pods per plant				
Lamu - cowpea	4.50	6.30	7.63	6.14	1.67	2.37	2.80	2.28
DH04 - cowpea	6.03	6.23	8.13	6.80	2.23	2.33	3.00	2.52
Mean-FYM	5.27	6.27	7.88		1.95	2.35	2.90	
P-value (CPS)	0.011				0.009			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.033				0.026			
$LSD_{0.05}$ CPS	0.47				0.18			
$LSD_{0.05}$ FYM	0.58				0.22			
$LSD_{0.05}$ CPS x FYM	0.86				0.33			
CV (%)	6.94				7.06			
				Cowpea number of grains per pod				
Lamu - cowpea	13.37	14.07	14.83	14.09	4.87	4.93	5.70	5.17
DH04 - cowpea	12.17	13.43	14.40	13.33	4.70	5.03	5.10	4.94
Mean-FYM	12.77	13.75	14.62		4.79	4.98	5.40	
P-value (CPS)	0.00				0.06			
P-value (FYM)	0.19				0.20			
P-value (CPS x FYM)	0.00				0.00			
$LSD_{0.05}$ CPS	0.36				0.25			
$LSD_{0.05}$ FYM	Ns				Ns			
$LSD_{0.05}$ CPS x FYM	0.66				0.45			
CV (%)	2.49				4.63			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

Cowpea intercropped with DH04 maize variety had higher number of cowpea pods per plant than cowpea intercropped with Lamu maize variety at both sites. Farmyard manure application rate of 2.5 t/ha increased the number of cowpea pods per plant at Kilifi and at Mtwapa by 19.0% and 20.5%, respectively, while 5.0 t/ha FYM increased the number of cowpea pods per plant in Kilifi and Mtwapa by 49.8% and 48.7%, respectively. The average numbers of pods per plant in Kilifi was 62.9% higher than in Mtwapa. Farmyard manure application had no significant effect on the number of cowpea grains per pod at both sites. There was however, no significant difference between the numbers of cowpea grains per pod for the two cropping systems in both sites.

8.4.8 Ears per plant and 100-grain weight of maize

Application of farmyard manure, cropping system and their interactions had significant effect on the number of maize ears per plant of both cropping systems and at both sites (Table 8.9). At Kilifi, application of farmyard manure rates of 2.5 t/ha and 5.0 t/ha increased the number ears per plant at Kilifi by 27.6% and 41.4%, respectively. Application of 2.5 t/ha and 5.0 t/ha farmyard manure levels at Kilifi increased the number of ears per plant by 31.0% and 53.5%, respectively, in Lamu maize intercropped with cowpea. The average number of maize ears per plant in Kilifi was 63.4% higher than in Mtwapa. Farmyard manure application and the interaction between farmyard manure and cropping system significantly affected maize 100-grain weight of both cropping systems at both sites (Table 8.10). Cropping system significantly affected maize 100-grain weight in Kilifi only. Application of 2.5 t/ha and 5.0 t/ha FYM significantly increased maize 100-grain weight by 7.1% and 12.1%, respectively at Kilifi. The cropping systems were not significantly different. The average 100-grain weight in Kilifi was 1.9% higher than Mtwapa.

Table 8.9: Effects of cropping system and farmyard manure application on number ears per plant and 100-grain weight (g) of maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS- mean	F_0	F_1	F_2	CPS- mean
	Maize number of ears per plant							
Lamu - cowpea	0.58	0.76	0.89	0.74	0.21	0.28	0.33	0.27
DH04 - cowpea	0.58	0.71	0.75	0.73	0.23	0.26	0.27	0.25
Mean-FYM	0.58	0.73	0.82		0.22	0.27	0.30	
P-value (CPS)	0.0001				0.0005			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.01				0.01			
$LSD_{0.05}$ FYM	0.02				0.01			
$LSD_{0.05}$ CPS x FYM	0.03				0.02			
CV (%)	1.7				3.21			
	Maize 100-grain weight (g)							
Lamu - cowpea	28.40	30.20	35.50	31.40	30.57	32.07	32.27	31.64
DH04 - cowpea	30.83	33.30	30.90	31.70	28.40	28.53	33.53	30.14
Mean-FYM	29.62	31.70	33.20		29.49	30.30	32.90	
P-value (CPS)	0.009				0.576			
P-value (FYM)	0.016				0.002			
P-value (CPS x FYM)	0.0002				0.0005			
$LSD_{0.05}$ CPS	1.01				Ns			
$LSD_{0.05}$ FYM	1.24				1.57			
$LSD_{0.05}$ CPS x FYM	1.86				2.35			
CV (%)	3.13				3.88			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

8.4.9 Cowpea 100-grain weight and grain yield

Farmyard manure application, cropping system and their interaction had significant effects on cowpea 100-grain weight of both cropping systems at Mtwapa but not at Kilifi (Table 8.10). Application of farmyard manure significantly reduced cowpea 100-grain weight in both cropping systems. However, there was no significant difference between 0 t/ha and 2.5 t/ha of farmyard manure applications. Cowpea intercropped with Lamu maize varieties had higher 100-grain weight than cowpea intercropped with DH04 maize variety.

Table 8.10: Effects of cropping system and farmyard manure application on 100-grain weight (g) and grain yield (t/ha) of cowpea at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS-mean	F_0	F_1	F_2	CPS- mean
					Cowpea 100-grain yield (g)			
Lamu - cowpea	14.84	14.83	14.00	14.56	5.82	5.55	5.26	5.54
DH04 - cowpea	13.96	13.25	14.52	13.91	5.47	5.28	4.92	5.22
Mean-FYM	14.4	14.04	14.26		5.65	5.42	5.09	
P-value (CPS)	0.156				0.0001			
P-value (FYM)	0.789				0.0001			
P-value (CPS x FYM)	0.169				0.0001			
$LSD_{0.05}$ CPS	Ns				0.02			
$LSD_{0.05}$ FYM	Ns				0.03			
$LSD_{0.05}$ CPS x FYM	Ns				0.04			
CV (%)	6.29				0.39			
					Cowpea grain yield (t/ha)			
Lamu - cowpea	0.36	0.15	0.12	0.21	0.23	0.22	0.13	0.19
DH04 - cowpea	0.15	0.13	0.11	0.13	0.23	0.19	0.19	0.20
Mean-FYM	0.26	0.14	0.12		0.23	0.21	0.16	
P-value (CPS)	0.002				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.195				0.0001			
$LSD_{0.05}$ CPS	0.01				0.01			
$LSD_{0.05}$ FYM	0.02				0.01			
$LSD_{0.05}$ CPS x FYM	Ns				0.02			
CV (%)	5.89				7.72			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

Farmyard manure application, cropping system and their interactions had significant effects on cowpea grain yield of both cropping systems at both sites (Table 8.10). Application of farmyard manure significantly reduced cowpea grain yield in both cropping systems at both sites. Application of 2.5 t/ha and 5.0 t/ha FYM decreased percent cowpea grain yield of cowpea intercropped with Lamu maize by 58.3% and 66.7%, respectively, at Kilifi. Cowpea grain yield at Mtwapa was higher than at Kilifi by 17.7%.

8.4.10 Stover yield and grain yield of maize

Farmyard manure application, cropping system and their interactions significantly affected maize stover yield and grain yield in both cropping systems at both sites (Table 8.11).

Table 8.11: Effects of cropping system and farmyard manure application on maize stover yield (t/ha) and grain yield (t/ha) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	F_0	F_1	F_2	CPS- mean	F_0	F_1	F_2	CPS- mean
					Maize stover yield (t/ha)			
Lamu - cowpea	3.59	4.48	4.61	4.23	1.03	1.55	1.65	1.41
DH04 - cowpea	3.67	4.07	4.24	3.99	0.95	1.05	1.35	1.12
Mean-FYM	3.63	4.28	4.43		0.99	1.30	1.50	
P-value (CPS)	0.0001				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0003				0.0001			
$LSD_{0.05}$ CPS	0.32				0.04			
$LSD_{0.05}$ FYM	0.39				0.04			
$LSD_{0.05}$ CPS x FYM	0.59				0.06			
CV (%)	0.01				2.68			
					Maize grain yield (t/ha)			
Lamu - cowpea	1.86	2.37	2.90	2.38	0.56	0.73	0.85	0.71
DH04 - cowpea	2.12	2.40	2.86	2.46	0.65	0.83	0.97	0.82
Mean-FYM	1.99	2.39	2.88		0.61	0.78	0.91	
P-value (CPS)	0.0001				0.0001			
P-value (FYM)	0.0001				0.0001			
P-value (CPS x FYM)	0.0020				0.0001			
$LSD_{0.05}$ CPS	0.17				0.02			
$LSD_{0.05}$ FYM	0.28				0.02			
$LSD_{0.05}$ CPS x FYM	0.31				0.03			
CV (%)	6.92				2.19			

F_0 = No farmyard manure; F_1 = 2.5 t/ha farmyard manure; and F_2 = 5.0 t/ha farmyard manure

Application of farmyard manure significantly increased maize stover yield and grain yield in both cropping systems at both sites. Application of 2.5 t/ha and 5.0 t/ha farmyard manure increased maize stover yields in Kilifi by 17.9% and 22.0%, respectively, while in Mtwapa the increase was 31.3% and 51.5%, respectively. The average maize stover yields at Kilifi were 69.3% higher than at Mtwapa. Farmyard manure application rates of 5.0 t/ha had higher grain yield than 2.5 t/ha at both sites. DH04 maize variety intercropped with cowpea had higher maize grain yield than Lamu maize variety intercropped with cowpea under all farmyard manure levels. Application of 2.5 t/ha and 5.0 t/ha farmyard manure increased average maize grain yield by 20.1% and 44.7% respectively in Kilifi. At Mtwapa, application of 2.5 t/ha and 5.0 t/ha farmyard manure increased average maize grain by 27.9% and 37.7%, respectively. The average maize grain yield at Kilifi was 68.2% higher than at Mtwapa.

8.5 Discussion

8.5.1 Soil moisture content

Application of 2.5 and 5 t/ha FYM/ha significantly increased the soil moisture content relative to the non-fertilized control at 20, 40 and 60 cm soil depths. Mossaddeghi *et al.*, (2000) reported an increase in soil moisture content due to farmyard manure application. The non-fertilized control plots and 2.5 t FYM /ha plots had higher moisture content than 5 t FYM/ha at 60 and 80 cm soil depths. This could be attributed to the fact that farmyard manure improves penetration and subsequent deep establishment of crop roots (Hati *et al.,* 2006; Li *et al*., 2010) that helps to help maintain high relative plant water content under soil moisture stress conditions (Hati *et al.,* 2006). Application of 5 t FYM /ha may have caused greater root penetration into the soil thus leading to greater exploitation of moisture at lower soil levels. Further, 5 t FYM/ ha may have provided higher nutrient levelsl thereby enhancing plant growth and water uptake (Rasool *et al.,* 2013). DH04–cowpea intercrop had significantly higher soil moisture content than Lamu-cowpea intercrop at all growth stages at 20, 40 and 60 cm, suggesting that Lamu maize variety used more moisture than DHO4 maize variety (see chapter 6 and 7).

8.5.2 Chlorophyll contents of cowpea and maize

Application of farmyard manure significantly reduced cowpea chlorophyll content at Kilifi. Shaker-Kooh *et al.,* (2014) reported significant reduction in chlorophyll content of mung-bean intercropped with sorghum under different replacement ratios. The cereal crop had a competitive advantage over the legume. Farmyard manure application resulted in an increase in maize chlorophyll content in both sole crop and intercrop systems at Kilifi. Ghosh *et al.* (2006) reported increase in chlorophyll content of sorghum intercropped with soybean due to farmyard manure application. The increase in chlorophyll content could be attributed to increased photosynthesis due to nutrient release and soil moisture conservation effect of the farmyard manure which was observed in the current study.

8.5.3 Canopy temperature

Application of farmyard manure resulted in significant reduction in canopy temperature of intercrops in both sites. This observation is in agreement with the study by Naresh *et al.,* (2014) who reported reduction in canopy temperature under maize legume intercrop. This was attributed to the water conservation effect of farmyard manure. According to Jones *et al.,* (2009), the major determinant of leaf temperature is the rate of evaporation or transpiration from the leaf. Water deficit results in stomatal closure, which leads to increased temperature. The significant reduction in canopy temperature observed with farmyard manure application indicates that there was no severe water stress conditions to trigger the closure of stomata to avoid dehydration (Hamidou *et al.,* 2007). In fact, farmyard manure application significantly increased moisture content relative to the control at all stages in this study. Cropping systems had significantly lower canopy temperatures in Kilifi than in Mtwapa. This could be attributed to the fact that Kilifi received 43.8 % higher amount of rainfall than Mtwapa (Appendix 1).

8.5.4 Cowpea root nodule number

Farmyard manure significantly reduced the number of cowpea root nodules in both cropping systems. This finding is in agreement with the study by Otieno *et al.,* (2007) who reported a reduction in nodulation in several legume species due to nitrogen from the mineralized manure which impacted negatively on nodulation. Organic manures commonly have C:N ratios of less than 30:1 and therefore decompose and often to release N rapidly (Giller, 2001). The nutrients released by farmyard manure could have resulted in increased maize growth parameters at the expense of cowpea growth parameters. Cowpea intercropped with DH04 had significantly higher number of cowpea root nodules than cowpea intercropped with Lamu. This observation could be attributed to the fact that Lamu variety which was taller than DH04 shaded cowpea more than DHO4. Egbe *et al.* (2013) reported that shading reduced nodule formation in cowpea. The average number of root nodules at Mtwapa was 34.2% lower than at Kilifi. Competition for moisture at Mtwapa could have resulted to the significantly lower number of cowpea root nodules because Kilifi received 43.8 % more rainfall than Mtwapa (Appendix 1).

8.5.5 Ground cover and growth parameters of cowpea and maize

The study has shown that application of farmyard manure resulted in a significant increase in percent ground cover and growth parameters of cowpea and maize. In studies by Adeoye *et al.,* (2011) and Mohamed *et al.,* (2011) application of farmyard manure increased cowpea leaf number and plant height. According to Adeyemo and Agele (2010), response of various maize growth parameters depended on farmyard manure levels applied. Further, organic manures improve soil-water-plant relations through modifying bulk density, total porosity, soil water retension (Obi and Ebo, 1995). Most of the cowpea growth parameters were higher under DH04 - cowpea intercrop. This could be explained by the fact that Lamu maize variety was taller than DH04 maize variety. The Lamu-cowpea intercrop had significantly lower soil moisture content at booting stage which could have made the cowpea to suffer greater interspecies competition. The increase in growth parameters was higher under 5.0 t/ha farmyard manure application rate than at 2.5 t/ha of farmyard manure. The increase in growth parameters was higher in Kilifi than in Mtwapa partly because Kilifi received higher amount of rainfall than Mtwapa (Appendix 1). Most of the maize growth parameters were higher under Lamu-maize intercropped with cowpea than under DH04 maize intercropped with cowpea.

8.5.6 Yield and yield components of cowpea and maize

The study has shown that application of farmyard manure reduced cowpea 100-grain weight and grain yield at both sites. Amujoyegbe and Elemo, (2013) reported that application of farmyard manure significantly reduced grain yield and yield components of intercropped cowpea. This could be attributed to the fact that farmyard manure application significantly increased maize growth, resulting in shading of cowpea intercrop. Eskandari (2012) reported that shading had a significant effect on cowpea under intercropping system because being the shorter component in the intercrop system it could not compete effectively for light resources. Cowpea yield and yield components were higher when cowpea was intercropped with DH04 maize variety than under intercrop with Lamu maize variety at both sites. Lamu maize variety was significantly taller than DH04 maize, hence it could have shaded the cowpea leading to low cowpea grain yield and yield components. Grain yield and yield components were higher at Kilifi than at Mtwapa possibly because Kilifi received 43.8 % more rainfall than Mtwapa (Appendix 1).

Farmyard manure application increased the number of ears per plant, 100-grain weight and grain yield of maize. Adeyemo and Ageles (2010) and Agbogidi (2010) reported an increase in maize yield and yield components due to manure application. Application of farmyard manure considerably improves soil physical properties and nutrient uptake resulting in increased yield and yield components (Awad *et al*., (2002). In this study farmyard manure application significantly increased moisture content relative to the control at all stages Application of 5 t FYM/ha had greater yield than 2.5 t FYM/ha possibly due to increased moisture and nutrient uptake. It is worth noting that plots supplied with 5 t FYM/ha had lower moisture content at 60 and 80 cm depths than 2.5 t FYM/ha Maize yield and yield components were significantly higher under Lamu-cowpea intercrop than under DH04-cowpea intercrop. The taller Lamu maize variety could have had an advantage over the shorter DH04 maize since plant height is a major determinant of a plant's ability to compete for light (Falster and Westoby, 2003). Maize yield and yield components were significantly higher in Kilifi than in Mtwapa because Kilifi received 43.8% higher amount of rainfall than Mtwapa.

8.6 Conclusion

Farmyard manure application significantly increased soil moisture content at all growth stages at 20, 40 and 60 cm soil depths. Application of FYM significantly reduced cowpea growth parameters, yield components and grain yield while the converse was true for maize under maize-cowpea intercropping system. The performance of DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop in most plant attributes measured.

CHAPTER NINE: EFFECT OF N-FERTILIZER APPLICATION ON SOIL MOISTURE CONTENT, CANOPY TEMPERATURE, GROWTH AND YIELD MAIZE - COWPEA INTERCROPS

9.1 Abstract

Nitrogen is a major yield determining nutrient in maize production. Soils in coastal lowland Kenya are generally low in N and require replenishment using inorganic fertilizers. The objective of the study was to investigate the effect of varying N-fetilizer application on soil moisture content, canopy temperature, growth and yield of maize-cowpea intercrop. An experiment was carried out at Pwani University and Kenya Agricultural Research Institute-Mtwapa in 2011 and 2012. The experiment was laid out in a randomized complete block design with a factorial arrangement of treatments and replicated three times. Treatments consisted of two cropping systems and three N-fertilizer rates. The cropping systems were: Dryland Hybrid 04 and Lamu maize varieties intercropped with cowpea variety Nyeupe. The N-fertilizer rates comprised: control (no N-fertilizer), 30 kg N/ha and 60 kg N/ha. Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea, cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize ears per plant and stover yield. Data was subjected to analysis of variance using SAS statistical package. Where the F values were significant, means were compared using the least significant difference (LSD) test, at p = 0.05. Application of N-fertilizer significantly increased soil moisture content, maize growth parameters, yield components and grain yield while the converse was true for cowpea. Maize under DH04-cowpea intercrop had higher performance than under Lamu-cowpea intercrop.

9.2 Introduction

Maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) are important components of traditional mixed cropping systems in many countries of the world (Iderawumi, 2014). Intercropping system has for long been used by traditional farmers as a risk avoidance mechanism against total crop failure and it can be used to increase food supply without decreasing the suitability of the soil (Rehman, 2010). A report by Saha (2007) indicates that over 90% of the smallholder farmers in the coastal lowland Kenya, intercrop or relay maize and cowpea during the long rains season. Adediran and Banjoko (1995) indicated that in crop production nitrogen is an essential macronutrient required by cereals and it is a major yield determining nutrient required for maize production. It is a component of proteins and nucleic acids and also enhances and facilitates the utilization of other nutrients like phosphorus, potassium and other elements (Adediran and Banjoko, 1995). Nitrogen is also the most vulnerable of all the plant nutrients in the soil; as it is highly volatile and can be readily leached. Increasingly high cost of fertilizer has made the knowledge of the effectiveness of its use by maize and other plants inevitable (Moll *et al.,* 1982). Usually the crop uses 30 to 50% of the inorganic nitrogen fertilizer applied, the rest is lost by volatilization, denitrification or leaching (Stewart *et al.*, 2005).

Amujoyegbe and Elemo (2013) and Thobatsi (2009) reported enhanced early ground cover, canopy formation in maize-cowpea intercrop with increase in fertilizer rates. When nitrogen fertilizer is added to cowpea intercropped with maize the cowpea use the inorganic nitrogen instead of fixing nitrogen from the air and thus competes with maize for nitrogen. However, when nitrogen fertilizer is not applied, the cowpea under intercrop will fix most of their nitrogen and not compete with maize for nitrogen resources (Adu-Gyamfi *et al.,* 2007). Maintenance of the soil fertility status is an important factor in order to obtain stable and sustainable agro-ecosystem (Graham and Vance, 2000). The use of a suitable and balanced use of fertilizers is one of the different factors which influence crop yield and its contributory factors (Rehamn, 2010). Therefore a study was set up to investigate the effect of varying N-fetilizer application on growth and yield of intercropped maize and cowpea in coastal lowland Kenya.

9.3 Materials and Methods

9.3.1 Study site

The study was carried out at Pwani University and Kenya Agricultural and Livestock Research Organization (KALRO) Mtwapa, both located at Kilifi County in the coastal region of Kenya. Pwani University is located 60 km north of Mombasa between latitudes 3^o S and 4^o S and longitudes 39^o E and 40^o E. Kenya Agricultural and Livestock Research Organization (KALRO) Mtwapa is situated at 30 m ASL, 39.219^o E and 4.347^o S, 20 km north of Mombasa (Jaetzold *et al.,* 2012). The two sites are situated in coastal lowland zone 4 (CL4). The region receives an average annual rainfall of 600–1100 mm that comes in two seasons (Sombroek *et al.,* 1982). The long rains are received in March/April through August while the short rains are received in October, November and December. The long rains season is the most important cropping season as it receives 75% of the annual rainfall (Saha, 2007). Mean monthly minimum and maximum temperatures of about 22^0C and 30^0C respectively, and mean relative humidity of 80% (Jaetzold *et al.*, 2012). According to Sombroek et al., (1982) the soils in coastal lowland Kenya are mostly ferralsols. These soils have low organic matter content, are deficient in essential plant nutrients (especially nitrogen), prone to leaching, and have a pH ranging between 5 and 7 (Mureithi *et al.,* 1995). The rainfall, temperature and relative humidity at the Kilifi and Mtwapa sites are shown in appendix 1.

9.3.2 Experimental design, treatments and crop husbandry

The study evaluated the effect of intercropping maize with cowpea variety under different N-fetilizer rates. The experiment was laid out in a randomized complete block design with a factorial arrangement of treatments and replicated three times. The experiment consisted of two cropping systems and three N-fertilizer rates. The cropping systems were: maize variety Dryland Hybrid 04 (DH04) intercropped with cowpea variety Nyeupe and Maize variety Lamu intercropped with cowpea variety Nyeupe. The N-fertilizer rates comprised: control (no N-fertilizer), 30 kg N/ha and 60 kg N/ha. A drought/insect pest resistant and farmer preferred cowpea variety Nyeupe was used for intercropping with maize. Plot size and spacing are as directed in previous chapters. Triple superphosphate (46% P_2O_5) was applied at the rate of 20 kg P/ha in all plots. The source of nitrogen was calcium ammonium nitrate (26 % N).

9.3.3 Data collected

Data collected included: soil moisture content, canopy temperature, weed biomass, chlorophyll content, percent ground cover, leaf number, plant height, grain weight and grain yield of maize and cowpea, cowpea root nodule number, numbers of pods per plant, number of grains per pod, maize ears per plant and stover yield. Data was collected as described in chapter six.

9.3. 4 Data analysis

Collected data were analyzed by the general linear model (GLM) procedure for analysis of variance using SAS statistical package (SAS Institute, 1993). Where the F values were significant, means were compared using the least significant difference (LSD) tests, at p = 0.05.

9.4 Results

9.4.1 Soil moisture content

Cropping systems, N-fertilizer application and their interaction had significant effects on soil moisture content at most sampling depths and growth stages (Table 9.1 and 9.2). Application of 30 kg N/ha caused a significant increase in soil moisture content at most growth stages and soil depths. Application of 60 N kg/ha had significantly lower soil moisture content than 30 N kg/ha at most growth stages and soil depths (Table 9.2). DH04-cowpea intercrop plots had significantly higher soil moisture content than Lamu-cowpea intercrop plots under 0 kg N/ha at most growth stages. In contrast, Lamu-cowpea intercrop generally had higher moisture content than DH04-cowpea intercrop at 30 and 60 kg N/ha at most growth stages.

9.4.2 Ground cover and canopy temperature

Cropping system, N-fertilizer application and their interactions significantly affected ground cover and canopy temperature at both sites (Table 9.3). Application of 60 kg/ha increased percent ground cover in both cropping systems and sites, while application of 30 kg N/ha increased percent ground cover in Lamu-cowpea intercrop at Kilifi and DH04-cowpea intercrop at Mtwapa. Increasing N-fetilizer application from 30 kg N/ha to 60 kg N/ha increased percent ground cover in Lamu-cowpea at Kilifi but not at Mtwapa. DHO4-cowpea intercrop had significantly higher percent crop ground cover than Lamu-cowpea intercrop at 0 and 30 kg N/ha at Kilifi and 30 and 60 kg N/ha at Mtwapa. Application of 60 kg N/ha N-fertilizer significantly reduced canopy temperatures in both cropping systems at Kilifi and Lamu-cowpea intercrop at Mtwapa (Table 9.3). . Application of 30 kg N /ha N-fertilizer level had no significant effect on canopy temperature. The two cropping systems had generally similar canopy temperatures across the different N levels except at 60 Kg N/ha at Mtwapa where Lamu-cowpea intercrop had a significantly lower temperature than DHO4-

cowpea intercrop. Crop canopy temperatures were significantly higher at Mtwapa than at Kilifi.

Table 9.1: Effects of cropping system and N-fertilizer application at different growth stages on soil moisture (% per volume) at 20 and 40 cm soil depths.

Cropping system (CPS)	20 cm soil depth				40 cm soil depth			
	0 kg/ha	30 kg/ha	60 kg/ha	Mean-CPS	0 kg/ha	30 kg/ha	60 kg/ha	Mean-CPS
				Booting stage				
Lamu-cowpea	9.47	10.20	11.22	10.30	18.59	22.42	19.53	20.18
DH04-cowpea	11.77	10.35	10.55	10.89	18.64	19.59	14.38	17.54
Mean-N-fert	10.62	10.28	10.89		18.62	21.01	16.96	
P-value (CPS)	0.002				0.0008			
P-value (N-fert)	0.019				0.0006			
P-value (CPS x N-fert)	0.0001				0.011			
$LSD_{0.05}$ (CPS)	0.30				1.25			
$LSD_{0.05}$ (N-fert	0.37				1.52			
$LSD_{0.05}$ (CPS x N-fert)	0.47				1.93			
				Silking stage				
Lamu-cowpea	18.59	22.42	19.53	20.18	21.28	26.81	19.45	22.51
DH04-cowpea	18.64	19.59	17.59	18.61	25.42	22.95	17.59	21.99
Mean-N-fert	18.62	21.01	18.56		23.35	24.88	18.52	
P-value (CPS)	0.019				0.347			
P-value (N-fert)	0.01				0.0001			
P-value (CPS x N-fert)	0.145				0.0009			
$LSD_{0.05}$ (CPS)	1.28				NS			
$LSD_{0.05}$ (N-fert	1.55				1.65			
$LSD_{0.05}$ (CPS x N-fert)	NS				2.10			
				Maturity stage				
Lamu-cowpea	8.68	9.87	8.77	9.11	12.48	14.47	11.74	12.90
DH04-cowpea	9.19	9.74	17.59	12.17	13.52	12.45	17.59	14.52
Mean-N-fert	8.94	9.81	13.18		13.00	13.46	14.67	
P-value (CPS)	0.0001				0.006			
P-value (N-fert)	0.0001				0.031			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ (CPS)	0.59				0.99			
$LSD_{0.05}$ (N-fert	0.72				0.88			
$LSD_{0.05}$ (CPS x N-fert)	0.91				1.53			

Table 9.2: Effects of cropping system and N-fertilizer application at different growth stages on soil moisture (% per volume) at 60 and 80 cm soil depths.

Cropping system (CPS)	60 cm soil depth				80 cm soil depth			
	0 kg/ha	30 kg/ha	60 kg/ha	Mean-CPS	0 kg/ha	30 kg/ha	60 kg/ha	Mean-CPS
				Booting stage				
Lamu-cowpea	18.59	22.42	19.53	20.18	8.68	9.87	8.77	9.11
DH04-cowpea	18.62	19.59	17.62	18.61	9.19	9.84	24.42	14.48
Mean-N-fert	18.61	21.01	18.58		8.94	9.86	16.60	
P-value (CPS)	0.014				0.0001			
P-value (N-fert)	0.007				0.0001			
P-value (CPS x N-fert)	0.115				0.0001			
$LSD_{0.05}$ (CPS)	1.22				0.54			
$LSD_{0.05}$ (N-fert	1.49				0.65			
$LSD_{0.05}$ (CPS x N-fert)	NS				0.83			
				Silking stage				
Lamu-cowpea	25.31	27.43	14.06	22.267	28.73	29.49	27.62	28.61
DH04-cowpea	28.38	27.65	17.59	24.540	29.76	30.23	17.59	25.86
Mean-N-fert	26.85	27.54	15.83		29.25	29.86	22.61	
P-value (CPS)	0.017				0.0001			
P-value (N-fert)	0.0001				0.0001			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ (CPS)	0.73				0.45			
$LSD_{0.05}$ (N-fert	0.89				0.55			
$LSD_{0.05}$ (CPS x N-fert)	1.13				0.70			
				Maturity stage				
Lamu-cowpea	15.40	21.25	13.41	16.69	22.54	24.23	18.55	21.77
DH04-cowpea	19.48	15.99	17.59	17.69	23.47	22.45	17.59	21.17
Mean-N-fert	17.44	18.62	15.50		23.01	23.34	18.07	
P-value (CPS)	0.365				0.138			
P-value (N-fert)	0.043				0.0001			
P-value (CPS x N-fert)	0.002				0.05			
$LSD_{0.05}$ (CPS)	NS				NS			
$LSD_{0.05}$ (N-fert	2.32				1.13			
$LSD_{0.05}$ (CPS x N-fert)	2.95				1.43			

Table 9.3: Effects of cropping system and N-fertilizer application on percent crop ground cover and canopy temperature (^{O}C) at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
					Percent ground cover			
Lamu - cowpea	76.77	82.33	86.03	81.71	23.43	28.77	30.60	27.60
DH04 - cowpea	83.77	85.40	86.63	85.27	25.33	46.33	54.57	42.08
Mean-N-fert	80.27	83.87	86.33		24.38	37.55	42.59	
P-value (CPS)	0.0002				0.0003			
P-value (N-fert)	0.0001				0.006			
P-value (CPS x N-fert)	0.002				0.001			
$LSD_{0.05}$ (CPS)	1.37				5.86			
$LSD_{0.05}$ (N-fert)	1.67				7.17			
$LSD_{0.05}$ (CPS x N-fert)	2.50				10.72			
CV (%)	1.56				16.00			
					Canopy temperature (^{O}C)			
Lamu - cowpea	25.47	24.87	23.27	24.54	27.61	27.28	24.04	26.31
DH04 - cowpea	26.20	25.43	23.33	24.99	26.82	26.80	25.50	26.37
Mean-N-fert	25.84	25.15	23.30		27.22	27.04	24.77	
P-value (CPS)	0.327				0.840			
P-value (N-fert)	0.196				0.067			
P-value (CPS x N-fert)	0.02				0.0004			
$LSD_{0.05}$ (CPS)	Ns				Ns			
$LSD_{0.05}$ (N-fert)	1.21				0.89			
$LSD_{0.05}$ (CPS x N-fert)	2.4				1.33			
CV (%)	3.79				2.63			

N_0 = No N-fertilizer; N_1 = 30 kg/ha N-fertilizer and N_2 = 60 kg/ha N-fertilizer

9.4.3 Chlorophyll contents of cowpea and maize

Cropping system, N-Fertilizer application and their interactions significantly affected cowpea chlorophyll content at both sites and maize chlorophyll content at Mtwapa (Table 9.4). Application of 60 kg N/ha reduced cowpea chlorophyll content relative to 30 kg N/ha and control in both cropping systems at both sites. Application of 30 kg N/ha had no significant effect on cowpea chlorophyll content at Kilifi, but decreased this parameter at

Mtwapa. Lamu maize intercropped with cowpea had higher chlorophyll content than DHO4 maize intercropped with cowpea at Kilifi, but the converse was the case at Mtwapa. The average chlorophyll content of cowpea at Kilifi was 10.5% higher than at Mtwapa. N-Application of N-fertilizer significantly increased maize chlorophyll content of both cropping systems at both sites. At Mtwapa however, there was no significant increase in maize chlorophyll content as N rate increased from 30 N kg/ha to 60 N kg/ha. Lamu maize intercropped with cowpea had higher maize chlorophyll content than DH04 maize intercropped with cowpea at 0 kg N/ha in Kilifi and 30 and 60 kg N/ha at Mtwapa. Average maize chlorophyll content at Mtwapa was higher by 20.6% than at Kilifi.

9.4.4 Leaf numbers of cowpea and maize

Cropping system, N-Fertilizer application and their interactions significantly affected cowpea and maize leaf numbers at both sites (Table 9.5). Application of N-fetilizer significantly reduced cowpea leaf numbers in both cropping systems at Kilifi and in DH04-cowpea intercrop system at Mtwapa. At Mtwapa, there were no significant differences in cowpea leaf number among all fertilizer rates in Lamu-cowpea intercrop and between 30 kg N/ha and 60 kg N/ha. The average ccowpea leaf number at Mtwapa was 24.9% higher than at Kilifi. Application of N-fertilizer significantly increased maize leaf number of cropping systems at Mtwapa but not at Kilifi (Table 9.5). There was no significant difference between 30 kg/ha and 60 kg/ha of N-fertilizer applications at Mtwapa. DHO4 maize intercropped with cowpea had significantly higher maize leaf number than Lamu maize intercropped with cowpea at Kilifi while, the converse was the case at Mtwapa.

Table 9.4: Effects of cropping system and N-fertilizer application on chlorophyll content (index) of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
				Cowpea chlorophyll index				
Lamu - cowpea	59.56	59.24	53.40	57.40	49.63	47.73	45.17	47.51
DH04 - cowpea	55.96	54.58	50.83	53.79	52.93	52.60	48.03	51.19
Mean-N-fert	57.76	56.91	52.12		51.28	50.17	46.60	
P-value (CPS)	0.0001				0.0001			
P-value (N-fert)	0.005				0.012			
P-value (CPS x N-fert)	0.002				0.0001			
$LSD_{0.05}$ CPS	1.38				1.15			
$LSD_{0.05}$ N-fert	1.69				1.38			
$LSD_{0.05}$ CPS x N-fert	2.53				2.06			
CV (%)	2.66				1.93			
				Maize chlorophyll index				
Lamu - cowpea	36.87	37.30	41.57	38.58	43.43	49.67	50.40	47.83
DH04 - cowpea	33.30	42.20	42.23	39.24	43.37	46.97	47.67	46.00
Mean-N-fert	35.09	39.75	41.90		43.40	48.32	49.04	
P-value (CPS)	0.27				0.001			
P-value (N-fert)	0.001				0.001			
P-value (CPS x N-fert)	0.001				0.001			
$LSD_{0.05}$ CPS	Ns				0.71			
$LSD_{0.05}$ N-fert	1.54				0.91			
$LSD_{0.05}$ CPS x N-fert	2.30				1.36			
CV (%)	3.08				1.51			

N_0 = No N-fertilizer; N_1 = 30 kg/ha N-fertilizer and N_2 = 60 kg/ha N-fertilizer

Table 9.5: Effects of cropping system and N-fetilizer application on cowpea leaf number at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
	Cowpea leaf number							
Lamu - cowpea	22.17	19.70	19.53	20.47	30.83	27.70	26.50	28.34
DH04 - cowpea	31.50	23.23	21.27	25.33	36.40	25.27	24.80	28.82
Mean-N-fert	26.84	21.47	20.40		33.62	26.49	25.65	
P-value (CPS)	0.014				0.008			
P-value (N-fert)	0.0001				0.057			
P-value (CPS x N-fert)	0.0001				0.022			
$LSD_{0.05}$ CPS	0.36				3.30			
$LSD_{0.05}$ N-fert	0.43				4.04			
$LSD_{0.05}$ CPS x N-fert	0.65				6.04			
CV (%)	1.19				13.72			
	Maize leaf number							
Lamu - cowpea	16.20	16.17	15.90	16.09	10.20	10.87	10.67	10.58
DH04 - cowpea	17.50	16.37	17.37	17.08	7.13	8.47	8.67	8.09
Mean-N-fert	16.85	16.27	16.64		8.67	9.67	9.67	
P-value (CPS)	0.008				0.0001			
P-value (N-fert)	0.314				0.001			
P-value (CPS x N-fert)	0.219				0.095			
$LSD_{0.05}$ CPS	0.66				0.40			
$LSD_{0.05}$ N-fert	Ns				0.40			
$LSD_{0.05}$ CPS x N-fert	Ns				Ns			
CV (%)	0.82				4.08			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

9.4.5 Plant heights of cowpea and maize

Cropping system, N-Fertilizer application and their interactions significantly affected plant height of both cropping systems at both sites (Table 9.6). Application of N-fetilizer application significantly reduced cowpea plant height in both intercrop systems in both sites. Cowpea plant height was significantly lower in 60 kg N/ha plots than in 30 kg N/ha plots. Cowpea intercropped with Lamu maize variety had significantly lower plant height than cowpea intercropped with DH04 maize variety. The average cowpea plant height was 166.5% higher at Mtwapa than at Kilifi.

Table 9.6: Effects of cropping system and N-fetilizer application on plant plant heights (cm) of cowpea and maize at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
	Cowpea plant height (cm)							
Lamu - cowpea	9.40	6.13	4.77	6.77	24.80	16.63	13.83	18.42
DH04 - cowpea	12.67	6.87	2.80	7.45	33.17	17.87	7.53	19.52
Mean-N-fert	11.04	6.50	3.79		28.99	17.25	10.68	
P-value (CPS)	0.0001				0.0001			
P-value (N-fert)	0.0001				0.0001			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.02				0.01			
$LSD_{0.05}$ N-fert	0.02				0.01			
$LSD_{0.05}$ CPS x N-fert	0.03				0.02			
CV (%)	4.12				3.13			
	Maize plant height (cm)							
Lamu - cowpea	154.03	150.63	145.40	150.02	146.17	161.27	166.13	157.86
DH04 - cowpea	129.17	128.93	140.80	132.97	99.40	133.23	156.00	129.54
Mean-N-fert	141.60	139.78	143.10		122.79	147.25	161.07	
P-value (CPS)	0.036				0.0001			
P-value (N-fert)	0.661				0.017			
P-value (CPS x N-fert)	0.073				0.288			
$LSD_{0.05}$ CPS	0.07				6.58			
$LSD_{0.05}$ N-fert	Ns				8.05			
$LSD_{0.05}$ CPS x N-fert	Ns				Ns			
CV (%)	8.44				4.36			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

N-Fertilizer application and cropping system significantly affected maize plant height in Mtwapa while in Kilifi only cropping system had significant effect (Table 9.6). Application of N-fetilizer application significantly increased maize plant height at Mtwapa. The plant height for Lamu maize intercropped with cowpea was taller than DHO4 maize intercropped with cowpea. The average maize plant height at Mtwapa was 1.6% higher than at Kilifi.

9.4.6 Cowpea root nodule number

Cropping system, N-Fertilizer application and their interaction significantly affected the number of cowpea root nodules at Kilifi but not at Mtwapa (Table 9.7). At Kilifi application of N-fertilizer resulted in significant reduction in the number of cowpea root nodules per plant in both cropping systems. Cowpea intercropped with Lamu maize had higher number of root nodules than cowpea intercropped with DHO4 maize at all N levels. Kilifi site had 68.3% higher number of nodules than Mtwapa.

Table 9.7: Effects of cropping system and N-fertilizer application on number of cowpea root nodules per plant at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
Lamu - cowpea	39.13	33.40	33.07	35.20	20.90	19.70	18.57	19.72
DH04 - cowpea	36.63	30.93	30.41	32.66	19.70	19.50	22.57	20.59
P-value (CPS)	0.008				0.565			
P-value (N-fert)	0.034				0.453			
P-value (CPS x N-fert)	0.0001				0.997			
$LSD_{0.05}$ CPS	0.58				Ns			
$LSD_{0.05}$ N-fert	0.71				Ns			
$LSD_{0.05}$ CPS x N-fert	1.07				Ns			
CV (%)	2.75				26.67			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

9.4.7 Pods per plant and grains per pod of cowpea

Cropping system, N-Fertilizer application and their interactions had significant effect on the number of cowpea pods per plant at both sites (Table 9.8). Application of 60 kg/ha N-fertilizer significantly reduced the number of cowpea pods per plant in both cropping systems at both sites. N-fertilizer application of 30 kg/ha had no significant effect on pods per plant at both sites. DH04 maize intercropped with cowpea had a higher number of pods per plant than

Lamu maize intercropped with cowpea at 0 kg N/ha and 30 kg N/ha N-fetilizer application in both sites, Mtwapa had 189.2% higher number of pods per plant than at Kilifi.

Table 9.8: Effects of cropping system, N-fetilizer application on number of pods per plant and grains per pod in cowpea at kilifi and at mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
				Number of pods per plant				
Lamu - cowpea	2.87	2.86	2.16	2.63	8.87	8.43	6.83	8.04
DH04 - cowpea	3.69	3.52	2.08	3.10	9.70	9.57	6.20	8.49
Mean-N-fert	3.28	3.19	2.12		9.29	9.00	6.52	
P-value (CPS)	0.02				0.002			
P-value (N-fert)	0.0001				0.0005			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.39				0.25			
$LSD_{0.05}$ N-fert	0.44				0.30			
$LSD_{0.05}$ CPS x N-fert	0.66				0.45			
CV (%)	4.13				8.17			
				Number of grains per pod				
Lamu - cowpea	8.54	12.83	8.58	9.98	15.97	15.83	14.37	15.39
DH04 - cowpea	7.62	11.97	12.72	10.77	16.63	15.00	15.00	15.54
Mean-N-fert	8.08	12.40	10.65		16.30	15.42	14.69	
P-value (CPS)	0.50				0.012			
P-value (N-fert)	0.949				0.0001			
P-value (CPS x N-fert)	0.002				0.0001			
$LSD_{0.05}$ CPS	Ns				0.58			
$LSD_{0.05}$ N-fert	Ns				0.71			
$LSD_{0.05}$ CPS x N-fert	0.91				1.05			
CV (%)	0.05				5.28			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

Application of 60 kg N/ha N-fertilizer significantly reduced the number of cowpea grains per pod of cropping systems at Mtwapa. In most cases, there were no differences in number of grains per pod between Lamu-cowpea and DH04-cowpea intercrop.

9.4.8 *Ears per plant and 100-grain weight of maize*

Cropping system, N-fertilizer and their interaction had significant effects on the number of ears per plant of maize of both cropping systems at sites (Table 9.9).

Table 9.9: Effects of cropping system and N-fetilizer application on number of ears per plant and 100-grain weight in maize

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
	Number of maize ears per plant							
Lamu - cowpea	0.56	0.58	0.65	0.60	0.17	0.21	0.25	0.22
DH04 - cowpea	0.56	0.61	0.72	0.63	0.21	0.23	0.28	0.23
Mean-N-fert	0.56	0.60	0.69		0.19	0.22	0.27	
P-value (CPS)	0.007				0.0004			
P-value (N-fert)	0.005				0.0001			
P-value (CPS x N-fert)	0.032				0.0001			
$LSD_{0.05}$ CPS	0.08				0.01			
$LSD_{0.05}$ N-fert	0.10				0.01			
$LSD_{0.05}$ CPS x N-fert	1.33				0.02			
CV (%)	12.14				3.35			
	Maize 100-grain weight (g)							
Lamu - cowpea	27.37	28.7	26.63	27.57	10.08	10.46	9.97	10.17
DH04 - cowpea	33.43	31.27	31.33	32.01	12.59	11.05	11.81	11.82
Mean-N-fert	30.4	29.99	28.98		11.34	10.76	10.89	
P-value (CPS)	0.0001				0.0002			
P-value (N-fert)	0.229				0.27			
P-value (CPS x N-fert)	0.13				0.059			
$LSD_{0.05}$ CPS	1.43				0.64			
$LSD_{0.05}$ N-fert	Ns				Ns			
$LSD_{0.05}$ CPS x N-fert	Ns				Ns			
CV (%)	4.57				5.55			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

Application of N-fertilizer significantly increased the number of ears per plant in both cropping systems and at both sites. Cropping system had significant effect on maize 100-grain weight in both sites. However, N-fetilizer application and the interaction between cropping system and N-fetilizer application had no significant effect on maize 100-grain weight in both sites. DH04 maize variety intercropped with cowpea had higher 100-grain weight than Lamu maize variety intercropped with cowpea.

9.4.9 Cowpea 100-grain weight and grain yield

Cropping system, N-Fertilizer application and their interactions had significant effects on cowpea 100-grain weight at Mtwapa and grain yield at Kilifi (Table 9.10).

Table 9.10: Effects of cropping system and N-fetilizer application on 100-grain weight (g) and grain yield (t/ha) of cowpea in Kilifi and Mtwapa sites during July – October 2011/2012 season

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
	Cowpea 100-grain weight (g)							
Lamu - cowpea	5.33	4.41	5.25	5.00	14.66	14.60	13.75	14.34
DH04 - cowpea	5.55	5.47	5.55	5.52	16.51	15.65	15.53	15.90
Mean-N-fert	5.44	4.94	5.40		15.59	15.13	14.64	
P-value (CPS)	0.0002				0.0001			
P-value (N-fert)	0.962				0.0001			
P-value (CPS x N-fert)	0.033				0.0001			
$LSD_{0.05}$ CPS	0.68				0.01			
$LSD_{0.05}$ N-fert	Ns				0.10			
$LSD_{0.05}$ CPS x N-fert	0.55				0.19			
CV (%)	3.83				0.14			
	Cowpea grain yield (t/ha)							
Lamu - cowpea	0.23	0.50	0.40	0.38	0.07	0.04	0.06	0.06
DH04 - cowpea	0.57	0.50	0.37	0.48	0.04	0.03	0.02	0.03
Mean-N-fert	0.40	0.50	0.39		0.06	0.04	0.04	
P-value (CPS)	0.018				0.002			
P-value (N-fert)	0.036				0.030			
P-value (CPS x N-fert)	0.002				0.112			
$LSD_{0.05}$ CPS	0.09				0.01			
$LSD_{0.05}$ N-fert	0.09				0.01			
$LSD_{0.05}$ CPS x N-fert	0.12				Ns			
CV (%)	17.06				21.06			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

Application of 60 kg N/ha, significantly reduced cowpea 100-grain weight at Mtwapa but not at Kilifi. DH04 maize variety intercropped with cowpea had higher 100-grain weight than Lamu maize variety intercropped with cowpea at all N-fertilizer levels. At Kilifi, application of 60 kg/ha N-fetilizer application significantly reduced cowpea grain yield in both cropping systems. However, no differences were noted between the cropping systems at all N-fertilizer levels. At Mtwapa, cowpea intercropped with DH04 maize variety had higher grain yield than cowpea intercropped with Lamu maize variety. Average cowpea grain yield was at Kilifi was 855.6 % higher than at Mtwapa.

9.4.10 Stover yield and grain yield of maize

Cropping system, N-fertilizer application and their interaction significantly affected maize stover yield and grain yield in both sites (Table 9.11). Application of 30 and 60 kg N/ha increased maize stover yields and grain yield in both cropping systems at both sites. Application of 60 kg/ha had higher maize stover yield and grain yield than 30 kg N/ha in both cropping systems at both sites. Lamu maize variety intercropped with cowpea had higher maize stover yield at 60 kg N/ha. The mean maize stover yield at Kilifi was 160.0 % higher than at Mtwapa. Application of 30 and 60 kg N/ha significantly increased maize grain yield in both cropping systems at both sites. DH04 maize variety intercropped with cowpea had higher grain yield than Lamu maize variety intercropped with cowpea at all N-levels at all N levels. On average, application of 30 and 60 kg N/ha increased maize grain yield by 20.7% and 51.0 %, respectively, at Kilifi and 78.6 % and 114.3 %, respectively, at Mtwapa. Average maize grain yield at Kilifi was 536.7 % higher than at Mtwapa.

Table 9.11: Effects of cropping system and N-fetilizer application maize stover yield (t/ha) and grain yield (t/ha) of maize at kilifi and at mtwapa sites during July – October 2011/2012 seasonn

Cropping system (CPS)	Kilifi				Mtwapa			
	N_0	N_1	N_2	CPS-mean	N_0	N_1	N_2	CPS-mean
	Maize stover yield (t/ha)							
Lamu - cowpea	2.34	2.77	4.26	3.12	1.02	1.07	1.52	1.20
DH04 - cowpea	2.06	2.55	3.25	2.62	0.75	0.89	1.20	0.95
Mean-N-fert	2.20	2.66	3.76		0.89	0.98	1.36	
P-value (CPS)	0.0001				0.0001			
P-value (N-fert)	0.0001				0.0001			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.07				0.02			
$LSD_{0.05}$ N-fert	0.08				0.02			
$LSD_{0.05}$ CPS x N-fert	0.12				0.03			
CV (%)	2.28				1.36			
	Maize grain yield (t/ha)							
Lamu - cowpea	1.50	1.77	2.17	1.81	0.13	0.15	0.23	0.28
DH04 - cowpea	1.60	1.97	2.50	2.02	0.15	0.13	0.26	0.32
Mean-N-fert	1.55	1.87	2.34		0.14	0.14	0.25	
P-value (CPS)	0.008				0.0003			
P-value (N-fert)	0.025				0.0001			
P-value (CPS x N-fert)	0.0001				0.0001			
$LSD_{0.05}$ CPS	0.13				0.01			
$LSD_{0.05}$ N-fert	0.16				0.01			
$LSD_{0.05}$ CPS x N-fert	0.20				0.01			
CV (%)	6.39				3.53			

N_0 = No N-fertilizer application; N_1 = 30 kg/ha N-fertilizer application and N_2 = 60 kg/ha N-fertilizer application

9.5 Discussion

9.5.1 Soil moisture content

Application of 30 N kg/ha significantly increased soil moisture content at all growth stages at 20 cm soil depth, while 60 N kg/ha application was higher than 0 N kg/ha at booting and silking stage for Lamu-cowpea but not DH04-cowpea. This could be attributed to an increase in soil water uptake at 60 kg N/kg due to high N levels from the inorganic fertilizer (Ofori *et al*., 2014). The high biomass production under 60 N kg/ha application associated with more soil moisture utilization (Gaiser *et al.,* 2001).

9.5.2 Ground cover and growth parameters of cowpea and maize

The study has shown that application of N-fertilizer increased cowpea and maize percent ground cover and maize growth parameters but the converse was true for cowpea growth parameters in both sites. Thobatsi (2009) reported that N-fertilizer application enhanced early ground cover of a maize-cowpea intercropping system. Amujoyegbe and Elemo (2013) reported that canopy formation in a maize-cowpea intercrop increased slightly with increase in N-fertilizer rate. This could be attributed to the fact that nitrogen is a constituent of chlorophyll, protein, amino acids and photosynthetic activity (Sumeet *et al.,* 2009). Nitrogen also enhances and facilitates the utilization of other nutrients like phosphorus, potassium and other elements (Adediran and Banjoko, 1995). Generally, ground cover intercepts both PAR, raindrops and retards runoff therefore promoting infiltration. Soil moisture availability is subsequently prolonged by reduced surface evaporation due to insulation and shading off of radiation transmittance by the main crop canopy (Odhiambo and Bomke, 2001).

N-fertilizer application resulted in significant increase in maize leaf number, plant height and maize stover yield at both sites. Amanullah *et al.,* (2013) reported that nitrogen fertilizer significantly increased maize leaf number, plant height and biomass yield. Increase in maize growth parameters due to nitrogen fertilizer application was also reported by Onasanya *et al.,* (2009). Several reports have attributed significant increase in the development of vegetative plant parts and dry matter accumulation to nitrogen which is an important constituent of chlorophyll, amino acid and nucleic acid (Adediran and Banjoko, 1995). Application of N-fertilizer significantly reduced cowpea leaf number and plant height in both sites. This finding is in agreement with the studies by Abayomi and Jatto, (1998) and Amujoyegbe and Elemo, (2013), who reported significant reduction in cowpea leaf number and plant height due to increase in N-fetilizer application in maize-cowpea intercrops. Cowpea growth parameters were significantly higher when intercropped with DH04 maize variety than when intercropped with Lamu maize variety. This could be because Lamu maize variety was taller than DH04 maize variety; hence the shading and competition for resources could have impacted negatively on the cowpea (Dahmardeh *et al.*, 2010).

9.5.3 Chlorophyll content of cowpea and maize

Application of N-fertilizer significantly reduced cowpea chlorophyll content at both sites. Prasanthi and Venkateswaralu (2014) reported reduction in cowpea chlorophyll content in maize-cowpea intercropping system. They attributed this to shading effect under intercropped situations. The fast and vigorous maize growth might have dominated and utilized the resources more efficiently and suppressed the cowpea. N-fertilizer application significantly increased maize chlorophyll content at both sites. Prasanthi and Venkateswaralu (2014) reported an increase in maize chlorophyll content due to N-fertilization in a maize-cowpea intercropping system.

9.5.4 Canopy temperature

Application of N-fertilizer significantly reduced canopy temperature of cropping systems. Elbashier *et al.*, (2012) reported reduction in canopy temperature of maize-wheat intercrop due to N-fertilizer application. This was attributed to promotion of photosynthesis by N-fertilizer application, which involves stomatal opening, leading to water loss and cooling of the canopy. In this study the increase in soil moisture content due to application of 30 kg N/ha suggests the observed improved moisture retention by the increase in ground cover.

9.5.5 Cowpea root nodule number

In this study application of 60 kg/ha N-fertilizer significantly reduced the number of root nodules. The findings of these studies are in agreement with study by Otieno *et al.,* (2007) who reported that the application of nitrogen fertilizer depressed nodulation in legumes. Fukai *et al*. (1980) reported that addition of nitrogen to a cereal/cowpea system is generally favoring the cereal at the expense of cowpea. If the intercropped non-legume is taller than the legume, shading will occur and photosynthesis and subsequently N-fixation will be reduced (Van Kessel and Hartley, (2000). Lamu maize variety had taller average height than DH04 maize variety, hence the number of root nodules in cowpea intercropped with DH04 maize variety were higher than in cowpea intercropped with Lamu maize variety. Also, moisture availability under DH04-cowpea intercrop was higher than under Lamu-cowpea intercrop. Root nodules at Kilifi were 68.3% higher than at Mtwapa. This could be because Kilifi received a higher amount of rainfall than Mtwapa (Appendix 1) because moisture enhances nodulation (Ofori *et al.,* 2014).

9.5.6 Yield and yield components of cowpea and maize

The study indicates that application of nitrogen fertilizer significantly reduced the number of pods per plant, number of grains per pod, 100-grain weight and grain yield of cowpea at both sites but the converse was true for maize number of ears per plant and grain yield. The reduction in cowpea yield and yield components and grain yield is in agreement with previous studies (Amujoyegbe and Elemo, 2013). In a system where cowpea was intercropped with maize shading had significant effects on cowpea yield and yield components because it is the shorter component, and could not compete effectively for resources (Eskandari, 2012). Cowpea grain yield and yield components were higher in cowpea intercropped with DH04 maize variety than cowpea intercropped with Lamu maize variety. This could be attributed to interspecies competition because Lamu maize variety was taller than DH04 maize variety. Cowpea yield and yield components were significantly higher at Kilifi than at Mtwapa possibly the former received a higher amount of rainfall than the latter. Grain yield of maize with N application at both sites is in agreement with the studies by Akmal *et al.,* (2010) and Karasu (2012) who observed that nitrogen fertilizer exerts strong influence on maize growth, development and yield. According to Purcell *et al.,* (2002) nitrogen availability increases maize general growth which leads to increased grain yiewld. Application of 60 kg/ha N-fertilizer had higher grain yield than 30 kg N-fertilizeer in all cropping system at both sites. Therefore, farmers intercropping maize-cowpea in the region can use 60 kg/ha N-fertilizer because it gives higher yields than 30 kg/ha N-fertilizer under normal rainfall conditions.

9.6 Conclusion

Application of N-fertilizer significantly reduced cowpea growth parameters, yield and yield components while the converse was true for maize under maize-cowpea intercropping system. Application of 60 N kg/ha had significantly higher performance than 30 N kg/ha while the converse was true for soil moisture content at all growth stages in all soil depths. The performance of maize under DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop.

CHAPTER TEN: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

10.1 General Discussion

Farmers' cowpea selection criteria in order of decreasing preference were high grain yield, drought tolerant, early maturity, ease of harvesting and leafiness. The most preferred cowpea varieties were KVU 419, Nyeupe, KVU 27-1 and Kutambaa while the least preferred varieties were K80, M66, Nyekundu and Kaima-koko. Farmers' selection criteria differed from those of plant breeders in that farmers considered color, taste and cooking time as important traits. From this study, involving farmers in variety selection is important because it complements plant breeder's selection process and enhances chances of adoption of newly developed varieties.

Water stress imposed at vegetative and flowering increased canopy temperature of Khaki and Kaima koko cowpea varieties while the converse was true for Macho and Nyekundu. It reduced growth parameters and chlorophyll content, but enhanced grain yield and yield components. This suggests that moderate stress may be beneficial for cowpea grown for grain production but not for vegetable production. The impact of water stress on growth may be dependent on the cowpea variety. Cowpea varieties which were superior in yield and harvest indices under water stress included Nyekundu, KVU 27-1, M66, and KVU 419. These may be the most suitable cowpea varieties for the coastal lowland region where rainfall is erratic and unreliable.

Insecticide application significantly reduced insect pest damage at pre-flowering, flowering and podding stages resulting in increase in cowpea growth parameters, yield and yield components. All the cowpea varieties evaluated were similarly affected by insect pests. For successful production of cowpea in the region, application of insecticides is necessary.

Cowpea varieties Macho, Kaima koko, Nyeupe and M66 were the most responsive to insecticide application.

Intercropping reduced cowpea and maize growth parameters, chlorophyll content, yield and yield components. Sole maize had significantly lower canopy temperature than sole cowpea and intercrops. This could be attributed to the fact that cowpea is a drought tolerant crop that may respond to water stress by closing the stomata, leading to increase in canopy temperature. On the other hand, the maize crop is likely to have transpired more than cowpea leading to low canopy temperature. There was significant increase in soil moisture content at all growth stages in 20 cm soil depth. Intercropping enhanced crop productivity as land equivalent ratio for both Lamu-cowpea and DH04-cowpea intercrops was above 1.2 in both sites. It is advisable for farmers in the coastal lowland Kenya to intercrop maize and cowpea.

Application of crop residue reduced canopy temperature of cowpea and maize but enhanced their growth parameters, chlorophyll content, yield and yield components. Incorporation of crop residues into the soil had increased growth parameters, yield and yield components of intercrops relative to surface mulching. The performance of DH04-cowpea intercrop was higher than Lamu-cowpea intercrop. This is attributed to shading effect of Lamu maize variety since it was taller than DH04 maize variety.

Farmyard manure application increased soil moisture content at all growth stages in 20, 40 and 60 cm soil depths. Application of FYM reduced cowpea chlorophyll content, growth parameters, yield and yield components, but increased maize yield and yield attributes under maize-cowpea intercropping system. Farmyard manure application reduced canopy temperature of cropping systems. The higher growth parameters and yield and yield components under 5.0 t/ha FYM application could have resulted in soil moisture depletion in

5.0 t FYM/ha application compared to 2.5 t FYM/ha. The performance of DH04-cowpea intercrop was higher than Lamu-cowpea intercrop.

Application of N-fertilizer reduced cowpea chlorophyll content, growth parameters, yield and yield components but increased these parameters in maize under maize-cowpea intercropping system. It also reduced canopy temperature of cropping systems. Application of 60 N kg/ha had significantly higher performance than 30 N kg/ha while the converse was true for soil moisture content at all growth stages in all soil depths. The performance of maize under DH04-cowpea intercrop was significantly higher than Lamu-cowpea intercrop. DH04 is an improved maize variety while Lamu is a local maize variety.

10.2 Conclusion

Cowpea varieties most preferred by coastal farmers were KVU 419, Nyeupe, KVU 27-1 and Kutambaa. Water stress reduced cowpea growth parameters and chlorophyll content, but enhanced grain yield and yield components. Cowpea varieties which were superior in yield and high harvest index under water stress included Nyekundu, KVU 27-1, M66, and KVU 419. Insecticide application significantly reduced insect pest damage at pre-flowering, flowering and podding stages resulting in increase in cowpea growth parameters, yield and yield components. Cowpea varieties Macho, Kaima koko, Nyeupe and M66 were the most responsive to insecticide application. Intercropping reduced cowpea and maize growth parameters, yield and yield components, but enhanced soil moisture content and canopy temperatures. However, intercropping enhanced crop productivity as land equivalent ratios for both Lamu-cowpea and DH04-cowpea intercrops were above 1.2 in both sites. Application of crop residue significantly increased soil moisture content and cowpea and maize growth parameters, yield and yield components but reduced canopy temperature. Incorporation of crop residues into the soil had significantly higher growth parameters, yield and yield components of intercrops than surface mulching. Application of FYM significantly reduced cowpea growth parameters, yield components and grain yield while it increased soil moisture and maize growth and yield attributes in maize-cowpea intercropping system. Application of N-fertilizer significantly reduced canopy temperature, cowpea growth parameters, yield and yield components while it increased soil moisture and maize growth and yield attributes in maize-cowpea intercropping system.

10.3 Recommendations

There is need to:

1. Promote drought tolerant varieties such as Nyekundu, KVU 27-1, M66, and KVU 419.
2. Integrate participatory variety selection in cowpea breeding to take into account farmers' knowledge and preferences.
3. Evaluate the compatibility of drought tolerant, high yielding cowpea varieties with locally adapted maize genotypes.
4. Source insect pest resistant cowpea germplasm so as to improve insect pest resistance in the Kenya grown cowpea varieties.
5. Integrate crop residues; apply farmyard manure and N-fertilizer in maize-cowpea cropping system to enhance their productivity.
6. Study to study nutrient use dynamics in maize-cowpea intercrop systems under various crop residue and fertilizer management options.

REFERENCES

Abayomi, Y.A. and Abidoye, T.O. 2009. Evaluation of cowpea genotypes for soil moisture stress tolerance under screen house conditions. *African Journal of Plant Science* 3 (10): 229-237.

Abayomi, Y.A. and Jatto, F.D.A. 1998. Performance of intercropped maize (Zea mays L) and cowpea (Vigna unguiculata) as affected by maize architecture and nitrogen fertilizer application. *Bioscience Research Communication*. 10 (3): 185 – 196.

Abdelshakoor, H. S. and Faisal E.A. 2010. Effects of water potentials on growth and yield of cowpea (*Vigna unguiculata* (L.) Walp). *Research Journal of Agriculture and Biological Science*. 6 (4): 401 – 410.

Abebe, G., Hattar, B. and Al-Tawaha, A.R.M. 2005. Nutrient availability as affected by manure application to cowpea (*Vigna unguiculata* L. Walp) on calcareous soils. *Journal of Agriculture and Social Sciences* 1 (10): 1 – 6.

Abidoye T.O 2004. Effects of soil moisture content on growth and yield of cowpea (Vigna unguiculata (L) Walp). B. Agric. Dissertation, University of Ilorin, Nigeria.

Abudulai, M. and Shepard, B.M. 2001**.** Timing insecticide sprays for control of pod-sucking bugs (Pentatomidae, Coreidae, and Alydidae) in cowpea, (*Vigna unguiculata* [L.] Walpers). *Journal of Agriculture and Urban Entomology* 18: 51–60.

Achieng, J.O., Ouma, G., Odhiambo, G. and Muyekho, F. 2010. Effect of farmyard manure and inorganic fertilizers on maize production on alfisols and ultisols in Kakamega, western Kenya. *Agriculture and Biology Journal of Nourth America* 1: 430–439

Adediran, J.A. and Banjoko, V.A. 1995. Response of maize to N, P, and K fertilizers in the savanna zone of Nigeria. *Communications in Soil Science and Plant Analysis* 26: 593 - 606.

Adeoye, P.A., Adebayo, S.E., Musa, J.J. 2011. Growth and yield response of cowpea (*Vigna unguiculata*) to poultry and cattle manure as amendments on a sandy loam soil plot. *Agriculture Journal* 6 (5): 218 - 221.

Adeyemo, A.J. and Agele, A.O. 2010. Effects of tillage and manure application on soil physicochemical properties and yield of maize grown on degraded intensively tilled alfisol in South-Western Nigeria. *Journal of Science and Environmental Management* 1 (8): 205 – 216.

Adcock, D., McNeill, A.M., McDonald, G.K and Armstrong, R.D. 2006. Subsoil constraints to crop production on neutral and alkaline soils in South Eastern Australia: A review of current knowledge and management strategies. *Australian Journal of Experimental Agriculture* 47 (11): 1245 – 1261.

Adu-Dapaah, H.K., Asibuo, J.Y., Danquah, O.A., Asumadu, H., Haleegoah, J. and Asafo-Adjei, B. 2007. Farmer participation in groundnut varietal selection. African Crop Science Conference Proceedings. 8: 1435 – 1439.

Adu-Dapaah, H.K., Asibuo J.Y., Danquah O.A., Asumadu H., Haleegoah J. and Asafo-Adjei B. 2004. Farmer participation in groundnut rosette resistant varietal selection in Ghana. In: Fisher et al., (Eds). New direction for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26th September – 1st October 2004.

Adu-Gyamfi, J.J, Myaka, F.A, Sakala, W.D., Odgaard, R., Vesterager, J.M. and Høgh-Jensen (2007) Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize–pigeonpea in semi-arid southern and eastern Africa. *Plant and Soil* 295: 127 - 136.

Agbogidi, O.M. 2010. Grain yield and yield components of maize (Zea mays L) as affected by crude oil in soil. *Journal of Plant Breeding and Crop Science* 2 (6): 148 – 151.

Ahmed, F. E., Hall, A.E. and DeMason, D.A. 1992. Heat injury during floral bud development in cowpea (*Vigna unguiculata* (L.) Walp). *American Journal Botany* 79: 784 – 791.

Ahmed, F.E. and Suliman, A.S. 2010. Effects of water stress applied at different stages of growth on seed yield and water use efficiency of cowpeas. *Agriculture and biology Journal of North America* 1 (4): 534 - 540

Ahmed, A., Sambo, B. E., Arunah, U. L. and Odion, E. C. 2014. Response of farmyard manure and inorganic Fertilizers for sustainable growth of carrot (*Daucus carota* L.) in Northern Nigeria. *Journal of Agriculture and Veterinary Science* 7 (2): 18-25

Akmal, M., Ur-Rehman, H., Farhatullah, M. A. and Akbar, H. 2010. Response of maize varieties to nitrogen application for leaf area profile, crop growth, yield and yield components. *Pakistan Journal of Botany* 42 (3): 1941-1947.

Akyeampong, E. 1985. Seed yield and water use efficiency of cowpea in response to drought stress at different development stages. Ph.D Thesis, Connell University.

Alabi, O.Y., Odebiyi, J.A., and Jackai, L.A.N., 2003. Field evaluation of cowpeas cultivars (*Vigna unguiculata* (L.) Walp) for resistance of flower bud thrips (*Megalrothrips sjostedti* Tyborn) Thysanoptera: Thripidae. *International Journal of Pest Management* 49 (4): 287 – 291.

Alika, J.K. and Emede, T.O. 2005. Evaluation of S2 Maize in soil nutrient and non-nutrient stress environment for agronomic traits and estimates of genetic parameters. *African Crop Science Conference Proceedings* 7: 219 – 223.

Almeida, W.S., Fernandes F.R.B., Teofilo, E.M. and Bertini, C.H.C.M. 2014. Correlation and path analysis in components of grain yield of cowpea genotypes. *Revista Ciencia Agronomica* 45 (2): 726 – 736.

Almekinders, C.J.M., Louwaars, N.P. and de Bruijn, G.H. 1994. Local seed systems and their importance for an improved seed supply in developing countries. *Euphytica* 78: 207 - 216.

Altieri, M.A. and Liebman, M. 1988. Weed seed population response to tillage and herbicide use in three irrigation cropping sequences. *Weed Science* 38: 511 – 517.

Amanullah, K., Khan, A.Z., Jan, A., Shah, Z., Ahmad, B., Khalil, S.K., Ali, A., Hidayatullah, Ahmad, F. and Nawaz, A. 2013. Foliar application of nitrogen at different growth stages influences the phenology, growth and yield of maize (Zea mays L.). *Soil Environment* 32 (2): 135-140,

Amanullah, K., Marwat, B., Shah, P., Maula, N. and Arifullah, S. 2009. Nitrogen levels and its time of application influence leaf area, height and biomass of maize planted at low and high density. *Pakistan Journal of Botany*. 41: 761-768.

Amatobi, C. I. 1994. Field evaluation of some insecticides for the control of insect pests of cowpea (Vigna unguiculata (L) Walp.) in the Sudano savannah of Nigeria. *Interntional Journal of Pest Management* 40 (1): 13 – 17.

Amini, R., Shamayeli, M., Mohammadinasab, A.D Sanam Ghanepour, S. and Alavi-Kia, S. 2013. Relative yield total of two- and three-species intercropping of soybean, maize and sunflower. *International Journal of Agriculture and Crop Sciences* 5 (11): 1260 - 1264.

Amujoyegbe, B.J. and Elemo, K.A. 2013. Growth performance of maize/cowpea in intercrop as influenced by time of introducing cowpea and nitrogen fertilizer. *International Research Journal of Plant Sciences* 4 (1): 1 – 11.

Anil, L, Park, J., Philips, R.H. and Miller, F.A. 1998. Temperate intercropping of cereals for forage: a review of the potential for growth and utilization with particular reference to UK. Grass Forage Science. 53: 301-317.

Anyia, A.O. and Herzog, H. 2004. Water use efficiency, leaf area and leaf gas exchange of cowpeas under mid-season drought. *European Journal of Agronomy* 20, 327 – 437.

Asante, S.K., Tamo, M. and Jackai, L.E.N. 2001. Integrated management of cowpea insect pests using elite cultivars, date of planting and minimum insecticide application. *African Crop Science Journal.* 9 (4): 655 – 665.

Asiwe, J.A.N. 2009. The impact of phosphate fertilizer as a pest management tactic in four cowpea varieties. *African Journal of Biotechnology 8: 1684 - 5315*

Awad, A.M, Tartoura, E.A., Elfouly, H.M. and Fattah, A.I. 2002. Response of potato growth, yield and quality to farmyard manure sulphur and gypsum levels application. 2nd Int. Conference of Horticultural Science, 10-12 Sept. Kafr El-Sheikh, Tanta University, Egypt, 24-39.

Ayeni, A.O. 1992. Weed management in crop production in Nigeria. In Aigelari, E. A., Lucas, E. O., Obatan, M.O. and Akinboade, A. O (eds). Fundamental of Agriculture 56 – 63.

Ayoola, O.T. and Makinde, E.A. 2007. Complementary organic and inorganic fertilizer application: Influence on growth and yield of cassava/maize/melon intercrop with a relayed cowpea. *Austrailian Journal of Basic and Applied Science* 1 (3): 187 – 192.

Baidoo, P.K and Mochiah, M.B. 2014. Varietal Susceptibility of Improved Cowpea *Vigna unguiculata* (L.) (Walp.) cultivars to field and storage pests. *Sustainable Agriculture Research* 3 (2): 69 – 76.

Banik, P., Midya, A., Sarkar, B.K., and Ghose, S.S. 2006. Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. *European Journal of Agronomy* 24: 325 - 332.

Baumann, D.T., Kropf, M.J. and Bastiaans, L. 2000. Intercropping leeks to suppress weeds. *Weed Research* 40: 361–376.

Beets, W.C. 1990. Raising and sustaining productivity of smallholder farming systems in the tropics. A Handbook of Sustainable Agricultural Development, AgBé Publishing. Alkmaar. Holland. 756.

Belel, M.D., Halim R.A., Rafii M.Y and Saud H.M. 2014. Intercropping of corn with selected legumes for improved forage production: a review. *Journal of Agricultural Science* 6 (3): 48 – 62.

Benbi, D.K., Biswas, C.R., Bawa, S.S. and Kumar, K. 1998. Influence of farmyard manure, inorganic fertilizers and weed control practices on some soil physical properties in a long - term experiment. *Soil Use and Management* 14:52 - 54

Bhatnagar, V.S. and Davies, J.C. 1981. Entomological studies in intercropping pigeon pea systems at ICRISAT Center: Future developments and collaborative research needs. In: Procedings of international Workshop on Pigeon peas. 2: 15 – 19. December 1980, ICRISAT Center, India, Patancheru, A. P. India: ICRISAT, pp. 415 – 426.

Blaser, B.C. 2009. Quantifying and predicting interseeded legume establishment in winter cereals. PhD Thesis. Iowa State University. Ames, Iowa.

Boart Longyear CPN, 1995. CPN 503 DR Hydroprobe Neutron Moisture Gauge, Operating Manual. Boart Longyear CPN; Martinez CA USA. pp50

Bocchi, S. and F. Tano. 1994. Effects of cattle manure and components of pig slurry on maize growth and production. *European Journal of Agronomy* 3 (3): 235 - 241.

Bonato, O. and Ridray, G. 2007. Effect of tomato deleafing on mirids, the natural predators of whiteflies. *Agronomy and Sustainable Development* 27: 167 – 170.

Booker, A. 2010. The Maize Subsector in Kenya: Mending the Granary. Heinrich Boll Stiftung East and Horn of Africa, Page 1 – 15.

Boomsma, C.R., Santini, J.B. Tollenaar, M. Vyn, T.J. 2009 – Maize morphophysiological response to intense crowing and low nitrogen availability: an analysis and review. *Agronomy Journal*. 101: 1426-1452.

Bottenberg, H. 1995. Farmers' perceptions of crop pests and pest control practices in rainfed cowpea cropping systems in Kano, Nigeria. *International Journal of Pest Management* 41: 195 - 200.

Bouman, B.A.M., Humphreys, E., Tuong, T.P. and Barker, R. 2007. Rice and water. *Advances in Agronomy* 92: 187 – 237.

Bressani, R. 1985. Nutritive value of cowpea. In: Singh S. R. and Rachie K. O. (Eds). Cowpea research, production, and utilization, Willey and Sons, Chester, UK. 353 360.

Cardoso, E.J.B.N., Nogueira, M.A. and Ferraz, S.M.G. 2007. Biological N_2 fixation and mineral N in common bean–maize intercropping or sole cropping in southeastern Brazil. *Exploratory Agriculture* 43: 319–330.

Carsky, J.R., Hayashi, Y., Tian, G. 1998. Benefits of mulching in the sub humid savanna zone: research needs and technology targeting. Draft Resource and Crop Management Research Monograph. IITA, Ibadan, Nigeria.

Carsky, R.J., Singh, B B. and Oyewole, B. 2001. Contribution of early season cowpea to late season maize in the savannah zone of West Africa. *Biological Agriculture and Horticulture* 18: 303 - 315.

Cassman, K.G., 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Science* U.S.A 96: 5952 – 5959.

Castiglioni, P., Warner, D., Bensen, R.J., Anstron, D.C., Harrison, J., Stoecker, M., Abad, M., Kumar, G., Salvador, S., D'Ordine, R., Navarro, S., Back, S., Fernandes, M., Targalli, J., Dasgupta, S., Bonin, C., Luethy, M.H. and Heard, J.E. 2008. Bacterial RNA Chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water limited conditions. *Plant Physiology* 147 (2): 446 – 455.

Cattivelli, L., Rizza, F., Badeck, F.W., Mazzucotelli, E., Mastrangelo, A.M., Francia, E., Mare, C., Tondelli, A. and Stanca, A.M. 2008. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. *Field Crops Research* 105 (1-2): 1 – 14.

Ceyhan, E. and Aliavci, M. 2005. Combining ability and heterosis for grain yield and some yield components in peas (*Pisum sativum* L.). *Pakistan Journal of Biological Science* 8 (10): 1447 – 1452.

Chambers, R. 1983. Rural Development: Putting the Last First. Longman, Essex.

Chaves, M.M., Flexas, J., Pinheiro, C. 2009. Photosynthetic under drought and salt stress; regulation mechanisms from whole plant to cell. *Annals of Botany* 103: 551 – 560.

Chemining'wa, G.N. and Nyabundi, J.O. 1994. Effect of proximity between intercropped maize and beans on growth and yield of maize under varying nitrogen levels. *East African Agricultural and Forestry Journal* 9: 269 - 279.

Chemining'wa, G.N., Muthoni, J.W. and Obudho, E.O. 2004. Effect of rhizobia inoculation and urea application on nodulation and dry matter accumulation of green manure legume at Katumani and Kabete sites of Kenya. Legume Research Network Project Newsletter Issue 11: 12 – 18.

Chibuike, S.U. and Parker, E.J. 2010. Comparative effect of "pestox" powdered insecticide on both serum aspartate aminotransferase and alanine aminotransferase of male and female albino rats. *Research Journal of Pharmacology and Pharmacodynamics* 2 (4): 309 – 313.

Chirwa, P.W., Ong, C.K., Maghembe, J. and Black, C.R. 2007. Soil water dynamics in cropping systems containing *Gliricidia sepium*, pigeonpea and maize in Southern Malawi. *Agroforestry Systems* 69: 29 – 43.

Choudhary, V.K., Suresh, K.P., and Bhagawati, R. 2012. Production potential, soil moisture and temperature as influenced by maize-legume intercropping. *International Journal of Science and Nature* 3 (1): 41 – 46.

Chupora, V.V. 1995. Effect of green manuring crops on intensity of production-destruction processes in agro-ecosystems of Central Siberia. *Agrokhimiya* Journal 2: 152 – 155.

Cisse N, Ndiaye M, Thiaw S, Hall A.E 1995. Registration of "Mouride" cowpea. *Crop Science* 35: 1215 – 1216.

Connor, D.J., Loomis, R.S. and Cassman, K.G. 2011. Crop ecology: productive and management in agricultural systems. University Press Cambridge.

CTIC, 2000. CTIC National Crop Residue Management Survey West Lafayette. IN. USA.

Dadson, R.B., Hashem, F.M., Javaid, I., Joshi, J., Allen, A.L. and Devine, T.E. 2005. Effects of water stress on the yield of cowpea (Vigna unguiculata (L.) Walp) genotypes in the Delmarva Region of the United States. *Journal of Agronomy and Crop Science* 191: 210 – 217.

Dahmardeh, D., Ghanbari, A., Syahsar, B.A., and Ramrodi, M. 2010. The role of intercropping maize (*Zea mays* L.) and Cowpea (*Vigna unguiculata* L.) on yield and soil chemical properties. *African Journal of Agricultural Research* 5 (8): 631 – 636.

Denevan W.M., 1995. Prehistoric Agricultural methods as models for sustainability. *Advanced Plant Pathology* 11: 21 – 43.

Dorward, A., Sabates-Wheeler, R., MacAuslan, I., Buckley, C. P., Kydd, J. and Chirwa, E. 2006. Promoting agriculture for social protection or social protection for agriculture: strategic policy and research issues. FAC Discussion Paper, Brighton, UK: *Future Agricultures Consortium.*

Dreyer, H., Baumgartner, J. and Tamo, M. 1994. Seed damaging field pests of cowpea (*Vigna unguiculata* (L) Walp) in Benin: Occurance and pest status. *International Journal of Pest Management* 40: 252 – 260.

Duflo, E., Kremer, M. and Robinson, J. 2008. Psychology and development: Theory and experimental experience. How high are rates of return to fertilizer? Evidence from field experience in Kenya. *American Economic Review: Paper proceedings* 98 (2): 482 – 488.

Dusa, E.M. and Stan, V. 2013. The Effects of intercropping on crop productivity and yield quality of oats (*Avena sativa* L.)/Grain leguminous species Peas (*Pissum sativa* L.) and Lentil (*Lens culinaris* L) cultivated in pure stand and mixtures in the organic agriculture system. *European Scientific Journal* 9 (21): 69 – 78.

Dzemo, W.D., Niba, A. S. and Asiwe, J.A.N. 2010. Effects of insecticide spray application on insect pest infestation and yield of cowpea (*Vigna unguiculata* (L.) Walp.) in the Transkei, South Africa. *African Journal of Biotechnology* 9 (11): 1673 – 1679.

Eakin, H. and Wehbe, M. 2009. Linking local vulnerability to system sustainability in a resilience framework: Two cases from Latin America. *Climatic Change 9* (3-4): 355 - 377.

Egbe, M.O., Alhassan G.A. and Ijoyah M. 2013. Nodulation nitrogen yield and fixation by Bambara groundnut (*Vigna subterranean* (L) Verdc.) landraces intercropped with cowpea and maize in Southern Guinea Savanna of Nigeria. *Agricultural Science* 1 (4): 15 – 28.

Egho, E.O. 2010. Management of major field insect pests and yield of cowpea (*Vigna unguiculata* (L) Walp) under calendar and monitored application of synthetic chemicals in Asaba, Southern Nigeria. *African Journal of General Agriculture* 6 (3): 177 – 186.

Egho, E. O. Enujeke, E. C. 2012. Effect of Native Soap on Insect Pests and Grain Yield of Cowpea (Vigna unguiculata (L) Walp) in Asaba and Abraka during the Late Cropping Season in Delta State, Nigeria. *Sustainable Agriculture Research*, 1 (2): 87 – 95.

Ekesi, S. 1999. Insecticide resistance in field populations of the legume pod-borer, *Maruca vitrata Fabricius* (*Lepidoptera: Pyralidae*), on cowpea, (*Vigna unguiculata* (L.) Walp) in Nigeria. *International Journal of Pest Management* 45: 57-59.

Elbashier, E.M.E., Tahir, I.S.A., Saad, A.S.I. and Ibrahim, M.A.S. 2012. Wheat genotypic variability in utilizing nitrogen fertilizer for a cooler canopy under a heat-stressed irrigated environment. *African Journal of Agricultural Research* 7 (3): 385 – 392.

Erenstein, O. 1999. Conservation farming and small-scale farmers: lessons and opportunities for mulching with crop residues and cover crops. Consultancy Report Rural Development Department of World Bank. Washington. DC.

Erenstein, O. 2002. Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil and Tillage Research* 67: 115 – 133.

Eskandari, H. 2012. Intercropping of maize (*Zea mays* L.) with cowpea (*Vigna sinensis*) and mung bean (*Vigna radiate*): Effects of complementarity of intercrop components on resources consumption, dry matter production and legume forage quality. *Journal of Basic and Applied Science Research* 2 (1): 355 – 360.

Eskandari, H. and Kazemi, K. 2011. Weed control in maize-cowpea intercropping system related to environmental resources consumption. *Notulae Scientia Biologicae* 3 (1): 57 - 60.

Farahani, H. J., G. A. Peterson, D. G. Westfall, L. A. Sherrod, and L. R. Ahuja. 1998. Soil water storage in dryland cropping systems: The significance of cropping intensification. *Soil Science Society of America Journal* 62 (4): 984 - 991.

Falster, D.S and Westoby, M. 2003. Plant height and evolutionary games. *Trends in Ecology and Evolution* 18: 337 – 343.

Fertilizer Use Recommendation Project (FURP). 1994. Fertilizer use recommendations. Volume 1. Coastal Districts. Kilifi, Kwale, Lamu. Kenya Agricultural Research Institute.

Filho, J.M.P.L. 2000. Physiological responses of maize and cowpea to intercropping. *Pesquisa Agropecuaria Brasileira* 35 (5): 915 - 921

Fisher, N.M., Raheja, A.K. and Elemo, K.A. 1987. Insect pests control for cowpeas in crop mixtures. *Experimental Agriculture* 2: 7–20

Foley, S. 2009. Growing resillence: adapting for climate change in upland Laos main report. A report prepared for Norwegian Church Limited Laos. Eco Asian Limited.

Francis, C.A. 1994. Increasing the sustained production from multiple cropping systems. *African Crop Science Conference Proceedings* 1: 14-18.

Franworth, C.R. and Jiggins, J. 2003. Participatory plant breeding and gender analysis. CGIAR Systemwide program on participatory research and gender analysis (PRGA Program), Cali, Colombia. 116 p. (PPB Monograph No. 4).

Fukai, S., Tsay, J.S. Wilson, G.I., Cenpukdee, U. and Grady, D.P.S. 1980. Cassava legume intercropping in the subtropics. *In the Proceeding 8th Symposium for Tropical Root Crops ISTRC, Bangkok Thailand*. pp: 203-209.

Fussel, L.K., Bidinger, F.R. and Bieler, P. 1991. Crop physiology and breeding for drought tolerance: Research and development. *Field Crops Research* 27: 183 – 199.

Gachene, C.C.K. and Makau, M. 2000. Screening legume cover crops for dry season survival in a semi arid environment of Kenya. Paper presented at the soil management and legume research proceedings at Kanamai on 24th – 26th March 1997.

Gacheru, E.N., G.M. Kamau, H.M. Saha, G.D. Odhiambo, and M.K. O'Neill. 1993. Effect of land preparation and weeding on maize grain yields in the coastal region of Kenya. *International Journal of Pest Management* 39 (1): 57 - 60.

Gaiser, T. and Graef, F. 2001. Optimization of a parametric land evaluation method for cowpea and pearl millet production in semi-arid regions. *Agronomic* 21: 705 – 712.

Gan, Y.T ., Jayakumar P.1., Symons, S. and McDonald, C.L. 2008. Synergic effect of N and moisture on biochemical property of nodules and seed yield in chickpea. *Australian Journal of Crop Science Southern Cross Journals* 1 (1):11-22.

Gao, Y., Duana, A. Qiua, X., Liua, Z., Suna, J., Zhanga, J. and Wanga, H. 2010. Distribution of roots and root length density in a maize/soybean strip intercropping system. *Agricultural Water Management 98*: 199–212

Gethi, J.G. 2002. Screening for common weevil resistance in single cross maize hybrids in Kenya. Proceedings of the 8th Biennial Scientific Conference. KARI Headquarters. Nairobi. Kenya.

Ghanbari-Bonjar, A. 2000. Intercropped wheat and bean as a low-input forage. PhD thesis. Wye College. Univ. London.

Ghanbari, A., Dahmardeh, M.., Siahsar, B.A. and Ramroudi, M. 2010. Effect of maize (*Zea mays* L.) - cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. *Journal of Food, Agriculture & Environment* 8 (1): 1 0 2 - 1 0 8

Ghosh, P.K., Manna, M.C., Bandyopadhyay, K.K., Ajay, A.K., Tripathi, R.H., Wanjari, K.M., Hati, A.K., Misra Charya, CL., and Subba Rao, A. 2006. Interspecific interaction and nutrient use in soybean/sorghum intercropping system *Agronomy Journal* 98: 1097 – 1108.

Giller K.E 2001. Nitrogen fixation in Tropical Cropping Systems. CAB International Wallingford (Oxford) 8DE UK.

Girma, A, Teshale A, Hussein H, Tewodrose M and Abdel-Rehman M.A. 2005. Participatory selection of drought tolerant maize varieties using mother and baby methodology: A case in the semi arid zones of the central Rift Valley of Ethiopia. *World Journal of Agricultural Sciences* 1 (1): 22 – 27.

Gobeze, L., Legese, H. and Markos, D. 2005. Screening of inter and intra row spacing on yield and yield components of cassava in moisture stress. *African Crop Science Conference Proceedings* 7: 147 - 150**.**

Gomez, A.A and Gomez, K.A. 1983. Multiple cropping in the Humid Tropics of Asia. IDRC 176 E, IDRC, Ottawa.

Gomez, J.K.O., Silva, P.S.L., Silva, K.M.B., Rodriges, Filho, F.F., Santos, V.G. 2007. Effects of weed control through cowpea intercropping on maize morphology and yield. *Planta Daninha Vicoasa* 25(3): 433 - 441

Graham, P.H. and Vance, C.P. 2000. Nitrogen fixation in perspective: an overview of research and extension needs. *Field Crops Research* 65 (1): 93 – 106.

Grisley, W. 1997. Crop – Pest yield loss: a diagnostic study in Kenya – highlands. *International Journal of pest management* 43 (2): 137 – 142.

Gulmaraes, A.A., Jaramillo, P.M.D., Nobrega, R.S.A., Florentino, L.A., Silva, K.B. and de Souza Moreira, F.M. 2012. Genetic and symbiotic diversity of nitrogen fixing bacteria isolated from agricultural soils in Western Amazon by using cowpea as the trap plant. *Applied and Environmental Microbiology*. 78(18): 6726 – 6733.

Guoth, A., Tari, I., Galle, A., Csiszar, j., Pecsvaradi, A. and Cseuz, L, 2008. Comparison of the drought stress responses of tolerant and sensitive wheat cultivars during grain filling: changes in flag leaf photosynthetic activity, IABA levels and grain yield. *Journal of Plant Growth Regulation* 28 (2): 167-176.

Hagan, D.L., Jose, S., Thetford, M. and Bohn, K. 2010. Partitioning of applied ^{15}N fertilizer in a long leaf pine and native wood ornamental intercropping system. *Agroforestry Systems* 79: 47 – 57.

Haines, C.P., 1991. Insect and arachnids of Tropical stored products: Their Biology and Identification. Crown, Chatham, Kent, UK., pp 246.

Hall, A. E., Cisse, N., Thiaw, S., Ismail, A.M., and Ehlers, J.D. 1997. Water use efficiency and drought adaptations of cowpea. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research, pp. 87 – 98. Co- publication of International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Center for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Halleegoah, J., Adu-Dapaah, H.K and Danquah, O.A. 2005. Farmers preferences for Bambara groundnut ideotype in two districts in the forest savannah transition zone of Ghana. *Ghana Journal of Horticulture* 4: 82 – 92.

Hamidou, F., Zombre, G. and Braconnier, S. 2007. Physiological and biochemical responses of cowpea genotypes to water stress under glasshouse and field conditions. *Journal of Agronomy and Crop Science* 193: 229 - 237

Hati, K., Mandal, K., Misra, A., Ghosh, P. and Bandyopadhyay, K. 2006. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in vertisols of Central India. *Bioresource Technology* 97 (16): 2182-2188.

Hauggard-Nielson, H., Ambu, P. and Jensen, E.S. 2001. Evaluating pea and barley cultivars for complementary in intercropping at different levels of soil N availability. *Field Crops Research.* 72: 185-196.

Hauggaard-Nielsen, H., Andersen, M.K., Jorsgaard, B. and Jensen, E.S. 2006. Density and relative frequency effects on competitive interactions and resource use in pea-barley intercrops. *Field Crops Research* 95, 256–267.

Hayatu, M. and Mukhtar, F.B. 2010. Physiological responses of some drought resistant cowpea genotypes (*Vigna Unguiculata* (L.) Walp) to water stress. *Bayero Journal of Pure and Applied Sciences* 3(2): 69 - 75

Heisey, P.W., and Edmeades, G.O. 1999. Maize production in drought stressed Environment: Technical Options and Resource Allocation. Part 1 of CIMMYT 1997/1998 World Facts and Trends; Maize production in Drought-Stressed.

Howeler, R.H., Ezumah, H.C., Midmore, D J. 1993. Tillage systems for root and tuber crops in the tropics. *Soil Tillage Research* 27: 211 – 240.

Hsiao, T.C. and Xu, L.K 2000. Sensitive of growth of roots versus leaves to water stress: biophysical anslysis and relation to water transport. *Journal of Experimental Botany* 51: 1595 – 1616.

Hudgens, R.E. 1996. Sustaining soil fertility in Africa: The potential for legume green manures. A paper presented at the 15th Conference of the Soil Science Society of East Africa, held at Sportsman Arms Hotel, Nanyuki, Kenya. August 19-23, 1996.

Huho, J.M., Ngaira, J.K.W. and Ogindo, H.O. 2009. Climate change and pastoral economy in Kenya: A blinking future. *Acta Geologica Sinica* 83 (5): 1017–1023.

Ibrahim, U., Auwalu B. M and Udom G. N. 2010. Effect of stage and intensity of defoliation on the performance of vegetable cowpea (*Vigna unguiculata* (L.) Walp). *African Journal of Agricultural Research* 5 (18): 2446-2451

Ibewiro, B., Onuh, M., Sanginga, N., Bernard, V. and Merckx, R. 2001. Symbiotic performance of herbaceous legumes in tropical cover cropping systems. *Scientific World Journal* 2: 17 - 21.

Iderawumi, A.M. 2014. Effects of cowpea on growth and yield parameter in a maize-cowpea intercrop. *Journal of Management and Science* 4 (1): 37 - 42

Idoko, J.E. and Adesina, J.M. 2012. Infestation levels of *Callosopruchus maculatus* on cowpea using different particles sizes of Eugenia aromatic and piger guineense powder. World Journal of Engineering and pure and applied Sciences 2(5): 156 – 160.

Irshad, M., Yamamoto, S., Eneji, A. E., Endo, T. and Honna, T. 2002. Urea and manure 8effects on growth and mineral contents of maize under saline conditions. *Journal of Plant Nutrition* 25 (1): 189 – 200.

Isubikalu, P., Erbaugh, J.M, Semana, and A.R, Adipala, E. 2000. The influence of farmer's perception on pesticide usage for management of cowpea field pests in Eastern Uganda. *African Crop Science Journal* 8 (3): 317 – 325.

Jackai, L.E.N. 1995. Integrated pest management of borers of cowpea and beans. *Insect Science and Its Application* 16: 237 – 250.

Jackai, L.E.N and Adalla C.B. 1997. Pest management practices in cowpea: A review In: Singh B. B, Mohan Raj D. R, Danshiel K. E and Jackai L. E. N (eds.) Advances in cowpea Research. International Institute of Tropical Agriculture (IITA) and Japan International Research Centre for Agricultural Sciences (JIRCAS), IITA, Ibadan, Nigeria.

Jackai, L.E.N. and Daoust, R.A. 1986. Insect pests of cowpeas. *Annual Review of Entomology* 31: 96 – 119.

Jackai, L.E.N, and Signh, S.R. 1983. Varietal resistance in the integrated pest management of cowpea pests. *Insect Science and Application* 4: 199 – 204.

Jackai, L.E.N. Goudou, C., Asiwe, J.A.N. and Tayo, B.O. 2001. Integrated control of the cowpea aphid using seed dressing and varietal resistance. *Samaru Journal of Agricultural Research* 17: 13 – 23.

Jackai, L.E.N., Singh, S.R., Raheja, A.K. and Wiedijk, K. 1985. Recent trends in the control of cowpea pests in Africa. In: Cowpea Research, Production and Utilization. Singh, S.R. and Rachie, K.O. (Eds.), 233 – 243. Chickester, John Wiley and Sons, U.K.

Jaetzold, R., Schmidt, H., Hornetz, B and Shisanya, C. 2012. Farm Management handbook of Kenya. Vol. II/ Part C, Sub-Part C2, Coast Province. Ministry of Agriculture, Kenya, in corporation with the German Agency of International Cooperation (GIZ).

Janiya, J.D. and Mood, K. 1989. Weed population in transplanted and wet-seeded rice as affected by weed control methods. *Tropical pest Management* 38: 8 – 11.

Jones, H.G., Serraj, R., Loveys, B.R., Xiong, L., Wheaton, A. and Price, A.H. 2009. Thermal infrared imaging of crop canopies for the remote diagnosis and quantification of plant responses to water stress in the field. *Functional Plant Biology* 36: 978–989.

Kabeh, J.D and Lale, N.E.S. 2008. Role of host plant resistance and intercropping in reducing field infestation of cowpea (*Vigna unguiculata* (L) Walp) by bruchids in the Nigerian Sudan Savanna. *Academic Journal of Entomology* 1 (1): 12 – 18.

Kamara, A., Defoer and de Groote, H, 1996. Selection of new varieties through participatory research, use of corn in South Mali, *Tropicultura* 14: 100 – 105.

Kamara, A.Y., Chikoye, D., Omoigui, L.O. and Dugje, I.Y. 2007. Cultivar and insecticide spraying regimes effects on insect pests and grain yield of cowpea in the dry savannah of north-eastern Nigeria. *African Crop Science Conference Proceedings* 8: 179 – 184.

Karasu, A. 2012. Effect of nitrogen levels on grain yield and some attributes of some hybrid maize cultivars (*Zea mays* indentata Sturt.) grown for silage as second crop. *Bulgarian Journal of Agricultural Science* 18 (1): 42 - 48.

Kariaga, B.M. 2004. Intercropping maize with cowpea and beans for soil and water management in Western Kenya. 13th International Soil Conservation Organization Conference. Conserving soil and water for society: Sharing solutions. Brisbane. July 2004.

Karuku, G.N., Gachene, C.K.K., Karanja, N., Cornelis, W. and Verplacke, H. 2014. Effects of different cover crop residue management practices on soil moisture content under a tomato crop (*Lycopersicon esculentum*). *Tropical and Subtropical Agroecosystems* 17 (3): 509 – 523.

Karungi, I., Adipala, E., Ogenga-Latigo, M.W., Kyamanywa, S and Oyobo, N. 2000. Pest management in cowpea. Part 1. Influence of planting time and planting density on cowpea field pests infestation in eastern Uganda. *Crop Protection* 19: 231–236.

Katsaraware, R.D. and Manyanhaire, I.O. 2009. Maize-cowpea intercropping in leaf stripped and detasselled maize in Zimbabwe. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 8 (11): 1218 – 1226.

Kenya Agricultural Research Institute (KARI) (1994). Fertilizer use recommendations. Vol. 1-22. Fertilizer Use Recommendation Project. Kenya Agricultural Research Institute, Nairobi, Kenya.

Khan, M., Abid, A.M., Hussain, N. and Masood, M.U. 2005. Effects of phosphorous levels on growth and yield of maize cultivar under saline conditions. *International Journal of Agriculture and Biology* 6 (3): 511 – 514.

Kiari, S., Ajeigbe, H.A., Omae, H., Tobita, S. and Singh, B.B. 2011. Potentials of cowpea (*Vigna unguiculata*) for dry season seed and fodder production in Sahelian sandy soils of Nigeria. *American-Eurasian Journal of Agricultural and Environmental Sciences* 11 (1): 71 – 78.

Kinama, J.M., 1997. The effects of hedgerows (alley cropping) on microclimate, soil and water conservation and competition for sustainable land use on the sloping areas of Machakos, Kenya. PhD thesis, University of Nairobi, Kenya.

Kinama J.M, Stigter C.J, Ong C.K, Ng‟ang‟a J.K, Gichuki F.N (2005) Evaporation from soils 586 below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agricultural and Forestry Meteorology. 130:149-162

Kinama J.M., Stigter C.K., Ng'ang'a J.K. and Gichuki F.K. 2007. Contour hedgerows and grass strips in erosion and runoff control on slopping land in semi-arid Kenya. *Arid Land Research and Management.* 21:1 - 19

Klocke, N. L., D. G. Watts, J. P. Schneekloth, D. R. Davison, R. W. Todd, and A. M. Parkhurst. 1999. Nitrate leaching in irrigated corn and soybean in a semi-arid climate. *Transactions of the ASAE* 42(6): 1621-1630.

Kombiok, J.M., Safo E.Y., and Quansah C. 2005. Yield and nitrogen fixation of cowpea as affected by tillage and cropping system in Northern Savanna zone of Ghana. *West African Journal of Applied Ecology* 7: 95 – 108.

Kouyate, Z., Franzluebbers, K., Juo, A.S.R. and Hossner, L. 2000. Tillage, crop residues, legume rotation, and green manure effects on sorghum and millet yields in the Semi-arid Tropics of Mali. *Plant and Soil* 225: 141-151

Kurata, T., 1986. A study on farming system in USSA. Quarterly Journal of Agronomy and Ecology 26: 179-205.

Lale, N.E.S and Sastawa, B.M. 2000. Evaluation of host plant resistance, sowing date modification and intercropping as methods for the control of *Mylabris* and *Coryna* species (Coleoptera: Meloidae) infesting pearl millet in the Nigerian Savanna. *Journal of Arid Environment* 46: 263 – 280.

Lemlem, A. 2013. The effect of intercropping maize with cowpea and lablab on crop yield. *Herald Journal of Agriculture and Food Science Research* 2 (5): 156 – 170.

Li, L., Sun, J.H, Zhang, F.S., Li, X.L., Yang, S.C. and Rengel, Z. 2006. Wheat/maize or wheat/soybean strip intercropping I. Yield advantage and inter-specific interactions on nutrients. *Field Crop Research* 71: 123-137.

Li, F., Yu, J., Nong, M., Kang, S. and Zhang, J. 2010. Partial root-zone irrigation enhanced soil enzyme activities and water use of maize under different ratios of inorganic to organic nitrogen fertilizers. *Agriculture and Water Management* 97 (2): 231-239.

Lisar, S.Y.S., Motafakkerazad, R., Hossain, M.M and Rahman, I.M.M. 2012. Water stress in plants: causes, effects and responses. In: Rahman IMM, ed. *Water Stress. InTech China*, 1-15.

Lithourgidis, A.S., Vasilakoglou, I.B., Dhima, K.V., Dordas, C.A. and Yiakoulaki, M.D. 2006. Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios. *Field Crops Research* 99: 106–113.

Lynch, J.P. and Wojciechowski T. 2015. Opportunities and challenges in the subsoil. Pathways to deeper rooted crops. *Journal of Experimental Botany* 1 – 13.

Mahapatra, A.K., Melton, S.L. and Isang, E.M. 2013. Effects of moisture content on thermal properties of cowpea flours. *Agricultural Engineering International: CIGR Journal*. 15(2): 251 – 255.

Makoi, J.H.J.R., and Ndakidemi P.A. 2011. Changes in plant growth, nutrient dynamics and accumulation of flavonoids and anthocyanins by manipulating the cropping systems involving legumes and cereals- a review. Australian *Journal of Agricultural Engineering* 2 (3): 56 - 65.

Marino, D. Frendo, P., Gonzalez, E. M., Puppo, A., and Arrese, C. 2007. NADPA recycling systems in oxidative stressed nodules; a key role for the NADP (+) dependent isocitrate dehydrogenase. *Planta* 225: 413 – 421.

Martin L S, Vallejo A, Dick J, Skiba U M. 2008. The influence of soluble carbon and fertilizer nitrogen on nitric oxide and nitrous oxide emissions from two contrasting agricultural soils. *Soil Biology and Biochemistry* 40: 142-151.

Massion-Boivian, C., Giraud, E., Perret, X., and Batut, J. 2009. Establishing nitrogen-fixing symbiosis with legumes: how many rhizobium recipes? Trend in Microbiology 17(10): 458 – 466.

Matusso, J.M.M, Mugwe, J.N, and Mucheru-muna, M. 2014. Potential role of cereal-legume intercropping systems in integrated soil fertility management in smallholder farming systems in Sub-saharan Africa. *Research Journal of Agriculture and Environmental Management.* 3(3): 162 – 174.

McGuire, V. L. 2009. Water-level changes in the high plains aquifer, Predevelopment to 2007, 2005-06, and 2006-07. Scientific Investigations Report 2009-5019. Lincoln, Nebraska. U.S. Geological Survey.

Mead, R and Willey, R. W. 1980. The concept of a 'land equivalent ratio' and advantages in yields from intercropping. *Experimental Agriculture* 16 (3): 217-228.

Mehdizadeh, M., Darbandi, E.I., Naseri-Rad, H. and Tobeh, A. 2013. Growth and yield of tomato (*Lycopersicon esculentum* Mill.) as influenced by different organic fertilizers. *International Journal of Agronomy and Plant Production*. 4 (4): 734 – 738.

Mehmood, T., Azam, F., Hussain, F. and Malik, K.A. 1997. Carbon availability and microbial biomass in soil under an irrigated wheat-maize cropping system receiving different fertilizer treatment. *Biology Fertilizer and Soil* 25 (1): 63 – 68.

Mertz, O., Mbow, C., Reenberb, A., Prouf, A. 2009. Farmers' perception of climate change and agricultural adoption strategies in rural Sahel. *Environmental Management* 43: 804 – 816.

Miguel, A.A. 2002. Agroecology: The Science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystem and Environment* 93: 1 – 24.

Ministry of Agriculture (MoA). 2010. Annual food and crop situation report, 2009. Provincial Director of Agriculture, Coast Province. 18 pp.

Mohammed, S.A.A. 2012. Assessing the land equivalent ratio (LER) of two leguminous pastures (Clitoria and Siratro) intercropping at various cultural practices and fencing at Zalingei- Western Darfur State. *Sudan ARPN Journal of Science and Technology* 2 (11): 1074 – 1080.

Mohamed, E.A., El Naim, A.M., Ebeadallah, B.E and Ibrahim, K.A. 2011. Effect of tillage and farmyard manure on yield and yields components of grain sorghum (*Sorghum bicolor* L.monech) in Rain-Fed. *International Journal of Current Research* 33 (6): 389 - 392.

Moldenhauer, W.C., Kemper, W.D., Schenz, D.I., Wessles, G.A., Hatfield, J.I., Laflen, J.M. 1994. Crop residue management for soil conservation and crop production. In: Napier, T. L., Camboni, S. M., El-Swaify, S. A. (Eds.). Adopting Conservation on the Farm: An international Perspective on the Socioeconomics of Soil and Water Conservation. SWCS. Ankeny pp. 37 – 46.

Moll, R.H., Kamprath, E.J and Jackson, W.A. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronony Journal* 74: 562-564.

Morrison, I. M., Asiedu, L. A., Stuchburg, T. and Powel, A. A. 1995. Determination of lignin and tannin contents of cowpea seed coats. *Annals of Botany* 76: 287 - 290

Mossaddeghi, M.R., Hajabbasi, M.A., Hemmat, A. and Afyuni, M. 2000. Soil compactibility as affected by soil moisture content and farmyard manure in Central Iran. *Soil and Tillage Research* 5: 87 - 97

Muchena, F. N., Onduru, D. D., Gachini G. N., de Jager A. (2005). Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. *Land Use Policy* 22: 23 - 31.

Mugendi, D., Mucheru-Muna, M., Mugwe, J. and Bationo, A. 2003. Enhancement of food productivity using leguminous shrubs in the Eastern highlands of Kenya. *African Crop Science Conference Proceedings* 6: 581 - 586.

Mugendi, E., Gitonga, N., Cheruiyot, R and Maingi, J. 2010. Biological nitrogen fixation by promiscous soybean (*Glycine max* L. Merril) in the central highlands of Kenya: response to soil amendends.*World Journal of Agricaultural sciences* 6: 381-387.

Mureithi, J.G., Tayler, R.S. and Thorpe, W. 1995. Productivity of alley farming with leucaena (*Leucaena leucocephala* Lam. de Wit) and Napier grass (*Pennisetum purpureum* K. Schum) in coastal lowland Kenya. *Agroforestry Systems* 31: 59 - 78.

Mureithi, J.G., H.M. Saha, M.N. Njunie, G.M. Kamau, T.L. Munga, A. Blokland, F.K. Muniu, M.B. Muli, A. Ramadhan and E. Wekesa. 1996. An appraisal of methods used by farmers to manage soil fertility in coastal Kenya. A paper presented at the 15th Conference of the Soil Science Society of East Africa, held in Nanyuki, Kenya, 19th - 23rd August 1996.

Mutai, C.C, and Ward, M.N. 2000. East African rainfall and the tropical circulation/convection on intra-seasonal to inter-annual timescales. *Journal of Climate* 13: 3915 – 3939.

Muthuri, J.K., Ithinji, J.K. and Kirigiah, R.M. 2014. Symbiotic effectiveness of *Bradyrhizobium japonicum* USDA 110 and *Sinorhizobium fredii* USDA 191 on two different soyabean cultivars. *European Scientific Journal* 10(12): 329 – 337.

Nandwa, S.M. 1995. Synchronization between soil N mineralization and maize uptake through management of maize stover. In P. L. Woomer and M. J. Swift (eds). The Biology and Fertility of Tropical soil. Intaprint Limited, Nairobi, Kenya. Pp 6 – 7.

Naresh, R.K., Tomar, S.S., Shahi, U.P., Singh, S.P., Singh P.B. and Kumar, P. 2014. Sustainability of maize wheat cropping system by different legume intercropping and nitrogen level treatments on light distribution, soil temperature and crop productivity. *African Journal of Plant Science*. 8 (4): 204 – 213.

Ndakidemi, P.A. 2006. Manipulating legume/cereal mixtures to optimize the above and below ground interactions in the traditional African cropping systems. *African Journal of Biotechnology* 5 (25): 2526 - 2533.

Ndiso, J.B, Kibe, A.M, Mugo, S., and Pathaka, R.S. 2012. Influence of drought stress on growth, yield and yield components of selected maize genotypes in coastal lowland Kenya. *International Journal of Agricultural Sciences* 2 (6): 178 – 185.

Nileemas, G, and Sreenivasa, M.N. 2011. Influence of liquid organic manures on growth, nutrient content and yield of tomato (*Lycopersicon esculentum* Mill.) in the sterilized soil. *Karantaka Journal of Agricultural Science* 24: 153 - 157.

Njunie, M.N., Saha, H.M., Muli, B.M. and Lewa, K.K. 2007. Soil and water management to enhance food security in coastal Kenya: End of project technical report (2002 – 2006). Technical report No. 5. KARI Mtwapa, July 2007.

Nkongolo, K. K., Chinthu, K.K.L., Malusi, M. and Vokhiwa, Z. 2008. Participatory variety selection and characterization of Sorghum (*Sorghum bicolor* (L.) Moench) elite accessions from Malawian gene pool using farmer and breeder knowledge. *African Journal of Agricultural Research* 3 (4): 273-283.

Nyakatawa, E.Z. 1997. Evaluation of sorghum stover and tree leaf mulches for sustainable maize, sorghum and sunflower cropping in a semi-arid region of Zimbabwe. *Journal of Sustainable Agriculture* 10 (2-3): 115 - 128.

Obi, M.E. and Ebo, P, 1995. The effect of organic and inorganic amendments on soil physical properties and production in a severely degraded sandy soil in southern Nigeria. *Bioresource Technology* 51 (2-3): 117- 123.

Obong'o, D.O., Kangunu, F.M., Mumu, T.T., Agesa, A.A., Jamoza, J.E., Marwanga. W. and Grisley. W. 1993. Farming systems in the Agro-ecological Zones CL2 and CL3 in the Msambweni and Matuga Divisions and CL4 and CL5 in the Kinango Division, Kwale District, Coast Province, Kenya. Ministry of Agriculture, Livestock Development, and Marketing and Kenya Agricultural Research Institute, Kwale District, 1993. *Kenya Farming Systems Series* No 4.

Odhiambo J. O. J., and Bomke A. A., 2001. Soil and crop management. Grass and legume cover crop effects on dry matter and nitrogen accumulation. *Agronomy Journal* 93, 299 - 307

Ofori, F. and Stern, W. R. 1987. Cereal-legume intercropping systems. *Advances in Agronomy* 41: 41-90.

Ofori, E., Oteng-Darko, P., Berchie, J.N., Nimako, F.O., Yeboah, S. and Owusu Danquah, E. 2014. Monitoring of soil moisture regime and water use efficiency under maize-cowpea intercropping system. *International Journal of Current Microbiology and Applied Sciences* 3(10): 837 – 848.

Oghiakhe, S., Jackai, L.L.E. and Makanjuola, W.A. 1995. Evaluation of cowpea genotypes for field resistance to legume pod borer, Maruca testulalis, in Nigeria, *Crop Protection* 14: 389 394.

Okafor, L.I, and Adegbite, A.A. 1991. Predominant weeds of cowpea (*Vigna unguiculata)* in Bauchi State of Nigeria. *Nigerian Journal of Weed Science* 4: 11 - 15.

Okeyo-Owuor, J.B., Agwardo, P.O., Simbi, C.O.J. 1983. Studies on the legume pod-borer, *Maruca testulalis* (Geyer)-V. Larval population. *Insect Science and its Application* 4: 75 - 81.

Okon, J. E. 2013. Effect of Water stress on some growth aspects of two varieties of cowpea, *Vigna unguiculata* (L.) Walp Fabaceae. *Bulletin of Environment, Pharmacology and Life Sciences* 2 (5): 69 -74

Omokanye, A.T., Kelleher, F.M. and McInnes, A. 2014. Maize managed on diverse cropping systems and N supply on yield and quality of maize stover silage. *International Journal of Agronomy and Agricultural Research* 4 (5): 65 - 74.

Omotayo, O.E and Chukwuka, K.S. 2009. Soil fertility restoration techniques in Sub-Saharan Africa using organic resources *African Journal of Agricultural Research Volume* 4 (3): 144 - 150.

Onasanya, A., Ekperigin, M.M. Nwilene, F.E. Sere, Y. and Onasanya, R.O. 2009. Two pathotypes of *Xanthomonas oryzae* pv. *oryzae* virulence identified in West Africa. *Current Research in Bacteriology* 2: 22-35.

Onuh, M.O and Donald, K.M. 2009. Effects of water stress on the rooting nodulation potential and growth of cowpea (*Vigna unguiculata* (L) Walp). *Science World Journal* 4 (3): 31 – 34.

Oparaeke, A.M., Dike, M.C. and Amatobi, C.I. 2005. Field evaluation of extracts of five Nigerian spices for control of post-flowering insect pests of cowpea, *Vigna unguiculata* (L) Walp. *Plant Protection Science* 41: 14 – 20.

Ortiz, R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T., Hodson, D., Dixon, J.M., Ortiz-Monasterio. J.I.and Reynolds, M. 2008. Climate change: can wheat beat the heat? *Agriculture, Ecosystem and Environment* 126: 46–58

Oso, A.S and Falade, M.J. 2010. Effect of variety and spatial arrangement on pest incidence, damage and subsequent yield of cowpea in a cowpea/maize intercrop. *World Journal of Agricultural Science* 6 (3): 274–276

Otieno, P.E., Muthomi, J.W., Chemining'wa, G.N. and Nderitu, J.H. 2007. Effects of rhizobia inoculation, farmyard manure and nitrogen fertilizer on nodulation and yield of food grain legumes. *Journal of Biological Sciences* 9 (4): 326 – 332.

Otieno, P.E., Muthoni, J.W., Chemining'wa, G.N. and Nderitu, J.H. 2009. Effects of rhizobia inoculation, farm yard manure and nitrogen fertilizer on nodulation and yield of food grain legumes. Journal of Biological Sciences 9(4): 326 – 332.

Owolade, O.F., Alabi, B.S., Osikalu, YO.K. and Odeyemi, O.O. 2004. On farm evaluation of some plant extracts as biofungicide and bioinsecticides in cowpea in southwestern Nigeria. *Food, Agriculture and Environment* 2: 237 – 240.

Passioura, J.B. 2006. The perils of pot experiments. *Functional Plant Biology* 33(12) 1075–1079.

Perrin, R. M. (1977). Pest management in multiple cropping systems. *Agro-Ecosystems* 3: 93–118.

Pieri, C. 1989. Fertilite des terres de savanes: Bilans de ternate ans de recherché et de development agricoles au sud du sahara Ministere de la Cooperation et du Development. CIRAD, Paris.

Pimentel, D. 1991. Diversification of biological control strategies in agriculture. *Crop Protection* 10: 243 – 253.

Poggio SL (2005). Structure of weed communities occurring in monoculture and intercropping of field pea and barley. *Journal of Agriculture, Ecosystems and Environment* 109: 48-58.

Popp A., Lotze-Campen, H. and Benjamin, B. 2010. Food consumption diet shift and associated non-CO_2 green-house gasses from Agricultural Production. *Global Environmental Change* 20 (3): 451 - 462

Prasanthi, K. and Venkateswaralu, B. 2014. Fodder quality in fodder maize-legume intercropping systems. *Journal of Tropical Agriculture* 52 (1): 86 – 89.

Preet, k. and Prunia, D. 2000. Proximate composition, phytic acid, polyphenols and digestibility (*in vitro*) of four brown cowpea varieties. *International Journal of Food Science and Nutrition* 50: 189 - 193.

Purcell, L.C, Rosalind, A.B., Reaper, D.J., and Vories, E.D. 2002. Radition use efficiency and biomass production in soybean at different plant population densities. *Crop Science* 42:172-177.

Quin, F.M., 1997. Introduction. In B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, eds. Advances in Cowpea Research. Pp. ix – xv. Co-publication of

International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Centre for Agricultural Sciences (JIRCAS), Sayce Publishing, Devon, UK.

Qadir, M. and Dreschsel, P. 2011. Managing salts while irrigating with waste water. In Plant Sciences reviews 2010 D. Hemming (Ed). CAB International.

Rabbinge, R. and van Ittersum, M.K. 1994. Tension between aggregation levels. In: Fresco, L.O., Stroosnijder, L., Bouma, J., Keulen, H. V. (Eds.). The Future of the Land: Mulching and Integrating Knowledge for Land Use Options. Wiley, Chichester, PP. 31 – 40.

Raheja, P.C. 1973. Mixed Cropping. ICAR Technical Bulletin (Agric) no. 42. Indian Council of Agricultural Research, New Delhi. India. pp 40.

Raheja, A.K. 1976. Assessment of losses caused by insect pests of cowpea in northern Nigeria. *Pesticides Action Network* 22: 299 – 333.

Rahman, S.A., Ibrahim, U. and Ajayi, F.A. 2008. Effects of defoliation at different growth stages on yield and profitability of cowpea (*Vigna unguiculata* (L) Walp). *Electronic Journal of Environmental, Agricultural and Food Chemistry* 7 (9): 3248 – 3254.

Ramesh, T., Devasenapathy, P. 2006. Physiological response of cowpea in a rainfed Alfisol ecosystem to the impulse of soil moisture conservation practices. *General Applied Plant Physiology* 32 (3-4): 181-190.

Rau, M.R. and Mathuva, M.N. 2000. Legumes for improving maize yields and income in semi arid Kenya. International Centre foe Research in Agroforestry.

Rasool, F.U., Hassan, B., Aalum, I. and Ganie, S.A. 2013. Effects of nitrogen, sulphur and farmyard manure on growth dynamics and yield of sunflower (*Helianthus annus* L.) under temperate conditions. *Scientific Research and Essays* 8(43): 2144 – 2147.

Rehman, H.U., Ali, A., Waseem, M., Tanveer, A. Tahir, M. Nadeem, M.A. and Zamir, M.S.I. 2010. Impact of Nitrogen Application on growth and yield of maize (Zea mays L.) grown alone and in combination with cowpea (Vigna unguiculata L.). American-Eurasian Journal of Agriculture and Environmental Sciences. 7(1): 43 – 47.

Remison, S.U. 1997. Performance of cowpea as influenced by weed competition. Journal of Agricultural Sciences 90: 523 – 530.

Richards, P. 1985. Indigenous Agricultural Revolution: Ecology and Food Production in West Africa. Hutchnison. London. UK. pp 192.

Rockström, J., Karlberg, L., Wani, S.P., Barron, J., Hatibu, N., Oweis, T. 2010. Managing water in rainfed agriculture: The need for a paradigm shift. *Agriculture and Water Management* 97:543–550.

Rosenzweig, C. and Tubiello, F.N. 2007. Adaptation and mitigation strateties in Agriculture: an analysis of potential synergies. *Mitigation Adaptation Strategies in Global Change* 12: 855 – 873.

Rowland, J.R.J. 1993. Dry land Farming in Africa. Macmillan Education Ltd. London and Basingtoke. 76.

Saha, H.M. 2007. Improving Resource use Under Maize – Green legume systems in coastal lowland Kenya. Ph.D Thesis, Jomo Kenyatta University of Agriculture and Technology.

Saha, H.M., and Muli, M.B. 2002. Effects of combining green manure legumes, farm yard manure and inorganic fertilizer on maize yield in coastal Kenya. In: J.G Mureithi, C.K.K Gachene, F.N. Muyekho, M. Onyango, L. Mose and O. Magenya (Eds.) Participatory technology development for soil management by smallholder farmers in Kenya. Proceedings of the 2nd Scientific Conference of the Soil Management and Legume Research Network Projects. Mombasa, Kenya. 26th – 30th June 2000.

Saha, H.M., Kamau, G.M., Masha, J.S., Mwangondi, Z., Gassare, A.A., Murage, E.T., Ndungu, G.K., Marwanga, W. and Grisley, W. 1993. Farming systems in the Agro-ecological zones CL3 (Malindi Division) CL4 (Ganze Division) CL5 (Kaloleni Division) of Kilifi District, Coast Province. MOALDM and KARI. Kenya Farming Systems Series No. 3.

Salako, F.K., Olowokere, F.A., Tian, G., Kirchhof, G. and Osiname, O. 2007. Ground cover by three crops cultivated on marginal lands in southwestern Nigeria and implications for soil erosion. *Spanish Journal of Agricultural Research* 5 (4): 497 - 505.

Saleem, R., Ahmed, Z.I., Ashiraf, M., Arif, M., Azim, M., Munir, M. and Khan, M.A. 2011. Response of maize-legume intercropping system to different fertility sources under rain-fed conditions. *Sahad Journal of Agriculture*. 27 (4): 503 – 511

Samson, H. and Helmut, H. 2007. Drought effect on yield, leaf parameters and evapotranspiration efficiency of cowpea. Conference of International Agricultural Research for Development, University of Kassel- Witzenhause and University of Gotteingen.

Sangakkara, U.R. 1999. Effects of weeds on yield and seed quality of two tropical grain legumes. *Tropical Science* 39: 227 – 232.

Sanginga, N.G., Tholta, P. and Dashiell, K. 2002. Effectiveness of rhizobia nodulating recent promiscuous soybean selections in the moist savannah of Nigeria. *Soil Biology and Biochemistry* 32: 127 – 133.

SAS Institute 1993. SAS/STAT users' guide. Release 6.08. Ed. SAS Cary. NC.

Schoonheven, L.M., Jermy, T., and van Loon J.J. 1998. Insect-plant biology: from physiology to evolution. Chapman and Hall: New York, pp 409.

Schroeder, C., Onyango K'oloo, T., Ranabhart, N.B., Jick N.A., Parzier, H.K., and Gemenet, D.C. 2013. Potentials of hybrid maize varieties for small holder farmers in Kenya: A review based on SWOT Analysis. *African Journal of Food, Agriculture, Nutrition and Development* 13 (2): 7562 – 7586.

Scopel, E., Da Silva, F.A.M., Corbeelsa, M., Affholdera, F., and Maraux, F. 2004. Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions. *Agronomie* 24: 383–395 383

Seinfeld, J.H. and Pandis, S.N. 2012. Atmospheric chemistry and physics: from air pollution to climate change, John Wiley & Sons publishers, New Jersey, USA.

Seran, T.H. and Brintha, I. 2010. Review on maize based intercropping. *Journal of Agronomy* 9: 135 – 145.

Shafi, M., Bakht, J., Attaullah and Mohammad, A.K. 2010. Effects of crop sequence and crop residues on soil C, soil N and yield of maize. *Pakistan Journal of Botany* 42 (3): 1651 – 1664.

Shafi, M., Bakht, J. Jan, M.T. and Shah, Z. 2007. Soil C and N dynamics and maize (Zea mays L.) yield as affected by cropping systems and residues management in North-western Pakistan. *Soil and Tillage Research* 94: 520 - 529.

Shah, Z., Shah, S.H. Peoples, M.B. Schwenke, G.D. and Herriedge, D.E. 2003. Crop residues and fertilizer N effects on nitrogen fixation and yields of legume-cereal rotations and soil organic fertility. *Field Crops Research* 83: 1-11**.**

Shaker-Kooh, S., Nasrollahzadeh, S. and Raei, Y. 2014. Evaluation of chlorophyll value, protein and yield of sorghum (*Sorghum bicolor* L.)/mung-bean (*Vigna radiatea* L.) intercropping. *International Journal of Biosciences* 4(8): 136 – 143.

Singh, B.B. 2002. Breeding cowpea varieties for resistance to *Striga gesneroides* and *Alectra vogelii*. In Challenges and opportunities for enhancing sustainable cowpea production.

(Eds. C.A. Fatokun, S. A. Tarawali, B.B. Singh, P. M. Kormawa and M. Tamo), pp. 154 – 166. IITA, Ibadan, Nigeria.

Singh, S.R. and Allen, D.J. 1980. Pest, diseases, resistance and protection in cowpea. In: Biology and Breeding for Resistance of Arthropod and Pathogens in Agricultural Plants, Ed. M. K. Harris. College Station, Texas. Texas Agricultural and Mechanical University Bulletin MP 1451, pp 605.

Singh, S.R. and Jackai, L.E.N. 1985. Insect pests of cowpea in African: their life cycle, economic importance and potential for control. In Cowpea Research, Production and Utilization. Singh, S. R. and K. O. Rachie (Eds); John Wiley and sons limited: Chi Chester. *African Crop Science Conference Proceeding* 3: 1421 – 1430.

Singh P. and Narayanna S.G. 2000. Biometrical techniques in plant breeding. Kalyani Publishers. New Delhi, India. 74 – 84.

Singh, B. B., Chambliss, O. L. and Sharma, B. 1997. Recent advances in cowpea breeding. In: B.B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai (eds). Advances in cowpea research, pp. 114 – 128. Co-publication of International Institute of tropical Agriculture (IITA), Ibadan, Nigeria and Japan International Research Center for Agriculture Science (JIRCAS), Sayce Publishing, Devon, UK.

Singh, B.K., Pathak, K.A. Verma, A.K., Verma, V.K. and Deka, B.C. 2011. Effects of vermicompost, fertilizer and mulch on plant growth, nodulation and pod yield of French bean (*Phaseolus vulgaris* L.). *Vegetable Crops Research Bulletin* 74: 153 – 165.

Singh, A., Olsen, S.I. and Pant, D. 2013. "Importance of life cycle assessment of renewable energy sources: In Life Cycle Assessment of Renewable Energy Sources, Green Energy and Technology Series, eds A. Singh, D. Pant, and S.I. Olsen (Lon- don: Springer-Verlag), 1–11.

Smith, R.J., and Hill, J.E. 1990. Weed control in U.S. rice. pp. 314-327. In: *Pest Management in Rice*, (eds.) B.T. Grayson, M.B. Green, and L.G. Copping. Elsevier Science Publishing Co. New York, NY

Sombroek, W.G., Braun, H.M.H. and van der Pouw, B.J. 1982. Exploratory Soil Survey Report No. E1, Kenya Soil Survey, Nairobi.

Souza, R.P., Machado, E.C., Silva, J.A.B., Lagoa, A.M.M.A. and SIlveira, J.A.G. 2004. Photosynthetic gas exchange, chlorophyll fluorescence and some associated metabolic changes in cowpea (*Vigna unguiculata*) during water stress and recovery. *Environment and Experimental Botany* 5: 45 - 56

Sreenivasa, M.Y., Dass R.S. and Janardhana, G.R. 2010. Post harvest fungi associated with sorghum grains produced in Karnataka (India). *Journal of Plant Protection Research* 50(3): 335-339.

Stewart, W.M., Dibb, D.W., Jhonston, A.E. and Smyth, T.J. 2005. The contribution of commercial fertilizer nutrients to food production. *Journal of Agronomy*. 97 (1): 1 – 6.

Sukanya, N and Doss, P.J. 2013. Neurotoxic effects of cypermethrin in western strain rats: Detoxification mechanisms. *CIBTech Journal of Zoology* 2(3): 37 43.

Sumeet, G, Shahid, U. and Suryapani, S. 2009. Nitrate accumulation, growth and leaf quality of spinach beet (*Beta vulgaris* Linn.) as affected by NPK fertilization with special reference to potassium. *Indian Journal of Science and Technology.* 2(2):35 - 40.

Swift, J. 1996. Desertification Narratives, Winners and Losers. In: Leach, M., Mearns, R. (Eds.). The Lie of the Land: challenging received wisdom on the African environment. The international African Institute. James Currey. Oxford. UK. pp 73 – 90.

Szumigalski, A. and Van Acker, R. 2005. Weed suppression and crop production in annual intercrops. *Weed Science* 53: 813–825.

Takim, F.O. 2012. Advantages of maize-cowpea intercropping over sole cropping through competition indices. *Journal of Agriculture and Biodiversity Research* 1(4): 53-59

Takim F.O and Uddin R.O. 2010. Effect of weed removal on insect populations and yield of cowpea (*Vigna unguiculata* (L.) Walp). *Australian Journal of Agricultural Engineering* 1 (15): 194 – 199.

Tamo, M., Bottenberg, H., Arodokoun, D. and Adeoti, R. 1997. The feasibility of classical biological control of two major cowpea insect pests. In Singh B. B, Mohan Raj D. R., Dashiell K. E. and Jackai L. E. N. (eds). Advances in Cowpea Research. Co publication of International Institute of Agricultural and Japan International Center for Agricultural Sciences. Nigeria Pp 259 – 270.

Tennakoon, N.A. and Hemamala Bandara, S.D.H. 2003. Nutrient content of some locally available organic materials and their potential as alternative sources of nutrients for coconut. *Cocos* 15: 23 - 30

Thobatsi, T. 2009. Growth and yield responses of maize (Zea mays L.) and Cowpea (*Vigna unguiculata* L.) in an Intercropping System. Msc. Thesis.University of Pretoria. Pp. 159.

Thomas, G.W.1996. Soil pH and soil acidity. In: Sparks, D.L. (ed.) Methods of soil analysis Part 3. 3rd ed. Madison, WI: SSSA, ASA. pp. 475–490.

Tijani-Eniola, H. 2001. Influence of intra-row spacing and weeding regime on the performance of cowpea (*Vigna unguiculata* (L) Walp). *Nigeria Journal of Weed Science* 14: 11 – 15.

Tilman, D., Cassman, K.G., Matson, P.A. Naylor, R. and Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418: 671-677

Tittonelli, P., Vanlauwe, B., Leffelaar, P.A., Shepherd, K.D. and Giller, K.E. 2005. Exploring diversity in soil fertility management of smallholder farms in Western Kenya: 11

within – farm variability in resource allocation, nutrient flow and soil fertility status. *Agriculture, Ecosystems and Environment* 110 (3-4): 166 – 184.

Tomlins, K.I., Manful, J. T., Larwer, P. and Hammond, L. 2005. Urban consumer acceptability and sensory evaluation of locally produced and imported parboiled and raw rice in West Africa. *Food Quality Preference* 16: 79–89.

Tomlins, K., Ndunguru, G., Stambul, K., Joshua, N., Ngendello, T., Rwiza, E., Amour, R. Ramadhani, B., Kapande, A., and Westby, A. 2007. Sensory Evaluation and consumer acceptability of pale-fleshed and orange-fleshed sweet potato by school children and mothers with preschool children. *Journal of Science, Food and Agriculture* 87 (13): 2436 - 2446.

Triplett, G.B. and Dick W.A. 2008. No-tillage crop production: A revolution in Agriculture. *American Society of Agronomy* 100: 153 – 165.

Tsubo, M, Mukhala, E, Ogindo, HO and S. Walker, 2003. Productivity of maize-bean intercropping in a semi-arid region of South Africa. *Water South Africa* 29 (4): 381-388**.**

Tsubo, M. and Walker, S. and Ogindo, H.O. 2005. A simulation model of cereal-legume intercropping systems for semi-arid regions I. Model development. *Field Crops Research* 93(1); 10 – 22.

Truong T.N.C., Phan V.L and Thelma P. 2007. Farmers' participation in rice variety selection. *Omonrice* 15: 159 – 163.

Turmel, M., Speratti, A., Baudron, F., Verhulst, N., and Govaerts, B. 2015. Crop residue management and soil health: A systems analysis. *Agricultural Systems* 134: 6–16

Turk, K.J. and Hall, A.E. 1980. Drought adaptation of cowpea III. Influence of drought on plant growth and relation with seed yield. *Agronomy Journal* 72: 428 – 433.

Undies, U.L, Uwah, D.F. and Attoe, E.E. 2012. Effect of intercropping and crop arrangement on yield and productivity of late season maize/soybean mixtures in the humid environment of southern Nigeria. *Journal of Agricultural Science* 4(4):37-50.

Unger, P.W. 1990. Conservation tillage systems, In R.P. Singh, J.F. Parr, and B.A. Stewart, Eds. Dryland Agriculture strategies for sustainability, *Advances in Soil Science* Vol. 13. Springer-Verlag, New York, 27 – 68.

United Nations Environment Programme. 1998. Annual Report. p24

van Cotthem, W. 2007. Cowpea: Possible breakthrough in biological control of pod borer pests. News, Views about Agriculture in Africa and beyond.

van Donk, S.J., Martin, D.L., Irmak, S., Melvin, S.R. Petersen, J. L. Davison, D. R. 2010. Crop residue cover effects on evaporation, soil water content, and yield of deficit irrigated corn in west Central Nebraska. *American Society of Agricultural and Biological Engineers* 53 (6): 1787-1797

van Donk, S.J., Shaver, T.M., Petersen, J.L. Davison, D.R. 2012. Effects of crop residue removal on soil water content and yield of deficit-irrigated soybean. *Society of Agricultural and Biological Engineers* 55 (1): 149-157

van Kessel, C. and Hartley, C. G. 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation? Field Crop Research. 65: 165–181.

Vanlauwe, B., Tittonell, P. and Mukalama, J. 2007. Within farm soil fertility gradients effects response of maize to fertilizer application in Western Kenya. A. Bationo (eds), Advances in integrated soil fertility management in Sub Saharan Africa: Challenges and Opportunities. 121 – 132.

Veerappa, R.1998. Phenol and tannin reduce the damage of cowpea pod borer Maruca testulalis. *Insect environment* 4: 5–6

Waaijenberg, H. 1994. Mijikenda agriculture in Coast Province of Kenya: Peasants in between tradition, ecology and Policy. Doctoral thesis, Wageningen Agricultural University. Wageningen. The Netherlands.

Wanjekeche, E., Kamadi, M., Mwangi, T., Powon, P. and Khaemba, J. 2000. Farmers participation in introduction and evaluation of grain legumes in north western Kenya. Paper presented at the soil management and legume research network preceeding conference at Kanamai on 24th – 26th March 1997.

Waseem, M., Ali, A., Tahir1, M., Nadeem, M. A., Ayub1, M. Tanveer, A., Ahmad, R. and Hussain, M. 2011. Mechanism of drought tolerance in plant and its management through different methods. *Continental Journal of Agricultural Science* 5 (1): 10 - 25,

Wasson P, Richards R, Chatrath R, Misra S.C, Prasad S.V.S, Rebetzke G.J, Kirkegaard J.A, Christopher J, Watt M. 2012. Traits and selection strategies to improve root systems and water uptake in water-limited wheat crops. *Journal of Experimental Botany* 63: 3485–3498.

Wekesa, E., Mwangi, W., Verkuiji, H., Dona, K. and De Groote, H. 2003. Adoption of maize production technologies in the coastal lowlands of Kenya. International maize and wheat improvement centre (CIMMYT).

Weltzien, E., Smith, L. S. Meitzien and Sperling, L. 2003. Technical and institutional issues in participatory plant breeding – Farm the perspective of farmer plant breeding. A global analysis of issues, results, and current experience. PPB Monograph No. 1. Cali: PRGA.

Willey, R. W. 1979. Intercropping – Its importance and research needs. Part 1. Competition and yield advantages. *Field Crop Abstract* 32: 1–10

Yancey, P.H. 1994. Covers challenge cotton chemicals. The New Farm. February p. 20–23.

Yilmaz, S., Atak, M. and Erayman, M. 2008. Identification of advantages of maize-cowpea intercropping over solitary cropping through competition indices in the East Mediterranean region. *Turkish Journal of Agriculture and Forestry* 32:111 – 119.

Zamir, M.S.I., Javeed, H.M.R., Ahmed, W., Ahmed, A.U.H., Sarwar, N., Shehzad, M., Sarwar, M.A. and Iqbal, S. 2013. Effects of tillage and organic mulches on growth, yield and quality of autum planted maize (Zea mays L.) and soil physical properties. *Cercetari Agronomice in Moldova* XLVI (2): 17 – 26.

Zhang, F.S. and Li, L. 2003. Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil* 248: 305-312.

Zimdahl, R.L., Moody, K., Lubigan, R.T. and Castin, E.M. 1988. Patterns of weed emergence in Tropical soils. *Weed Science* 36: 603 – 606.

APPENDIXES

Appendix 1: Temperature, relative humidity and rainfall data of the two sites for the period of July to December 2012

Month	Mean temperature (^oC)		Relative humidity (%)		Total rainfall (mm)	
	MTP	KLF	MTP	KLF	MTP	KLF
Jul	25.25	24.3	78.5	72.1	35.7	42.0
Aug	25.2	24.15	77.5	73.6	80.7	137.9
Sept	24.55	25.75	73.5	69.3	24	22.5
Oct	26.85	26.15	79.5	75.3	112.8	245.5
Nov	27.95	26.85	77	77.2	184.1	129.5
Dec	28.15	27.7	73	74.1	78.8	164.5

MTP – Mtwapa and KLF –Kilifi

Appendix 2: Initial soil testing results at Pwani University and KALRO Mtwapa research farms

Soil component	Kilifi		Mtwapa	
	Value	Class	Value	Class
pH	5.6	Moderate acidic	6.66	Slightly high
Total N	0.04%	low	0.15%	Low
Organic carbon	0.34%	low	1.34%	Moderate
Phosphorus	43.79 ppm	High	10 ppm	Low
Potassium	0.21 me%	Medium	0.74 me%	Adequate
Calcium	1.73 me%	Low	2.4 me%	Adequate
Magnesium	0.37 me%	Low	1.90 me%	Adequate
Manganese	0.24 me%	Adequate	0.40 me%	Adequate
Copper	0.68 pmm	Low	3.67 ppm	Adequate
Iron	17.62 ppm	Adequate	26.5 ppm	Adequate
Zinc	1.26 ppm	Low	5.12 ppm	Adequate
Sodium	0.14 me%	Low	0.22 me%	Adequate

Appendix 3: Nutrient composition of the farmyard manure used at Kilifi and Mtwapa

Nutrient	Amount	Class	Nutrient	Amount	Class
pH	10.98	Alkaline	Magnesium	0.28 mg/kg	Adequate
Total Nitrogen	3.15%	High	Iron	2067.0 mg/kg	Adequate
Organic carbon	5.79%	Adequate	Copper	23.3 mg/kg	Adequate
Phosphorus	0.47%	Adequate	Manganese	343.0 mg/kg	Adequate
Potassium	0.95%	Adequate	Zinc	90.0 mg/kg	Adequate
Calcium	1.11%	Adequate	-	-	-