PERFORMANCE OF FARMER-PREFERRED MAIZE VARIETIES INTERCROPPED WITH BEANS IN THE SEMI-ARID REGIONS OF KENYA

Kitonyo, Onesmus Musembi

(B.Sc. Agriculture, UoN)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2010

DECLARATION

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

Kitonyo, Onesmus Musembi

Signature................................. Date...24/08/2010.......

This thesis has been submitted for examination with our approval as university supervisors.

Dr. George N. Chemining'wa

Department of Plant Science and Crop Protection

University of Nairobi

Signature................................. Date...24/08/2010.......

Dr. James W. Muthomi

Department of Plant Science and Crop Protection

University of Nairobi

Signature................................. Date...25/8/2010.......

DEDICATION

I wish to dedicate this piece of work to my family.

ACKNOWLEDGEMENTS

I would like to thank the Almighty God for the gift of life, good health and enabling me go through the programme.

This work was made possible with funds provided by the project: "Mitigating Mycotoxin Hazards in Maize and Maize Products in Kenya" under the auspices of the Kenya Agricultural Productivity Programme (KAPP). Special thanks go to Dr. George Chemining'wa and Dr. James Muthomi for their invitation to take up the project, their supervision, constructive criticisms and guidance throughout the study. My thanks are extended to colleague students Rose and Florence, the project research assistant, Ng'eno and the field assistant, Godfrey for their assistance in data collection and monitoring of the crop.

My gratitude also goes to my parents, Mr and Mrs Kitonyo, sister Juliet and cousin Mecko for their effort and moral support. Special appreciation to my loving family for standing by me and their encouraging me throughout the entire period of my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

Recurrent droughts are often associated with maize crop failures and therefore food insecurity especially in semi-arid areas of Kenya. To cope with drought, farmers are advised to adopt drought tolerant maize varieties and maize-legume intercropping as a diversification strategy. As such, a study was conducted in Machakos, Mwea and Waruhiu in 2008 short rains and 2009 long rains to determine the performance of maize varieties currently grown in the semi-arid regions and their compatibility with a commonly grown bean variety Katumani bean 1, KB 1. Sixteen maize varieties sold by seed stockists in the semi-arid regions were evaluated. The maize varieties comprised two composites, Katumani and KCB, and fourteen hybrids which included the DHO series (DHO 1, DHO 2, DHO 4), the Five series (H513, H515, H516), H614D, Duma 43, DK 8031, the Pannar series (Pannar 4M, Pannar 67, Panner 77 and Pannar 7M) and pioneer hybrid (PHB 3253). The maize varieties were grown either as sole crops or as intercrops with KB 1. The experiments were laid out in a randomized complete block design with a split plot arrangement and replicated three times. Maize variety was assigned to the main plot while the maize-bean intercrop system was assigned to the sub plot. Data collected included maize plant height at 57 days after emergence (DAE), bean plant height at 43 DAE, bean nodulation, plant shoot biomass, plant stand count, lodging percentage, DAE to 50% flowering and maturity of maize, maize and bean yield and yield components. Land equivalent ratio (LER) and Monetary Advantage (MA) indices were calculated to evaluate ecological and economic productivity of intercropping.

In 2008 short rains the component crops were severely affected by drought at Machakos before any data could be obtained while the beans component dried up at seedling stage at Mwea and Waruhiu. During 2009 short rains in Machakos, the maize component dried at the flowering stage but its shoot biomass data was collected. Results showed that performance of maize was not significantly affected by the bean component in a maize/bean intercrop system.

Maize flowered and matured significantly earlier in Mwea (60.3 and 108.1 DAE respectively) than in Waruhiu (75.3 and 118.5 DAE respectively). KCB and Katumani composites took significantly shorter time (88 DAE) to mature than the rest of the varieties. Among the DHO series, DHO 1 and DHO 2 took significantly shorter time to mature (average 101.6 DAE) than DHO 4 which took 122 DAE. The Five series took an average of 120.9 DAE to mature while the Pannar series took an average of 117.2 DAE to mature. DK 8031, Duma 43 and PHB 3253 took 112, 114.4 and 117.2 DAE respectively to mature. H614D took significantly the longest duration of 131.5 DAE to mature. Maize varieties differed significantly in grain yield and yield components. Significant differences in grain yield were noted in 2009 long rains with Duma 43 giving the highest grain yield of 2.9 t ha^{-1} while H614D gave the least grain yield of 1.33 t ha^{-1}. Variety PHB 3253 which was among the high yielding varieties had significantly more number of kernel-rows per cob. Harvest index was inversely related to time taken to physiological maturity. Thus, the early maturing varieties were more efficient in growth resource allocation to the grain. The late maturing varieties had low harvest indices. Varieties KCB, Katumani, DHO 1 and DHO 2, which had high harvest indices, manifested high lodging percentages.

Performance of beans was significantly affected by the maize component in the intercrop system and bean yields were depressed by 51.5% to 58.9%. The declined bean seed yields are also associated with reduced pods per plant and number of seeds per pod by the intercrop beans as opposed to the sole crop beans. However, according to LER and monetary advantage indices, intercropping was ecologically and economically superior to sole cropping.

The results indicate that varieties KCB, Katumani, DHO 1 and DHO 2 may be suitable for the semi-arid regions because they flower significantly early. Since several researchers have cited

early withdrawals of rainfall especially at flowering stage, these early maturing varieties can therefore escape drought if planted early in the growing season.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

The world's human population is estimated to have reached 8 billion and growing at 2.2 percent yearly (U.S Census Bureau, 2008). The Kenya population estimated at 38 million is growing at the rate of 2.8% per annum (Kenya National Bureau of Statistics, 2008). How to feed these growing ranks is a formidable challenge of all mankind.

Globally, maize (*Zea mays L.*) is essential for food security after rice and wheat (Campos *et al.*, 2004). The current global acreage of maize is over 142 million hectares and production records are over 637 million metric tonnes (MT) with USA taking the lead at an average yield of 3.41 MT per hectare (FAO, 2003). However, demand for maize in the developing world is expected to surpass both wheat and rice by 2020 meaning that maize supplies need to double to meet the demand (IFPRI, 2000). Maize is the most widely grown staple crop in Africa, and is the main food source for more than 300 million Africans. Maize requirements will increase from 282 million tonnes in 1995 to 504 million tonnes in 2020, posing a challenge to the developing countries (IFPRI, 2000; Pingali, 2001). Kenya's national maize production for year 2008 was 2.43 million MT or 27 million 90 kg bags against a national consumption of 3.15 million MT or 35 million 90 kg bags (Ministry of Agriculture, 2009a). The national maize output for the 2009 production season was projected to be about 2.16 million MT (Ministry of Agriculture, 2009a), thus a deficit of 190,000 MT was anticipated.

Grain legumes are important in the developing countries for dietary requirements. The bulk of protein intake in these countries comes from legumes with the common beans (*Phaseolus vulgaris L.*) taking the largest proportion (Mauyo *et al.*, 2003). Its importance in nutrition security in Africa is evident by multiple research work to improve its productivity per unit area and expand its productivity in marginal areas. Recently, development and utilization of biofortified bean varieties is an effective and sustainable strategy for reducing micronutrient deficiencies in Africa (Pan-African Bean Research Alliance, 2007). In the year 2008, total production of beans in Kenya was approximated to be 2.9 million 90 kg bags against an estimated consumption level of 6.6 million 90 kg bags (Ministry of Agriculture, 2009b). These growing deficits are a challenge to Kenya's food security, the chief millennium development goal (Mabesa, 2008). These deficits are compounded by increasing population hence the urgency to expand food production.

Production of maize and beans in Kenya is rainfed with small acreages under irrigation, especially for seed maize and export beans. Kenya is divided into seven agro-climatic zones governed by moisture regimes for growing major food and cash crops. Based on the agro-climatic zonation, 18% of Kenya's land mass is potentially arable with over 80% falling under arid and semi-arid lands. Agroecological zone *III*, the transitional zone, is the maize basket for Kenya. Further, over 80% of the cultivated land in ASALs is under maize and beans hence the need to improve productivity of these crops in these areas. Many maize and beans varieties have been released for cultivation in the various agro-climatic zones. Maize and beans are grown in a wide range of soils incluiding andosols. vertisols, phaeozomes, cambisols, luvisols, nitisols, acrisols and ferralsols (Muchene *at al.*, 1988).

Maize research in Kenya is organized to serve broadly defined adaptation zones. There are six maize growing agro-climatic zones in Kenya, which are defined by altitude, total rainfall per annnum, length of growing season and maturity period of adapted maize varieties (Hassan *et al.*, 1998; FAO, 2000). Since the early 1960s the objective of maize improvement research in Kenya was to develop maize germplasm to suit four environments: late maturing varieties for the highland tropics (HT), medium maturing varieties for non-moisture-stressed mid-altitudes (MAT), early maturing varieties for moisture-stressed MAT (semi-arid), and lowland varieties for the humid low tropics (LT) which covers the coastal belt. These environments were defined on the basis of altitude and moisture availability and are consistent with the CIMMYT's categories for maize mega environments (Hassan and Njoroge, 1996). Farmers use a variety of seed maize including local landraces, composites and hybrids. Many maize farmers may be growing maize varieties that are not really recommended for their regions.

Since maize is the main staple food for over 90% of the Kenya population, maize crop occupies a number of agro- ecological zones in the country compared to other crops (KARI, 2006; Ngesa, 1993; James, 2003) with the bulk of production coming from small holder farmers (Muui, 2007). In most areas, maize is intercropped or rotated with other crops such as common bean, pigeon pea, soybean, groundnut, dolicho beans, sweet potato, Irish potato or cowpea (Almelikinders and Louwaars, 1999). In the semi-arid areas maize is commonly intercropped or rotated with the common beans (Muthamia *et al.*, 2001). When intercropped with beans, maize is usually the primary component while the bean is the secondary component.

The major constraints to maize and bean production in the semi-arid regions are water stress and declining soil fertility (Diallo, 2004). These problems are compounded by increased frequencies of drought and continuous cultivation of the fragile ASALs (Gachimbi *et al.*, 2002; Mafongoya *et al.*, 2006; Nyariki, 2007). Rainfall variability from season to season has been shown to reduce maize yields in semi-arid eastern Kenya (Kinama *et al.*, 2007). These constraints have led to a corresponding decline in crop yields, hence food insecurity, dependence on food aid and environmental degradation. As a result, maize and bean yields have considerably declined to less than 1 t ha^{-1} and 0.5 t ha^{-1}, respectively (Jagtap and Abamu, 2003). However, there exists potential to boost maize and bean yields to 6 t/ha and 5t/ha respectively through deploying genes of drought tolerance and use appropriate agronomic practices. In 2006, average maize grain yield in Kenya ranged from 1.35 t/ha to 1.75 t/ha (Economic Review of Agriculture, 2006). A lot of research has been done in an effort to counter these problems. Breeding programmes have released drought tolerant maize and bean varieties of short cycle and inherent adaptability as a priority for addressing food deficit problems in the ASALs. Maize-bean intercropping has been promoted to increase productivity per unit area and to diversify risks in times of poor weather. In their study, Mafongoya *et al.* (2006) suggested that legumes can be used to diversify farm system productivity. Thus, during harsh conditions, farmers who practice intercropping can at least get a portion of either crop (Trenbath, 1999).

1.2 Problem Statement and Justification

Maize is widely grown and a highly valued staple food crop in Kenya. Despite its importance, its yield is very low, thus creating food deficits. Households in the semi-arid areas are net importers of maize staple (Kinama *et al.*, 1997). Droughts which are associated with late arrival and early withdrawal of rains culminating to inadequacy and poor distribution are cited as the major constraints to maize production and productivity in the semi arid areas (Gachimbi *et al.*, 2002; Diallo, 2004). This phenomenon adversely affects maize crops which account for more than 80% of the total cultivated land in the semi arid areas. Rainfall in these regions is bimodal with the October-December short rains season being more reliable than the March-June long rains season. Average rainfall in the ASALs of 250 – 300 mm is below the optimal 600 - 800 mm required for a good maize crop in the tropics (Kinama *et al.*, 1990).

The frequent droughts are associated with expansive crop failure thus heightened food insecurity (Mwikya, 2009). However, to cope with the vagaries of droughts farmers have adopted drought tolerant maize varieties and maize-bean intercropping as a risk diversification strategy (Muthamia *et al.*, 2001). Farmers who intercrop maize with beans are assured of some yield per unit area. Breeding activities by the Kenya Agricultural Research Institute, Kenya Seed Company and private companies have produced what are considered to be drought tolerant maize varieties. Varieties Katumani and Katumani composite B (KB 1) were developed for drought escape and avoidance via early maturity (Mugo *et al.,* 1998). The Kenya Seed Company released the dryland hybrids, DHO 1 and DHO 2, in 1995. These maize varieties alongside other varieties have been adopted for cultivation. The National Drylands Research Centre-Katumani developed a drought tolerant bean variety KB 1 which is widely adopted for intercrop and sole crop systems in the region. Various researchers have emphasized the development of drought tolerant crop varieties of short cycle as a priority in addressing the food deficit problems in the ASALs (Hornetz *et al.,* 2000; Shisanya, 2002). Despite these efforts to deploy drought tolerance in maize and in addition tailored cropping systems, crop failures due to drought persist. Intercropping of maize with legumes such as common bean, pigeon pea and cowpea has been widely practiced in pursuit of improved productivity per unit area and resource use efficiency. The liberalization of the seed industry in 1993 has led to many players that trade in seed (Nyoro, 2003; Waiyaki *et al.,* 2006). As a result, farmers have access to a wide range of seed maize comprising composites, hybrids and even local materials hence the risk of growing what may not be recommended for these regions.

A significant knowledge gap exists in the adaptability of the currently grown varieties and the extent of drought tolerance of the so called drought tolerant maize varieties recommended for the semi arid regions. Farmers may not be growing what is really recommended for these regions. Further, maize plus bean intercrops, which are most prevalent in these areas, may not necessarily give the best returns in terms of yield or cash because farmers do not necessarily select the most compatible maize varieties for intercropping. Little has been published on the compatibility of these maize varieties with the most commonly grown bean varieties.

Moreover, studies on maize-bean intercropping have highlighted contrasting results on the effect of intercropping on maize and bean yields.

Clear demonstration of the performance of the currently grown varieties may influence decision making of farmers, government (ministry of agriculture), maize seed stockists, Non-governmental organizations (NGOs) and other agricultural sector stakeholders in terms of which maize varieties and cropping system are most suitable in the semi arid areas of Kenya. Therefore, this study was designed to evaluate the agronomic performance of farmer-preferred maize varieties and the performance of these varieties under sole and bean-intercrop systems in the semi-arid areas of Kenya.

1.3 Objectives

This study was conceived with the following specific objectives:

1. To determine the agronomic performance of maize varieties that are currently grown in the semi-arid areas.
2. To determine the compatibility of maize varieties that are currently grown in semi-arid areas with KB 1 bean variety under an intercrop system.

1.4 Hypotheses

1. All maize varieties grown in the semi-arid areas of Kenya are drought tolerant.
2. All maize varieties grown in semi-arid areas are compatible with KB 1 bean variety under an intercrop system.

CHAPTER TWO: LITERATURE REVIEW

2.1 Importance of maize in food security

Maize (*Zea mays L.*) is the most important staple crop in Kenya for over 90% of the population with the small holder farming systems accounting for about 75-80% of the total production (Muui *et al.*, 2007). Maize provides more than a third of the calories and proteins consumed in the country (Jayne *et al.*, 2001; Wekesa *et al.*, 2003; CIMMYT, 2009). The per capita consumption of maize in Kenya is approximately 125 kg per year (Pingali, 2001). Its key importance in food security is evidenced by the total area under maize crop. Virtually every farmer in the country grows maize even in the harshest environments. The main food crop consumption levels in the year 2008 were estimated to be: maize - 36 million 90 kg bags, wheat - 10 million 90 kg bags, rice - 0.3 million 90 kg bags, beans - 6.5 million 90 kg bags and Irish potatoes - 3.4 metric tonnes (Ministry of Agriculture, 2009).

When the national food production levels are constrained, maize grain importation takes the greatest share of the government expenditure on food importation. Further, food security in the country is pegged on the number of maize grain bags harvested or the projected maize grain harvest. The strategic grain reserve in the country which is majorly maize grain reserve has been proposed to be raised from 4 million to 6 million 90 kg bags by the end of 2010/2011 financial year (Ministry of Agriculture, 2009). These statistics show the importance of maize in food security in the country. The initiation of a comprehensive maize research program in 1955, which developed and released more than twenty varieties in the ensuing five decades (Hassan and Karanja, 1990) clearly shows the importance of maize in the country. Correspondingly, the adoption of maize varieties post-1965 was faster than the spread of hybrid maize among U.S. Corn Belt farmers in the 1930's and 1940's (McCann, 2005). Projecting to the future, maize, with its versatile production systems, high yield potential and ease of processing, marketing and storage for consumers has considerable potential in reversing the downward vicious cycle of food production in Africa. Since maize is the principal staple food crop produced and consumed by most households in Kenya, it is viewed to be a socially, economically and politically important crop (Brooks *et al.*, 2009).

2.2 Constraints to maize production in semi-arid areas

Maize yields have been on the decline as indicated by the yield gap between experimental research station plots and average yields that farmers typically realize on their farms. Generally, declining per capita food production is attributed to biotic and abiotic stresses (Muchena, 2000; DeVries and Toenniessen, 2001). The biotic constraints include insect pests, diseases and weeds while the abiotic constraints comprise water stress, high temperatures and low soil fertility. Other constraints include lack of certified seed, high prices of farm inputs and high cost and unavailability of farm labour (Almelikinders and Louwaars, 1999; Pingalis, 2001; Vanlauwe *et al.*, 2008). The significance of these factors varies across Kenya's agro-ecological zones (Mwangi *et al.*, 2004). However, drought and declining soil fertility are frequently cited as the most limiting factors to maize production and productivity in the semi-arid tropics (Diallo *et al.*, 2004). Low and poorly distributed rainfall constrains production at flowering and tasseling stages (Kinama *et al.*, 1990).

Attack by insect pests especially the stem borers is consistently cited as a major constraint to maize production everywhere in the country (Hassan *et al.*, 1998; De Groote, 2002). Stemborers, including *Chilo partellus, C. orichalcociliellus, Busseola fusca, Eldana saccharina and Sesamia calamistis*, are estimated by Kenyan farmers to cause losses of around 15 per cent and in some areas are recognized as the most severe pest problem facing maize production (De Groote, 2002; Mugo *et al.*, 2002) by contributing up to 80% grain yield losses (Kfir *et al.*, 2002). The spotted stem borer (*Chilo pertellus*) and the African stem borer

(*Busseola fusca*) are of greater economic importance in Kenya (Songa *et al.*, 2001 and Songa *et al.*, 2002a). Stem borers are most destructive at the larval stage when they tunnel inside the stalk after hatching thus making them very difficult to control. Once inside, their feeding may lead to dead heart, reductions in the number of ears, or structural damage which predisposes the plant to lodging (Nderitu, 1999; Mugo *et al.*, 2001). In some cases, the pests also attack maize ears making the cobs vulnerable to cob rots, such as *Aspergillus flavus*, which produce harmful aflatoxins. Other maize insect pests include field pests such as African armyworm, African bollworm, maize aphids, cutworms, leafhoppers, white grabs, termites and storage pests which include angoumois grain moth, the larger grain borer, the lesser grain borer, maize weevil and the red flour beetle. Diseases of economic importance include grey leaf spot, head and ear smut, northern leaf corn blight, maize streak virus and ear rots. Weeds of high economic impotance include purple witch weed (*Striga* spp.), couch grass (*Cynodon dactylon*) and *Cyperus rotundas.*

Soils in the semi-arid regions have been over-cultivated, eroded and thus highly depleted of nutrients. Several decades of nutrient depletion have transformed originally fertile soils that yielded 2 to 4 tonnes/ha of cereal grain into infertile ones where cereal crop yields of less than 1 ton/ha are common (Qureshi, 1991; Swift *et al.*, 1994; Kapkiyai, 1996; Bekunda *et al.*, 1997). Besides, the semi-arid areas are experiencing a profound change due to rapid population growth partially caused by increased migration from densely populated high potential areas to these marginal rainfall areas in search of new farmland (Gachimbi *et al.*, 2002). When they move, farmers continue to use the production technologies common in their place of origin, but which are inappropriate to the conditions in the new area and sometimes have disastrous consequences to the natural resource base of the semi-arid lands. This migratory trend has increased the population density in semi-arid areas, intensifying pressure on land and heightening the risk of further degrading soils in these zones (Kinama, 1997 and Gachimbi *et al.*, 2002).

Land degradation is becoming a significant problem in the semi arid regions (Stoorvogel *et al.*, 1993 and Smaling, 1998). Enormous quantities of nutrients are mined from the soils or lost from the system during cultivation resulting in reduced quantities of organic matter and low levels of N and P. Semi-arid land soils vary in depth depending on parent material and slope. They are generally low in organic matter and deficient in nitrogen and phosphorus but with adequate levels of Potassium (Kwabiah *et al.*, 2003). Low infiltration rates and susceptibility to surface sealing make the soils prone to erosion as heavy rains fall mainly at the beginning of growing seasons when the land is bare (Jaetzold and Schimidt, 1983; Kilewe and Mbuvi, 1987; Gachimbi, 1996). Signs of declining soil fertility in semi-arid regions are characterized by weak and stunted crops, low yields, failure of crops to flower, appearance of weeds characterizing poor soil fertility, hard and compacted soils which are easily eroded (Gachimbi *et al.*, 2002).

Drought is prioritized as the major constraint to maize production and productivity in the semi-arid regions of Kenya. The arid and semi-arid lands that cover approximately 80 per cent of Kenya have long experienced water shortages and drought due to unreliable and poorly distributed rains. Maize and other food crop yields in these regions have been seriously depressed putting lives and livelihoods at greater risk (Hassan *et al.*, 1998). The problem of recurrent droughts is being compounded by climate change whose effects are damaging to livelihoods in the ASALs. The phenomenon of droughts is the main reason why this region is a net importer of food maize during most years (Hassan *et al.*, 1993).

Other major constraints to small scale farmers include lack of seed, low use of fertilizers, poor storage facilities and lack of farm labour. Seed maize is expensive thus many farmers usually recycle their seed including the hybrids. Recycling of seed is associated with compromised maize grain yield. The informal seed sector and unscrupulous seed traders have increased use of uncertified seed maize hence contributing to reduced yields (Waiyaki *et al.*, 2006). Low and inefficient use of fertilizer and manures is compounding the problem of declining productivity per unit area. Lack of good storage facilities is a constraint which has led to fatal aflatoxin contamination. Deaths have been reported in southeastern Kenya following consumption of aflatoxin contaminated maize. Land preparation in these areas relies on oxen draught or tractor power. Due to the mechanization dilemma associated with semi-arid areas, land preparation is always late, seasons are prolonged and the crops do not get sufficient water requirements for growth. Every day planting is delayed may lead to about 1-2% maize grain yield loss (AIC, 2002).

2.3 Effects of drought stress on maize production

By definition drought stress is a water deficit factor that limits resource capture and utilization (Karteji *et al.*, 2003). Rainfall is the single most important factor affecting agriculture in Africa, largely determining the agricultural potential, the crops grown, the farming systems followed and the sequence and timing of growing operations. Farmer and Wigley (1985) conceived three categories of drought. One, meteorological drought, when precipitation is significantly below expectation for a given time of year and location. Two, hydrological drought, when the water resources used for agriculture, human and animal consumption and industry become depleted. This is usually manifest in low levels of rivers, lakes, reservoirs and ground water. Three, agricultural drought, when water supplies used directly for agriculture are scarce and there is a constantly high soil moisture deficit over the growing season.

Semi-arid areas depend solely on rain-fed agriculture, thus, this study will confine the definition of drought to meteorological drought. Meteorological drought leads to depletion of soil moisture and this almost always has an impact on crop production. Drought may be prolonged due to a total failure of rains, but it is more likely to be sporadic, and to result from rains which start late and/or finish early. Entirely, the erratic nature of drought impedes breeding for drought tolerance.

Drought stress of short duration is common during the life cycle of maize in rainfed production areas. Substantial reductions in grain yield can be attributed to unfavorable production environments, of which water stress is a major limiting factor (Boyer, 1982). Drought decreases water availability hence changing the plant water status, which in turn affects the gaseous exchange in the short term and carbon balance in the long term (Katerji *et al.,* 2003). Drought affects maize yields by restricting season length and through unpredictable stress that can occur at anytime during the cropping cycle (Edmeades *et al.,* 1994). Drought occurring at flowering leads to greater yield losses than when it occurs at other developmental stages (Grant *et al.,* 1989; Cakir, 2004; Zaidi *et al.,* 2004). In addition, by flowering time farmers can no longer adjust management practices, such as fertilizer application, weed control and replanting (Myers, 1985). Water deficit lasting only one or two days during tasselling or pollination may cause as much as 22% reduction in yield (Hall *et al.,* 1981; Moser *et al.,* 2006). Deployment of drought tolerance and provision of yield stability is thus an inevitable part of the solution to cut yield losses (Aslam, 2007). However, agronomic interventions also have their role, since genetic solutions are unlikely to close more than 30% of the gap between potential and realized yield under water stress (Edmeades *et al.,* 2004).

2.3.1 The magnitude of maize grain loss attributed to drought

Droughts have been associated with significant maize grain losses throughout Kenya with the vulnerable semi-arid areas being the most hit. Depending on the severity of drought, yield losses can go up to 100%. For example, a 60% production decline was reported during severe drought of 1991/ 1992 in southern Africa (Rosen and Scott, 1992). Most areas of Southeastern Kenya experienced a 100% crop failure from drought during 2008/09 cropping seasons. Moreover, during the last three years, rainfall has been deficient leading to crop failure in the drought vulnerable areas, thus famine and death of humans, livestock and wildlife have been reported (Mwikya, 2009). This led to the Government of Kenya's declaration of the famine a national disaster and formation of a Special Programmes Ministry to handle food relief and drought recovery activities (Mwikya, 2009).

Maize yield losses due to drought are expected to increase with global climate change as temperatures rise and rainfall amounts and distribution change in key traditional production areas (Campos *et al.,* 2004). Nyariki (2007) indicated that drought cycles seem to have shortened to every two to three years instead of the five to seven years in the past. These trends, coupled with an expansion of cropping into the fragile marginal areas, are generating increasingly drought-prone maize production environments. This poses a great challenge because the current varieties which are considered drought tolerant are succumbing to droughts. Hence the need to determine the performance of existing varieties recommended for the semi-arid regions. Overwhelming reliance on maize instead of the more drought tolerant sorghum, millets, cowpeas, and cassava often exaggerate crop losses, particularly during mediocre and poor seasons. In 2009, food prices were at record levels: maize prices were 40-110 percent higher than normal, while bean prices were 40-55 percent above normal, underlining the pressure on purchasing capacities already compromised by a series of poor harvests (Kenya Food Security Update, 2009).

2.3.2 Maize phenological stages susceptible to drought

Maize is highly drought-sensitive despite the fact that its C_4 metabolism confers a high photosynthetic rate combined with a relatively low transpiration rate. The degree of damage is usually dependent on the developmental stage in which water deficit is experienced. Since every phenological stage of maize has some susceptibility to drought, three stages: early growth stage when plant stands are established, flowering and mid-to-late grain filling stage, are considered critical (Mugo *et al.*, 1998). In the early growth stages, leaf growth is one of the most sensitive processes to drought (Tardieu *et al.*, 2000; Neves-Piestun and Bernstein, 2005). However, drought is reported to be devastating when it occurs at flowering and pollination (Shaw, 1977; Otegui, 1995; Cakir, 2004; Zaidi *et al.*, 2004) causing marked reductions in grain number.

Most droughts are occasioned by early withdrawal of rains when maize is just about to flower. However, when it affects plant stand at beginning of a season, drought can strongly curtail yield. Campos *et al.* (2006) quantified a 45–60% yield loss when drought stress coincided with flowering period. Yield reduction as high as 90% and an incidence of barreness reaching 77% were recorded by NeSmith and Retchie (1992) when plants were stressed in the interval from just prior to tassel emergence to the beginning of grain filling. Water stress slows ear growth, and consequently silk emergence, more than tassel growth or anthesis, resulting in a widening interval between anthesis and silking (Shaw, 1977; Grant *et al.*, 1989). In a classical study, Diallo *et al.* (2004), evaluated maize inbred lines in both stress and non-stress environments. The workers reported significant differences among the lines for grain yield, days to silking and ears per plant in both environments. They observed that, under drought stress, there was a delay in days to silking hence greater anthesis to silking interval (ASI) and a reduction in ears per plant. Probability of drought in maize growing environments in the tropics is highest at the start and end of the rainy season and therefore the crop is prone to facing water deficit at establishment and flowering/grain filling stage (Banziger and Diallo, 2001).

2.3.3 Maize physiological traits affected by drought stress

The key physiological traits affected by drought can be expressed at cellular and whole plant levels. At the cellular level, abscisic acid (ABA) accumulation is important. ABA is generated mainly in the roots, where it stimulates growth. It moves to the leaves where it causes leaf rolling, stomatal closure and accelerates leaf senescence (Cramer and Quarrie, 2002). This happens even before hydraulic mechanisms reduce leaf turgor (Zhang *et al.*, 1987). It seems likely that it is this "root signal" that causes the plant to reduce water loss. Thus, ABA is a plant growth regulator that helps the plant to survive drought stress but does not seem to contribute to production under drought. Abundant evidence shows that ABA is involved in turning on many stress-responsive genes and that it plays a key role in cell growth regulation, especially during flowering (Landi *et al.*, 2001). When ABA passes to the grain, it contributes to the abortion of tip grains during grain filling. Under mild to moderate drought stress, cell expansion is inhibited. This manifests itself in reduced leaf area expansion, followed by reduced silk growth, then reduced stem elongation, and finally reduced root growth, as stress intensifies (Liu *et al.*, 2005). Under severe drought stress, cell division is inhibited, so even if the stress is alleviated the affected organs may lack the cells for full expansion.

At whole plant level, drought can affect maize production by decreasing plant stand during the seedling stage, by decreasing leaf area development and photosynthesis rate during the pre-flowering period, by decreasing ear and kernel set during the two weeks bracketing flowering, and by decreasing photosynthesis and inducing early leaf senescence during grain-filling (Liu *et al.*, 2005). Additional reductions in production may come from an increased energy and nutrient consumption of drought adaptive responses, such as increased root growth under drought.

2.3.4 Maize traits associated with tolerance to drought

Maize in the developing world is almost exclusively grown under rainfed conditions with minimal input and management by the small scale farmers that grow it. Although drought can strike at any time, the plants are most prone to damage due to limited water during establishment and flowering time (Cakir 2004; Zaidi *et al.,* 2004). Seedling survival, biomass production, unrolled leaves and ability to recover after water potentials are favourable are the morphological traits commonly used as main selection criteria for seedling drought tolerance (Banziger *et al.*, 1997). Mugo *et al.*, (1998) indicated that, water status traits like leaf abscisic acid concentration, osmotic adjustment, water uptake, and leaf waxiness among others could potentially be useful in selection for seedling stage drought tolerance.

At flowering and pollination stages, synchrony between male and female flowering time is particularly important (Edmeades *et al.,* 1999). This synchrony is called the Anthesis Silking Interval (ASI). When drought stress occurs a few days before and during flowering period, a delay in silking is observed resulting in an increase in the silking anthesis interval (Shaw, 1977; Hall *et al.,* 1982; Grant *et al.,* 1989; Westgate and Bassetti, 1990; Bolanos and Edmeades, 1993) thus decreased grain yield. The ASI has been considered as a precise secondary trait, which has high heritability and is correlated with grain yield under drought stress (Hall *et al.,* 1981, Westgate and Boyer, 1986, Bolanos and Edmeades 1993). Selection for short ASI can contribute to a high ratio of ear setting to grain yield (Bolanos *et al.*, 1993; 1996; Ribaut *et al.,* 1997; Edmeades *et al.,* 1999).

Regulation of carbohydrates is also of interest to researchers working on drought tolerance. Diminished supply of carbohydrates to the developing floral and seed organs that may occur due to drought reduces seed set (Koch, 1996). Stress at early kernel development has a much greater negative effect on final yield than stress at a later stage of kernel filling. Abundant evidence shows that absissic acid (ABA) is involved in turning on many stress-responsive genes (Finkelstein and Gibson, 2001), and that it plays a key role in cell growth regulation, especially during flowering. Therefore, genes involved in ASI, genes in the carbohydrate production pathway, and genes in the ABA production pathway or genes affected by ABA itself, can be very important for the development of drought resistant maize. However, due to the complexity of the genetic mechanism of drought tolerance in maize, the yield trait is strongly influenced by both genotype and environment thus, genotype-by-environment interaction is remarkable (Guo *et al.*, 2008)

2.3.5 Traits of maize varieties bred for semi-arid areas

Plants can achieve drought tolerance through different approaches, involving combinations of escape, avoidance and tolerance of the effects of water deficit on the growth and development processes that impact yield (Mugo *et al.*, 1998). Many different traits have been proposed as selection targets to improve levels of drought tolerance and yield under water deficit conditions. Many of these putative drought tolerance traits have been recommended for indirect selection and used as targets for genetic analysis (Ludlow and Muchow, 1990; Edmeades *et al.* 2000). In maize, drought tolerance at seedling and flowering stages is key (Mugo *et al.*, 1998).

Traits for maize adaptability in the semi-arid areas can be grouped into three major categories: drought escape, drought tolerance (Blum, 1988) and water use efficiency. Under drought escape, the plant completes critical physiological processes before drought sets in, while drought tolerance implies the presence of physiological mechanisms that allow the plant a reasonable level of production despite the presence of drought (Blum, 1988). In their attempts to expand maize production in semi-arid and marginal areas, breeders have developed quick maturing maize varieties by selecting for early maturity to escape drought (Dowker, 1981; Mugo and Njoroge, 1997). Concequently, varieties katumani composite and KCB were developed and improved for early maturity and drought escape (Mugo *et al.*, 1998). Features of drought tolerant maize varieties include early silking in synchrony with pollen shedding, reduced ASI, reduced tassel size, longer shedding periods for the tassels, increased ears per plant, delayed senescence and relatively high leaf chlorophyll during late grain filling (Njoroge, 1982; Ashley *et al.*, 1992; Zaidi *et al.*, 2002). Earliness is usually as important as yield in breeding varieties for cultivation in semi arid areas (Njoroge, 1992). Tolerance to water stress is a desirable attribute built in such varieties if yields are to be stabilized under erratic rainfall conditions.

Harvest index (HI) which reflects the partitioning of photosynthate between the grain and the vegetative plant is an important trait for drought tolerance. Improvements in harvest index emphasize the importance of carbon allocation to grain production. The harvest index is the proportion of grain dry matter to total shoot dry matter. Tropical maize varieties usually have higher harvest indices than temperate maize (Costa *et al.*, 2002; Earl and Davis, 2003). However, HI of tropical maize varies considerably and seems to depend on variety, crop management, growing season, among other factors (Hay and Gilbert, 2001).The HI can be very low on soils with decreasing water supply (Bolanos and Edmeades, 1993).

2.4 Effect of intercropping on performance of maize-bean intercrops

Intercropping is the growing of two or more crop species simultaneously on the same piece of land. Intercropping cereals with legumes is a common practice that dominates most of tropical subsistence agriculture (Wiley, 1979; Hauggaard-Nielsen *et al.*, 2001; Tsubo *et al.*, 2005). Intercropping maize and common bean was commonly practised in the higher rainfall areas of Kenya and, as population pressure increased, the practice has spread to the semi-arid regions (Pilbeam *et al.*, 1994). Intercropping has been adopted by the majority of smallholder farmers mainly for dietary reasons. Maize is normally grown as the principal crop while the legume is a secondary crop (Walker and Ogindo, 2003).

Intercropping systems are regularly reported to be more productive than sole crops grown on the same area of land (Davis *et al.*, 1981; Francis *et al.*, 1982; Harris *et al.*, 1987; Carlson, 2008). The usual explanation given for this advantage is that the species make partially complementary use of resources, in either time or space, and thus use resources more efficiently (Pilbeam *et al.*, 1994). Intercropping studies by Willey and Osiru (1972), indicated that growing cereals with beans gives higher yields than when each crop is grown in sole culture. In their study, maize-bean mixtures yielded 38% more than pure stands. Dawo *et al.* (2008) indicated that maize can profit from the presence of the companion legume by utilizing nitrogen fixed by rhizobia-legume symbiosis. However, working in a semi-arid environment Southeastern Kenya, Mwangi *et al.*, (2001) concluded that intercropping common beans and maize considerably suppresses the yield of the former.

The merits of intercropping have been well documented. It is viewed as a production strategy by most small holder farmers towards increased efficiency in use of environmental resources by plants of different heights, rooting systems, nutrient requirements (Andrews, 1972; Baker and Yusuf, 1976; Willey 1979; Willey and Osiru 1972), checking soil erosion by beating action of rain and direct sunshine. Further intercropping is viewed as an insurance against crop failure (Okigbo, 1987), reduces the spread of diseases and pests (Kayumbo, 1976; Mukiibi, 1976) and where legumes are grown with grasses, the grasses may benefit from nitrogen fixed by the companion legume (Agboola and Fayemi 1971; Trenbath, 1972). Intercrops smother weeds in cereal crops (Odhiambo and Ariga, 2001). Once the crops are established increased leaf cover helps reduce weeds by cutting light transmission to the weeds below (Beets, 1990).

When two or more crops are grown on the same field, the risk for crop failure is minimized because the crops vary in periods and patterns of growth and exploit resources at different depths and are affected by different diseases. If one of the crops fails, either due to drought, pests or diseases, there still is a harvest from the other crop (Helenius and Jokinen, 1994). This increases food security upon diversification of crop risks. In good years, the yield of two crops grown on the same field as an intercrop is often higher than the yield of the same crops grown separately.

Reduction of disease spread and pest infestation in intercrops is consistently reported. Working in Uganda, Sekamatte *et al.* (2003), reported that intercropping maize with various legumes caused a significant reduction in termite attack, reduced loss in grain yield of maize and increased the nesting of predatory ants in maize fields. Further, they indicated that maize-soybean and maize-groundnut intercrops had significantly lower termite attack than maize-common bean intercrops. Termites can cause yield losses of between 10% to 30% by their feeding damage on roots, stem bases and leaves resulting to plant lodging and damage of cobs (Sekamatte *et al.*, 2003). Integrating *Phaseolus* beans into push-pull technology developed for stem-borer and striga control in maize-based cropping systems reported significantly lower *Striga hermonthica* counts and stem-borer damage (Khan *et al.*, 2009). Similarly, significantly higher maize grain yields were recorded in bean integration plots.

Increased plant diversity in intercropped fields may reduce the impact of pest and disease outbreaks by providing more habitat for predatory insects and increasing the distance between plants of the same crop. Other ecological benefits of intercropping include less land needed for crop production, reduction of pesticide and herbicide use, and a reduction in soil erosion. In intercrop systems, insect pests and weeds are reduced (Szumigalski *et al.*, 2005; Poggio, 2005; Banik *et al.*, 2006). The distance between plants of the same species is increased when crops of different species are planted in between them (ICIPE, 2000). Species differ in competitive ability with weeds. The differences in competitive abilities are due to variations in plant characteristics, environment and relative emergence dates (Songa *et al.*, 2007). Shading of the soil and competition for nutrients will suppress weed germination and growth. Intercropping studies by Odhiambo and Ariga (2001) and Oswald *et al.*, (2002) showed that intercropping maize with beans suppresses striga infestations.

2.5 Resource use in intercropping systems

Maize plus bean intercropping, widely practiced in small scale subsistence agriculture involves little or no inputs at all (Walker and Ogindo, 2003), thus full dependency on the natural resource base. Adoption of intercropping systems by subsistence farmers may not only be explained by socio-economic reasons, but also by a more efficient use of natural resources (Sinoquet and Cruz, 1995; Hauggaard-Nielsen *et al.*, 2001; Tsubo *et al.*, 2005). Greater resource use efficiency by the component crops in the intercropping is the primary cause of obtaining intercropping advantages (Willey, 1979; Chowdhury and Rosario, 1994). Canopy structures and rooting systems of cereal crops are generally different from those of legume crops and in most cereal–legume intercropping, cereal crops form higher canopy structures than legume crops, and the roots of cereal crops grow to a greater depth than those of legume crops. This suggests that the component crops probably have differing spatial and temporal use of environmental resources. Consequently, yield is a valid indicator of the competitiveness of that component for the scarce growth resources under any given set of conditions. It was indicated by Francis (1987) that, over centuries, farmers selected mixtures of species to make better use of rainfall and native soil fertility and the choices of patterns were made among the best performing combination observed through experience. Combination of crops is determined by the length of growing season and the adaptation of crops to particular environments.

Productivity of a cropping system comprising intercrops of two or more species depends upon the degree of complementarity between them. Enhancing productivity of maize and bean intercrops requires improving the interspecies complementarity or reducing competition effects (Rezende and Ramalho, 1994). This might be achieved through manipulation of plant arrangements, plant densities and planting compatible cultivars (Rao and Mittra, 1990). Ofori and Stern (1987) proposed that the growth and yield of the legume component is reduced markedly when intercropped with high densities of the cereal component. In a maize-bean intercrop system, increasing maize density three-fold, from 18, 000 to 55, 000 plants ha^{-1}, reduced bean leaf area by 24% and seed yield by 70% (Gardiner and Craker, 1981).

Spatial arrangement of component crops is one of the most important agronomic factors that determine whether an intercrop system will be advantageous or not with regard to yield gains (Natarajan and Shumba, 1990). Distinct row arrangements, in contrast to arrangements of component crops within the same row or hill, improves the amount of light transmitted to the lower legume. Such arrangements can enhance legume yields and efficiency in cereal-legume intercrop systems (Mohta and De, 1980). Productivity of the intercrop systems can be enhanced through selection of maize cultivars suitable for intercropping as they have different growth habits, which may result in different interactions with beans in the intercrop. In semi-arid Kenya, farmers tend to mostly grow one specific bean cultivar, KB 1, which was specifically bred for these regions. Working in Zimbabwe, Davis and Garcia (1983) pointed out that, maize cultivars with short internodes and broad leaves shade beans relatively more than cultivars of a similar height with long internodes and narrow leaves. Tall cultivars generally give more shadding to understorey crops.

Solar energy can not be captured and stored for later use in the way other natural resources are managed. Light is instantaneously available and needs to be instantaneously intercepted and used if the resource is going to be useful to produce photosynthate and plant dry matter (Tsubo *et al.*, 2001). If water and nutrients are not limiting, then light is frequently the most limiting resource (Willey, 1979; Tsubo *et al.*, 2003). Competition for light occurs between leaves rather than between the plants, hence plants grow taller to position their leaves above the others to intercept solar radiation. Plants that are favoured in an intercrop mixture are those whose leaves are positioned to intercept solar radiation. Leaves that receive below compensation point will soon perish (Tsubo *et al.*, 2001). Comparing radiation use efficiency of sole crop/intercrop systems, Tsubo *et al.* (2001) observed that intercrops intercepted more radiation while sole maize presented higher radiation use efficiency than the other cropping systems. Further, in a modeling study to understand radiation interception and use by a maize-bean intercrop canopy, Tsubo and Walker (2002) reported that intercropping was equivalent in growth efficiency to the sole cropping whereas beans showed greater radiation use efficiency in intercropping than in solecropping. Erect growing crops may provide support for intercropped climbing species. The support allows the climbing species to achieve greater vertical separation of the leaves which may improve the photosynthetic effectiveness of the leaves of the climbers. Climbing bean varieties are usually intercropped with maize and many researchers have studied the compatibility of climbing bean varieties in maize intercrops (Geleta *et al.*, 2004; Gebeyehu *et al.*, 2006) and cited the importance of the maize compoenent in offering support to the beans.

Long-term advantages in soil nutrient use of intercropping systems over sole cropping may be related: to more complete soil cover which leads to reduced nutrient losses through runoff, erosion and leaching and to more favourable micro-climate (Anil *et al.*, 1998); more biomass production which leads to higher nutrient uptake and less leaching; more crop residues with their positive effects on physical and biological soil properties, better synchronization of nutrient release from organic matter and uptake by crops which leads to less leaching (Whitmore and Schroder, 2007); higher biological nitrogen fixation; and more efficient mobilization of soil nutrients such as exudation, root growth and mycorrhizae by one or more transfer to the other component crop (Sinoquet and Cruz, 1995; Ibeawuchi, 2007).

Maize can profit from the presence of intercropped legumes by utilizing nitrogen fixed by rhizobia in root nodules, although in some cases competition between the two plant species can also decrease cereal grain yields. Increased N uptake could come about either through lowered inter-plant competition for soil N because of the use of atmospheric N by the legumes or because of direct transfer of fixed N from the legume to the nonlegume. Such transfer could occur through decomposition and mineralization of legume root exudates or through inter-plant hyphal connections of mycorrhizas (Dawo *et al.*, 2008). Systems that intercrop maize with a legume are able to reduce the amount of nutrients taken from the soil as compared to a maize monocrop. 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. However, when nitrogen fertilizer is not applied, intercropped legumes will fix most of their nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi *et al.*, 2007).

Water is often the most limiting factor for growth in the semi-arid areas of Kenya. Lack of water during vegetative and/or reproductive growth stages is one of the most limiting factors for bean growth (Boutraa and Sanders, 2001). The ability of plant roots to explore a large soil volume and extract water is very critical. The use of water in an intercrop provides a condition in which competition for a limited resource might occur. If the component crops have different rooting habits, intercrops may be more efficient in exploring a larger soil volume for water and nutrients. In analyzing the intercooperative interaction between intercrops, Ibeuwuchi (2007) suggested that intercropping enhances water use efficiency.

2.6 Indices for evaluating the performance of intercropping systems

Various indices have been proposed for examining intercropping yield advantages over sole cropping (Willey, 1979; Mead and Willy, 1980; Banik *et al.,* 2000; Ghosh 2004; Ageguebu *et al.,* 2006; Banik *et al* 2006; Dhima *et al.,* 2007). Broadly they fall into two categories, either they describe the overall advantage of the intercrop relative to the sole crop (Mead and Willey 1980; Azam-Ali *et al.,* 1990; Dhima, 2007), or they assess the relative performance of the components of the mixture in relation to their performances as sole crops (McGilchrist and Trenbath 1971). These indices include land equivalent ratio, relative crowding coefficient, competitive ratio, actual yield loss, monetary advantage and intercropping advantage.

The practical objective of evaluating intercrops embraces the aims and the constraints that determine the amounts of crops to be grown. It was suggested by Willey (1979) that, three criteria can be used when considering practical assessments of intercropping advantages. First, where intercropping must give full yield of a main crop and some yield of the secondary crop. It involves a situation where the primary requirement is for a full yield of the staple food or a commercial crop. The yield advantage occurs when there is a yield of the second crop and the second crop does not significantly affect the yield of the main crop. Second, where the combined intercrop yield must exceed the higher sole crop yield. This advantage criterion is based on the assumption that, unit yield of each component crop is equally acceptable and therefore the requirement is simply for maximum yield regardless of the crop from which it comes and thirdly where the combined intercrop yield must exceed the combined sole crop yield. A criterion of this kind considers factors which influence farmer decision making. It assumes that the farmer needs to grow more than one crop in order to guard against environmental risks, market risks, to satisfy dietary needs and to spread labour peaks. In this situation yield advantage occurs when intercropping results in higher yields than sole crops. This is the commonest situation in practice in the semi-arid regions of Kenya.

The land equivalent ratio (LER) is the most commonly used method as suggested by Willey (1979). The LER compares the yields from growing two or more crops together with yields from growing the same crops in monocultures or pure stands. The idea behind intercropping is to capitalize on the beneficial interactions between crops while avoiding negative interactions. Essentially, the LER measures the effect of both beneficial and negative interactions between crops. LER is defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping. When LER is equal to unity, there is no intercropping advantage in comparison to sole cropping. On the other hand, LER greater than unity implies that a larger area of land is required to produce the same yield of sole crop of each component grown separately than an intercropped mixture.

Willey's LER was challenged by Hiebach and McCollum (1987) arguing that LER was not an accurate technique for comparing relative production potentials of intercropping and solecropping systems. They suggested the use of the area time equivalent ratio (ATER) by redefining yield to be quantity per unit area per unit time. It takes into account the duration of the crop from time of planting to harvesting.

Economic performance of intercropping systems can be evaluated to determine whether maize yield and additional bean yield are sufficient to justify farmers to adopt intercropping. This can be reliably computed using the monetary advantage index (MAI).

According to Willey (1979), MAI can be computed as follows:

$$\text{MAI} = \text{Value of combined intercrop yield} \times \{(\text{LER} - 1) \div \text{LER}\}$$

The higher the MAI value, the more profitable is intercropping system (Ghosh, 2004). The calculations should be based on the prevailing mean producer prices of maize and beans in the region. Occassionally, higher LER values are associated with increased MAI (Ghosh, 2004; Dhima *et al.,* 2007).

Generally, in the evaluation of intercropping systems, several factors are included. The factors include competitive effects, relative production potential, labour requirements, water and nutrient use efficiency and socio economic impacts. Therefore a fair evaluation would require a team effort involving agronomists, crop physiologists, soil scientists and agricultural economists. Additionally, as suggested by Hildebrad (1976) and Weigett and Jolliffe (2003) the criteria for the choice of an evaluation index should be: common to all products and inputs, relatively easy to measure, capable of reflecting quality differences between the products, meaningful to the farmer in such a way that it helps in allocation of resources between competing uses and meaningful to the researcher so that new technologies can be compared with existing ones.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Experimental sites

The study was carried out in Machakos Agricultural Training Centre (ATC), Waruhiu Agricultural Training Centre and Kenya Agricultural Research Institute, Mwea. Machakos ATC is located 5 km west of Machakos town and about 70 km east of Nairobi with centre coordinates of 01° 32' S and 37° 14' E and at an altitude of 1575 metres above sea level (m.a.s.l). The centre is located in agroecological zone LM 5 and receives an annual rainfall of 400 mm to 700 mm with annual temperatures of 19.2 °C. The soils are well drained, dark reddish brown and sandy clay. Waruhiu ATC is in Githunguri in Kiambu district, about 50 km north west of Nairobi town with centre coordinates of 0° 56' S 37° 05' E and at an altitude of 2200 m a.s.l. It is located in agroecological zone UM 2 and receives mean annual rainfall of 1200-1400 mm with mean temperatures of 18.4 °C to 19.5 °C. The soils are well drained, extremely deep, dusky red to dark reddish brown, friable clay nitisols. The KARI-Mwea is in Kirinyaga south district, Central Province and is located at an altitude of 1140 m, latitude 0°, and longitude 37° 27'E about 160 km south east of Nairobi. The KARI-Mwea farm is 6 km east of the research station in agroecological zone LM 4 with annual rainfall of 450 – 900 mm and mean temperatures of 21° C. In all sites rainfall is bimodal with two rainy seasons called short rains (November to January) and the long rains (March and June). The first experiment was performed during the short rains (November 2008 to March 2009) while the second experiment was run during the long rains (April 2009 to September 2009). Soils were sampled before planting at 30 cm depth and analyzed for pH, carbon, CEC, macronutrients and micronutrients (Appendix 1).

3.2 Experimental design and treatments

The materials comprised sixteen maize varieties grown in the semi-arid regions. The varieties were bought from seed stockists in Machakos and Wote towns while the bean variety was obtained from Kenya Agricultural Research Centre, Katumani seed unit. They comprised the Five series hybrids, namely, H513, H515, H516; hybrids H614D, Duma 43, DK 8031, pioneer 3253; the dryland hybrids namely DHO1, DHO2, DHO4; the Pannar series namely Pannar 77, Pannar 7M, Pannar 4M, Pannar 67; and composites Katumani Composite B (KCB) and Katumani (Table 1). The test bean variety was Katumani Bean 1 (KB 1), a determinate bean variety developed by the National Dryland Research Centre-Katumani.

The treatments included maize varieties grown as sole crops, maize varieties intercropped with beans and sole KB 1 bean variety. These treatments were laid out in a randomized complete block design with a split plot arrangement and replicated three times. The maize varieties were assigned to the main plots while the cropping systems were assigned to the subplots. The experimental plot sizes were 5 m by 6.75 m. Maize was planted at hill spacing of 75 cm by 30 cm. In the intercrop treatments, one row of beans was grown between two rows of maize with intra-row spacing of 25 cm while sole beans were sown at hill spacing of 25 cm. The companion crops were sown at the same time at the onset of the rains.

The land was ploughed and harrowed to a moderate seedbed tilth. Planting was done at the onset of rains in October 2008 and March 2009 for the short rains season and the long rains season respectively. Two seeds were planted per hill at the recommended spacing. After emergence plants were thinned to one plant per hill. Fertilizer NPK 20-20-0 was applied at planting in each hole at the rate of 25 kg N/ha and 25 kg P_20_5/ha. DAP was not used as a source of N and P due to the high acidity associated with the soils of Waruhiu. At flowering maize was top dressed with 25 kg/ha N. The fields were kept weed free by hand weeding using hoes. Bean fly was controlled using Sumithion super® with active ingredients: 250 g/L fenitrothion and 12.5 g/L esfenvalerate.

Table 1: Description of maize and bean varieties used in the study

Variety	Year of release	Owner	Maintainer and seed source	Optimal production altitude (m.a.s.l)	Months to maturity	grain yield (t ha^{-1})
H513	1995	Kenya Seed Co.	Kenya Seed Co.	1200-1600	4-5	6-8
H515	2000	Kenya Seed Co.	Kenya Seed Co.	1200-1500	4-5	6-8
H516	2001	Kenya Seed Co.	Kenya Seed Co.	1200-1500	4-5	7-9
H614D	1986	Kenya Seed Co/ KARI	Kenya SeedCo. Ltd /K.A.R.I	1500-2100	6-9	8-10
Duma 43	2004	AgriSeedCo Ltd	SEEDCO Zambia	800-1800	4-5	6-7
DK 8031	2003	Monsanto	Monsanto	900-1700	4 - 4.7	6-8
DHO1	1995	Kenya Seed Co.	Kenya Seed Co.	900-1400	3-4	4-6
DHO2	1995	Kenya Seed Co.	Kenya Seed Co.	900-1400	3-4	4-6
DHO4	2001	Kenya Seed Co.	Kenya Seed Co.	900 - 1500	3-4	5-6
Pannar 77	2008	Pannar seed (PTY) Ltd	Pannar Seed (K) Ltd SA	800 – 1600	3 -4	4-6
Pannar7M	2008	Pannar Seed (PTY) Ltd	Pannar Seed (K) Ltd SA	900-1500	3-4	4-6
Pannar4M	2008	Pannar Seed (PTY) Ltd	Pannar Seed (K) Ltd SA	900-1500	3-4	4-6
Pannar 67	2001	Pannar Seed Company	Pannar Seed (K) Ltd SA	800 - 1600	4-5	5-6
PHB 3253	1995	Pioneer Hybrid	Pioneer Hybrid, Zimbabwe	800-1800	4-5	7-9
KCB	1967	Kenya Seed Co/ KARI	Kenya Seed Co/KARI.	900-1350	3-4	3-5
Katumani KB 1 (Kathika)	1987	KARI- Katumani	KARI-Katumani	1000-1800	2.5	1.2-1.5

Source: Kenya Plant Health Inspectorate Service, 2009: National Crop Variety List; KARI: Kenya Agricultural Research Institute; SA: South Africa; Co: Company

3.3 Data collection

Data collected comprised growth parameters of both crops such as bean nodulation and biomass, plant stand count, phenological development, stand count, lodging, yield and yield components, harvest indices and assessment of intercropping advantage using land equivalent ratio and monetary advantage indices. As a result of severe weather conditions during 2008 short rains in Mwea and Waruhiu, the bean component dried up at seedling stage before any data could be collected. On the other hand, no data could be collected in Machakos during 2008 short rains but bean yield and maize shoot biomass data were obtained before the crop dried up during 2009 long rains.

3.4 Determination of maize and bean plant height

Nine maize plants were sampled in each plot and measurements for height taken at 2, 4, 6, 8 and 10 weeks after emergence (WAE). Nine bean plants were sampled and measurements taken for height at 2, 4, 6 WAE. Plant height was measured as the distance from the soil surface to the tip of the plant.

3.5 Determination of bean nodulation and dry matter accumulation

Three bean plants were randomly selected for nodule count and biomass accumulation at 21 days after emergence and at 50% flowering. The bean plants were dug up gently, washed with water and the nodules recorded for each plant. The roots were discarded and shoot biomass was determined after oven drying at 70°C to a constant weight.

3.6 Determination of maize grain yield, yield components, shelling percentage and total stover weight

At physiological maturity in both seasons, maize was hand harvested from four rows of each plot equivalent to 13.16 m^2. The outer rows were regarded as guard rows and therefore were not harvested. Grain and stover were separated. Eighteen randomly selected cobs per plot were used for determination of maize yield components. Cob length was determined by measuring the full length of the cob using a 30 cm ruler. Number of kernel rows per cob and number of kernels per cob-row were determined by physical counting. Shelling was done by hand and four randomly selected cobs per plot were used to determine maize shelling percentage. After drying the shelled grain and the four unshelled cobs to 12.5% grain moisture content, 100 kernel weight, shelling percentage and grain yield were obtained. Four sets of 100 randomly selected maize kernels were weighed to determine 100 kernel weight per plot. Shelling percentage was obtained by expressing the weight of shelled grain per cob as a percentage of the total cob weight. Grain yield per plot was converted to tonnes per hectare. Total stover weight per plot was determined after the stover had dried to a constant weight.

3.7 Determination of bean seed yield and yield components

At physiological maturity, nine bean plants were randomly selected in each plot and all rows and number of pods per plant determined. The pods were shelled and number of seeds per pod determined. The beans were hand harvested in each plot in an area equivalent to 10.5 m^2. Bean seed yield and 100-seed weight were obtained after drying the beans to 15% seed moisture content. Four sets of 100 randomly selected seeds were weighed and 100 seed weight determined per plot.

3.8 Determination of maize harvest indices

The yields of maize grain per plot in t ha^{-1} and stover yield per plot in t ha^{-1} were used to calculate maize harvest indices. Crop harvest index (HI) is the ratio of grain weight to total plant weight (Costa *et al.*, 2002). Maize harvest index was used to reflect the partitioning of photosynthate between the grain and the vegetative plant thus the higher HI the greater efficiency of carbon allocation to grain production.

3.9 Assessment of intercropping productivity and monetary value

The yields of maize and beans were used to calculate Land Equivalent Ratios (LERs) and Monetary Advantage Indices (MAI) to evaluate the productivity of the intercrop system. LER was calculated as below (Mead and Willey, 1980):

$$\text{LER} = \left\{\frac{\text{Yield of intercrop maize}}{\text{Yield of solecrop maize}}\right\} + \left\{\frac{\text{Yield of intercrop beans}}{\text{Yield of solecrop beans}}\right\}$$

If LER =1, then there is no advantage of intercropping. If LER < 1 then intercropping reduces total yield and therefore not advantageous. If LER > 1, intercropping increases total yield thus advantageous. MAI was calculated as follows:

$$\text{MAI} = \text{Value of combined intercrop yield} \times \{(\text{LER} - 1) \div \text{LER}\}$$

The higher the MAI value, the profitable is the intercropping system. Average farm gate producer prices of Kshs. 20 per kg of maize and Kshs. 45 per kg of beans were used to calculate the value of maize and beans (Kenya Agricultural Commodity Exchange, 2009).

3.10 Data analysis

All data were subjected to analysis of variance (ANOVA) using Genstat statistical package (Lawes Agricultual Trust, Rothamsted Experimental Station, 2006, version 9). Differences among treatment means were compared and separated where appropriate using Fisher's Least Significant Difference (LSD) test at 5% probability level (Gomez and Gomez, 1984). Correlation analysis was done using SPSS 12.0 for windows. Maize varietal attributes that were subjected to correlation analysis include grain yield, DAE to 50% anthesis, DAE to 50% silking, DAE to 50% physiological maturity, number of ears per plant, cob length, number of rows per cob, 100 kernel weight and shelling percentage.

CHAPTER FOUR: RESULTS

4.1 Effect of maize variety and intercropping on plant height, plant stand, lodging and biomass accumulation

Significant ($P \leq 0.05$) varietal differences in maize plant height at 57 DAE were noted in all sites and seasons (Table 2). Significant differences in maize plant height were also noted for site and its interaction with variety. Cropping system and its interaction with variety and site had no significant effects on plant height (Appendix 3). Over the short rains, maize in Machakos was severely affected by drought at seedling stage and data could not be taken. However, maize grown in Mwea was significantly taller than maize grown in Waruhiu. Variety DK 8031 was significantly taller than all varieties except DHO 1, DHO 2, DHO 4, Duma 43, H513, Katumani, Pannar 67 and PHB 3253 while H516 was significantly the shortest. Over the long rains, all varieties were significantly ($P \leq 0.05$) shorter in Machakos than in the rest of the sites. All varieties except H614D and Pannar 67 were significantly taller in Mwea than in Waruhiu in both seasons. DHO 2 was significantly taller than all varieties except DHO 1, Duma 43, H513, H516, Katumani, KCB, and Pannar 4M. Pannar 77 was significantly shorter than all varieties except DHO 4, DK 8031, H515, H614D, Pannar 67, Pannar 7M and PHB 3253.

No significant ($P \leq 0.05$) varietal differences in maize stand count were noted across the sites and seasons. Variety and its interaction with site had no significant effects on maize stand count (Table 3). Intercropping and its interaction with variety and site had no significant effects on maize stand establishment (Appendix 4). Over the short rains, maize grown in Mwea had better stand establishment than maize grown in Waruhiu. During the long rains, significantly ($P \leq 0.05$) higher maize stand counts were established in Machakos than in Mwea and Waruhiu. Maize stand counts in the latter two sites were not significantly different.

Table 2: Mean plant height (cm) at 57 DAE of sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Machakos during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains			
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1	192.3	70.4	131.3	218.0	156.0	97.0	157.0
DHO 2	182.8	76.7	129.7	226.4	176.6	107.8	170.2
DHO 4	183.1	64.8	123.9	220.6	133.1	86.3	146.6
DK 8031	190.4	81.8	136.1	207.6	150.8	95.4	151.2
DUMA 43	168.4	79.6	124.0	210.0	159.0	99.9	156.3
H513	182.9	66.3	124.6	238.5	164.4	86.0	162.9
H515	161.7	64.6	113.1	205.4	149.0	84.0	146.1
H516	156.6	57.6	107.1	214.0	163.2	100.8	159.3
H614D	160.5	64.8	112.6	177.3	183.4	92.3	151.0
KATUMANI	175.9	77.7	126.8	229.6	166.2	105.5	167.1
KCB	170.0	66.4	118.2	223.9	141.1	104.2	156.4
PANNAR 4M	156.2	61.8	109.0	220.5	150.1	97.2	155.9
PANNAR 67	168.3	68.0	118.1	182.4	155.8	95.0	144.4
PANNAR 77	156.1	72.4	114.2	199.8	128.6	83.2	137.2
PANNAR 7M	176.0	47.9	111.9	192.0	157.6	94.1	147.9
PHB 3253	165.4	68.3	116.8	246.1	125.4	75.2	148.9
Mean	171.6	68.1	119.8	213.2	153.7	93.9	153.6
LSD $_{(P\leq 0.05)}$ **V**		**21.0**			**17.0**		
LSD $_{(P\leq 0.05)}$ **Site**		**4.3**			**7.8**		
LSD $_{(P\leq 0.05)}$ **V*Site**		**24.1**			**30.5**		
CV%		**12.7**			**30.5**		

CV: coefficient of variation; LSD: least significant difference

No significant ($P\leq 0.05$) varietal and site effects on maize lodging were noted over the short rains. However, variety and its interaction with site significantly affected plant lodging in both sites (Table 4). Intercropping and its interaction with variety had no significant effects on maize plant lodging (Appendix 5). In the short rains, DHO 2 had significantly higher lodging

Table 3: Mean plant stand count of sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Machakos during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains			
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1	82.6	42.5	62.5	73.5	78.0	77.6	76.3
DHO 2	76.9	46.5	61.7	74.0	75.5	75.6	75.0
DHO 4	83.1	49.8	66.4	74.5	77.5	79.0	77.0
DK 8031	81.6	55.5	68.5	74.8	75.5	79.6	76.6
DUMA 43	81.6	56.6	69.1	68.5	67.0	72.0	69.1
H513	82.6	44.6	63.6	73.8	75.0	78.6	75.8
H515	82.4	50.6	66.5	70.8	71.6	75.0	72.5
H516	80.9	52.0	66.4	69.5	70.6	73.5	71.2
H614D	82.9	58.8	70.9	68.8	74.5	76.8	73.3
KATUMANI	78.6	42.6	60.6	72.6	77.0	76.8	75.5
KCB	85.4	54.5	69.9	75.0	73.0	76.8	74.9
PANNAR 4M	80.4	52.1	66.3	66.3	69.6	71.6	69.2
PANNAR 67	81.8	55.1	68.4	70.8	76.5	74.8	74.0
PANNAR 77	82.9	55.8	69.4	70.1	70.1	76.3	72.2
PANNAR 7M	81.1	53.1	67.1	77.1	76.3	80.1	77.8
PHB 3253	79.8	49.0	64.4	78.3	68.5	82.0	76.2
Mean	81.5	51.2	66.4	72.4	73.5	76.6	74.2
LSD $_{(P\leq0.05)}$ V		**NS**			**NS**		
LSD $_{(P\leq0.05)}$ Site		**1.9**			**1.3**		
LSD $_{(P\leq0.05)}$ V*Site		**NS**			**NS**		
CV%		**10.4**			**6.3**		

NS: not significant at 5% probability level; CV: coefficient of variation; LSD: least significant difference

percentage in Waruhiu than in Mwea while the converse was the case with respect to H515 and H614D. Over the long rains, DHO 1, DHO 2, Katumani and Pannar 4M lodged significantly more in Mwea than in Waruhiu. In contrast, KCB lodged significantly more in Waruhiu than in Mwea. Duma 43 and Pannar 7M did not lodge. Overall, maize grown in

Mwea lodged significantly more than maize grown in Waruhiu while KCB lodged significantly more than the rest of the varieties.

Table 4: Mean lodging percentage of sixteen maize varieties grown in Mwea and Waruhiu during 2007 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	8.0	8.6	8.3	3.4	0.4	1.9
DHO 2	3.9	10.3	7.1	10.0	3.3	6.7
DHO 4	5.4	3.6	4.5	0.0	0.6	0.3
DK 8031	3.4	3.0	3.2	0.0	0.2	0.1
DUMA 43	10.5	7.3	8.9	0.0	0.0	0.0
H513	3.6	6.1	4.8	0.0	0.5	0.2
H515	6.8	1.5	4.2	0.0	0.7	0.3
H516	4.3	2.8	3.6	0.0	1.4	0.7
H614D	7.0	1.9	4.5	0.0	0.2	0.1
KATUMANI	8.4	7.3	7.8	12.0	5.4	8.7
KCB	6.2	6.6	6.4	9.2	14.1	11.6
PANNAR 4M	7.0	4.2	5.6	3.8	1.2	2.5
PANNAR 67	4.6	2.4	3.5	0.0	0.8	0.4
PANNAR 77	5.0	5.2	5.1	0.0	0.7	0.3
PANNAR 7M	3.1	1.5	2.3	0.0	0.0	0.0
PHB 3253	2.5	3.5	3.0	0.0	1.2	0.6
Mean	5.6	4.7	5.2	2.4	1.9	2.1
LSD $_{(P\leq 0.05)}$ V	**NS**				**1.3**	
LSD $_{(P\leq 0.05)}$ Site (S)	**NS**				**0.3**	
LSD $_{(P\leq 0.05)}$ V*Site	**4.9**				**1.7**	
CV%	**67.3**				**61.1**	

NS: not significant at 5% probability level; CV: oefficient of variation; LSD: least significant difference

Variety, site and variety×site interaction had significant ($P \leq 0.05$) effects on maize shoot biomass (Table 5). Intercropping and its interaction with variety and site had no significant effects in this parameter (Appendix 6). Over the short rains, DHO 2, H513, H515, H516, Katumani, Pannar 67, Pannar 77 and Pannar 7M had significantly higher shoot biomass in Mwea than in Waruhiu. Variety DK 8031 had significantly higher shoot biomass than all varieties except DHO 4, H513, H515, H614D, Pannar 67, Pannar 77 and Pannar 7M. KCB had significantly lower shoot biomass than all varieties except Katumani, DHO 1, DHO 2, Duma 43, Pannar 4M and PHB 3253. Over the long rains, DHO 4 and Pannar 77 had significantly higher shoot biomass in Mwea than in Waruhiu while the converse was the case with respect to DK 8031, H516, Pannar 67 and Pannar 7M. Maize grown in Machakos had significantly the least shoot biomass. Variety H614D had significantly the highest shoot biomass while KCB had less shoot biomass than all varieties except DHO 1, DHO 2 and Katumani.

4.2 Effect of maize variety and intercropping on time to anthesis, silking and physiological maturity

Variety, site and variety×site interaction significantly ($P \leq 0.05$) affected time taken by maize to reach 50% anthesis, 50% silking and 50% physiological maturity (Tables 6, 7 and 8). Intercropping and its interaction with variety and site had no significant ($P \leq 0.05$) effects on time taken by the maize varieties to flower and mature (Appendices 7, 8 and 9). In the short rains, all varieties recorded significantly shorter time to reach 50% anthesis in Mwea than in Waruhiu except varieties DHO 1, DHO 2, Duma 43, KCB and Pannar 7M. Variety KCB took significantly ($P \leq 0.05$) shorter time to reach 50% anthesis than all varieties except Katumani, DHO 1, DHO 2 and PHB 3253 while variety H614D took a significantly longer time. DHO 4 was significantly the latest to reach 50% anthesis among the DHO series while no significant differences were noted among the Five and the Pannar series. Over the long rains, all the varieties attained 50% anthesis significantly ($P \leq 0.05$) earlier in Mwea than in Waruhiu.

Table 5: Mean plant shoot biomass (t ha^{-1}) of sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Machakos during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains			
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1	14.1	9.8	11.9	12.2	13.4	3.9	9.8
DHO 2	16.3	9.2	12.8	11.0	9.7	4.5	8.4
DHO 4	28.4	22.5	25.5	30.9	20.2	3.6	18.2
DK 8031	27.7	25.6	26.7	25.4	32.9	6.0	21.4
DUMA 43	19.9	13.6	16.8	19.6	16.2	5.0	13.6
H513	30.7	17.3	24.0	24.5	27.1	3.6	18.4
H515	27.0	17.6	22.3	25.8	23.6	5.7	18.4
H516	22.2	13.0	17.6	17.5	33.3	6.3	19.0
H614D	30.0	17.5	23.8	42.8	40.6	3.5	29.0
KATUMANI	16.6	10.2	13.4	9.8	10.3	4.7	8.2
KCB	13.5	8.5	11.0	12.4	6.7	3.5	7.5
PANNAR 4M	19.8	12.2	16.0	20.0	16.6	4.2	13.6
PANNAR 67	26.5	15.9	21.2	19.1	30.2	5.6	18.3
PANNAR 77	28.0	16.5	22.2	38.9	22.0	5.3	22.1
PANNAR 7M	24.2	16.3	20.2	20.5	31.4	4.9	18.9
PHB 3253	16.3	10.1	13.2	25.3	26.6	3.0	18.3
Mean	22.6	14.7	18.7	22.2	22.6	4.6	16.5
LSD $_{(P\leq0.05)}$ V		**6.2**			**2.8**		
LSD $_{(P\leq0.05)}$ Site		**0.5**			**1.5**		
LSD $_{(P\leq0.05)}$ V*Site		**6.2**			**5.6**		
CV%		**10.9**			**32.3**		

CV: coefficient of variation; LSD: least significant difference

Table 6: Mean days after emergence (DAE) to 50% anthesis of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	58.3	64.6	61.5	43.6	60.6	52.1
DHO 2	59.0	66.6	62.8	42.6	56.0	49.3
DHO 4	63.0	78.6	70.8	51.6	74.6	63.1
DK 8031	65.0	79.0	72.0	49.3	65.0	57.1
DUMA 43	63.6	69.6	66.6	50.6	67.6	59.1
H513	61.0	78.6	69.8	53.0	75.3	64.1
H515	65.6	81.0	73.3	52.3	69.3	60.8
H516	67.0	78.6	72.8	55.3	72.6	64.0
H614D	69.8	82.3	76.0	63.0	81.6	72.3
KATUMANI	53.0	66.0	59.5	35.6	53.0	44.3
KCB	55.3	62.6	59.0	32.0	51.6	41.8
PANNAR 4M	65.0	81.6	73.3	53.3	67.6	60.5
PANNAR 67	64.6	77.0	70.8	54.3	68.6	61.5
PANNAR 77	65.0	77.6	71.3	54.6	73.3	64.0
PANNAR 7M	65.6	73.3	69.5	54.0	76.6	65.3
PHB 3253	56.6	69.6	63.1	53.6	72.3	63.0
Mean	62.3	74.2	68.2	49.9	67.9	58.9
LSD $_{(P\leq 0.05)}$ V		**7.5**			**1.1**	
LSD $_{(P\leq 0.05)}$ Site		**1.0**			**0.2**	
LSD $_{(P\leq 0.05)}$ V*Site		**7.9**			**1.3**	
CV %		**5.1**			**1.5**	

CV: coefficient of variation; LSD: least significant difference

In the short rains, all varieties took significantly ($P\leq 0.05$) shorter time to reach 50% silking in Mwea except varieties DHO 1, Duma 43 and KCB which were not significantly different in both sites. In both sites, KCB generally took significantly shorter time to reach 50% silking than all varieties except Katumani, PHB 3253, DHO 1 and DHO 2. Variety H614D took significantly longer time to attain 50% silking than most varieties especially in 2009 long rains. Variety DHO 2 and H515 silked significantly earlier among the DHO series and the Five series respectively while Pannar 4M and Pannar 67 silked earlier among the Pannar series. The maize varieties attained 50% silking significantly ($P \leq 0.05$) earlier in Mwea than in Waruhiu.

Table 7: Mean days after emergence (DAE) to 50% silking of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	61.3	68.0	64.6	49.0	65.0	57.0
DHO 2	62.0	70.6	66.3	47.6	60.3	54.0
DHO 4	66.0	83.3	74.6	57.3	80.3	68.8
DK 8031	68.0	83.6	75.8	55.0	69.6	62.3
DUMA 43	66.6	73.0	69.8	55.0	73.0	64.0
H513	64.0	83.0	73.5	59.0	80.3	69.6
H515	69.0	85.6	77.3	59.0	74.0	66.5
H516	70.0	80.0	75.0	61.3	77.3	69.3
H614D	73.0	88.0	80.5	68.3	86.0	77.1
KATUMANI	56.0	69.6	62.8	40.0	57.3	48.6
KCB	58.1	65.0	61.5	37.0	56.6	46.8
PANNAR 4M	68.0	86.6	77.3	57.6	73.0	65.3
PANNAR 67	67.6	81.0	74.3	59.0	73.0	66.0
PANNAR 77	68.0	81.3	74.6	60.6	77.6	69.1
PANNAR 7M	68.6	77.3	73.0	60.0	80.3	70.1
PHB 3253	59.6	74.0	66.8	58.6	76.6	67.6
Mean	65.3	78.1	71.7	55.2	72.5	63.9
LSD $_{(P\leq0.05)}$ V		**7.4**			**1.1**	
LSD $_{(P\leq0.05)}$ Site		**0.9**			**0.2**	
LSD $_{(P\leq0.05)}$ V*Site		**7.9**			**1.3**	
CV %		**4.8**			**1.5**	

CV: coefficient of variation; LSD: least significant difference

Over the short rains, all varieties except Duma 43 and PHB 3253 took significantly ($P \leq 0.05$) shorter time to reach 50% physiological maturity in Mwea than in Waruhiu. In both seasons, variety KCB took significantly shorter time to reach 50% maturity than all varieties except DHO 1 while H614D took longer time to reach 50% maturity. No significant differences in time to maturity were noted among the Five series and the Pannar series while DHO 4 took longer time to mature among the DHO series. During the long rains, all varieties took significantly ($P \leq 0.05$) shorter time to mature in Mwea than in Waruhiu. Among the Pannar series, Pannar 67 and Pannar 7M took significantly shorter and longer time respectively to reach 50% maturity.

4.3 Effect of maize variety and intercropping on yield and yield components

Variety had no significant ($P \leq 0.05$) effects on grain yield over the short rains but significant effects were noted in this parameter during the long rains (Table 9). Significant site effects on grain yield were noted during the short rains only. However, significant differences were noted in both seasons for variety-site interaction. Intercropping and its interaction with variety and site had no significant effects on maize grain yield (Appendix 10). Within the sites, Duma 43 was significantly out-performed by DHO 4, DK 8031 and H513 in Mwea while Pannar 67 significantly out-yielded DK 8031 and H515. Over the short rains, varieties DHO 4, DK 8031, H513, H614D and Pannar 7M had significantly higher grain yield in Mwea than in Waruhiu. During the long rains, DK 8031, Duma 43 and PHB 3253 gave significantly ($P \leq 0.05$) higher grain yield in Mwea than in Waruhiu while Pannar 67 yielded significantly higher in Waruhiu. In Mwea, variety Duma 43 had significantly higher grain yield than all varieties except DHO 1, DHO 4 and H513 while variety H614D had significantly lower grain yield than most varieties. Variety DHO 2 significantly out-yielded more than half of the varieties. No significant differences in grain yield were noted among the DHO series, the Five series and the Pannar series.

Table 8: Mean days after emergence (DAE) to 50% physiological maturity of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	86.0	94.0	90.0	102.0	121.6	111.8
DHO 2	88.6	100.3	94.5	99.6	120.6	110.1
DHO 4	104.6	114.0	109.3	129.3	142.6	136.0
DK 8031	96.6	114.0	105.3	113.0	124.3	118.6
DUMA 43	100.3	105.6	103.0	123.0	128.3	125.6
H513	103.6	113.3	108.5	125.3	140.0	132.6
H515	102.3	118.0	110.1	127.6	136.0	131.8
H516	108.3	116.0	112.1	124.0	136.6	130.3
H614D	116.3	122.0	119.1	136.3	151.3	143.8
KATUMANI	82.3	100.0	91.1	96.0	116.6	106.3
KCB	80.0	90.0	85.0	93.3	114.3	103.8
PANNAR 4M	102.1	115.0	108.5	120.6	127.0	123.8
PANNAR 67	102.0	113.0	107.5	115.6	128.0	121.8
PANNAR 77	104.6	116.0	110.3	124.3	129.0	126.6
PANNAR 7M	104.6	114.6	109.6	120.0	138.0	129.0
PHB 3253	102.0	106.6	104.3	123.3	136.6	130.0
Mean	99.0	109.5	104.3	117.1	130.7	123.9
LSD $_{(P\leq0.05)}$ V		**5.0**			**1.1**	
LSD $_{(P\leq0.05)}$ Site		**1.1**			**0.2**	
LSD $_{(P\leq0.05)}$ V*Site		**5.9**			**1.3**	
CV %		**3.9**			**0.7**	

CV: coefficient of variation; LSD: least significant difference

Table 9: Mean grain yield (t ha^{-1}) of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	1.4	1.4	1.4	2.4	2.8	2.6
DHO 2	1.6	1.3	1.4	2.3	2.1	2.2
DHO 4	2.4	1.7	2.1	2.6	2.2	2.4
DK 8031	2.4	1.2	1.8	2.4	1.6	2.0
DUMA 43	1.6	1.5	1.6	3.2	2.5	2.9
H513	2.3	1.4	1.8	2.2	2.5	2.4
H515	1.8	1.2	1.5	2.0	1.9	2.0
H516	2.0	1.5	1.7	2.0	1.8	1.9
H614D	2.0	1.4	1.7	1.2	1.4	1.3
KATUMANI	1.7	1.3	1.5	1.8	2.4	2.1
KCB	1.8	1.4	1.6	2.0	1.7	1.8
PANNAR 4M	2.1	1.5	1.8	2.4	1.8	2.1
PANNAR 67	2.1	1.9	2.0	1.7	2.4	2.0
PANNAR 77	2.1	1.6	1.8	2.0	1.8	1.9
PANNAR 7M	2.1	1.3	1.7	1.9	2.5	2.2
PHB 3253	1.8	1.6	1.7	2.8	1.8	2.3
Mean	1.9	1.5	1.7	2.2	2.1	2.1
LSD $_{(P\leq0.05)}$ V		**NS**			**0.5**	
LSD $_{(P\leq0.05)}$ Site		**0.1**			**NS**	
LSD $_{(P\leq0.05)}$ V*Site		**0.6**			**0.7**	
CV%		**14.6**			**12.9**	

NS: not significant at 5% probability level; CV: coefficient of variation; LSD: least significant difference

Variety did not significantly ($P\leq0.05$) affect number of ears per plant in both seasons (Table 10). Over the short rains no significant differences in this parameter were noted between sites but significant differences were noted for variety-site interaction. Number of ears per plant were not significantly affected by intercropping (Appendix 11). Varieties had no significant differences in number of ears per plant between the sites except DHO 4 and DK 8031 which had significantly higher number of ears per plant in Mwea and Waruhiu, respectively. Site significantly ($P\leq0.05$) affected number of ears per plant over the long rains. However, site-variety interaction was not significant. Maize grown in Waruhiu had significantly more ears per plant than in Mwea.

Table 10: Mean number of ears per plant of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	1.0	1.1	1.1	1.0	1.2	1.1
DHO 2	1.2	1.1	1.2	1.0	1.2	1.1
DHO 4	0.8	1.3	1.1	1.1	1.0	1.0
DK 8031	1.5	1.1	1.3	1.0	1.0	1.0
DUMA 43	1.2	1.3	1.3	1.0	1.1	1.1
H513	1.2	1.0	1.1	1.1	1.1	1.1
H515	1.2	1.0	1.1	1.0	1.1	1.1
H516	1.2	1.0	1.1	1.1	1.1	1.1
H614D	1.2	1.0	1.1	1.1	1.0	1.0
KATUMANI	1.2	1.0	1.1	1.0	1.1	1.1
KCB	1.2	1.1	1.2	1.0	1.0	1.0
PANNAR 4M	1.3	1.1	1.3	1.1	1.1	1.1
PANNAR 67	1.1	1.2	1.2	1.0	1.0	1.0
PANNAR 77	1.1	1.0	1.1	1.0	1.0	1.0
PANNAR 7M	1.1	1.1	1.1	1.0	1.1	1.1
PHB 3253	1.1	1.1	1.1	1.1	1.0	1.0
Mean	1.2	1.1	1.1	1.0	1.1	1.1
LSD $_{(P\leq0.05)}$ V		**NS**			**NS**	
LSD $_{(P\leq0.05)}$ Site		**NS**			**0.02**	
LSD $_{(P\leq0.05)}$ V*Site		**0.2**			**NS**	
CV %		**15.9**			**8.6**	

NS: not significant at 5% probability level; CV: coefficient of variation;

LSD: least significant difference

Significant ($P \leq 0.05$) varietal differences in cob length were noted in all seasons. Significant differences in cob length were also noted for site and its interaction with variety over the seasons (Table 11). This parameter was not significantly affected by intercropping (Appendix 12). Over the short rains, varieties H516 and Pannar 67 had significantly longer cobs in Waruhiu than in Mwea while no significant differences were noted among the rest of the varieties between the two sites. Variety H614D had significantly longer cobs than DHO 1, Katumani, KCB, Pannar 77, Pannar 7M and PHB 3253. Variety KCB had significantly shorter cobs than all varieties except DHO 1, DHO 2, Duma 43, Katumani, Pannar 77, Pannar 7M and PHB 3253. Over the long rains, varieties H516, H614D, Pannar 67 and Pannar 7M had significantly longer cobs in Waruhiu than in Mwea. No significant differences in cob length were noted for the rest of the varieties between the two sites. Variety H516 had significantly longer cobs than all varieties except H614D, Duma 43, H513, H515, Pannar 4M, Pannar 7M and PHB 3253. Variety KCB had significantly shorter cobs than all varieties except Katumani, DHO 1, DHO 2 and Pannar 67. No significant differences in cob length were noted among the DHO series, the Five series and the Pannar series. Overall, maize grown in Waruhiu had longer cobs over the seasons.

Variety had no significant ($P \leq 0.05$) effects on number of kernel-rows per cob over the short rains but significant differences were noted over the long rains (Table 12). Site and its interaction with variety significantly ($P \leq 0.05$) affected number of kernel-rows per cob in both seasons. Intercropping and its interaction with variety and site had no significant effects on this parameter (Appendix 13). Varieties DK 8031, Duma 43, Katumani, KCB, Pannar 77 and PHB 3253 had significantly higher number of kernel-rows per cob in Mwea than in Waruhiu over the short rains. Over the long rains, varieties DHO 4, KCB and PHB 3253 had significantly higher number of kernel-rows per cob in Mwea than in Waruhiu. PHB 3253 had significantly higher number of kernel-rows per cob than all varieties while KCB had significantly lower number of kernel-rows per cob than all varieties except Katumani, DHO 2, DK 8031 and the five series. Among the Pannar series, Pannar 7M had significantly more kernel-rows per cob while no significant differences were noted among the DHO series and the Pannar series.

Table 11: Mean cob length (cm) of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	12.4	12.9	12.7	12.3	13.8	13.1
DHO 2	15.8	13.1	14.5	12.7	14.2	13.4
DHO 4	14.0	13.9	14.0	14.4	13.7	14.1
DK 8031	15.3	15.8	15.5	14.5	14.1	14.3
DUMA 43	14.2	14.2	14.2	15.5	15.8	15.6
H513	14.1	14.6	14.3	14.9	16.2	15.6
H515	15.3	15.4	15.4	15.5	16.2	15.9
H516	13.0	16.5	14.7	15.3	17.6	16.4
H614D	15.3	17.0	16.2	14.7	16.0	15.3
KATUMANI	12.8	13.5	13.2	11.7	13.6	12.6
KCB	11.5	12.3	11.9	12.8	12.2	12.5
PANNAR 4M	14.3	14.4	14.3	15.0	16.4	15.7
PANNAR 67	13.2	17.7	15.4	12.1	15.1	13.6
PANNAR 77	13.0	13.1	13.1	13.8	15.1	14.4
PANNAR 7M	11.6	13.9	12.8	13.3	17.7	15.5
PHB 3253	12.6	13.1	12.8	15.8	15.3	15.6
Mean	13.7	14.5	14.1	14.0	15.2	14.6
LSD $_{(P\leq0.05)}$ V		**2.3**			**1.3**	
LSD $_{(P\leq0.05)}$ Site		**0.6**			**0.4**	
LSD $_{(P\leq0.05)}$ V*Site		**2.8**			**1.9**	
CV%		**14.0**			**11.5**	

CV: coefficient of variation; LSD: least significant difference

Table 12: Mean number of kernel-rows per cob of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	13.5	11.9	12.7	12.3	12.3	12.3
DHO 2	13.4	12.0	12.7	12.5	12.0	12.2
DHO 4	14.0	12.8	13.4	13.3	12.4	12.8
DK 8031	13.6	12.0	12.8	12.2	12.2	12.2
DUMA 43	13.4	11.4	12.4	12.6	12.2	12.4
H513	12.8	12.8	12.8	12.2	12.1	12.2
H515	13.2	12.0	12.6	12.1	12.2	12.2
H516	12.9	11.8	12.3	12.4	12.1	12.3
H614D	12.7	12.5	12.6	12.7	13.0	12.9
KATUMANI	14.2	11.7	13.0	12.1	11.8	11.9
KCB	12.6	11.2	11.9	12.3	11.1	11.7
PANNAR 4M	13.1	12.2	12.7	12.7	12.7	12.7
PANNAR 67	13.1	12.5	12.8	12.1	11.6	11.8
PANNAR 77	13.9	11.8	12.9	13.4	13.0	13.2
PANNAR 7M	13.7	12.8	13.2	14.1	13.8	14.0
PHB 3253	14.6	13.0	13.8	15.4	13.7	14.6
Mean	13.4	12.1	12.8	12.8	12.4	12.6
LSD $_{(P\leq0.05)}$ V		**NS**			**0.6**	
LSD $_{(P\leq0.05)}$ Site		**0.1**			**0.1**	
LSD $_{(P\leq0.05)}$ V*Site		**1.5**			**0.8**	
CV%		**4.9**			**5.0**	

NS: not significant at 5% probability level; CV: coefficient of variation; LSD: least significant difference

Number of kernels per cob-row differed significantly among the varieties over the long rains, with no significant differences noted over the short rains (Table 13). Site and variety-site interaction effects in this parameter were noted during the short rains and the long rains, respectively. Intercropping and its interaction with variety and site did not significantly affect number of kernels per cob-row (Appendix 14). Significantly ($P \leq 0.05$) higher number of kernels per cob-row were noted in Mwea than in Waruhiu over the short rains. Over the long rains, DHO 4, DK 8031, and PHB 3253 had significantly higher number of kernels per cob-row in Mwea than in Waruhiu while Panner 7M had significantly higher kernels per cob-row in Waruhiu. Variety Duma 43 had significantly higher number of kernels per cob-row than all varieties except DHO 4, DK 8031, H516, Pannar 4M, Pannar 77 and PHB 3253. Variety KCB had significantly lower number of kernels per cob-row than all varieties except Katumani, H614D and Pannar 7M.

Over the short rains, variety did not significantly ($P \leq 0.05$) affect 100 kernel weight (Appendix 15). However site and its interaction with variety had significant ($P \leq 0.05$) effects on 100 kernel weight (Table 14). Cropping system and its interaction with variety and site had no significant effects on 100 maize kernel weight. Varieties DHO 4, DK 8031, H513, H515, H614D, KCB, Pannar 4M, Pannar 7M and PHB 3253 had significantly higher 100 kernel weight in Mwea than in Waruhiu. No significant differences in kernel weight were noted among DHO 1, DHO 2, H516, Katumani, Pannar 67 and Pannar 77 between the two sites. Significant ($P \leq 0.05$) varietal and site effects were noted for 100 kernel weight during the long rains. However, variety and its interaction with site, cropping system and its interaction with variety and site had no significant effects on kernel weight. Variety H513 had significantly higher kernel weight than all varieties except DK 8031, Duma 43, H614D, Katumani, KCB, Pannar 67 and PHB 3253. Maize grown in Mwea had significantly heavier kernels than maize grown in Waruhiu.

Table 13: Mean number of kernels per cob-row of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	26.9	24.1	25.5	24.7	28.0	26.3
DHO 2	26.6	25.0	25.8	25.8	27.1	26.5
DHO 4	31.7	26.6	29.1	32.3	26.2	29.2
DK 8031	33.7	27.6	30.6	31.4	26.4	28.9
DUMA 43	30.6	26.2	28.4	30.3	29.9	30.1
H513	28.7	26.9	27.8	27.7	26.6	27.2
H515	29.8	26.2	28.0	25.2	27.6	26.4
H516	26.7	28.5	27.6	27.0	30.6	28.8
H614D	29.7	25.5	27.6	24.7	24.8	24.7
KATUMANI	26.6	22.5	24.5	22.6	24.6	23.6
KCB	24.0	22.7	23.4	23.9	22.3	23.1
PANNAR 4M	30.0	22.4	26.2	28.9	27.8	28.3
PANNAR 67	28.3	27.1	27.7	24.6	27.4	26.0
PANNAR 77	28.5	26.4	27.5	30.0	27.6	28.8
PANNAR 7M	22.3	24.5	23.4	23.0	27.4	25.2
PHB 3253	25.6	23.9	24.8	32.0	22.8	27.4
Mean	28.1	25.4	26.7	27.1	26.7	26.9
LSD $_{(P\leq0.05)}$ V		**NS**			**2.8**	
LSD $_{(P\leq0.05)}$ Site		**1.1**			**NS**	
LSD $_{(P\leq0.05)}$ V*Site		**NS**			**4.3**	
CV%		**14.7**			**15.4**	

NS: not significant at 5% probability level; CV: coefficient of variation; LSD:least significant difference

Table 14: Mean 100 kernel weight (g) of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

Variety (V)	2008 short rains			2009 long rains		
	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	23.9	22.6	23.2	23.3	24.6	23.9
DHO 2	23.9	24.2	24.1	23.2	22.9	23.0
DHO 4	25.4	22.5	24.0	25.7	23.1	24.4
DK 8031	29.4	21.1	25.3	25.5	24.7	25.1
DUMA 43	26.8	23.4	25.1	26.6	24.0	25.3
H513	27.7	22.2	25.0	29.3	24.5	26.9
H515	26.7	22.4	24.6	25.7	23.4	24.5
H516	23.7	21.0	22.4	25.1	24.0	24.6
H614D	24.5	20.7	22.6	26.6	24.7	25.6
KATUMANI	25.9	25.6	25.8	24.9	27.0	26.0
KCB	24.5	21.1	22.8	26.8	23.9	25.4
PANNAR 4M	25.9	21.3	23.6	26.1	22.9	24.5
PANNAR 67	26.5	24.1	25.3	26.4	25.9	26.2
PANNAR 77	23.8	23.8	23.8	21.6	21.1	21.4
PANNAR 7M	25.5	21.7	23.6	23.2	24.6	23.9
PHB 3253	26.3	22.3	24.3	27.8	24.6	26.2
Mean	25.7	22.5	24.1	25.5	24.1	24.8
LSD $_{(P\leq 0.05)}$ V		**NS**			**2.1**	
LSD $_{(P\leq 0.05)}$ Site		**0.4**			**0.8**	
LSD $_{(P\leq 0.05)}$ V*Site		**2.5**			**NS**	
CV %		**5.8**			**12.3**	

NS: not significant at 5% probability level; CV: coefficient of variation; LSD: least significant difference

Variety, site and variety×site interaction had significant ($P\leq 0.05$) effects on shelling % of maize (Table 15). However, shelling % of the maize varieties were not significantly ($P\leq 0.05$) affected by intercropping and its interaction with variety and site (Appendix 16). Over the short rains, varieties DHO 2, DHO 4, H516, Katumani, Pannar 77 and Pannar 7M had significantly higher shelling % in Mwea than in Waruhiu. In Mwea, Pannar 7M had a higher shelling % than all varieties except PHB 3253, Panner 77, Pannar 67, KCB, Katumani, H516, H513, DK 8031 and DHO 2 while H614D had a lower shelling % than all varieties except DHO 1, DHO 4, Duma 43, H513, H515, KCB, Pannar 4M and Pannar 77. In Waruhiu variety PHB 3253 had higher shelling % than all varieties except Pannar 67, Pannar 4m, KCB, H515, H513, DK 8031, Duma 43 and DHO 1 while H516 had a significantly lower shelling %. Over the long rains, DHO 2, DHO 4, DK 8031, H516, Pannar 4M and Pannar 7M had significantly higher shelling % in Mwea than in Waruhiu. In Mwea, H516 a higher shelling % than all varieties except DHO 1, DHO 2, DHO 4, Duma 43, Katumani, KCB, Pannar 67, Pannar 7M and PHB 3253 while H614D had a lower shelling % than all varieties except Pannar 4M and Pannar 77. In Waruhiu, Pannar 67 had a higher shelling % than all varieties except Duma 43, Katumani and PHB 3253 while Pannar 4M a lower shelling % than all varieties except DHO 2. Overall, maize grown in Mwea had significantly higher shelling % than maize grown in Waruhiu.

Variety had significant effects ($P \leq 0.05$) effects on harvest index in both seasons (Table 16). Harvest index was significantly affected by site and its interaction with variety over the short rains only. Intercropping and its interaction with variety and site had no significant effects in harvest indices of the maize varieties (Appendix 17). Over the short rains, harvest index for all maize varieties did not differ significantly between the sites except for KCB and PHB 3253 which had significantly higher harvest indices in Waruhiu. Variety KCB had significantly higher harvest index than all varieties except Katumani, Pannar 4M, PHB 3253, DHO 1 and DHO 2 in Mwea and PHB 3253 in Waruhiu. Varieties DK 8031 and H515 had significantly lower harvest indices than most of the other varieties. During the long rains, variety KCB had significantly higher harvest index than all varieties except Katumani while

H614D had significantly lower harvest index than all varieties except Pannar 67 and Pannar 77. Overall, maize grown in Waruhiu had higher harvest indices than maize grown in Mwea.

Table 15: Mean shelling % of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	82.4	80.9	81.6	83.5	80.2	81.9
DHO 2	86.3	78.0	82.2	83.7	77.1	80.4
DHO 4	82.6	74.9	78.8	83.4	78.7	81.1
DK 8031	84.9	83.3	84.1	81.7	78.7	80.2
DUMA 43	82.6	81.3	82.0	84.5	83.9	84.2
H513	83.9	80.4	82.1	81.9	79.9	80.9
H515	81.9	81.3	81.6	80.7	77.9	79.3
H516	84.4	66.2	75.3	86.0	79.2	82.6
H614D	80.3	79.1	79.7	77.8	80.7	79.2
KATUMANI	86.1	79.0	82.6	85.0	81.9	83.4
KCB	83.0	80.7	81.9	84.4	81.6	83.0
PANNAR 4M	82.8	80.0	81.4	79.8	74.9	77.4
PANNAR 67	84.8	80.7	82.8	84.9	84.7	84.8
PANNAR 77	83.7	79.2	81.5	79.8	78.4	79.1
PANNAR 7M	86.5	79.9	83.2	83.9	79.0	81.4
PHB 3253	84.6	83.6	84.1	84.9	82.0	83.4
Mean	83.8	79.3	81.5	82.9	79.9	81.4
LSD $_{(P\leq0.05)}$ V		**3.6**			**2.8**	
LSD $_{(P\leq0.05)}$ Site		**0.8**			**0.8**	
LSD $_{(P\leq0.05)}$ V*Site		**4.2**			**3.7**	
CV%		**3.5**			**3.8**	

CV: coefficient of variation; LSD: least significant difference

Table 16: Mean harvest index (HI) of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains

	2008 short rains			2009 long rains		
Variety (V)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	0.10	0.15	0.13	0.20	0.23	0.22
DHO 2	0.10	0.15	0.12	0.21	0.23	0.22
DHO 4	0.09	0.08	0.08	0.09	0.12	0.10
DK 8031	0.09	0.05	0.07	0.12	0.05	0.09
DUMA 43	0.08	0.11	0.10	0.17	0.16	0.17
H513	0.08	0.09	0.08	0.10	0.10	0.10
H515	0.07	0.07	0.07	0.08	0.09	0.09
H516	0.09	0.14	0.11	0.12	0.06	0.09
H614D	0.07	0.08	0.08	0.03	0.03	0.03
KATUMANI	0.11	0.13	0.12	0.23	0.24	0.23
KCB	0.14	0.21	0.17	0.20	0.36	0.28
PANNAR 4M	0.11	0.13	0.12	0.12	0.12	0.12
PANNAR 67	0.09	0.12	0.10	0.09	0.08	0.08
PANNAR 77	0.07	0.10	0.09	0.06	0.09	0.08
PANNAR 7M	0.09	0.08	0.09	0.10	0.08	0.09
PHB 3253	0.12	0.18	0.15	0.11	0.07	0.09
Mean	0.09	0.12	0.10	0.13	0.13	0.13
LSD $_{(P\leq0.05)}$ V		**0.05**			**0.05**	
LSD $_{(P\leq0.05)}$ Site		**0.01**			**NS**	
LSD $_{(P\leq0.05)}$ V*Site		**0.05**			**NS**	
CV%		**23.60**			**52.80**	

CV: coefficient of variation; LSD: least significant difference

4.4 Relationship among maize plant maturity, yield and yield components

There were significant positive correlations in Mwea over the short rains between grain yield and time to 50% anthesis (r = 0.51, P≤ 0.05), time to 50% silking (r = 0.50, P≤ 0.05) and 100-kernel weight (r = 0.56, P≤ 0.05) (Table 17). Time taken to 50% anthesis correlated positively with time to 50% silking (r = 0.99, P≤ 0.01) and time to maturity (r = 0.76, P≤ 0.01) while time to 50% silking correlated positively with time to 50% maturity (r = 0.76, P≤ 0.01). Cob length and ears per plant were positively correlated with 50% maturity (r = 0.49, P≤ 0.05) and 100-kernel weight (r = 0.54, P≤ 0.05) respectively. Harvest index correlated negatively with time to 50% anthesis (r = 0.61, P≤ 0.05), time to 50% silking (r = 0.62, P≤ 0.05), time to 50% maturity (r = 0.61, P≤ 0.05).

Table 17: Pearson correlation coefficients relating maize grain yield, crop development and yield components in Mwea, 2008 short rains

	Grain yield t/ha	50% Anthesis	50% Silking	50% Maturity	Ears/ plant	cob length	rows/ cob	100 Kernel weight	Shelling%
50% Anthesis	.51*								
50% Silking	.50*	.99**							
50% Maturity	.49	.76**	.76**						
Ears/plant	.25	.22	.22	-.01					
cob length	.21	.42	.43	.49*	.34				
rows/cob	.33	-.03	-.03	.01	-.26	.09			
100 Kernel weight	.56*	.18	.17	.14	.55*	.26	.09		
Shelling %	.06	-.19	-.20	-.13	-.28	-.29	.16	.04	
Harvest index	-.05	-.62*	-.62*	-.62*	.09	-.59*	-.02	-.09	.19

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level (2-tailed)

In Mwea over the long rains, there were significant positive correlations between time to 50% anthesis and time to 50% silking (r = 0.99, P≤ 0.01), time to 50% physiological maturity (r = 0.93, P≤ 0.01), ears per plant (r = 0.53, P≤ 0.01), cob length (r = 0.60, P≤ 0.05) (Table 18). Time to 50% silking positively correlated with time to 50% physiological maturity (r = 0.93, P≤ 0.05), number of ears per plant (r = 0.59, P≤ 0.05) and cob length (r = 0.76, P≤ 0.01). Number of ears per plant positively correlated with cob length (r = 0.58, P≤ 0.05). However, significant negative correlations were noted between harvest index and time to 50% anthesis (r = 0.88, P≤ 0.01), time to 50% silking (r = 0.89, P≤ 0.01), time to 50% physiological maturity (r = 0.89, P≤ 0.01).

Table 18: Pearson correlation coefficients relating maize grain yield, crop development and yield components in Mwea, 2009 long rains

	Grain yield t/ha	50% Anthesis	50% Silking	50% Maturity	Ears/ plant	cob length	rows/ cob	100 Kernel weight	Shelling%
50% Anthesis	-.14								
50% Silking	-.16	.99**							
50% Maturity	-.02	.93**	.93**						
Ears/plant	-.01	.53*	.54*	.59*					
cob length	.39	.60*	.610*	.76**	.58*				
rows/cob	.31	.32	.31	.32	.13	.32			
100 Kernel weight	.13	.13	.11	.26	.55*	.47	-.03		
Shelling %	.32	-.46	-.47	-.47	-.26	-.29	.08	.043	
Harvest index	.30	-.88**	-.89**	-.89**	-.42	-.52*	-.29	-.15	.58*

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level (2-tailed)

In Waruhiu over the short rains (Table 19), significant positive correlations were noted between time to 50% anthesis and time to 50% silking (r = 0.99, P≤ 0.01), time to 50% anthesis and time to 50% physiological maturity (r = 0.85, P≤ 0.01), time to 50% silking and time to 50% physiological maturity (r = 0.88, P≤ 0.01), time to 50% silking and cob length (r = 0.72, P≤ 0.01), time to 50% rows per cob (r = 0.59, P≤ 0.05). However, there were significant negative correlations between time to 50% anthesis and ears per plant (r = 0.52, P≤ 0.01), time to 50% anthesis and harvest index (r = 0.71, P≤ 0.01), time to 50% silking and ears per plant (r = 0.589, P≤ 0.05), time to 50% anthesis and harvest index (r = 0.74, P≤ 0.01), time to 50% physiological maturity and ears per plant (r = 0.66, P≤ 0.01), time to physiological maturity and harvest index (r = 0.69, P≤ 0.01).

Table 19: Pearson correlation coefficients relating maize grain yield, crop development and yield components in Waruhui 2008 short rains

	Grain yield t/ha	50% Anthesis	50% Silking	50% Maturity	Ears/ plant	cob length	rows/ cob	100 Kernel weight	Shel-ling %
50% anthesis	.32								
50% Silking	.31	.99**							
50% Maturity	.29	.86**	.88**						
Ears/plant	-.05	-.53*	-.59*	-.67**					
cob length	.38	.70**	.72**	.76**	-.45				
rows/cob	.43	.46	.48	.59*	-.28	.41			
100 Kernel weight	.20	-.29	-.29	-.30	.22	-.31	-.30		
Shelling %	-.13	-.27	-.23	-.27	.02	-.14	-.08	.47	
Harvest index	.19	-.72**	-.75**	-.69**	.44	-.41	-.43	.32	-.01

**Correlation is significant at 0.01 level: *Correlation is significant at 0.05 level (2-tailed)

In Waruhiu over the long rains season, there were significant positive correlations between time to 50% anthesis and time to 50% silking (r = 0.99, P≤ 0.01), time to 50% physiological maturity (r = 0.93, P≤ 0.01), cob length (r = 0.71, P≤ 0.01), number of rows per cob (r = 0.66, P≤ 0.01) (Table 20). Time to 50% silking correlated positively with time to 50% physiological maturity (r = 0.93, P≤ 0.01), cob length (r = 0.70, P≤ 0.01), number of rows per cob (r = 0.64, P≤ 0.01). Time to 50% physiological maturity correlated positively with cob length (r = 0.62, P≤ 0.01) and number of rows per cob (r = 0.57, P≤ 0.05). Cob length positively correlated with number of rows per cob (r = 0.54, P≤ 0.05) while 100-kernel weight positively correlated with shelling % (r = 0.61, P≤ 0.05). However, there were significant negative correlations between harvest index and time taken to 50% anthesis (r = 0.86, P≤ 0.01), time to 50% silking (r = 0.85, P≤ 0.01), 50% physiological maturity (r = 0.76, P≤ 0.01), cob length (r = 0.71, P≤ 0.01) and rows per cob (r = 0.60, P≤ 0.01).

4.5 Effect of intercropping on bean plant height and root nodulation

The maize variety and its interaction with site did not significantly (P≤0.05) affect beans plant height at 43 DAE (Appendix 18). However, significant site effects in this parameter were noted (Table 21). Beans grown in Waruhiu were significantly taller than beans grown in Mwea and Machakos. Plant height in the later two sites was not significantly different.

Intercropping had a significant (P≤0.05) effect on number of nodules per plant at 21 days after emergence (DAE) in all the sites but had no significant effects on this parameter at 50% flowering (Table 22, Appendix 19). A significantly higher number of nodules per plant was noted in Waruhiu than in Mwea which in turn had significantly higher number of nodules per plant than Machakos. At 21 DAE, nine of sixteen maize varieties intercropped with beans significantly increased bean nodulation relative to sole beans. Only varieties DHO 2, H515, H516, H614D, Pannar 4M and Pannar 7M had no effect on bean nodulation. Beans intercropped with H614D had significantly fewer noduless than beans intercropped with most of the other varieties. No significant differences in bean nodulation were noted within intercrop systems involving the DHO series, the five series and the Pannar series. Significant differences in bean nodulation among the sites were noted at both 21 DAE and 50% flowering.

Table 20: Pearson correlation coefficients relating grain yield, crop development and yield components in Waruhiu, 2009 long rains

	Grain yield t/ha	50% Anthesis	50% Silking	50% Maturity	Ears/ plant	cob length	rows/ cob	100 Kernel weight	Shel-ling %
50% Anthesis	-.15								
50% Silking	-.15	.99**							
50% Maturity	-.19	.94**	.94**						
Ears/plant	.48	-.31	-.31	-.31					
cob length	.01	.72**	.70**	.62**	.23				
rows/cob	-.14	.66**	.64**	.58*	-.19	.54*			
100 Kernel weight	.31	-.21	-.23	-.11	-.03	-.10	-.19		
Shelling %	.28	-.09	-.10	-.09	-.35	-.21	-.23	.62*	
Harvest index	.25	-.86**	-.85**	-.76**	.27	-.71**	-.60*	.074	.14

**Correlation is significant at 0.01 level; *Correlation is significant at 0.05 level (2-tailed)

Table 21: Mean plant height (cm) at 43 days after emergence (DAE) of KB 1 bean intercropped with sixteen maize varieties grown in Mwea, Waruhiu and Machakos during 2009 long rains.

	Plant height 43 DAE			
Cropping System (CS)	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	47.2	56.7	41.8	48.6
DHO 2 + beans	47.6	50.6	44.9	47.7
DHO 4 + beans	47.4	49.9	39.9	45.8
DK 8031 + beans	48.1	59.5	44.7	50.8
DUMA 43 + beans	48.0	54.7	45.2	49.3
H513 + beans	47.7	56.0	41.9	48.5
H515 + beans	47.3	53.2	45.8	48.8
H516 + beans	47.4	43.8	45.1	45.4
H614D + beans	48.2	57.9	43.3	49.8
Katumani + beans	51.5	66.2	49.1	55.6
KCB + beans	47.2	57.3	55.3	53.3
PANNAR 4M + beans	47.9	56.0	46.4	50.1
PANNAR 67 + beans	46.9	58.4	50.3	51.8
PANNAR 77 + beans	48.0	47.8	51.0	48.9
PANNAR 7M + beans	47.4	55.0	51.6	51.4
PHB 3253 + beans	47.6	62.2	42.9	50.9
KB 1 sole beans	47.6	55.1	41.3	48.0
Mean	47.8	55.3	45.9	49.7
LSD $_{(P\leq0.05)}$ CS		**NS**		
LSD $_{(P\leq0.05)}$ Site		**3.8**		
LSD $_{(P\leq0.05)}$ CS*Site		**NS**		
CV %		**19.6**		

NS: not significantly different at 5% probability level; LSD: least significant difference; CV: coefficient of variation

Table 22: Mean nodule count at 21 days after emergence (DAE) and at 50% flowering of KB 1 bean intercropped with sixteen maize varieties in Machakos, Mwea and Waruhiu during 2009 long rains

	21 DAE				50% Flowering			
Cropping System (CS)	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	8.3	17.5	5.5	10.5	17.7	33.4	10.2	20.5
DHO 2 + beans	7.5	16.7	3.7	9.3	17.1	34.3	9.0	20.1
DHO 4 + beans	8.3	17.5	5.5	10.4	17.1	30.7	10.8	19.6
DK 8031 + beans	7.9	17.3	5.6	10.3	17.3	31.3	11.5	20.1
DUMA 43 + beans	8.5	17.8	6.0	10.7	17.6	33.8	11.1	20.9
H513 + beans	7.7	17.3	5.3	10.1	16.9	33.3	9.8	20.1
H515 + beans	6.6	14.9	3.9	8.5	15.2	31.9	9.3	18.8
H516 + beans	7.1	14.1	3.7	8.3	16.1	31.8	10.4	19.4
H614D + beans	6.5	13.9	3.6	8.0	15.5	30.8	8.7	18.7
Katumani + beans	7.7	16.8	4.8	9.8	16.0	34.2	9.4	19.9
KCB + beans	8.4	19.7	5.2	11.1	18.5	35.4	9.4	21.1
PAN 4M + beans	7.2	15.9	4.7	9.2	17.0	33.7	10.1	20.3
PAN 67 + beans	9.4	17.2	6.1	10.9	18.1	35.4	10.1	21.2
PAN 77 + beans	7.5	17.7	4.8	10.0	17.3	33.5	9.1	19.9
PAN 7M + beans	7.6	15.8	4.2	9.2	16.6	31.6	9.8	19.3
PHB 3253 + beans	8.1	18.5	5.6	10.7	17.5	34.6	9.7	20.6
KB 1 sole beans	6.1	16.4	4.6	9.1	16.9	34.0	7.8	19.6
Mean	7.7	16.8	4.9	9.8	17.0	33.2	9.8	20.0
LSD $_{(P\leq0.05)}$ CS		**1.6**				**NS**		
LSD $_{(P\leq0.05)}$ Site		**0.6**				**0.8**		
LSD $_{(P\leq0.05)}$ CS*Site		**NS**				**NS**		
CV %		**17.8**				**10.3**		

NS: not significantly different at 5% probability level; CS: cropping system; LSD: least significant difference; CV: coefficient of variation; PAN: Pannar

Intercropping had no significant ($P \leq 0.05$) effects on bean shoot biomass at 21 DAE (Appendix 20). However, significant differences in this parameter were noted at 50% flowering (Table 23). Significant differences in shoot biomass were also noted among the sites. Intercropping and its interaction with site did not significantly affect this parameter at the respective sampling stages. At 50% flowering, significantly higher bean shoot biomass was noted for KCB/bean than for all other intercrop systems. H516/bean intercrop system had significantly lower bean shoot biomass than all bean intercrop systems of DHO 1, Katumani, KCB, Pannar 4M. At both sampling stages, beans grown in Waruhiu had significantly higher shoot biomass. At 21 DAE, beans grown in Mwea had significantly lower shoot biomass than beans grown in Waruhiu and Machakos. However, bean shoot biomass in Mwea and Machakos was not significantly different at 50% flowering.

4.6 Effect of intercropping on bean yield and yield components

Intercropping, site and intercropping×site interaction had significant ($P \leq 0.05$) effects on bean seed yield and bean yield decline (Table 24). Significantly ($P \leq 0.05$) higher bean yields were obtained for all cropping systems in Waruhiu than the rest of the sites except H513/bean intercrop system whose yields were not significantly different among the sites (Appendix 22). Higher bean yield of 924 kg ha^{-1} was obtained when KB 1 was grown as a sole crop, while a lower yield of 335 kg ha^{-1} was obtained when KB 1 was intercropped with H515. Significantly lower bean yields were obtained in Machakos than in the rest of the sites.

Intercropping significantly ($P \leq 0.05$) depressed bean seed yields (Table 24). Average yield declines taking sole crop yield as 100% were 58.92%, 56.01% and 51.46% in Mwea, Machakos and Waruhiu respectively. Significantly high yield declines of 75.2% and 77.9% were noted when KB 1 was intercropped with H513 in Waruhiu and Pannar 7M in Machakos respectively. Yield declines ranged from 33.8% (H513) to 69.9% (DHO 1) in Mwea. 32.3%

(KCB) to 75.2% (H513) in Waruhiu and 16.8% (Katumani) to 77.9% (Pannar 7M) in Machakos. Across the sites, intercropping beans with Pannar 7M caused the greatest decline in bean seed yields (68.8%). Bean seed yield declines in Waruhiu and Machakos were significantly lower than yield declines in Mwea.

Table 23: Mean shoot biomass (g m^{-2}) at 21 days after emergence (DAE) and at 50% flowering of KB 1 bean intercropped with sixteen maize varieties grown in Mwea, Waruhiu and Machakos during 2009 long rains

Cropping System (CS)	21 DAE				50% Flowering			
	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	106.2	158.1	143.5	132.2	195.0	254.5	220.0	224.8
DHO 2 + beans	113.8	153.4	99.2	133.6	191.4	270.1	175.7	230.8
DHO 4 + beans	79.7	120.9	102.8	100.3	163.4	233.9	179.3	198.7
DK 8031 + beans	109.0	175.3	129.9	142.2	186.1	240.9	198.4	213.5
DUMA 43 + beans	100.0	166.1	132.5	133.1	167.5	241.7	201.0	204.6
H513 + beans	91.1	173.3	95.9	132.2	174.8	300.4	164.4	237.6
H515 + beans	91.1	107.2	111.2	99.2	166.8	193.8	212.7	180.3
H516 + beans	54.8	131.1	102.3	93.0	164.4	177.1	174.8	170.8
H614D + beans	108.8	136.2	128.0	122.5	176.2	268.9	192.5	222.6
Katumani + beans	102.6	177.2	120.0	139.9	167.2	275.4	196.5	221.3
KCB + beans	154.9	175.7	98.1	165.3	336.7	303.7	209.2	320.2
PAN 4M + beans	99.5	156.0	168.6	127.8	177.1	231.6	231.5	204.4
PAN 67 + beans	103.5	153.3	118.2	128.4	166.8	228.9	185.1	197.9
PAN 77 + beans	97.4	142.9	157.9	120.2	173.1	218.5	220.7	195.8
PAN 7M + beans	83.5	193.4	116.2	138.5	159.2	232.1	206.5	195.7
PHB 3253 + beans	96.3	168.3	103.5	132.3	173.9	264.7	176.0	219.3
KB 1 sole beans	74.2	152.6	109.0	113.4	164.8	228.2	177.5	196.5
Mean	98.0	155.4	119.8	126.7	182.6	245.0	195.4	213.8
LSD $_{(P\leq0.05)}$ CS		**NS**				**40.7**		
LSD $_{(P\leq0.05)}$ Site		**16.2**				**17.1**		
LSD $_{(P\leq0.05)}$CS*Site		**NS**				**NS**		
CV %		**33.1**				**20.9**		

NS: not significantly different at 5% probability level; PAN: Pannar

Table 24: Mean seed yield (kg ha^{-1}) and percent yield decline of KB 1 bean intercropped with sixteen maize varieties grown in Mwea, Waruhiu and Machakos during 2009 long rains

Cropping System (CS)	Grain yield (kg ha^{-1})				Percent yield decline			
	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	204.0	752.0	117.0	478.0	69.9	53.6	72.4	61.8
DHO 2 + beans	273.0	877.0	183.0	575.0	59.5	46.1	57.2	52.8
DHO 4 + beans	338.0	905.0	229.0	621.5	50.0	44.9	46.1	47.5
DK 8031 + beans	268.0	737.0	164.0	502.5	60.4	53.7	61.2	58.4
DUMA 43 + beans	219.0	649.0	247.0	434.0	67.5	60.3	41.5	56.4
H513 + beans	447.0	405.0	214.0	426.0	33.8	75.2	49.7	52.9
H515 + beans	225.0	647.0	134.0	436.0	66.7	60.8	68.0	65.2
H516 + beans	261.0	693.0	175.0	477.0	61.4	57.8	59.8	59.6
H614D + beans	288.0	1037.0	186.0	662.5	57.3	35.0	55.2	49.1
Katumani + beans	290.0	643.0	361.0	466.5	57.1	62.0	16.8	45.3
KCB + beans	256.0	1102.0	167.0	679.0	62.2	32.3	60.2	51.5
PAN 4M + beans	347.0	1023.0	196.0	685.0	48.6	39.7	52.4	46.9
PAN 67 + beans	248.0	794.0	270.0	521.0	63.5	53.5	50.1	55.7
PAN 77 + beans	221.0	592.0	109.0	406.5	67.4	65.5	73.7	68.8
PAN 7M + beans	307.0	887.0	93.0	597.0	54.3	45.4	77.9	59.2
PHB 3253 + beans	249.0	1026.0	196.0	637.5	63.1	37.6	54.0	51.5
KB 1 sole beans	676.0	1661.0	437.0	1168.5				
Mean	301.0	848.8	204.6	574.9	58.9	51.5	56.0	55.4
LSD $_{(P\leq 0.05)}$ CS		**144.6**				**11.8**		
LSD $_{(P\leq 0.05)}$ Site		**60.7**				**5.1**		
LSD $_{(P\leq 0.05)}$ CS*Site		**250.4**				**20.4**		
CV %		**34.2**				**22.7**		

LSD: least significant difference; CV: coefficient of variation; PAN: Pannar

Number of pods per plant were significantly ($P \leq 0.05$) affected by intercrop system (Table 25). However, no significant ($P \leq 0.05$) differences in number of seeds per pod were noted (Appendix 23). Across the sites, significant differences in number of pods per plant and number of seeds per pod were noted. Intercropping and its interaction with site did not significantly affect these two parameters. Sole crop system of KB 1 had significantly ($P \leq 0.05$) higher number of pods per plant than the KB 1/maize intercrop systems. DK 8031/KB 1 and Panner 4M/KB 1 intercrop system gave the highest and the least pods per plant respectively. Intercropping reduced the number of pods per plant by 56.2% to 42.1% in Mwea, 45.6% to 16.6% in Waruhiu and 29.0% to 37.7% in Machakos. Significantly higher number of pods per plant and seeds per pod were noted in Mwea and Waruhiu than in Machakos.

Intercropping and its interaction with site had no significant ($P \leq 0.05$) effects on 100 seed weight (Appendix 24) but significant differences in this parameter were noted among the sites (Table 26). Significantly higher 100 seed weights were obtained in Waruhiu than in Mwea and Machakos.

Table 25: Mean number of pods per plant and seeds per pod of KB 1 bean intercropped with sixteen maize varieties grown in Mwea, Waruhiu and Machakos during 2009 long rains

Cropping System (CS)	Pods per plant				Seeds per pod			
	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	6.9	7.7	3.5	7.3	4.1	4.4	3.1	4.2
DHO 2 + beans	7.9	6.7	4.6	7.3	4.1	4.1	3.2	4.1
DHO 4 + beans	8.7	7.8	4.7	8.2	4.5	4.0	3.3	4.2
DK 8031 + beans	6.5	6.5	3.7	6.5	4.3	4.0	3.0	4.1
DUMA 43 + beans	6.8	6.6	4.1	6.7	4.4	3.9	3.4	4.2
H513 + beans	9.0	7.3	3.8	8.1	4.6	4.2	2.8	4.4
H515 + beans	8.9	6.6	3.8	7.7	4.5	3.8	3.2	4.1
H516 + beans	7.9	7.2	3.6	7.6	4.6	3.8	3.0	4.2
H614D + beans	6.7	7.3	4.4	7.0	4.2	4.1	3.1	4.1
Katumani + beans	8.3	9.0	4.3	8.7	4.6	4.1	3.4	4.4
KCB + beans	7.5	10.0	3.7	8.7	4.5	4.2	3.0	4.3
PAN 4M + beans	9.3	8.7	4.3	9.0	4.1	4.1	3.3	4.1
PAN 67 + beans	8.2	8.0	4.5	8.1	4.5	3.9	3.1	4.2
PAN 77 + beans	6.6	6.6	3.8	6.6	3.8	4.0	3.4	3.9
PAN 7M + beans	8.6	8.4	4.3	8.5	4.3	4.4	3.0	4.3
PHB 3253 + beans	8.9	8.1	3.8	8.5	4.7	4.0	3.0	4.4
KB 1 sole beans	11.0	10.5	8.1	10.8	4.5	4.5	4.8	4.5
Mean	8.1	7.8	4.3	8.0	4.4	4.1	3.3	4.2
LSD $_{(P\leq0.05)}$ CS		**1.4**				**NS**		
LSD $_{(P\leq0.05)}$ Site		**0.6**				**0.2**		
LSD $_{(P\leq0.05)}$CS*Site		**NS**				**NS**		
CV %		**23.4**				**11.5**		

NS: not significant at 5% probability level; LSD: least significant difference;

CV: coefficient of variation; PAN: Pannar;

Table 26: Mean 100 seed weight (g) of KB 1 bean intercropped with sixteen maize varieties grown in Mwea, Machakos and Waruhiu during 2009 long rains

	100 seed weight			
Cropping System (CS)	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	33.3	46.1	26.2	39.7
DHO 2 + beans	37.0	42.4	30.1	39.7
DHO 4 + beans	38.4	44.0	28.7	41.2
DK 8031 + beans	35.2	44.4	29.2	39.8
DUMA 43 + beans	37.7	43.3	31.0	40.5
H513 + beans	36.8	42.6	28.0	39.7
H515 + beans	37.0	42.8	28.2	39.9
H516 + beans	35.9	43.6	30.1	39.8
H614D + beans	35.0	44.7	29.7	39.9
Katumani + beans	35.2	41.6	30.7	38.4
KCB + beans	36.4	42.5	28.0	39.5
PANNAR 4M + beans	37.8	43.8	29.5	40.8
PANNAR 67 + beans	34.9	43.3	29.9	39.1
PANNAR 77 + beans	33.2	40.9	27.7	37.0
PANNAR 7M + beans	38.4	44.2	28.9	41.3
PHB 3253 + beans	36.7	44.0	30.9	40.3
KB 1 sole beans	36.4	38.4	27.5	37.4
Mean	36.2	43.1	29.1	39.6
LSD $_{(P\leq0.05)}$ CS		**NS**		
LSD $_{(P\leq0.05)}$ Site		**0.9**		
LSD $_{(P\leq0.05)}$ CS*Site		**NS**		
CV %		**6.7**		

NS: not significantly different at 5% probability level; LSD: least significant difference; CV: coefficient of variation

4.7 Productivity and monetary value of intercropping

The maize varieties had no significant effect on LER of maize/bean intercrop (Appendix 25). Site significantly affected LER but its interaction with cropping system did not significantly affect this parameter (Table 27). However, data presented in this table indicates that intercropping KB 1 with the maize varieties increases food production per unit area. Yield advantages ranged from 16% for H515/KB 1 intercrop to 84% for H513/KB 1 intercrop in Mwea. In Waruhiu yield advantage ranged from 41% for H513/KB 1 intercrop to 92% for Pannar 67/KB 1 intercrop. Significantly higher yield advantages were obtained in Waruhiu than in Mwea. In Mwea the LER revealed that it would require 1.16 to 1.84 more units land with farmers who practice sole cropping of maize and beans to produce comparable yield to intercropping KB 1 bean variety with maize. Similarly in Waruhiu, it would require on average 1.57 more units of land of maize and bean monocultures to produce comparable yield in maize/bean intercrop system.

According to MAI, monetary advantage for intercropping was not significantly ($P \leq 0.05$) affected by maize variety in maize/bean intercrop (Table 27) (Appendix 26). Numerically higher returns of Kshs. 23, 771 for DHO 4/KB 1 intercrop and Kshs. 43, 326 for Pannar 67/KB 1 intercrop system were obtained in Mwea and Waruhiu respectively. Significantly higher intercropping returns were realized in Waruhiu than in Mwea.

Table 27: Mean Land Equivalent Ratio (LER) and Monetary Advantage Index (MAI) of intercropping KB 1 bean with sixteen maize varieties in Mwea and Waruhiu during 2009 long rains

	LER			MAI (KShs)		
Cropping System (CS)	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1 + Beans	1.2	1.5	1.4	9861.0	28374.0	19117.5
DHO 2 + Beans	1.4	1.7	1.6	17712.0	33192.0	25452.0
DHO 4 + Beans	1.4	1.5	1.5	23771.0	26585.0	25178.0
DK 8031 + Beans	1.3	1.3	1.3	20923.0	21227.0	21075.0
DUMA 43 + Beans	1.5	1.3	1.4	18667.0	17290.0	17978.5
H513 + Beans	1.8	1.4	1.6	27950.0	21664.0	24807.0
H515 + Beans	1.1	1.5	1.4	5745.0	25094.0	15419.5
H516 + Beans	1.3	1.5	1.5	15065.0	25901.0	20483.0
H614D + Beans	1.3	1.7	1.5	12677.0	31035.0	21856.0
Katumani + Beans	1.4	1.2	1.3	13234.0	23699.0	18466.5
KCB + Beans	1.5	1.5	1.5	15540.0	28789.0	22164.5
PANNAR 4M + Beans	1.4	1.8	1.6	17461.0	36701.0	27081.0
PANNAR 67 + Beans	1.4	1.9	1.6	15892.0	43326.0	29609.0
PANNAR 77 + Beans	1.3	1.5	1.4	12794.0	22659.0	17726.5
PANNAR 7M + Beans	1.5	1.5	1.5	15467.0	36912.0	26189.5
PHB 3253 + Beans	1.4	1.9	1.6	19994.0	38173.0	29083.5
Mean	1.4	1.5	1.5	16422.0	28788.8	22605.4
LSD $_{(P\leq0.05)}$ CS		**NS**			**NS**	
LSD $_{(P\leq0.05)}$ Site		**0.1**			**5047.1**	
LSD $_{(P\leq0.05)}$ CS*Site		**NS**			**NS**	
CV %		**22.5**			**54.7**	

NS: not significantly different at 5% probability level; LSD: least significant difference; CV: coefficient of variation

CHAPTER FIVE: DISCUSSION

5.1 Effect of maize variety, intercropping and site on maize growth, flowering and maturity

There were significant varietal differences and site effects in maize plant height at 57 DAE. The bean component did not significantly affect maize plant height. This finding agrees with observations of Harwood *et al.* (2000) and Tamado *et al.* (2007) who noted that beans had no significant effects on maize plant height. Maize grown in Mwea had significantly higher mean plant height values probably due to high temperatures in the region which led to higher thermal degree days thus faster crop growth. High lodging percentages were presented by varieties Katumani, KCB, DHO 1 and DHO 2 with 8.3%, 9.0%, 5.1% and 6.9% respectively. These varieties had thin stalks which predisposed them to lodging. Their thin and weak stalks can also be explained by their high harvest indices meaning that they had more carbohydrate translocation to the grain.

Maize shoot biomass varied significantly among the varieties and in the different sites. The composites, DHO 1 and DHO 2 had significantly the least shoot biomass. Most of the late maturing hybrids such as H614D, DK 8031, the Five series and Pannar series had high shoot biomass. The negative correlation between number of days taken to reach physiological maturity and harvest index is a clear indication that biomass accumulation is directly related to maturity period. The early maturing composites, DHO 1 and DHO 2 accumulated less shoot biomass while the late maturing hybrids accumulated more biomass. This can be explained by shorter and prolonged photosynthesis of the early and late maturing varieties respectively. The early maturing varieties had less time for photosynthetically active radiation (PAR) and biomass accumulation relative to later maturing varieties. Biomass accumulation in cereals is positively correlated to days to maturity (Araus *et al.*, 2008).

Significant varietal differences in time to reach 50% anthesis, 50% silking and 50% physiological maturity were noted. Varieties Katumani and KCB took the shortest time to flower and mature followed by DHO and DHO 2. The five series, Pannar series, DHO 4, Duma 43, DK 8031 and PHB 3253 took relatively longer time to flower and mature. Further, variety H614D took the longest time to flower and mature. Maize phenological development was not significantly affected by intercropping. In their study Mugo et al. (1998), observed earliness in Katumani composite reaching anthesis in 66 days. In this study the longest time taken by Katumani to flower was 61 days in Waruhiu. The difference of 5 days could be attributed to weather conditions during the two studies. However, this study considers the difference negligible. In their intercropping studies, Moser *et al.* (2006) reported that bean component had no significant effects on time taken by maize to flower and mature. Lack of marked effects of bean component in a maize/bean intercrop system has been reported elsewhere (Muraya *et al.*, 2006).

5.2 Effect of maize variety, intercropping and site on maize yield and yield components

Varietal differences in grain yield were noted in the 2009 long rains only. Grain yield of DHO 1, DHO 2, Katumani, KCB, H515 and H516 remained relatively stable between the sites in the two seasons. The least grain yield was obtained from H614D. Stability in grain yield of DHO 1, DHO 2, KCB and Katumani may be due to their inherent adaptability in semi-arid areas. These varieties were specifically bred for cultivation in the semi-arid regions. Consistency in shelling % of these varieties was also a trait associated with their yield stability.

Following little rainfall in Machakos over the two seasons, performance of maize was highly constrained. Death of maize crop at seedling stage in 2008 short rains and at tasseling stage during 2009 long rains in Machakos is clear evidence that Machakos is not an ideal maize growing zone. To cope with the vagaries of climate change, farmers in the semi-arid regions need to diversify crop production by growing drought tolerant crops species such as sorghum, millet and cassava.

The results revealed that the bean component did not significantly affect maize grain yield and yield components in the intercrop system. Muraya *et al.* (2006) made similar observations indicating that maize performance in pure stands and in intercrop systems does not differ markedly. Further, modeling studies of radiation interception and use in a maize-bean intercrop system, showed that growth efficiency of intercrop maize was equivalent to sole maize (Tsubo *et al.*, 2001; Tsubo and Walker, 2002). However, earlier contradictory observations by Francis *et al.* (1982) and Fininsa (1997) indicated significant maize yield reductions in maize-bean intercrop systems. Lack of significant effects of the bean component in the intercrop system can be explained by the fact that the bean is less competitive. The maize component derives its competitive ability from its more resource use efficient four-carbon dicarboxylic (C_4) pathway than the bean's C_3 pathway (Gitonga *et al.*, 1999).

Number of ears per plant did not vary significantly among the varieties in all seasons. In Waruhiu maize yield components such as kernel-rows per cob, kernels per cob-row, 100 kernel weight and shelling % were significantly higher than in Mwea. This could be attributed to sufficiently higher moisture levels in this site. Variety PHB 3253 had consistently the highest number rows per cob, a trait which may explain why farmers have adopted it in the semi-arid regions. The composites and the dryland hybrids had the most efficient resource allocation to the grain. Their efficiency in photosynthate partitioning is indicated by their high harvest indices. However, harvest index of maize is known to vary considerably and seems to depend on variety, crop management, growing season, and other factors (Hay and Gilbert, 001). Moser *et al.* (2006) concluded that drought, especially pre-anthesis drought can ecrease the harvest index of tropical maize to 0.56.

3 Effect of maize variety, intercropping and site on bean growth, yield and yield components

Bean plant height was not significantly affected by the maize component. However, beans were significantly taller in Waruhiu, probably due to high rainfall in this site. Significant intercropping effects on bean nodulation were noted at 21 DAE with no significant effects at 50% flowering. At 21 DAE KCB/bean and H614D/bean intercrop systems had significantly the highest and least number of nodules per plant respectively. Bean nodule count per plant were significantly higher in Waruhiu than in Mwea and Machakos. Bean nodulation was significantly the lowest in Machakos which had the least rainfall. These results are in agreement with findings of many researchers who cited decreased bean nodulation in semi-arid regions (Hornetz *et al.*, 2001; Shisanya, 2002 and Mnasri *et al.*, 2007). A probable reason to decreased bean nodulation in Machakos and Mwea could be due to water stress and/or high temperatures in these sites in relation to Waruhiu. In addition, these two factors could have constrained establishment of rhizobia-legume symbiosis. High bean nodulation in KCB/bean intercrop system as opposed to depressed nodulation in H614D/bean intercrop system could be due to decreased competition from the composite KCB. In H614D/bean intercrop system, the beans could have faced increased competition for growth resources such as soil water hence decreased nodulation. High bean nodulation in Waruhiu could have also been influenced by potentially high populations of indigenous rhizobia. However, indigenous rhizobia populations in soils of the various sites were not quantified.

Significant differences were noted in bean shoot biomass at 50% flowering with significantly higher shoot biomass accumulation in Waruhiu than in Mwea and Machakos. Soil water and trogen were higher in Waruhiu hence higher biomass accumulation. In their study, Mnasiri al. (2007) also reported decreased bean shoot biomass accumulation under water limiting nditions. The maize varieties had mixed effects on bean shoot biomass accumulation. Bean ntercrop systems involving KCB, DHO 1 and Katumani had significantly higher bean shoot iomass accumulation but shoot biomass was significantly reduced by intercrop systems nvolving H516 and most hybrids. Varieties KCB, DHO 1 and Katumani had a less dense canopy than canopies of H516 and most of the hybrids, thus the differences in shoot biomass of the understory beans. It may be inferred that KCB, Katumani and DHO were less competitive for growth resources, especially light and water.

Higher bean yields were obtained in Waruhiu site (848.8 kg/ha) which had better growth conditions in terms of high soil moisture and lower temperatures thus favouring beans productivity. However, bean seed yields were significantly depressed by the maize component with yield declines ranging from 33.8% to 69.9% in Mwea, 32.3% to 75.2% in Waruhiu and 16.8% to 77.9% in Machakos. The yield reduction was related to reduced number of pods per plant and number of seeds per pod in the intercrop systems. Similar findings were reported by Tamado *et al.* (2007) and Gebeyehu *et al.* (2006) in Ethiopia. Working in Southeastern Kenya, Maingi *et al.* (2001) and Shisanya (2003) noted that intercropping maize and beans suppresses the yield of the later under semi-arid conditions. Santalla *et al.* (2001) reported 55% and 44% bean yield decline under field maize intercropping and sweet maize intercropping, respectively. Muraya *et al.* (2006) obtained bean yield declines of between 48.3% and 77.2% in maize-common bean intercropping. Working in Zimbabwe, Mutungamiri *et al.* (2001) noted bean yield reductions of 11% to 18% in maize-bean intercrops. Such significant reductions in bean yield from maize-bean intercropping have also been reported before (Santalla *et al.*, 2001; Niringiye *et al.*, 2005; Tsubo *et al.*, 2005).

gher bean yield declines were noted in intercrop systems involving H513 and Pannar 77 hile the least declines were obtained in Katumani and KCB intercrop systems. It can be ferred that, these maize varieties were more competitive than the beans. Varieties Katumani nd KCB had less canopy thus the bean component received lesser competition for growth sources. Hybrids H513 and Pannar 77 had dense canopy cover, thus more competitive than the beans. Competition for light is considered one of the major factors contributing towards reduction in yield and growth of plants in intercrops. Since bean yield tends to decrease with decrease in light transmission, it can be inferred that the yield of beans were reduced because of shading. Kinama *et al.*, 2007, showed that indeed intercropping cowpea in semi-arid Kenya reduced cowpea yield from shading effects. Yield reduction of the beans in intercropping, although specifically not determined, could also have been due to interspesific competition (Zhang and Li, 2003) for resources such as nutrients and water. The finding of this study suggest that, to maximize ecological productivity of maize-bean intercrops, varietal selection based on growth characteristics is important. Muraya *et al.* (2006) noted that, in order to to breed maize varieties suitable for common beans intercropping, maize variety growth chacteristics, especially reduced canopy density would be paramount.

5.4 Ecological and economic productivity of intercropping

This study showed that intercropping is ecologically and economically superior to sole cropping. Ecological productivity of maize-bean intercrops is indicated in this study by land equivalent values which were greater than one, thus showing the advantage of intercropping over sole cropping. However, similar to studies by Tamado *et al.* (2007), no significant differences in LERs were noted among the intercrop systems. The high LER values of 1.8 in Mwea and 1.8 in Waruhiu and their corresponding means of 1.41 and 1.6 in Mwea and Waruhiu respectively are within LER values of up to 1.8 reported by Mbah *et al.* (2007) and Tamado *et al.* (2007). Similar results of intercropping advantage were reported by Ogindo

003) in a semi-arid region, Yilmaz *et al.* (2007) in the East Mediterranean region, Mbah *et* (2007) in Southeastern Nigeria and Tsubo *et al.* (2003) in a semi-arid region of South frica. These results are also supported by the findings of Rahman *et al.* (2009) in ustard/lentil intercrops. The yield advantages from such intercropping can be attributed to etter utilization of both above ground and below ground growth resources. Better utilization of solar radiation, soil water and nutrients leads to higher yields in intercrops (Tsubo *et al.*, 004).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study found that in a maize/bean intercrop system, the bean component does not significantly affect maize grain yield and yield components. However, the maize component significantly affects beans performance. The choice of a compatible maize variety is thus essential to maximize bean productivity. The nature of growing season, especially rainfall rather than the agro-ecological zone per se significantly affects the performance of the currently grown varieties in the semi-arid regions. Maize plant height and plant stand count did not vary among the varieties but significant differences in the two sites were noted during the short rains. This is an indication that stand establishment of these varieties is entirely dependent on growth conditions. Fluctuations in grain yield were noted in the varieties in the different sites and seasons.

Performance of the currently grown varieties in the semi-arids depends on the amount of rainfall received during the growing season. Composites Katumani and KCB, DHO 1 and DHO 2 showed consistency in early maturity. These varieties can be adopted in the semi-arid regions if they are planted early in the growing season to optimize use of available resources especially soil moisture. Among the dryland hybrids (DHO series), variety DHO 4 may not be recommended for the semi-arid regions due its significantly long maturity duration. Variety H614D which is a late maturing variety may not be recommended for cultivation in semi-arid regions. Though varieties Katumani and KCB can tolerate drought, their unpopularity among the farmers may be attributed to their susceptibility to logding. This could be a reason why farmers have gone to other varieties that do not lodge as much but are not bred for these regions. Variety PHB 3253 may be adopted in these regions due to its high yield potential, a trait shown by its significantly higher number of kernel-rows per cob. However, this variety ay be widely grown incases where the growing season has been predicted to meet the ptimal growth conditions for maize.

To optimize the ecological and economic benefits of maize/bean intercrop in terms of yield, selection of compatible varieties of the component crops should be made using established gronomic management practices involving the two crops. Suitable maize varieties for maize/bean intercrop systems should have less dense canopies to ensure less shading effect to the understorey beans. Further, spatial arrangement of the component crops would be essential to avoid significant negative effects especially to the less competitive crop. Hence, to improve maize grain food security and enhance productivity of maize-bean intercrops in semi-arid regions, varieties Katumani, KCB, DHO 1 and DHO 2 may be adopted. Earliness of these varieties is a key trait for drought tolerance. Additionally, their high harvest indices is an indication of their efficiency in translocating carbohydrates to the grain.

6.2 Recommendations

Thus, as a result of the findings of this study, it is recommended that:

1. A similar study be conducted to test the compatibility of the same maize varieties with various bean varieties.
2. A similar study be done to determine the effect of intercropping beans with local maize varieties and newly released drought tolerant CIMMYT inbred lines.
3. Since the factors which led to bean yield reduction under intercropping could not be established, a similar study should be performed to establish the interactve factors leading to bean yield decline.
4. To cope with vagaries of climate change and improve food security in the semi-arid areas, farmers should diversify crop production by growing drought tolerant crops such as sorghum, millet and cassava.

REFERENCES

Adu-Gyamfi, J. J., Myaka, F. A., Sakala, W. D., Odgaard, R., Vesterager, J. M. and Hogh-Jensen, J. 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.

Agboola, A. A. and Fayemi, A. A. 1971. Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria. Journal of Agricultural Science 77: 219 – 225.

Agegnehu, G, Ghizam A. and Sinebo, W. 2006. Yield performance and land use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. European Journal of Agronomy 25: 249-456.

Agricultural Information Resource Centre (AIC), Kenya. 2002. Field Crops Technical Handbook

Andrews, D. J. 1992. Intercropping with sorghum in Nigeria. Experimental Agriculture 8: 139 – 150.

Anil, L., Park, J., Phipps, 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 the UK. Grass Forage Science 53: 301-317.

Araus, J. L., Slafer, G. A., Royo, C. and Serret, M. D. 2008. Breeding for yield potential and stress adaptation in cereals. Critical Reviews in Plant Science 2: 377– 412.

Aslam, M. 2007. Assessment of physio-genetic traits for drought tolerance in maize. PHD thesis, University of Agriculture, Faisalabad, Pakistan.

Ashley, J. 1992. Drought and crop adaptation. In: Rowland, J. R. (Eds), Dryland farming in Africa. Macmillan, London. 46 – 67.

am-ali, S. N., Matthews, R. B., Williams, J. H and Peacock, J. M. 1990. Light use, water uptake and performance of individual components of a sorghum/groundnut intercrop. Experimental Agriculture 26: 413-427.

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

Banik, P., Sasmal T., Ghosal, P. K. and Bagchi, D. K. 2000. Evaluation of Mustard (*Brassica compestris var. toria*) and legume intercropping under 1:1 and 2:1 row-replacement series systems. Journal of Agronomy 185: 9-14

Banziger, M. and Diallo, A. O. 2001. Stress tolerant maize for farmers in sub-Saharan Africa. In: CIMMYT Maize Research Highlights 1999–2000. CIMMYT, Mexico. D.F., 1–8.

Banzinger, M., and Diallo A. O. 2004. Progress in developing drought and nitrogen stress tolerant maize cultivars for Eastern and Southern Africa. In Friesen D.K. and Palmar A.F.E. (eds). Intergrated approaches to higher maize productivity in the new millenium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5 – 11 February, 2002: CIMMYT/KARI, Nairobi, kenya. 189 – 193.

Banziger, M., Betran, F. J. and Lafitte, H. R. 1997. Efficiency of high-nitrogen selection environments for improving maize for low-nitrogen target environments. Crop Science 37: 1103–1109.

Beets, W. C. 1990. Raising and sustaining productivity of smallholder farming systems in the tropics. Alkmaar, Holland: AgBe Publishing.

Bekunda, M. A., Bationo A. and Ssali, H. 1997. Soil fertility management in Africa: A review of selected research trials. Sub-Saharan Africa special publication. Madison, WI 51: 63 – 80.

ran, F. J., Beck, D., Banziger, M. and Edmeades G. O. 2003. Secondary traits in parental inbreds and hybrids under stress and non-stress environments in tropical maize. Field Crops Research 83: 51 – 65.

um, A. 1988. Genetic and environmental considerations in the improvement of drought stress in sorghum. In food grains production in semi-arid Africa. Eds. Menyonga, J. M. Bezuneh, T. and Youdeowei, A. OAU/STRCSAFGRAD publications 91 – 99.

Bolanos, J. and Edmeades, G. O. 1993. 8 cycles of selection for drought tolerance in lowland tropical maize. 1: Responses in grain yield, biomass, and radiation utilization. Field Crops Research 31: 233–252.

Bolanos, J. and Edmeades, G. O. 1993. Eight cycles of selection for drought tolerance in lowland tropical maize. Responses in reproductive behavior. Field Crops Research 31: 253-268.

Bolanos, J., Edmeades, G. O. 1996. The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. Field Crops Research 48: 65–80.

Boutraa, T. and Sanders, F. E. 2001. Influence of water stress on grain yield and vegetative growth of two cultivars of bean (*Phaseolus vulgaries L.*). Journal of Agronomy and Crop Science 187: 251 – 257.

Boyer, J. S. 1982. Plant productivity and environment. Science. Science 218: 443 – 448.

Brooks, S., Thompson, J., Odame, H., Kibaara, B., Nderitu, S., Karin, F. and Millstone, K. 2009. Environmental change and maize innovation in Kenya: Exploring pathways in and out of maize. STEPS. www.steps-centre.org.

Bruce, W.B., Edmeades, G. O. and Barker, T. C. 2001. Molecular and physiological approaches to maize improvement for drought tolerance. Journal Experimental Botany 53:13–20.

Cakir, R. 2004. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Research 89: 1–6.

Campos, H., Cooper, M., Edmeades, G. O., Loffer, C., Schussler, J. R. and Ibanez, M. 2006. Changes in drought tolerance in maize associated with fifty years of breeding for yield in the US corn-belt. Maydica 51:369–381

Campos, H. Cooper, M., Habben, J. E., Edmeades, G. O. and Schussler, J. R. 2004. Improving drought tolerance in maize: a view from industry. Field Crops Research 90:19–34.

Campos, H., Cooper, M., Habben, J. E., Edmeades, G. O. and Schussler, J. R. 2004. Improving drought tolerance in maize: A view from industry. Field Crops Research 90:19–34.

Carlson, J. D. 2008. Intercropping with Maize in Sub-arid Regions. Community planning and analysis technical brief. April, 16.

Chemeda, F. 1997. Effects of planting pattern, relative planting date and intra-row spacing on a haricot bean/maize intercrop. African Crop Science Journal. 5. 1: 15 – 22.

Chemining'wa, G. N.1992. Effects of increased intimacy between maize and beans in an intercrop system on growth of maize under varying nitrogen levels. MSc Thesis, University of Nairobi.

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 59: 269- 279.

Chowdhury, M. K. and Rosario, E. L. 1994. Comparison of nitrogen, phosphorus and potassium utilization efficiency in maize/mungbean intercropping. Journal of Agricultural Science 122: 193-199.

Costa, C., Dwyer, L. M., Stewart, D. W. and Smith, D. L. 2002. Nitrogen effects on grain yield and yield components of leafy and non-leafy maize genotypes. Crop Science Journal 42: 1556–1563.

Cramer, G. R. and Quarrie, S. A. 2002. Abscisic acid is correlated with the leaf growth inhibition of four genotypes of maize differing in their response to salinity. Functional Plant Biology 29: 111-115.

Davis, J.H.C. and Garcia, S. 1983. Competitive ability and growth habit of indeterminate beans and maize for intercropping. Field Crops Research 6:59-75.

Dawo, I. M., Wilkinsona J. M. and Pilbeam, J. D. 2008. Interactions between plants in intercropped maize and common bean. Journal of Science, Food and Agriculture 89: 41–48.

De Groote, H. 2002. Maize yield losses from stem borer in Kenya. Insect Science and its Application 22:89-96.

De Vries, J. and Toenniessen, G. 2001. Securing the harvest: Biotechnology, breeding and seed systems for African crops. CABI publishing, New York, USA 99 – 108.

Dhima, K. V., **Lithourgidis, A. A., Vasilokoglou I. B. and Dordas, C. A., 2007.** Competition indices of common vetch and cereal intercrops in two seeding ratio. Field Crops Research 100: 249-256.

Diallo, A. O., **Kikafundi, L., Wolde, O., Odongo, Z. O., Mduruma, W. S., Chivasti, D. K., Friesen and Banzinger, M. 2004.** Drought tolerant and low nitrogen tolerant hybrids for the mid-altitude ecology of Eastern Africa. In Friesen D.K. and Palmar A.F.E. (eds). Intergrated approaches to higher maize productivity in the new millenium. Proceedings of the 7th Eastern and Southern Africa regional maize conference, 5 – 11 February, 2002: CIMMYT/KARI, Nairobi, kenya. 206 – 212.

DuPlessis, D. P. and Dijkhuis, F. J. 1967. The influence of time lag between pollen shedding and silking on the yield of maize. South African Journal of Agricultural Sciences 10: 667-674.

Earl, H. J. and Davis, R. F. 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of maize. Agronomy Journal 95: 688–696.

Economic Review of Agriculture. 2008. Ministry of Agriculture report. pg 17 – 20.

Edmeades, G. O., Bolanos, J., Chapman, S. C., Lafitte, H. R. and Banziger, M., 1999. Selection improves drought tolerance in tropical maize populations. Direct and correlated responses among secondary traits. Crop Science 39: 1315-1324.

Edmeades, G. O., Banziger, M., Campos, H. and Schussler, J. 2004. Improving tolerance to abiotic stresses in staple crops: A random or planned process? In K. Lamkey and M. Lee (ed.) Proceedings Arnel R. Hallauer International Symposium on Plant Breeding, Mexico City, Mexico.17–22.

Edmeades, G. O., Bolanos, J., Elings, A., Ribaut, J. M., Banziger, M. and Westgate, M. E., 2000. The role and regulation of the anthesis-silking interval in maize. In: Westgate, M. E., Boote, K. J. (Eds.), Physiology and Modeling Kernel Set in Maize. CSSA, Madison, WI, CSSA Special Publication 29: 43–73.

Edmeades, G. O., Lafitte, H. R., Bolanos, J., Chapman, S. C., Banziger, M. and Deutsch, J. A. 1994. Developing maize that tolerates drought or low nitrogen conditions. In: Stress Tolerance Breeding: Maize that Resists Insects, Drought, Low Nitrogen, and Acid Soils. Edmeades, G. O. and Deutsch J. A (Eds.). 21 – 84.

FAO. 2000. Global Agroecological zones (GAEZ). http://www. iisa.ac.at/Research/ LUC/ GAEZ/index.htm.

FAO. 2003. World wheat, corn , rice production. http://www.nuekstate.edu/.

FAO. 2008. Crop Prospects and Food Situation. http://www.fao.org

FAOSTAT. 2003. Statistical Database of the Food and Agriculture Organization of the United Nations. http://www.fao.org

Farmer, G. and Wigley, T. M. L. 1985. Climatic trends for tropical Africa. Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, UK.

eil, B., Thiraporn, R. and Lafitte, H. R., 1993. Accumulation of nitrogen and phosphorus in the grain of tropical maize cultivars. Maydica 38: 291–300.

Fininsa, C. 1997. Effects of planting pattern, relative planting date and intrarow spacing on a haricot bean/maize intercrop. African Crop Science Journal 5: 15–22.

Finkelstein, R. R. and Gibson, S. I., 2001. Absissic acid and sugar interactions regulating development: Cross-talk or voices in a crowd. Plant Biology 5: 26-32.

Francis, C. A. 1987. Multiple cropping systems. Macmillan Publishing Company, New York.

Francis, C.A., Prager, M. and Tejada, G. 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris L.*) and maize (*Zea mays L.)* intercropping patterns. Field Crops Research 5:45-54.

Gachimbi, L. N. 1996. A comparison of three methods of reducing soil erosion in Machakos District, Kenya. East African Agricultural and Forestry Journal 61: 283 - 287.

Gachimbi, L. N., De Jager, A., Van Keulen, H., Thuranira, E. G. and Nandwa, S. M. 2002. Participatory diagnosis of soil nutrient depletion in semi-arid areas of Kenya. Managing Africa's Soils. 26

Gardiner, T. R. and Craker, L. E. 1981. Bean growth and light interception in a bean/maize intercrop. Field Crops Research 4:313-320.

Gebeyehu, S., Simana B. and Kirkby R. 2006. Genotype × cropping system interaction in climbing beans (*Phaseolus vulgaries L.*) grown as sole crop and in association with maize (*Zea mays L.*) European Journal of Agronomy 24: 396 – 403.

Geleta, N., Daba, C. and Gebeyehu, S. 2004. Determination of plant proportion and planting time in maize climbing bean intercropping system. In: Proceedings of the 10th annual conference of the crop science society of Ethiopia. 10: 176 – 182.

Gethi, J. G., Smith, M. E., Mitchell, S. E. and Kresovich, S. 2005. Genetic diversity of Striga hermonthica and Striga asiatica populations in Kenya. Weed Research 45: 64–73.

hosh, P. K. 2004. Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. Field Crops Research 88:227-237

itonga, N. M., Shisanya, C. A., Hornetz, B. and Maingi, J. M. 1999. Nitrogen fixation by *Vigna radiata L.* in pure and mixed stands in SE-Kenya. Symbiosis 27: 239– 250.

Gomez, A. A., and Gomez, K. A. 1983. Multiple cropping in humid tropics of Asia. IDRC. Ottawa. IDRC-176e. 249. [Online]. Available: www.ottawa.co. Date accessed: 12/10/09

Gomez, K. A. and Gomez, A. A. 1984. Statistical procedures for agricultural research. Wiley-Interscience publication. 1 – 657.

Grant, R. F., Jackson, B. S., Kiniry, J. R. and Arkin, G. F. 1989. Water deficit timing effects on yield components in maize. Agronomy Journal 81: 61-65.

Harris, D., Natarajan M. and Willey R. W. 1987. Physiological basis for yield advantage in a sorghum/groundnut intercrop exposed to drought. Dry-matter production, yield and light interception. Field Crops Research 37: 85 – 94.

Hart, R.D. 1994. The design and evaluation of beans, corn and manioc polyculture cropping systems for the humid tropics. PhD dissertation, University of Florida, Gainesville Florida, 175.

Hart, R. D and Pinchinat, A. M., 1982. Intergrative agricultural systems research. In Caribbean seminar on Farming systems Research methodology. IICA. San Jose, Costa Rica, 555-565.

Harwood, R. R. Jeranyama, P., Hesterman, O. B. and Waddington, S. R. 2000. Relay intercropping of sun hemp and cowpea to a smallholder maize system in Zambia. Agronomy Journal 92: 109 – 124.

Hassan, R. M. and Karanja, D. D. 1997. Increasing maize production in Kenya. Technology, Institutions and Policy. In: Byerlee, D. and Eicher, C. K. Africa's emerging maize revolution. Boulder London. Lynne Reinner Publishers. 81 – 93.

Hassan, R. M. and Njoroge, K. 1996. Integrating farmers information with geographic information systems for targeting of maize research in Kenya. African Crop Science Journal 4:1-9.

Hassan, R. M., Nyango, R. and Rutto, J. K. 1998. Relevance of maize research in Kenya to maize production problems perceived by farmers. In: Maize technology Development and transfer: a GIS Application for research in Kenya. Hassan, R.M. (Ed.), pp.71-88. CAB International, Wallingford, UK.

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

Hay, R. K. M. and Gilbert, R. A. 2001. Variation in the harvest index of tropical maize: evaluation of recent evidence from Mexico to Malawi. Annals of Applied Biology 138: 103–109.

Hall, A. J., Lemcoff, J. H. and Trapani, N. 1981. Water stress before and during flowering in maize and its effects on yield, its components, and their determinants. Maydica 26: 19-38.

Hall, A. J., Vilella, F., Trapani, N. and Chimenti, C. 1982. The effects of water stress and genotype on the dynamics of pollen-shedding and silking in maize. Field Crops Research 5: 349–363.

Hassan R. M., Murithi, F. and Kamau, G. 1998. Determinants of fertilizer use and the gap between farmers' maize yields and potential yields in Kenya. In: Hassan R. M. (ed.).Maize technology development and transfer. A GIS application for research planning in Kenya. Oxon. UK: CAB International 137-162.

Helenius, J. and Jokinen, K. 1994. Yield advantage and competition in intercropped oats (*Avena sativa L.)* and faba bean (*Vicia faba L.*): application of the hyperbolic yield density model. Field Crops Research 37: 85–94.

Hiebach, C. K. and McCollum, R. E. 1987. Area × time equivalency ratio. A method of evaluating the productivity of intercrops. Agronomy Journal 79: 15-22.

Hildebrand, P.E. 1976. Multiple cropping systems are dollars and sense agronomy. In: Multiple Cropping, Stelly, M. S., Kral, D. M., Elsele, L. C. and Nanseef J. H. (Eds.). American Society of Agronomy 27: 347 - 371.

Hornetz, B., Shisanya, C. A. and Gitonga, N. M. 2001. Crop water relationships and thermal adaptation of ksthika beans (*Phaseolus vulgaries L.)* and green grams (*Vigna radiata L. Wilczek*) with special reference to temporal patterns of potential growth in the dryland of SE-Kenya. Journal of Arid Environments 48: 591 – 601.

Ibeawuchi, I. I. 2007. Intercropping - A Food Production Strategy for the Resource Poor farmers. Nature and Science 5:1

ICIPE. 2002. ICIPE scientific report. International Centre of Insect Physiology and Ecology, Nairobi, Kenya.

IFPRI. 2000. Annual report. http://www.ifpri.org.publication/2000.

CIMMYT (International Maize and Wheat Improvement Centre). 2009. CIMMYT's ElectronicNewsletter.6:3.http://www.Cimmyt.org/english/wps/news/2009 /may/ maizeKenya.htm.

IRMA (Insect Resistant Maize for Africa) 2001. IRMA Updates, December 2001, Vol. 2,Issue.4.www.cimmyt.org/ABC/InvestIn-InsectResist/htm/InvestIn-InsectResist.htm.

Jaetzold, R. and Schmidt, H. 1983. Farm management Handbook of Kenya. Vol. II/C, East Kenya. Natural Conditions and Farm Management Information. Ministry of Agriculture and German Agricultural Team (GTZ).

Jagtap, S. S. and Abamu, F. J. 2003. Matching improved maize production technologies to the resource base of farmers in a moist savanna. Agricultural Systems 76: 1067–1084.

James, C. 2003. Global review of commercialised transgenic crops: 2002 Feature: Bt Maize. ISAAA Briefs No. 29: Ithaca, NY.

Jayne, T. S., Yamano, T., Nyoro, J. and Awour, T. 2001. Do farmers really benefit from high food prices balance rural interests in Kenya's maize pricing and marketing policy. Working paper 2b, Tegemeo Institute, Nairobi, Kenya.

Kanampiu, F., Friesen, D. and Gressel, J. 2002. CIMMYT unveils herbicide-coated maize seed technology for Striga control. Haustorium 42: 1–3.

Katerji, N., van Hoorn, J. W., Hamdy, A. and Mastrorilli, M. 2004. Comparison of corn yield response to plant water stress caused by salinity and by drought. Agricultural Water Management 65: 95–101.

Katerji, N., van Hoorn, J. W., Hamdy, A. and Mastrorilli, M. 2003. Salinity effect on crop development and yield, analysis of salt tolerance according to several classification methods. Agricultural Water Management 62: 37–66.

Kayumbo, H. Y. 1976. Crop protection in mixed ecosystems. Paper presented at the symposium of intercropping in semi-arid areas, Morogoro, Tanzania.

Keating, B. A. and Carberry, P. S. 1993. Resource capture and use in intercropping: solar radiation. Field Crops Research 34: 273 – 301.

Kenya Agricultural Commodity Exchange. 2009. Commodity exchange portal in Kenya. www.kacekenya.com.

Kenya Agricultural Research Institute (2006). KARI, Annual report. Acquiring and contributing knowledge for innovative solutions. KARI, Nairobi, Kenya.

Kenya Food Security Update. 2009. http://www. Kenyafoodsecurity.org/monthly bulletins /2009/feb.pdf.

Kenya National Bureau of Statistics. 2008. www.knbs.or.ke

Khan, Z. R., Midega, C. A. O., Amudavi, D. M., Njuguna, E. M., Wanyama, J. W. and Pickett, J. A. 2009. Intergration of edible beans (*Phaseolus vulgaries L.*) into the push-pull technology for stemborer and striga control in maize-based cropping systems. Crop Protection 38: 997 – 1006.

Kilewe, A. M. and Mbuvi, J. P. 1987. Evaluation of soil erodibility factors using natural runoff plots. East African Agricultural and Forestry Journal. 53:57-63.

Kinama, J. M. 1990. Actual versus potential soil degradation hazard assessment in a semi-arid Kenya environment. Msc. Thesis, University of East Anglia (U.K).

Kinama, J. M., Stigter, C. J., Ong, C., Ng'ang'a, J. K. and Gichuki, F. N. 2007. Alley cropping (contour hedgerow intercropping) maize or cowpea/senna for increased drymatter production in the semi-arid areas of Eastern Kenya. Proceedings of African Crop Science Society (ACSS) in Melkia – Egypt, November, 2007.

Kinama, J. M. 1997. The effects of alley cropping on Microclimate, soil and water conservation and competition on the sloping lands for sustainable land use in Machakos District, Kenya. PhD. Thesis, University of Nairobi.

Kipkiyai, J. N. 1996. Dynamics of soil soil organic carbon, nitrogen and microbial biomass in a long-term experiment as affected by inorganic ferlilizers. MSc. Thesis, University of Nairobi, Department of soil science, Kenya.

Kfir, R. 1998. Maize and grain sorghum: Southern Africa. In: Polaszek, A. (Ed.). African cereal stemborers: Economic importance, taxonomy, natural enemies and control. CAB International, Wallington, Oxon, United Kingdom. 29–37.

Kfir, R., Overholt, W. A., Khan, Z. R. and Polaszek, A. 2002. Biology and management of economically important lepidopteran cereal stemborers in Africa. Annual review of Entomology 47: 701–731.

Koch, K. 1996. Carbohydrate-modulated gene expression in plants. Annual Review Plant Physiology. Plant Molecular Biology 47: 509-540.

Kwabiah, A. B, Stoskopf, N. C., Palm, C. A., Voroney, R. P., Rao, M. R. and Gacheru, E. 2003. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short term study in Western Kenya. Agriculture Ecosystem and Environment 95: 49-59.

Landi, P., Sanguineti, M. C., Conti, S. and Tuberosa, R. 2001. Direct and correlated responses to divergent selection for leaf abscisic acid concentration in two maize populations. Crop Science 41: 335-344.

Liu, F., Andersen, M. N. and Jensen, C. R. 2003. Loss of pod set caused by drought stress is associated with water status and ABA content of reproductive structures in soybean. Functional Plant Biology 30: 271-280.

Liu, F., Jensen, C. R. and Andersen, M. N. 2005. A review of drought adaptation in crop plants: changes in vegetative and reproductive physiology induced by ABA-based chemical signals. Australian Journal of Agricultural Research 56: 1245-1252.

Ludlow, M.M. and Muchow, R.C., 1990. A critical evaluation of traits for improving crop yields in water-limited environments. Advances in Agronomy 43: 107-153.

Mabesa R. 2008. Footsteps. Improving food security, Tearfund, UK: 1-5.

Mafongoya, P. L., Bationo, E. A., Kihara, E. and Waswa, B.S. 2006. Appropriate technologies to replenish soil fertility in southern Africa. Nutr Cycl Agroecosyst 76:137 – 151.

Magorokosho, C., Pixley K. V. and Tongoona, P. 2003. Selection for drought tolerance in two tropical maize populations. African Crop Science Journal 3: 151-161.

Maingi, J. M., Shisanya, C. A., Gitonga, N. M. and Hornetz, B. 2000. Nitrogen fixation by common bean (*Phaseolus vulgaris L.*) in pure and mixed stands in semi-arid south-east Kenya. European Journal of Agronomy 14: 1–12.

Mansouri-Far, C., Sanavy, S. A. M. M. and Saberali, S. F. 2009. Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semi-arid climatic conditions. Agricultural Water Management 97: 12 – 22.

Muthamia, J. G. N., Musembi, F., Maina, J. M., Okuro, J. O., Amboga, S., Muriithi, F., Micheni, A. N., Terry, J., Overfield, D., Kibata, G. and Muthura, J. 2001. Participatory on-farm trials on weed control in smallholder farms in maize-based cropping systems. Proceedings of Seventh Eastern and South Africa Regional Maize Conference. 468-473.

Mauyo, L. W., Maritim, H. K., Okalebo, J. R., Kimani, P. M., Kirkby, R. A. and Ugen, M. A. 2003. Structure and conduct of cross-border bean marketing in East Africa: The case of Western Kenya and Eastern Uganda. Presented at the African Crop Science Conference, 12-17 October 2003, Nairobi, Kenya.

Mbah, E. U., Muoneke, C. O. and Okpara, D. A. 2007. Effect of compound fertilizer on the yield and productivity of soybean and maize in soybean/maizze intercrop in Southeastern Nigeria. Tropical and Subtropical Agroecosystems 7: 87 – 95.

McGilchrist, C. A. and Trenbath, B. R. 1971. A revised analysis of plant competition experiments. Biometrics 27: 659-671.

Mead, R. and Willey, R. W. 1980. The concept of 'land equivalent ratio' and advantages in yield from intercropping. Experimental Agricuture 16: 217- 228.

Ministry of Agriculture. 2009b. Economic review of Agriculture. www. kilimo.go.ke.

Ministry of Agriculture. 2009a. Food security report. www.kilimo.go.ke.

Mnasri, B., Aouani, M. E. and Mhamdi, R. 2007. Nodulation and growth of common bean (*Phaseolus vulgaris L.)* under water deficiency. Soil Biology and Biochemistry 39: 1744 – 1750.

Morgado, L. B, Wiley, R. W. 2003. Effects of plant population and nitrogen fertililizer on yield and efficiency of maize/bean intercropping. Field Crops Research 38: 1257-1264.

Moser, S. B., Feil, B., Jampatong S. and Stamp, P. 2006. Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. Agricultural Water Management 81: 41–58.

Mugo, S. N. and Njoroge, K. 1997. Alleviating the effects of drought on maize production in the moisture stress areas of Kenya through escape and tolerance. In: Developing Drought and Low-N Tolerant Maize. Edmeades, G.O., Banziger, M., Mickelson, H.R. and Pena-Valdivia C.B. (Eds.), 475-480. CIMMYT, El Batan, Mexico.

Mugo, S. N., **De Groote, H., Songa, J., Mulaa M., Odhiambo, B., Taracha, C., Bergvinson, D., Hoisington, D. and Gethi, M. 2001.** A dvances in developing insect resistant maize varieties for Kenya within the insect resistant maize for Africa (IRMA) project. Seventh Eastern and Southern Africa Maize Regional Conference. 31-37.

Mugo S. N., **Smith, M. E., Banziger, M., Setter, T. L., Edmeades, G. O. and Elings, A. 1998.** Performance of early maturing katumani and kito maize composites under drought at the seedling and flowering stages. African Crop Science Journal 6: 329-344.

Mugo, S. N., **Songa, J. M., De Groote, H. and Hoisington, D. 2002.** Insect Resistant Maize for Africa (IRMA) Project: An overview, Paper presented to the Syngenta Symposium, Washington, DC, 25 June, 2002, the Syngenta staff in Greensboro, North Carolina, 26 June, 2002, and to the Syngenta staff in Bassel, Switzerland, 27 June, 2002.

Mukiibi J. K. 1976. Possible relationships between intercropping and plant disease problems in Uganda (abstract). In: Intercropping in Semi-Arid Areas (Ed. by J. H. Monyo, A. D. R. Ker & M. Campbell), p. 45. IDRC, Ottawa, Ontario.

Muraya, M. M., Omolo, E. O. and Ndirangu, C. M. 2006. Development of high yielding synthetic maize (*Zea mays L.)* varieties suitable for intercropping with common bean (*Phaseolus vulgaris L.*). Asian Journal of Plant Sciences 5: 163 – 169.

Mutungamiri, A., Mariga, I. K. and Chivinge, A. O. 2001. Evaluation of maize (*Zea mays L.*) cultivars and density for dryland maize-bean intercropping. Tropical Agriculture 78: 8-12.

Muui, C. W., Muasya, R.M., Rao, N. and Anjichi V. E. 2007. Pollen longevity in ecologically different zones of western Kenya. African Crop Science Journal 15: 43-49.

Mwikya, J. 2009. Impacts of drought on maize crop in Kenya. Kenya Meteorological Department. http://wamis.org/agm/meetings/anadia 06/.

Myers, O. 1985. Breeding for drought tolerance in maize. In: To Feed Ourselves. A Proceedings of the First Eastern, Central and Southern Africa Regional Maize Workshop. Lusaka, Zambia. March, 10-17.

Natarajan, M. and Shumba, E. M. 1990. Intercropping research in Zimbabwe: Current status and outlook for the future. In: Research Methods for Cereal/Legume Intercropping. Proceedings of a Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa. Waddington, S.R., Palmer, A.F.E. and Edje, O.T. (Eds.), pp. 190-193. CIMMYT, Harare, Zimbabwe.

Nderitu, C. G. 1999. Biotechnology in Africa. Why the controversy?. In: Persely, G. N. and Lantin, M. M. (Eds.). Agricultural Biotechnology and the poor: Proceedings of an international conference, Washington D.C., 21 -22, October 1999. Consultative Group on International Agricultural Research, Washington, D. C. 109 – 114.

NeSmith D. S. and Ritchie J. T. 1992. Effects of soil water deficit during tassel emergence on development and yield components of maize. Field Crops Research 28: 251-256.

Neves-Piestun, B. G. and Bernstein, N. 2005. Salinity-induced changes in the nutritional status of expanding cells may impact leaf growth inhibition in maize. Functutional Plant Biology 32: 141–152.

Niringiye, C. S., Kyamanywa, S. and Ssekabembe, C. S. 2006. Effect of plant population on yield of maize and climbing bean grown in an intercropping system. African Crop Science Journal 24: 109 – 121.

Njoroge, K. 1987. Earliness and yield in maize: An evaluation of some Katumani maize varieties. East African Agricultural and Forestry Journal 48:40-50.

Njoroge, K. 1992. Improve and sustain maize production through adoption of known techniques. Kenya Agricultural Research Institute, KARI.

Nyariki, D. M. 2007. Kenya position paper on the Horn of Africa initiative on tackling food insecurity: 2- 9.

Nyoro, J. K. 2003. Impact of market reform on seed development, multiplication and distribution. Working paper, Tegemeo Institute, Egerton University.

Odhiambo, G. D. and Ariga, E. S. 2001. Effect of intercropping maize and beans on striga incidence and grain yield. Seventh Eastern and southern African regional maize conference. February 11 – 15. 183 – 186.

Ofori, F. and Stern, W. R. 1987. Cereal-legume intercropping systems. Advanced Agronomy 41: 41 – 90.

Ogindo, H. O. 2003. Comparing precipitation efficiency of maize bean intercropping with sole cropping in semi-arid Ecotase. Ph.D. dissertation. University of the Free State, Republic of South Africa.

Okigbo, B. N. 1979. Evaluation of plant interactions and productivity in complex mixtures as a basis for improved cropping systems design. In: Willey, R. W. (Ed.). Proceedings of the International Workshop on Intercropping. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, 10-13 Jan. 1979.

Oswald, A., Ransom, J. K., Kroschel, J. and Sauerborn, J. 2002. Intercropping controls striga in maize based farming systems. Crop Protection 5: 367 – 374.

Otegui, M. E., 1995. Prolificacy and grain yield components in modern Argentinean maize hybrids. Crop Science 40: 371–376.

Pan-Africa Bean Research Alliance. 2007. http://www.webapp.ciat.org/Africa/pdf/pabra-outlook07/.

Park, S. C., Benjamin, R. L. and Watkinson, A. R. 2000. Comparing biological productivity in cropping systems: a competition appproach. Journal of Applied Ecology 39: 416 – 426.

Pilbeam, C. J., Okalebo, J. R., Simmonds, P. and Gathua K. W. 1994. Analysis of maize-common bean intercrops in semi-arid Kenya. Journal of Agricultural Science 123: 191-198.

Pingali, P. L. (Ed.). 2001. CIMMYT. 1999 – 2000. World maize facts and trends. Meeting world maize needs: Technological opportunities and priorities for the public sector. Mexico DF.: CIMMYT. 1 – 57.

Poggio, S. L. 2005. Structure of weed communities occurring in monoculture and intercropping of field pea and barley. Agricultural Ecosystem and Environment 109: 48-58.

Qureshi, J. N. 1991. The cummulative effects of of N-P fertilizers, manure and crop residues on maize and bean yields and some soil chemical properties at Kabete. In: Recent advances in KARI's research programmes – proceedings of the 2nd Annual KARI scientific conference. Kenya Agricultural Research Institute – KARI, Nairobi 160-167.

Rahman, M. M., Awal, M. A., Amin, A. and Parvej, M. R. 2009. Compatatibility, growth and production potentials of mustard/lentil intercrops. International Journal of Botany 5: 100 – 106.

Rao, M. R. and Mathuva, M. D. 2000. Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment 78: 123–137.

Rao, L.J. and Mittra, B. N. 1990. Evaluation of groundnut (*Arachis hypogea*) genotypes for intercropping with two types of pigeon pea (*Cajanus cajan*). Journal of Agricultural Science 115:337-342.

Reddy, N. M. and Chetty, R. C. K. 1984. Staple land equivalent ratio for assessing yield advantage from intercropping. Experimental Agriculture 20: 202-207.

Rezende, G. D. S. P. and Ramalho, M. A. P. 1994. Competitive ability of maize and common bean (*Phaseolus vulgaris L.)* cultivars intercropped in different environments. Journal of Agricultural Science 123:185-190.

Ribaut, J. M., Jiang C., Gonzalez-de-leon D., Edmeades, G. O. and Hosington, D. 1997. Identification of quantitative trait loci under drought conditions in tropical maize. 2. Yield components and marker-assisted selection strategies. Crop Science 94:887-896.

Rosen, S. and Scott, L. 1992. Famine grips sub-Saharan Africa. Agriculture Outlook. 191:20–24.

Santalla, M., Rodino, A.P., Casquero, P.A. and de Ron, A.M. 2001. Interactions of bush bean intercropped with field and sweet maize. European Journal of Agronomy 15: 185 – 196.

Sekamatte, B. M., Ogenga-Latigo, M. and Russell-Smith, A. 2003. Effects of maize–legume intercrops on termite damage to maize, activityof predatory ants and maize yields in Uganda. Crop Protection 22: 87–93.

Shaw, R. H., 1977. Water use and requirements of maize-a review. Agrometeorology of the Maize (Corn) Crop. World Meteorologicaal Organization Publication 480: 119 - 134.

Shisanya, C. A. 2002. Improvement of drought adapted tepary bean (*Phaseolus acutifolius A. Gray var. latifolius*) yield through biological nitrogen fixation in semi-arid SE-Kenya. European Journal of Agronomy 16: 13–24.

Shisanya, C. A. 2003. Yield and nitrogen fixation response by drought tolerant tepary bean (*Phaseolus acutifolius A. Gray Var. Latifolius*) in sole and maize intercrop systems in semi-arid Kenya. Pakistan Journal of Agronomy 2: 126 – 137.

Sinoquet, H. and Cruz, P. 1995. Ecophysiology of tropical intercropping. INRA., Paris.

Smaling, E. M. A. 1998. Nutrient balances as indicators of productivity and sustainability in Sub-African Agriculture. Agriculture Ecosystem and Environment 71: 3-12

Songa J. M., Jiang N., Schulthess F., Omwega C. 2007. The role of intercropping different cereal species in controlling lepidopteran stemborers on maize in Kenya. Journal of Applied Entomology 131:40-49

Songa J. M., Zhou, G. and Overholt, W. A. 2001. Relationships of stem borer damage and plant physical conditions to maize yield in a semi-arid zone of eastern Kenya. Insect Science and its Application 21: 243 – 249.

Songa, J. M., Overholt, R. O., Okello and Mueke, J. M. 2002a. Regional distributon of lepidopteran stem borers and their parasitoids among wild grasses in the semi arid eastrem kenya. African Crop Science Journal 10: 183 – 194.

Stoorvogel, J. J., Smaling, E. M. A. and Janssen, B. H. 1993. Calculating soil nutrient balances at different scale. I. Supra-national scale. Fertilization Research 35: 227- 235.

Swift, M. J., Seward, P. D., Frost, P. G. H., Qureshi, J. N. and Muchena, F. N. 1994. Long term experiments in Africa: developing a database for sustainable land use under global change. In Leigh R. A., Johnson, A. E. (eds). Long term Experiments in Agricultural and Ecological Sciences: 229–251.

Szumigalski, A. R. and Van Acker, R. C. 2008. Land equivalent ratios, light interception, and water use in annual intercrops in the presence or absence of in-crop herbicides. Agronomy Journal 100: 1145 – 1154.

Tamado, T., Fininsa, C. and Worku, W. 2007. Agronomic performance and productivity of common bean (*Phaseolus vulgaries L.)* varieties in double intercropping with maize (*Zea mays L.)* in eastern Ethiopia . Asian Journal of Plant Sciences 6: 749 – 756.

Tardieu, F., Reymond, M., Hamard, P., Granier, C. and Muller, B. 2000. Spatial distributions of expansion rate, cell division rate and cell size in maize leaves: a synthesis of the effects of soil water status, evaporative demand and temperature. Journal of Experimental Botany 51: 1505–1514.

Thiraporn, R., Feil, B. and Stamp, P. 1992. Effect of nitrogen fertilization on grain yield and accumulation of nitrogen, phosphorus and potassium in the grains of tropical maize. Journal of Agronomy 169: 9–16.

Trenbath, B. R. 1974. Biomass productivity of mixtures. Advanced Agronomy 26: 177 – 210.

Trenbath, B. R. 1999. Multispecies cropping systems in India—predictions of their productivity, stability, resilience and ecological sustainability. Agroforestry Systems 45: 81–107.

Tsubo, M., Mukhala, E., Ogindo, H. O. and Walker, S. 2003. Productivity of maize bean intercropping in a semi-arid region of South Africa. Water South Afriaca 29: 381 – 388.

Tsubo, M., Ogindo, H. O. and Walker, S. 2004. Yield evaluation of maize-bean intercropping in a semi-arid region of South Africa. African Crop Science Journal 12: 351-358.

Tsubo, M. and Walker, S. 2002. A model of radiation interception and use by a maize–bean intercrop canopy. Agricultural and Forest Meteorology 110: 203–215.

Tsubo, M. and Walker, S. 2005. Shade effects on *Phaseolus vulgaris L.* intercropped with *Zea mays L.* under well-watered conditions. Journal of Agronomy 190: 168–176.

Tsubo, M., Walker, S. and Mukhala, E. 2001. Comparisons of radiation use efficiency of mono-inter-cropping systems with different row orientations. Field Crops Research 71: 17-29.

Tsubo, M., Walker, S. and Ogindo, H. O. 2005. A simulation model of cereal–legume intercropping systems for semi-arid regions. II. Model application. Field Crops Research 93: 23-33.

U. S. Census Bureau. 2008. http://www. prb.org/presentations/

Vanlauwe, B., Kanampiu, F., Odhiambo, G. D., De Groote, H., Wadhams, L. J. and Khan, Z. R. 2008. Integrated management of Striga hermonthica, stemborers, and declining soil fertility in western Kenya. Field Crops Research 107:102–115.

Waiyaki, N., Mwakubo, S., Odhiambo, W., Nzuma, J., Murithi, F., Gamba, P., Muhammed, L., Nyongesa, D., Nambiro, E., King'ori, B. and Obunde, P. 2006. Determinants of seed maize pricing in Kenya. The Kenya Institute of Public Policy Research and Analysis (KIPPRA). Discussion paper 61.

Walker, S and Ogindo, H. O. 2003. The water budget of rain-fed maize and bean intercrop. Physics and chemistry of the Earth 28: 919 – 926.

Weigelt, A. and Jolliffe, P. 2003. Indices of plant competition. Journal of Ecology 91: 707 – 720.

Wekesa, E., Mwangi, W., Verkuijl, H., Danda, K. and De Groote, H. 2003. Adoption of maize production technologies in the coastal lowlands of Kenya. Mexico, D.F.: CIMMYT.

Westgate, M. E and Bassetti, P. 1990. Heat and drought stress in corn: what really happens\to the corn plant at pollination? In: Wilkinson, D. (Ed.). Proceedings of the 45th annual corn and sorghum research conference, Chicago, 5-6 December, 1990. ASTA. Wishington DC. 12 - 28.

Westgate, M. E., Boyer, J. S.1986. Water status of the developing grain of maize. Agronomy Journal 78: 714–719.

Whitmore, A. A. and Schroder, J. J. 2007. Intercropping reduces nitrate leaching from under field crops without loss of yield: A modelling study. European Journal of Agronomy 27:81–88.

Willey, R. W. 1979. Intercropping-its importance and research needs. Part 1. Competition and yield advantages. Field Crops Abstracts 32: 1-10.

Willey, R. W. and Osiru, D. S. O. 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. Journal of Agricultural Science 79:5 17-529

Willey, R. W. and Rao, M. R. 1980. A competitive ratio for quantifying competition between intercrops. Experimental Agriculture 16: 117-125.

Willey, R. W. and Rao, M. R. 1981. A systematic design to examine effects of plant population and spatial arrangement in intercropping, illustrated by an experiment on chickpea/safflower. Experimental Agriculture 17: 63-73

Yilmaz, S., Atak, M. and Erayman, M. 2007. Identification of advantages of maize-legume intercropping over solitary cropping through competition indices in the East Mediterranean region. Turkey Journal of Agriculture 32: 111 – 119.

Zaidi, P. H., Srinivasan G., Cordova, H.S. and Sanchez, C. 2004. Gains from improvement for mid season drought tolerance in tropical maize (*Zea mays L.*) Field Crops Research 89:135–152.

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

Zhang, J., Schurr, U. and Davies, W. J. 1987. Control of stomatal behaviour by abscisic acid which apparently **originates** in the roots. Journal of Experimental Botany 38: 1174-1181.

APPENDICES

Appendix 1: Soil characteristics of Mwea, Waruhiu and Machakos experimental sites in 2008 short rains and 2009 long rains

	Mwea		Waruhiu		Machakos
Chemical Property	2008 SR	2009 LR	2008 SR	2009 LR	2009 LR
Soil pH	6.03	5.78	5.41	5.45	6.24
Total Nitrogen (%)	0.14	0.14	0.26	0.24	0.08
Organic Carbon (%)	2.26	2.05	2.68	2.77	0.99
Phosphorus (ppm)	175.00	173.00	5.00	2.00	49.00
Potassium (me %)	1.92	1.34	0.36	0.12	0.86
Calcium (me %)	6.00	4.60	2.00	1.40	3.80
Magnesium (me %)	4.69	4.93	1.69	1.61	1.59
Manganese (me %)	0.46	0.50	0.48	0.62	0.57
Copper (ppm)	3.60	3.40	1.70	1.50	3.60
Iron (ppm)	95.10	104.00	27.70	27.50	24.90
Zinc (ppm)	8.90	3.70	11.60	11.50	4.10
Sodium (ppm)	0.14	0.14	0.12	0.10	0.20

SR: short rain; LR: long rain; ppm: parts per million; me: milli equivalent

Appendix 2: Rainfall and temperature data at the Kenya Agricultural Research Institute-Mwea, Waruhiu Agricultural Training Centre and Machakos Agricultural Training Centre for 2008 short rains and 2009 long rains

	Mwea		Waruhiu		Machakos	
Month	Rainfall (mm)	MDT (°C)	Rainfall (mm)	MDT (°C)	Rainfall (mm)	MDT (°C)
October	210.5	23.6	230.4	19.2	25.0	25.4
November	70.3	23.2	197.4	18.8	17.0	25.1
December	0.0	22.3	0.0	18.4	10.0	25.2
January	98.0	22.3	45.3	18.8	0.0	24.5
February	0.0	21.0	41.8	19.1	0.0	25.3
March	96.7	22.5	87.2	19.4	78.7	26.7
April	205.1	24.2	182.4	19.3	183.5	25.6
May	87.9	23.0	144.6	18.7	35.0	24.7
June	0.0	22.0	38.4	17.7	0.0	22.9
July	0.0	21.1	11.0	17.0	0.0	21.1
August	0.0	22.0	6.4	18.2	0.0	22.0
Mean	69.9	22.5	89.5	18.6	31.7	24.4

MDT: Mean Daily Temperature

Appendix 3 a: Analysis of variance (ANOVA) table for plant height at 57 DAE for sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	8957.0	4478.5	7.06	
variety	15	13016.6	867.8	1.37	0.226
Residual	30	19035.2	634.5	9.19	
CS	1	454.7	454.7	6.59	0.015
variety.CS	15	275.2	18.3	0.27	0.996
Residual	32	2208.3	69.0	0.30	
site	1	515063.3	515063.3	2238.21	<.001
variety.site	15	6769.9	451.3	1.96	0.033
CS.site	1	452.5	452.5	1.97	0.166
variety.CS.site	15	286.1	19.1	0.08	1.000
Residual	64	14727.9	230.1		
Total	191	581246.7			

Appendix 3 b: Analysis of variance (ANOVA) table for plant height at 57 DAE for sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Mwea during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	2236.4	1118.2	1.78	
variety	15	20478.8	1365.3	2.17	0.035
Residual	30	18871.0	629.0	4.01	
CS	1	379.6	379.6	2.42	0.130
variety.CS	15	3375.1	225.0	1.43	0.191
Residual	32	5023.4	157.0	0.21	
site	2	682661.5	341330.8	449.81	<.001
variety.site	30	42429.2	1414.3	1.86	0.009
CS.site	2	52.0	26.0	0.03	0.966
variety.CS.site	30	3425.1	114.2	0.15	1.000
Residual	128	97130.3	758.8		
Total	287	876062.5			

Appendix 4 a: Analysis of variance (ANOVA) table for plant stand count at 57 DAE for sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	620.78	310.39	3.19	
variety	15	1683.62	112.24	1.15	0.356
Residual	30	2918.22	97.27	212.20	
CS	1	1.14	1.14	2.49	0.124
variety.CS	15	2.80	0.19	0.41	0.966
Residual	32	14.67	0.46	0.01	
site	1	44242.87	44242.87	932.08	<.001
variety.site	15	954.15	63.61	1.34	0.206
CS.site	1	2.71	2.71	0.06	0.812
variety.CS.site	15	3.73	0.25	0.01	1.000
Residual	64	3037.88	47.47		
Total	191	53482.55			

Appendix 4 b: Analysis of variance (ANOVA) table for plant stand count at 57 DAE for sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Machakos during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	624.81	312.41	4.38	
variety	15	1957.39	130.49	1.83	0.078
Residual	30	2141.97	71.40	2.11	
CS	1	100.35	100.35	2.97	0.094
variety.CS	15	388.88	25.93	0.77	0.701
Residual	32	1080.78	33.77	1.53	
site	2	928.77	464.39	21.06	<.001
variety.site	30	860.67	28.69	1.30	0.159
CS.site	2	116.26	58.13	2.64	0.076
variety.CS.site	30	666.52	22.22	1.01	0.466
Residual	128	2823.11	22.06		
Total	287	11689.50			

Appendix 5 a: Analysis of variance (ANOVA) table for lodging % of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 rains rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	530.63	265.31	6.79	
variety	15	752.02	50.13	1.28	0.271
Residual	30	1171.90	39.06	348.69	
CS	1	0.08	0.08	0.76	0.390
variety.CS	15	0.27	0.02	0.16	1.000
Residual	32	3.58	0.11	0.01	
site	1	354.50	354.50	22.88	<.001
variety.site	15	301.07	20.07	1.30	0.231
CS.site	1	0.00	0.00	0.00	0.990
variety.CS.site	15	0.18	0.01	0.00	1.000
Residual	64	991.49	15.49		
Total	191	4105.73			

Appendix 5 b: Analysis of variance (ANOVA) table for lodging % of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	5.946	2.973	1.11	
variety	15	2314.956	154.330	57.38	<.001
Residual	30	80.691	2.690	4.13	
CS	1	1.259	1.259	1.94	0.174
variety.CS	15	38.206	2.547	3.92	<.001
Residual	32	20.818	0.651	0.37	
site	1	10.766	10.766	6.08	0.016
variety.site	15	397.578	26.505	14.96	<.001
CS.site	1	0.696	0.696	0.39	0.533
variety.CS.site	15	36.514	2.434	1.37	0.188
Residual	64	113.379	1.772		
Total	191	3020.809			

Appendix 6 a: Analysis of variance (ANOVA) table for shoot biomass (t/ha) sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	4.448	2.224	0.04	
variety	15	4897.266	326.484	5.81	<.001
Residual	30	1686.812	56.227	239.30	
CS	1	0.017	0.017	0.07	0.791
variety.CS	15	3.205	0.214	0.91	0.562
Residual	32	7.519	0.235	0.06	
site	1	2945.560	2945.560	709.49	<.001
variety.site	15	432.115	28.808	6.94	<.001
CS.site	1	0.002	0.002	0.00	0.984
variety.CS.site	15	2.959	0.197	0.05	1.000
Residual	64	265.705	4.152		
Total	191	10245.607			

Appendix 6 b: Analysis of variance (ANOVA) table for shoot biomass (t/ha) for sixteen maize varieties intercropped with beans in Mwea, Waruhiu and Machakos during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	68.23	34.12	1.93	
variety	15	9274.14	618.28	34.92	<.001
Residual	30	531.16	17.71	3.97	
CS	1	4.27	4.27	0.96	0.336
variety.CS	15	52.45	3.50	0.78	0.686
Residual	32	142.84	4.46	0.16	
site	2	20287.81	10143.91	357.63	<.001
variety.site	30	7592.85	253.09	8.92	<.001
CS.site	2	8.22	4.11	0.14	0.865
variety.CS.site	30	194.32	6.48	0.23	1.000
Residual	128	3630.65	28.36		
Total	287	41786.95			

Appendix 7 a: Analysis of variance (ANOVA) table for days to 50% anthesis of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	61.89	30.94	0.38	
variety	15	5284.66	352.31	4.35	<.001
Residual	30	2431.95	81.06	15564.47	
CS	1	0.01	0.01	1.00	0.325
variety.CS	15	0.08	0.01	1.00	0.479
Residual	32	0.17	0.01	0.00	
site	1	6733.17	6733.17	553.89	<.001
variety.site	15	637.24	42.48	3.49	<.001
CS.site	1	0.01	0.01	0.00	0.984
variety.CS.site	15	0.08	0.01	0.00	1.000
Residual	64	778.00	12.16		
Total	191	15927.24			

Appendix 7 b: Analysis of variance (ANOVA) table for days to 50% anthesis of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	4.2917	2.1458	1.21	
variety	15	11916.6458	794.4431	449.33	<.001
Residual	30	53.0417	1.7681		
CS	1	0.0000	0.0000		
variety.CS	15	0.0000	0.0000		
Residual	32	0.0000	0.0000	0.00	
site	1	15444.1875	15444.1875	19008.23	<.001
variety.site	15	382.8125	25.5208	31.41	<.001
CS.site	1	0.0000	0.0000	0.00	1.000
variety.CS.site	15	0.0000	0.0000	0.00	1.000
Residual	64	52.0000	0.8125		
Total	191	27852.9792			

Appendix 8 a: Analysis of variance (ANOVA) table for days to 50% silking of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	86.16	43.08	0.53	
variety	15	5816.20	387.75	4.80	<.001
Residual	30	2422.34	80.74	1722.56	
CS	1	0.05	0.05	1.00	0.325
variety.CS	15	0.70	0.05	1.00	0.479
Residual	32	1.50	0.05	0.00	
site	1	7815.76	7815.76	659.33	<.001
variety.site	15	846.33	56.42	4.76	<.001
CS.site	1	0.05	0.05	0.00	0.950
variety.CS.site	15	0.70	0.05	0.00	1.000
Residual	64	758.67	11.85		
Total	191	17748.45			

Appendix 8 b: Analysis of variance (ANOVA) table for days to 50% silking of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	4.2917	2.1458	1.13	
variety	15	12347.3333	823.1556	432.92	<.001
Residual	30	57.0417	1.9014		
CS	1	0.0000	0.0000		
variety.CS	15	0.0000	0.0000		
Residual	32	0.0000	0.0000	0.00	
site	1	14283.0000	14283.0000	15943.81	<.001
variety.site	15	349.6667	23.3111	26.02	<.001
CS.site	1	0.0000	0.0000	0.00	1.000
variety.CS.site	15	0.0000	0.0000	0.00	1.000
Residual	64	57.3333	0.8958		
Total	191	27098.6667			

Appendix 9 a: Analysis of variance (ANOVA) table for days to 50% physiological maturity of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	19.91	9.95	0.27	
variety	15	15628.16	1041.88	28.64	<.001
Residual	30	1091.26	36.38	6984.07	
CS	1	0.01	0.01	1.00	0.325
variety.CS	15	0.08	0.01	1.00	0.479
Residual	32	0.17	0.01	0.00	
site	1	5281.51	5281.51	312.79	<.001
variety.site	15	700.24	46.68	2.76	0.002
CS.site	1	0.01	0.01	0.00	0.986
variety.CS.site	15	0.08	0.01	0.00	1.000
Residual	64	1080.67	16.89		
Total	191	23802.08			

Appendix 9 b: Analysis of variance (ANOVA) table for days to 50% physiological maturity of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	2.3750	1.1875	0.63	
variety	15	22512.6458	1500.8431	799.86	<.001
Residual	30	56.2917	1.8764		
CS	1	0.0000	0.0000		
variety.CS	15	0.0000	0.0000		
Residual	32	0.0000	0.0000	0.00	
site	1	8883.5208	8883.5208	10933.56	<.001
variety.site	15	1365.4792	91.0319	112.04	<.001
CS.site	1	0.0000	0.0000	0.00	1.000
variety.CS.site	15	0.0000	0.0000	0.00	1.000
Residual	64	52.0000	0.8125		
Total	191	32872.3125			

Appendix 10 a: Analysis of variance (ANOVA) table for grain yield (t/ha) of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.50624	0.25312	0.55	
variety	15	6.63081	0.44205	0.97	0.511
Residual	30	13.74064	0.45802	1697.73	
CS	1	0.00000	0.00000	0.01	0.914
variety.CS	15	0.00302	0.00020	0.75	0.722
Residual	32	0.00863	0.00027	0.00	
site	1	11.33411	11.33411	176.23	<.001
variety.site	15	4.41052	0.29403	4.57	<.001
CS.site	1	0.00007	0.00007	0.00	0.974
variety.CS.site	15	0.00397	0.00026	0.00	1.000
Residual	64	4.11603	0.06431		
Total	191	40.75404			

Appendix 10 b: Analysis of variance (ANOVA) table for grain yield (t/ha) of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.9900	0.4950	1.36	
variety	15	21.8838	1.4589	4.02	<.001
Residual	30	10.8965	0.3632	2.29	
CS	1	0.0000	0.0000	0.00	1.000
variety.CS	15	1.9019	0.1268	0.80	0.670
Residual	32	5.0779	0.1587	0.42	
site	1	0.5901	0.5901	1.58	0.213
variety.site	15	12.4924	0.8328	2.23	0.014
CS.site	1	0.0391	0.0391	0.10	0.747
variety.CS.site	15	1.6265	0.1084	0.29	0.995
Residual	64	23.9147	0.3737		
Total	191	79.4129			

Appendix 11 a: Analysis of variance (ANOVA) table for ears per plant of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.43851	0.21926	2.27	
variety	15	1.25903	0.08394	0.87	0.600
Residual	30	2.89252	0.09642	13.37	
CS	1	0.00701	0.00701	0.97	0.332
variety.CS	15	0.10006	0.00667	0.92	0.548
Residual	32	0.23083	0.00721	0.22	
site	1	0.02567	0.02567	0.78	0.380
variety.site	15	1.88223	0.12548	3.82	<.001
CS.site	1	0.00827	0.00827	0.25	0.618
variety.CS.site	15	0.09703	0.00647	0.20	0.999
Residual	64	2.10360	0.03287		
Total	191	9.04477			

Appendix 11 b: Analysis of variance (ANOVA) table for ears per plant of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.135078	0.067539	6.73	
variety	15	0.241458	0.016097	1.60	0.132
Residual	30	0.301172	0.010039	2.61	
CS	1	0.000042	0.000042	0.01	0.917
variety.CS	15	0.059733	0.003982	1.04	0.447
Residual	32	0.123050	0.003845	0.47	
site	1	0.047188	0.047188	5.75	0.019
variety.site	15	0.171787	0.011452	1.40	0.177
CS.site	1	0.000005	0.000005	0.00	0.981
variety.CS.site	15	0.064204	0.004280	0.52	0.919
Residual	64	0.525167	0.008206		
Total	191	1.668883			

Appendix 12 a: Analysis of variance (ANOVA) table for cob length of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	52.916	26.458	3.42	
variety	15	271.651	18.110	2.34	0.023
Residual	30	232.200	7.740	284.62	
CS	1	0.011	0.011	0.39	0.537
variety.CS	15	0.151	0.010	0.37	0.978
Residual	32	0.870	0.027	0.01	
site	1	30.094	30.094	7.70	0.007
variety.site	15	118.284	7.886	2.02	0.027
CS.site	1	0.004	0.004	0.00	0.974
variety.CS.site	15	0.078	0.005	0.00	1.000
Residual	64	250.099	3.908		
Total	191	956.359			

Appendix 12 b: Analysis of variance (ANOVA) table for cob length of sixteen maize varieties intercropped withbeans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.408	0.204	0.08	
variety	15	284.994	19.000	7.00	<.001
Residual	30	81.452	2.715	1.44	
CS	1	2.741	2.741	1.45	0.238
variety.CS	15	23.129	1.542	0.82	0.654
Residual	32	60.533	1.892	0.66	
site	1	65.824	65.824	23.06	<.001
variety.site	15	86.100	5.740	2.01	0.028
CS.site	1	3.101	3.101	1.09	0.301
variety.CS.site	15	11.412	0.761	0.27	0.997
Residual	64	182.707	2.855		
Total	191	802.401			

Appendix 13 a: Analysis of variance (ANOVA) table for kernel rows per cob of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	9.2317	4.6159	1.50	
variety	15	33.5964	2.2398	0.73	0.737
Residual	30	92.1168	3.0706	99.11	
CS	1	0.0006	0.0006	0.02	0.886
variety.CS	15	0.3160	0.0211	0.68	0.784
Residual	32	0.9914	0.0310	0.08	
site	1	78.2530	78.2530	197.83	<.001
variety.site	15	19.1766	1.2784	3.23	<.001
CS.site	1	0.0296	0.0296	0.07	0.785
variety.CS.site	15	0.2143	0.0143	0.04	1.000
Residual	64	25.3153	0.3956		
Total	191	259.2419			

Appendix 13 b: Analysis of variance (ANOVA) table for kernel rows per cob of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.3888	0.1944	0.28	
variety	15	107.5355	7.1690	10.51	<.001
Residual	30	20.4675	0.6823	2.93	
CS	1	0.3024	0.3024	1.30	0.263
variety.CS	15	3.5821	0.2388	1.03	0.456
Residual	32	7.4511	0.2328	0.59	
site	1	7.9300	7.9300	20.02	<.001
variety.site	15	11.5521	0.7701	1.94	0.035
CS.site	1	0.0032	0.0032	0.01	0.929
variety.CS.site	15	3.7143	0.2476	0.62	0.844
Residual	64	25.3563	0.3962		
Total	191	188.2833			

Appendix 14 a: Analysis of variance (ANOVA) table for 100 kernel weight of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	6.912	3.456	0.44	
variety	15	191.721	12.781	1.62	0.128
Residual	30	237.078	7.903	94.90	
CS	1	0.010	0.010	0.12	0.727
variety.CS	15	0.470	0.031	0.38	0.976
Residual	32	2.665	0.083	0.04	
site	1	477.654	477.654	240.10	<.001
variety.site	15	215.437	14.362	7.22	<.001
CS.site	1	0.033	0.033	0.02	0.898
variety.CS.site	15	0.243	0.016	0.01	1.000
Residual	64	127.322	1.989		
Total	191	1259.544			

Appendix 14 b: Analysis of variance (ANOVA) table for 100 kernel weight of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	12.876	6.438	0.96	
variety	15	333.896	22.260	3.33	0.002
Residual	30	200.334	6.678	1.49	
CS	1	0.070	0.070	0.02	0.902
variety.CS	15	71.613	4.774	1.06	0.425
Residual	32	143.814	4.494	0.48	
site	1	88.477	88.477	9.49	0.003
variety.site	15	165.379	11.025	1.18	0.308
CS.site	1	7.112	7.112	0.76	0.386
variety.CS.site	15	28.883	1.926	0.21	0.999
Residual	64	596.430	9.319		
Total	191	1648.884			

Appendix 15 a: Analysis of variance (ANOVA) table for shelling % of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	193.265	96.633	5.19	
variety	15	831.743	55.450	2.98	0.005
Residual	30	558.809	18.627	17.36	
CS	1	0.001	0.001	0.00	0.972
variety.CS	15	10.732	0.715	0.67	0.796
Residual	32	34.342	1.073	0.13	
site	1	983.141	983.141	117.24	<.001
variety.site	15	887.802	59.187	7.06	<.001
CS.site	1	0.004	0.004	0.00	0.983
variety.CS.site	15	10.482	0.699	0.08	1.000
Residual	64	536.690	8.386		
Total	191	4047.011			

Appendix 15 b: Analysis of variance (ANOVA) table for shelling % of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	5.898	2.949	0.26	
variety	15	782.895	52.193	4.59	<.001
Residual	30	341.331	11.378	1.42	
CS	1	2.571	2.571	0.32	0.575
variety.CS	15	182.620	12.175	1.52	0.156
Residual	32	256.121	8.004	0.83	
site	1	413.787	413.787	43.05	<.001
variety.site	15	269.895	17.993	1.87	0.043
CS.site	1	25.040	25.040	2.61	0.111
variety.CS.site	15	118.505	7.900	0.82	0.650
Residual	64	615.114	9.611		
Total	191	3013.776			

Appendix 16 a: Analysis of variance (ANOVA) table for harvest index of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2008 short rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.0000132	0.0000066	0.00	
variety	15	0.1578285	0.0105219	3.12	0.004
Residual	30	0.1011788	0.0033726	588.14	
CS	1	0.0000022	0.0000022	0.38	0.542
variety.CS	15	0.0000528	0.0000035	0.61	0.842
Residual	32	0.0001835	0.0000057	0.01	
site	1	0.0235512	0.0235512	38.50	<.001
variety.site	15	0.0354011	0.0023601	3.86	<.001
CS.site	1	0.0000025	0.0000025	0.00	0.949
variety.CS.site	15	0.0000506	0.0000034	0.01	1.000
Residual	64	0.0391450	0.0006116		
Total	191	0.3574094			

Appendix 16 b: Analysis of variance (ANOVA) table for harvest index of sixteen maize varieties intercropped with beans in Mwea and Waruhiu during 2009 long rains

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.012479	0.006240	1.54	
variety	15	0.906621	0.060441	14.95	<.001
Residual	30	0.121316	0.004044	4.38	
CS	1	0.000189	0.000189	0.21	0.653
variety.CS	15	0.009039	0.000603	0.65	0.808
Residual	32	0.029515	0.000922	0.20	
site	1	0.001554	0.001554	0.34	0.565
variety.site	15	0.121422	0.008095	1.75	0.064
CS.site	1	0.002434	0.002434	0.53	0.471
variety.CS.site	15	0.014073	0.000938	0.20	0.999
Residual	64	0.296620	0.004635		
Total	191	1.515263			

Appendix 17: Analysis of variance (ANOVA) table for plant height of KB1 bean at 43 DAE intercropped with sixteen maize varieties during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	451.78	225.89	2.39	
variety	16	924.19	57.76	0.61	0.869
site	2	2515.98	1257.99	13.29	<.001
variety.site	32	1342.77	41.96	0.44	0.995
Residual	100	9464.84	94.65		
Total	152	14699.57			

Appendix 18 a: Analysis of variance (ANOVA) table for nodule count per plant at 21 days after emergence of KB 1 bean variety grown in Mwea, Waruhiu and Machakos under sole crop and intercropped with sixteen maize varieties during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	8.345	4.172	1.37	
variety	16	129.551	8.097	2.65	0.002
site	2	3946.481	1973.241	646.11	<.001
variety.site	32	41.490	1.297	0.42	0.996
Residual	100	305.402	3.054		
Total	152	4431.268			

Appendix 18 b: Analysis of variance (ANOVA) table for nodule count per plant at 50% flowering of KB 1 bean variety grown in Mwea, Waruhiu and Machakos under sole crop and intercropped with sixteen maize varieties during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	42.942	21.471	5.09	
variety	16	84.668	5.292	1.25	0.242
site	2	14626.976	7313.488	1733.40	<.001
variety.site	32	104.741	3.273	0.78	0.791
Residual	100	421.915	4.219		
Total	152	15281.242			

Appendix 19: Analysis of variance (ANOVA) table for shoot biomass (g/m^2) at 50% flowering of KB 1 bean variety grown in Mwea, Waruhiu and Machakos under sole crop and intercropped with sixteen maize varieties during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	62984.	31492.	16.65	
variety	16	76244.	4765.	2.52	0.003
site	2	110659.	55330.	29.26	<.001
variety.site	32	76575.	2393.	1.27	0.189
Residual	100	189118.	1891.		
Total	152	515580.			

Appendix 20: Analysis of variance (ANOVA) table for seed yield (kg/ha) of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	12234.	6117.	0.26	
variety	16	2767583.	172974.	7.24	<.001
site	2	12313072.	6156536.	257.62	<.001
variety.site	32	2008537.	62767.	2.63	<.001
Residual	100	2389810.	23898.		
Total	152	19491236.			

Appendix 21: Analysis of variance (ANOVA) table for percent yield decline of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	1224.8	612.4	3.86	
variety	15	6649.4	443.3	2.80	0.001
site	2	1354.1	677.1	4.27	0.017
variety.site	30	13166.0	438.9	2.77	<.001
Residual	94	14896.6	158.5		
Total	143	37290.9			

Appendix 22: Analysis of variance (ANOVA) table for pods per plant of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	4.835	2.418	0.96	
variety	16	140.805	8.800	3.49	<.001
site	2	455.686	227.843	90.48	<.001
variety.site	32	50.570	1.580	0.63	0.933
Residual	100	251.821	2.518		
Total	152	903.716			

Appendix 23: Analysis of variance (ANOVA) table for seeds per pod of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.0753	0.0377	0.18	
variety	16	5.4333	0.3396	1.64	0.072
site	2	35.6084	17.8042	85.91	<.001
variety.site	32	8.9570	0.2799	1.35	0.132
Residual	100	20.7236	0.2072		
Total	152	70.7976			

Appendix 24: Analysis of variance (ANOVA) table for 100 seed weight (gms) of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	19.321	9.660	1.66	
variety	16	142.111	8.882	1.53	0.105
site	2	5006.096	2503.048	430.33	<.001
variety.site	32	199.059	6.221	1.07	0.388
Residual	100	581.658	5.817		
Total	152	5948.244			

Appendix 25: Analysis of variance (ANOVA) table for Land Equivalent Ratios of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	0.6932	0.3466	3.09	
variety	15	1.1357	0.0757	0.67	0.799
site	1	0.6054	0.6054	5.39	0.024
variety.site	15	1.6003	0.1067	0.95	0.516
Residual	62	6.9616	0.1123		
Total	95	10.9962			

Appendix 26: Analysis of variance (ANOVA) table for Monetary Advantage Index (MAI) in Kshs of KB 1 bean intercropped with sixteen maize varieties in Mwea, Waruhiu and Machakos during 2009 long rains.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	4.637E+08	2.318E+08	1.52	
variety	15	1.663E+09	1.109E+08	0.72	0.750
site	1	3.670E+09	3.670E+09	23.99	<.001
variety.site	15	1.964E+09	1.309E+08	0.86	0.614
Residual	62	9.486E+09	1.530E+08		
Total	95	1.725E+10			