

**BEAN DENSITY SUPPRESSION OF WEEDS IN MAIZE BEAN
INTERCROPPING UNDER CONVENTIONAL AND CONSERVATION
TILLAGE SYSTEMS IN ARUSHA, TANZANIA**

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**A DISSETATION SUBMITTED IN THE PARTIAL FULFILMENT OF THE
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ABSTRACT

The field experiment to evaluate the effectiveness of bean plant population under conservation and conventional tillage systems in suppressing weeds in maize-bean intercropping systems was conducted at the Tropical Pesticides Research Institute (TPRI) for the 2010 short rains and 2011 long rains season. A split-split plot experiment laid out in a Randomized Complete Block Design (RCBD) was used with three replications. The main treatments were: the conventional and conservation tillage systems, having five sub plot factors namely: sole maize, sole bean, maize-bean intercrops at a constant maize spacing of 75cm x 30 cm and a varied spacing of bean at 75cm x 20cm, 50cm x 20cm and 25cm x 20cm. The sub-sub plot factors were four weed management practices namely: weeding once at 28 days after planting, pre-emergence selective herbicide application without weeding, weeding twice at 14 and 28 days after planting, and control (i.e. without weeding). Data were analyzed by Gen-stat software and means were separated by Tukey's Honestly Significant Differences Test (THSDT). The results showed that maize intercropped with bean at a spacing of 50cm x 20cm gave significantly higher grain yield (5.1 t/ha) while maize grown as a sole crop gave lowest grain yield (3.3 t/ha) during the 2010 short rains season. For the long rain season, maize intercropped with bean at a spacing of 50cm x 20cm resulted in a significantly higher grain yield (4.8 t/ha) while maize grown as a sole crop gave significantly lower grain yield (3.7 t/ha) during the 2011 long rains season. The use of pre-emergence selective herbicide resulted in an increased yield of both maize and beans in both seasons. The conventional tillage showed superiority in controlling weeds than conservation tillage. Bean intercropped at 50cmx20cm was the best bean population for suppressing weeds without affecting maize yield.

DECLARATION

I, Baltazari Anna, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

To my parents, BaltazariSemeteiKaaya and ElieremisaMathayoSumari, who laid the foundation of my education.

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LIST OF ABBREVIATIONS AND SYMBOLS

a.i	Active ingredient
ATER	Area Time Equivalent Ratio
ATTRA	Appropriate Technology Transfer for Rural Areas
C ₄	4-Carbon
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
D	Density
DAP	Days After Planting
DAS	Days After Sowing
DF	Degree of Freedom
F	Frequency
FU	Field Uniformity
HI	Harvest Index
IFSA	International Farming Systems Association
LAI	Leaf Area Index
LER	Land Equivalent Ratio
N	Nitrogen
pH	Power of hydrogen
RA	Index of Relative Abundances
RBD	Randomized Block Design
RUE	Radiation Use Efficiency
SLER	Stable Land Equivalent Ratio
SUA	Sokoine University of Agriculture
THSDT	Tukey's Honestly Significant Differences Test
TPRI	Tropical Pesticides Research Institute

CHAPTER ONE

1.0 INTRODUCTION

Maize is the most widely grown crop in Tanzania, produced by about 82% of all Tanzanian farmers (NBS, 2007). In sub-Saharan Africa, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories. Intercropping is a common cropping system in Africa, Asia and Latin America of which more than 80% of smallholder farmers grow the bulk of the food crops and some of the cash crops (Waddington *et al.*, 1989). In Eastern Africa, maize is often intercropped with legumes such as beans, cowpeas and pigeon peas (Waddington *et al.*, 1989). In Tanzania smallholder farmers intercrop maize and legumes such as beans, cowpeas, pigeon peas, green peas and bambara nuts (Waddington *et al.*, 1989).

Bean (*Phaseolus vulgaris* L.) is one of the most important legumes in the world because of its commercial value, extensive production, consumer use and nutrient value (Xavery *et al.*, 2006; CABI, 2007). In East Africa, Tanzania is a major beans producing country where it is estimated that over 75% of rural households in Tanzania depend on beans for home consumption as well as cash crop income (Hillocks *et al.*, 2006). In Tanzania as beans are consumed as mature grain, as immature seed, as well as a vegetable (both leaves and pods (Hillocks *et al.*, 2006).

In Africa, women farmers, who have limited access to fertilizer compared to men farmers, more often grow beans. Intercropping of beans with cereals (maize, millet or sorghum), bananas and plantains or root and tuber crops is common practice (Santalla *et al.*, 2001). Given these problems, it is not surprising that average yields are low. Much of the bean

crop is lost to diseases as well as insect pests or drought, low soil-fertility and other abiotic stresses (Broughton *et al.*, 2003).

According to the National Bureau of Statistics, maize production estimates in Tanzania in 2005-2007 were 3.4 million tones, which were grown on an area of two million hectare or about 45% of the cultivated area (NBS, 2007). Low maize productivity is associated with high level of dependency of agriculture to exogenous factors such as drought, flooding, pests and high costs of agro-inputs (Nkonya *et al.*, 1998).

Weeds compete with crop plants for available nutrients, water, light, and carbon dioxide. In addition to direct competition with crops (or parasitism), weeds cause indirect damage by harbouring insect pests and pathogens (Vissoret *et al.*, 2004). Worldwide, 13% loss of agricultural production is attributed to weeds, in spite of the control measures taken by farmers. If no action were taken to protect crops from weeds, the losses would amount to 30% to 100% (Akobundu, 1987). Globally, weeds cause 5% losses in agriculture in the most developed, 10% in the less developed and 25% in the least developed countries (Vissoret *et al.*, 2004). Weeds have been reported to be a problem in both conventional and in conservation tillage systems (Forcella and Lindstrom, 1988). The higher the soil is disturbed the higher the weed seed bank (Ortega, 1991). The presence of light during soil cultivation has been reported to stimulate weed germination in fields (Buhler, 1995).

Despite the competitive benefits associated with intercrops, their ability to suppress weeds has still not been extensively studied. Although several studies of intercropping have been conducted, there is limited literature published on beans density suppression of weeds in maize-beans intercropping under conventional tillage and conservation tillage systems, thus this study.

The main objective of this study was to evaluate the effectiveness of bean plant population under conservation and conventional tillage in suppressing weeds in maize-bean intercropping systems.

The specific objectives were:

- i. To investigate the effects of conservation and conventional tillage methods on weed species composition in maize-bean intercrops.
- ii. To determine the contribution of bean intercrops to weed suppression in maize.
- iii. To derive weed assessment variables under conventional and conservation tillage system in maize-bean intercrop.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize

2.1.1 Origin

Archeological and molecular data indicates that modern maize was domesticated from annual Balsasteosinte (*Zea mays ssp. parviglumis*) in southern Mexico between 6600 and 9000 years ago. Selection soon followed: favorable alleles at loci controlling plant morphology and kernel nutritional quality were fixed at least 4400 years ago, and further selection by Native Americans facilitated maize adaptations to varied environments (Nassaret *al.*, 2010).

The domestication and selection of maize is believed to have begun in central and south western Mexico about 700years ago. In East Africa, it was introduced in the 16th and 17th centuries by Portuguese traders to the coastal areas from the Caribbean (Rao andPandey, 2007). The bulk of the crop is grown in tropical and subtropical regions. It is grown mainly from 58°N to 40°S and from sea-level up to about 3000metre altitude at the equator. In Tanzania, maize is grown in all agricultural zones (CABI, 2007).

2.1.2 Botanical description

Maize is a tall, robust annual, usually with a single dominant stem. Its leaves are distichous (two ranks of single leaves born in alternate positions), with overlapping sheaths and relatively long broad leaves. Maize possesses the C₄dicarboxylic acid pathway of photosynthesis (plants that use C₄photosynthesis to fix atmospheric carbon dioxide). C₄ photosynthesis is so called because the initial product of photosynthesis is a four carbon compound (oxaloacetate). C₄ photosynthesis essentially eliminates the oxygenase activity

of Rubisco via anatomical, biochemical and ultrastructural modifications in leaves (CABI, 2007). The upper epidermis is pubescent and has longitudinal rows of bulliform cells which, by change of turgor, cause leaves to roll and unroll. The lower leaf epidermis is glabrous (without hairs) and usually has considerably more stomata than the upper surface.

Maize is a monoecious plant which produces staminate flower in terminal inflorescence (tassel) and its pistillate flower on lateral shoots (ears). Maize is a protandrous (male flowering usually occurs one or two days before appearance of style. Maize is a cross pollinated species because of separation of an ear and a tassel and the protandry of flowering. Kernels are firmly attached to a rigid axis, the cob and the entire ear is enclosed in a modified leaf sheath called the husks (CABI, 2007). Maize is susceptible to drought, intolerant of nutrient-deficient soils, and prone to be uprooted by severe winds due to its shallow root system.

2.1.3 Climatic and soil requirements

Maize is a monoecious plant, with its large number of cultivars differing in period to maturity. Maize has a wide range of tolerance of temperature conditions, but an average temperature of 20-24⁰C is ideal (CABI, 2007). Maize needs optimum moisture conditions at the time of planting. In the tropics it does best with 600-900mm of rainfall during the growing season, and irrigation is used in areas of low rainfall and is particularly valuable at the time of tasselling and fertilization (Nkonya *et al.*, 1998). Maize performs best on well-drained, well-aerated, deep soils containing adequate organic matter and well supplied with available nutrients. Maize can be grown on soils with a pH from 5-8, but 5.5-7 is optimal. It is sensitive to salinity (CABI, 2007).

2.1.4 Growth stages

For standardization of definitions, maize researchers (Bell *et al.*, 2006) developed a guide for identifying different growth stages of maize. Not all plants in a field reach a particular stage at the same time. Therefore, researchers assume that the crop reaches a specific stage when at least 50% of the plants show the corresponding features.

Standardization of definitions allows researchers to relate problems to specific growth stages. Researchers can also compare the phenology of maize under different environmental conditions and experimental treatments.

Researchers divide growth stages into two broad categories: vegetative (V) and reproductive (R). Additionally, growth stages can be grouped into four major periods

- i. Seedling growth (stages V_E and V₁),
- ii. Vegetative growth (stages V₂, V₃... V_n),
- iii. Flowering and fertilization (stages V_T, R₀, and R₁),
- iv. Grain filling and maturity (stages R₂ to R₆) (Table 1).

Table 1: Growth stages of maize

Period	Stage	DAS*	Features
Seedling growth	VE	5	The coleoptile emerges from the soil surface.
	V1	9	The collar of the first leaf is visible.
	V2	12	The collar of the second leaf is visible.
Vegetative growth	Vn		The collar of the leaf number 'n' is visible. The maximum value of 'n' represents the final number of leaves, which is usually 16-23, but by flowering, the lower 4-7 leaves have disappeared.
	VT	55	The last branch of the tassel is completely visible.
Flowering and fertilization	R0	57	Anthesis or male flowering. Pollen shed begins.
	R1	59	Silks are visible.
	R2	71	Blister stage. Kernels are filled with clear fluid and the embryo can be seen.
	R3	80	Milk stage. Kernels are filled with a white, milky fluid.
	R4	90	Dough stage. Kernels are filled with a white paste. The embryo is about half as wide as the kernel. The top parts of the kernels are filled with solid starch.
Grain filling and maturity	R5	102	Dent stage. If the genotype is a dent type, the grains are dented. The 'milk line' is close to the base when the kernel is viewed from the side in both flint and dent types.
	R6	112	Physiological maturity. The black layer is visible at the base of the grain. Grain moisture is usually about 35%

DAS*: approximate number of days after sowing in lowland tropics, where maximum and minimum temperatures may be 33° C and 22° C, respectively. In cooler environments, these times are extended.

Source: (Bell *et al.*, 2006)

2.1.5 Uses

Maize is the world's third most important crop after rice and wheat. Maize is the staple food for majority of the people in developing countries who are poor and maize stalks are used to feed farm animals. Maize grains are used as starch products; corn oil; baby foods; popcorn; maize-based food items; maize flour; forage for animals; maize stalks providing dry season feed for farm animals; maize silage for winter animal feed in cold temperate regions; and maize stalks as a soil mulch where it is in abundance. Maize can be classified on the basis of its protein content and hardness of the kernel. These include popcorn, flint, flour, Indian and sweet corn (Fischer and Palmer, 1984).

In industrialized countries maize is largely used as livestock feed and as raw material for industrial products. In Australia for instance, maize is used as feed, silage, breakfast food and processing (breakfast cereals, corn chips, grits and flour), industrial starch and popcorn. In low income countries it is mainly used for human consumption (CABI, 2007).

In sub-Saharan Africa, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season (Fischer and Palmer, 1984).

2.2 Beans

2.2.1 Origin and domestication

Common bean (*Phaseolus vulgaris* L.) originated in the Central Americas and was domesticated in Mexico, Peru and Colombia 8000 years ago. It was introduced in East

Africa and other parts of the old world by the Portuguese (Evans, 1976). It is now widely cultivated in many parts of the tropics and subtropics and throughout the temperate regions. It is a minor crop in India and most of tropical Asia, where indigenous pulses are preferred (Nassaret *al.*, 2010). Area of diversity and domestication occurs in the highlands of Meso-America and northern South America in 500 to 1800m altitude range (Evans, 1976), with a high frequency of wild types recorded at around 1200 (Miranda, 1974).

2.2.2 Botanical description

Phaseolus vulgaris is a highly polymorphic species showing considerable variation in growth habit, vegetative characters, flower colour and size, shape, and colour of both seeds and pods (Lainget *al.*, 1984). Like many flowers, those found on legume plants are hermaphroditic, containing both the stamen and pistil. This makes the plants self-fertile, meaning that an individual plant is able to reproduce by itself which can have the effect of limiting genetic diversity (Nassaret *al.*, 2010).

The flower typically has five petals and an ovary with one carpel, cavity, and style. The distinctive nature of the flowers is not in the parts but in the shape of the parts. The general pattern of legume flowers follows that of the pea blossom. The result of this arrangement is that of a papilionaceous design, which means butterfly like. The petals of the legume plants are shaped into a cup. Due to their shape these petals are referred to as the keel (Nassaret *al.*, 2010).

After pollination the flower will die and reveal the growing ovary which becomes the pod. The legume pod is a one-celled seed container formed by two sealed parts called valves. Legume pods always split along the seam which connects the two valves. This characteristic is called dehiscent; from the Latin word meaning to gape or burst open.

However, not all pods are shaped the same (Nassaret *al.*, 2010). The thickness, length, curve, and fleshy nature of the pods can vary. In addition, some pods are winged or indehiscent (meaning the pods do not split open at maturity). Colours of flowers and seeds vary greatly from white to scarlet to blue (Nassaret *al.*, 2010).

Beans are annual legumes with great variation in growth habit. Liebenberg (2002) and CABI (2007) distinguished two types of common bean growth habits: (1) determinate growth habit, in which the main axis terminates in an inflorescence and produces no vegetative nodes after flowering; and (2) indeterminate growth habit, in which the vegetative terminal bud on the main stem and branches, node and leaf production occur after flowering commences. Time to flowering varies with cultivar, temperature and photoperiod, and is usually 28-42 days, after planting. Seed-filling period may take from as few as 23 days to nearly 50 days. Full maturity with dry seed is reached 65-150 days after sowing (CABI, 2007).

There is great variation in seed characteristics, that is, seeds vary in colour, size and shape. Beans colour also varies from white, pink to purple. Main crop characteristics are mainly based on the morphological, physiological and genetic modifications during domestication and subsequent evolution processes (Liebenberg, 2002).

2.2.3 Climatic requirements

Beans are a quantitative short-day plant. It grows optimally at temperatures of 18 to 24°C. The maximum temperature during flowering should not exceed 30°C. High temperatures during the flowering stage lead to abscission of flowers and a low pod set, resulting in yield loss. Day temperatures below 20°C will delay maturity and cause empty mature pods to develop (CABI, 2007).

Cultivated under rainfed conditions, the bean requires a minimum of 400 to 500mm of rain during the growing season, but an annual total of 600 to 650mm is considered ideal. Water stress is very serious constraint during flowering, which may cause increased flower abortion (Allen and Edje, 1990). Common beans are sensitive to frost. Drought or water logging is detrimental. Irrigation is beneficial in semi-arid regions, with overhead irrigation preferred over flood irrigation. Beans are extremely sensitive to soil moisture deficit and thus reducing grain yield significantly under water stress. Continuous lack of rainfall and inaccessibility to water during critical growth periods affect growth and development, and yield of beans (Anonymous, 2005).

Beans grow well in soils with a depth of at least 90cm that have no nutrients deficiencies, and are well drained. Suitable soil types range from light to moderately heavy soils with good drainage. Beans prefer an optimum soil pH range of 5 to 8, and are very sensitive to acidic and saline soils (Anonymous, 2005; Allen and Edje, 1990). They will also not grow well in soils that are compacted or poorly drained.

2.2.4 Beans as a food crop

The common bean is an important source of protein (dry beans contain 20 to 28percent protein) and calories in human diets in tropical and subtropical developing countries. The immature pods are eaten as green vegetables worldwide (Lainget *al.*, 1984). In some parts of the tropics, young leaves are used as vegetable. The straw can be used as forage (CABI, 2007).

2.3 Intercropping

Intercropping can be defined as a system in which two or more crops are grown simultaneously in rows in a definite pattern and on the same field. It also means the

growing of two or more crops on the same field with the planting of the second crop after the first one has completed its development (Szumigalski, 2005; Jalloh, 2002). Intercropping is a way to increase the diversity of the farming system. More diversity generally means more stability resulting in risks spreading and reduced pests incidences.

Grossman and Quarles (1993) divided intercropping into four basic spatial arrangements which include:

- i. Mixed or multiple cropping - the cultivation of two or more crops simultaneously on the same field without any distinct row arrangement.
- ii. Relay cropping - the planting of the second crop into already standing crop at the time when the standing crop is at its reproductive stage or has completed its development but before harvesting.
- iii. Row intercropping - the cultivation of two or more crops simultaneously on the same field with a row arrangement.
- iv. Strip cropping - the planting of two or more crops together in strips wide enough to permit separate crop production practices using machines but close enough for the crops to interact.

Intercropping is the commonest and the most popular cropping system in Africa, Asia and Latin America (Waddington *et al.*, 1989; Liebman and Dyck, 1993; Szumigalski, 2005). In these areas, 80% or more of smallholder farmers, who grow the bulk of the food crops and some of the cash crops, grow two or more crops in association (Waddington *et al.*, 1989).

Maize is the most important cereal crop produced in Eastern Africa and it is often intercropped with legumes such as beans, cowpeas and pigeon peas (Waddington *et*

al.,1989; Ncube, 2007). Almost all farmers in Eastern Africa who practice intercropping can be defined as small-scale farmers (possess less than 100 hectares land).

The objectives of farmers in crop production are to produce a crop of good quality, in sufficient quantities, be able to cover expenses, and make a profit. In order to increase agricultural production, the yield of individual crop per unit area should be improved. Farmers with limited resources have limited capacity to tolerate production failure and, therefore, are compelled to practice intercropping (Henriet *et al.*, 1997). This resource - poor farmers mostly practice intercropping due to scarcity of land, agricultural inputs (fertilizers, seeds and pesticides) and labour (Nkonya *et al.*, 1998).Maize and bean intercrops are common in Maize/Legume type of farming systems, which is found in Rukwa, Ruvuma, Arusha, Kagera, Shinyanga, Iringa, Mbeya, Kigoma, Tabora, Tanga, Morogoro, Kahama, Biharamulo.

2.3.1 Advantages of intercropping

According to Wrigley (1969), the advantages of intercropping include: reduced erosion and protection of topsoil, especially in contour strip cropping; attraction of beneficial insects, especially when flowering crops are included the cropping system; increased or maximization of land productivity, particularly in the high rainfall areas increased total production and farm profitability, ensuring contribution to better farm labour use and even harvesting period and reduction of storage problems. Also, where legumes and cereals are grown, the cereal crop may benefit from the nitrogen fixed by the companion leguminous crop.

Ncube (2007) reported that when two or more crops with different rooting systems, different patterns of water and nutrients demand, and a different aboveground growth habit

were planted together, water, nutrients and sunlight were used more efficiently, thus higher yields in intercrop than in pure stands.

Intercropping presents a large level of risk reduction for the smallholder farmer (Waddington *et al.*, 1989). If one crop is entirely lost due to pest or drought damage, the farmer may still harvest the other crop in the field. Given the unpredictable rainy season and the different water requirements of each crop, planting many varieties of the same crop in an intercropped field gives the farmer a better chance that some crops will survive (Carlson, 2008). Also, it increases stability of yield in different environmental conditions compared with sole cropping (Deveikyte *et al.*, 2009).

Carlson (2008) found that intercropping maize with legumes was capable of reducing the amount of nutrients taken from the soil as compared to a maize sole crop; this was due to the fact that when nitrogen fertilizer was added to the field, intercropped legumes use the inorganic nitrogen instead of fixing nitrogen from the air and thus competition with maize for nitrogen. However, when nitrogen fertilizer was not applied, intercropped legumes fixed most of their nitrogen from the atmosphere and no competition with maize for nitrogen resources was observed (Adu-Gyamfi *et al.*, 2007).

Innis (1997) in the study of maize and soybean intercrops found that planting crop varieties with different root systems in the soil reduced water loss, increased water uptake and transpiration. This makes the microclimate cooler, along with increased leaf cover which cooled the soil and reduces evaporation.

Increased leaf cover in intercropping systems helps to reduce weed populations once the crops are established (Beets, 1990). Increased plant diversity in intercropped fields may

reduce the impact of pest and disease outbreaks by providing more habitats for predatory insects and increasing the distance between plants of the same crop (Waddington *et al.*, 1989).

2.3.2 Disadvantages of intercropping

Waddington *et al.* (1989) reported that experimentation with intercropping was more complex, took large land size and generally difficult to manage than sole cropping experiments while Scholl and Nieuwenhuis (2004) reported difficulties to combat diseases, pests and weeds in intercropping due to denseness of the crops. Schöll and Nieuwenhuis (2004) reported that mechanization of an intercropping system was difficult to achieve in larger scale farming particularly planting, weeding, harvesting and during fertilizer and herbicides application.

Wolfswinkel (2006) reported that labour requirement of an intercropping system when two or more different crops planted at the same time or shortly after one another were higher than that of sole cropping. On the other hand, labour requirement might also be less in an intercropping system, for example due to reduction in weeding requirement when weeds are suppressed by the intercrop (Thobatsi, 2009). Also, if sowing and harvesting period and duration of different intercropped crops vary, it is easier to spread the available labour over the entire season thus avoiding higher peaks of labour (Wolfswinkel, 2006).

Competition is another potential problem of intercropping. Light and carbon dioxide are absorbed by the leaves and water, nutrients and oxygen mainly by the roots. Fukai and Trenbath (1993) reported that when the crops in the intercrops grew to the proximity of the shoot and root systems it led to mutual interference in the interception and absorption (or uptake) of the growth factors. Growth rates fall below those found in isolated plants.

The magnitude of suppressed growth depends on the degree of the interference. Crop plants and weeds interfere with growth activities of each other to varied degrees subject to the extent of competition for moisture, mineral nutrients, and light (Maqboob *et al.*, 2006). Weeds also are capable of hindering harvest operation (Eue, 1986).

2.3.3 Assessment of yields under intercropping

2.3.3.1 Land equivalent ratio

One of the reasons why farmers practice intercropping is to ensure that there is increased and diverse productivity per unit area obtained compared with sole cropping (Waddington *et al.*, 1989). Land equivalent ratio can be used to assess land returns from the pure stand yields and from each separate crop within the mixture. Land equivalent ratio is defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping (Waddington *et al.*, 1989). It is usually stipulated that the level of management must be the same for intercropping and sole cropping.

$$\text{LER} = \left(\frac{\text{Intercrop maize}}{\text{sole maize}} \right) + \left(\frac{\text{Intercrop legume}}{\text{sole legume}} \right) \dots\dots\dots(1)$$

Generally, monoculture legumes have higher yields than those intercropped (Waddington *et al.*, 1989). However, in most cases, land productivity measured by land equivalent ratio shows the advantages of mixed cropping of cereals and legumes (Yunusa, 1989). Yield advantages from intercropping as compared with sole cropping are often attributed to mutual complementarily effects of component crops such as a better total use of available resources (Thobatsi, 2009). Land equivalent ratio gives an indication of magnitude of sole cropping required to produce the same yield on a unit of the intercropped land.

An important concept inherent in the use of land equivalent ratios is that, whatever their type or level of yield, different crops are placed on a direct comparable basis (Waddington *et al.*, 1989). Although based on land areas, land equivalent ratio reflects relative yields, that is, the land equivalent ratio can be taken as a measure of relative yield advantage (Waddington *et al.*, 1989). Mead and Wiley (1980) reported that the ratio greater than 1 signals advantage and a ratio less than 1 indicates a yield disadvantage.

The land equivalent ratio concept has some limitations particularly when used to compare productivity of intercrop and sole crops. One major problem is that the computation of land equivalent ratio needs maximum yields of sole crops obtained at optimum plant densities (Willey, 1979). When yields of sole crops at recommended densities are compared with these of intercrops it will be likely that the advantage of intercropping is overestimated since density may be altered as an experimental variable to determine the optimum density overestimated (Ifenkweet *et al.*, 1989). This is most likely to occur in an additive experiments where intercropping of two component crops do have twice the plant density of the individual sole crops (Ofori and Stern, 1986). Another problem is that land equivalent ratio does not give the exact value of yields, instead, it represents the yield advantages or disadvantages of intercrops compared with sole crops and the time factor is less considered for crop maturity (Mead and Willey, 1980).

2.3.3.2 Area time equivalent ratio

Since the concept of land equivalent ratio does not include the time factor, it seem to overestimate the advantages of intercropping particularly when component crops will not be utilized after harvest until harvesting of late maturity crop. But in most times in intercropping practices, the canopy of late maturing crop would spread to occupy the whole area, but in case of a sole crop, another crop may be planted immediately after the

harvesting of an early maturing crop (Fukai and Trenbath, 1993). The limitation of land equivalent ratio can be overcome by calculating yield production per day as an area time equivalent ratio (ATER) (Hiebsch and McCollum, 1987).

$$\text{ATER} = \frac{(L_i t_i + L_j t_j)}{T} \dots\dots\dots(2)$$

Where: L_i and L_j are relative yield of partial land equivalent ratio for component crops i and j ,

t_i and t_j are durations in (days) for crops i and j , and

T is the duration (days) of the whole intercrop system.

The area time equivalent ratio might however, underestimate the advantage of intercropping especially when component crops differ in their growth duration (Reddy and Chetty, 1984). This is because in the semi-arid areas it is not possible to plant another crop after harvesting like in humid tropics where the growing season is continuous (Thobatsi, 2009). The growing season might not be long enough to have double sole cropping but it may be possible to have a long duration crop. It therefore, appears that in semi-arid areas where double cropping is not possible, land equivalent ratio may be used for comparison, whereas in the humid tropics with continuous growing conditions area time equivalent ratio may be more appropriate (Fukai and Trenbath, 1993).

2.3.3.3 Stable land equivalent ratio (SLER)

Stable land equivalent ratio describes the intensity of land use if land use is regarded as total some of combined yield or sum of yield advantages/disadvantages of each crop,

which can adopt ranging values from < than 1 to > 1 that indicates different levels of biological efficiency (Hirpa, 2013).

This mostly applies where the primary objective is to get the fixed yield production of one component (stable) crop, which in most cases is a cereal, and yields of the legume. Reddy and Chetty (1984) proposed an extension of land equivalent ratio and stable land equivalent ratio, which is based on the assumption of a basic requirement for minimum supply of major crop such as the cereal. This concept of staple land equivalent ratio is widely used in India (Reddy and Chetty, 1984).

$$\text{SLER} = \sum_{i=1}^n \frac{Y_i^i}{Y_i^m} \times Z_i \dots \dots \dots (3)$$

Where: Y_i^i and Y_i^m are yields of i^{th} component in intercrop and monocrop respectively, and

Z_i is its sown proportions in intercrop.

2.3.3.4 Methods of determining land equivalent ratio

Although there are several alternatives for assessing yields under intercropping, LER is the only method that allows comparison of different intercropping situations (Waddington *et al.*, 1989).

Several methods have been suggested for calculating LER using different sole crop values and standardization factors (Waddington *et al.*, 1989). The choice of sole crop yield for standardizing a mixture yield in the estimation of land equivalent ratio consists of averaging all sole yields in each block (Fisher, 1977), averaging sole yields in the entire

experiment (Mead and Stern, 1980), averaging sole yields at each treatment level in studies that involve graded levels of factor A and B and using the yield of the best sole crop treatment of each crop (Mead and Willey, 1980). These methods cannot be generalized because a choice of which one to use will depend on the aim of the experiment.

2.4 Radiation Interception and Dry Matter Production

Differences in the competitive abilities of component crops in intercrop affect the performance of the entire system (Azam-Ali and Squire, 2002). Solar radiation must be intercepted and utilized instantaneously as it cannot be stored for later use. Keating and Carberry (1993) reported that intercropping could increase the interception of solar radiation and maintain higher radiation use efficiency. Willey (1990) concluded that the radiation capture required to produce actual intercropping yield at sole crop efficiencies was about 30% more than the actual radiation, implying an increase in efficiency of radiation use by intercrops.

The production, retention and function of leaf area are key processes, since green leaf area are fundamental to radiation interception and capture and thus plant growth (Birch *et al.*, 2003). The yield potential of crops varies according to location, variation in radiation, temperature and water supply conditions (Birch *et al.*, 1999). In light competition, not only foliage height, but also foliage inclination angles are important. The shading effect of vertically dominant species in an intercrop can be partly reduced if taller species has erectophile leaves above an understorey species with planophile leaves (Willey, 1990).

Increased productivity of intercropping over sole cropping is believed to be attributed to better use of solar radiation, nutrients and water (Willey, 1990; Enninet *et al.*, 2002). Better

use of solar radiation by intercrops is due to increased interception and/or greater radiation use efficiency (RUE) (Willey, 1990). Spatial arrangement of intercrops is an important management practice that can improve radiation interception through more complete ground cover (Reddy *et al.*, 1989). However, Keating and Carberry (1993) have suggested that increased radiation interception due to better ground cover of intercrops may be due to the sub-optimal sole crop population densities used in comparisons. The availability of nutrients and water enhances exploitation of available solar radiation for greater crop productivity (Mariscale *et al.*, 2000). There is potential for higher productivity of intercrops when interspecific competition is less than intraspecific competition for a limiting resource (Mead, and Willey, 1980; Francis, 1989).

2.5 Intercropping and Weeds

Intercropping is widely practiced in certain countries and an enormous variety of intercropping systems have been developed (Vandermeer, 1992). In successful intercrops weed suppression is usually superior to that of either of the component crops when grown alone (Waddington *et al.*, 1989). Crop density, crop diversity, crop spatial arrangement, choice of crop species and cultivar will all affect weed growth in intercropping systems. If water or nutrients are limiting then growth of one or both intercrops will suffer (Hirpa, 2013). Improved weed control alone is unlikely to justify their use and there must be other obvious benefits if the change in cropping practice is to prove economic (Waddington *et al.*, 1989; Vandermeer, 1992).

Intercropping can be an effective way of suppressing weeds when growing crops that are poor competitors (Waddington *et al.*, 1989). The most likely cause of this weed suppression was that the intercrops captured more light than the sole crops, due to the different growth habits and heights of the intercrops (Szumigalski, 2005). The study by

Deveikyteet *al.* (2009) in peas and barley showed that mixed culture is one effective method in sustainable crop production and it resulted in better use of resources, in comparison with monoculture.

Farmers usually apply high seed rate to compensate for poor germination and suppress weeds and the findings are also used for the expected sparse germination and reducing weeds intensity in rainfed condition. Suppression of weeds by higher seed rates seems attractive but above optimum plant density may lead to higher competition between the plants for the already meager moisture (McIntyre *et al.*, 1997). Increasing the plant density of sole crops often allows the crop to compete better with weeds, and it follows that increasing the density of intercrops would have the same effect. This effect is more pronounced in intercropping systems than in sole cropping systems where the land equivalency ratios tend to rise when intercrops are seeded at higher densities (Liebman and Dyck, 1993). This is because two crops grown as an intercrop can be seeded at close to their sole crop seeding rates, resulting in a much higher total plant density than in a sole crop. While such a high plant density in a sole crop would only cause competition between plants of the same species, the different resource use patterns of crops in intercropping systems allow for a higher total plant density without creating competition between crop plants (Liebman and Dyck, 1993).

Main purpose of intercropping is to produce a greater yield on a given piece of land by making use of resources in the way of maximum efficiency. Intercropping provides an efficient utilization of environmental resources, decreases the cost of production, provides higher financial stability for farmers, decreases pest damages, inhibits weeds growth more than monocultures, and improves soil fertility through nitrogen increasing to the system and increase yield and quality it is now clear that the weeds could interfere with crops by

increasing competition (for light, water, nutrients and space) and/or allelopathy. Weeds declines many of crops yields and it lead to higher cost in agricultural productions (Wanjari *et al.*, 2001).

2.6 Tillage

Tillage involves the movement and mixing of soil which serves several purposes such as control of residues (effective use of residues), control of competing vegetation, control of flow of water, distribution of fertilizers, pesticides and amendments to create favourable environment for crop establishment (Yusuf *et al.*, 1999).

There are two major systems/methods of tillage, conventional and conservation tillage. Ortega (1991) defined conventional tillage as the methods of seedbed preparation that involve maximum ploughing, disking once or twice, and harrowing to pulverize the soil and collect plant materials. Conventional tillage deals most effectively with heavy stubble, provides the most uniform seedbeds, the best assurance of crop stand and the best weed control.

Buhler (1995) defined conservation tillage as a tillage system that creates a suitable soil environment for growing a crop and that conserves soil, water and energy resources mainly through the reduction in the intensity of tillage and retention of plant residues. Conservation tillage is also referred to as minimum tillage/reduced tillage because it leaves about 30% or more of crop residues on the soil surface (Vencill and Philip, 1994). The system has been gaining popularity because it can lower farm expenses; reduce runoff and erosion, aid in soil organic matter conservation and increases soil moisture retention.

Conservation tillage is designed to reduce erosion and maintain or improve soil health properties, conservation tillage increases infiltration by reducing surface sealing and enhancing macro pore connectivity and flow (Shrestha *et al.*, 2006).

A major drawback of conservation tillage is the increased consumption of pesticide and nitrogen (Weill, 1989). Conservation tillage harbours the crop pests (insects pests, rodents), and it also increase the possibility of soil crusting and compaction (Ofori and Stern, 1987).

2.6.1 Tillage and weed management

Tillage has been a major agricultural weed control technique for several decades. Tillage affects weeds by uprooting, dismembering and burying them deep enough the soil to prevent emergence (Shrestha *et al.*, 2006). It changes the soil environment and in so promoting or inhibiting the weeds germination and establishment and by moving their seeds both vertically and horizontally (Vencill and Philip, 1994). Tillage also incorporates herbicides into the soil and also removes surface residues that may impede the herbicides effectiveness (Shrestha *et al.*, 2006).

Tillage is often necessary for removing established weeds, especially perennial weeds emerging from storage roots, rhizomes, or other underground vegetative propagules. Perennial weeds, especially wandering perennials that propagate through rhizomes and other underground structures, often require careful selection of tools and methods for removing them. The choice of the tools and method to use depends on type and depth of the underground structures by which they persist and propagate.

Buhler and Daniel (1988) reported that tillage reduced weed population and also provided an environment for weed and herbicide interaction. On the other hand, Donoran and

McAndrew (2000) reported that although most tillage practices could be effective in removing existing weeds, over time their effect on weed seed bank could vary from reducing to greatly enhancing subsequent weed emergence.

Some concerns about weed management in conservation tillage include emergence from recently produced weed seeds that remain on the soil surface, interception of herbicides by thick surface residues, lack of disruption of perennial weeds roots, and changes in the timing of weed emergence (Bullied *et al.*, 2003). Perennial weeds are known to thrive from several structural organs than seeds. Conservation tillage may encourage these perennial reproductive structures (Vencill and Philip, 1994).

Other problems associated with conservation tillage include the difficulty in managing perennial weeds, since their control requires the integration of cultural, mechanical and chemical methods (Wright and Vargas, 2003; Shrestha *et al.*, 2006).

Cultivated soils have larger seed bank when frequently cultivated than the conservation tillage (Ortega, 1991). Crop land seed bank has numerous species present. The higher the soil is disturbed the higher the weed seed bank (more the species) (Ortega, 1991; Burler, 1995). The presence of light during soil cultivation has been reported to stimulate weed germination in fields (Burler, 1995).

Reports of weed species shifts, however, have been inconsistent. For example, Cussans (1976) reported an increase of some dicot weeds in conventional tillage while Wrinkle and Arnold (1985) reported a similar distribution of dicot weeds in both conventional and conservation tillage systems. Derksen *et al.* (1993) suggested that changes in weed communities were influenced more by environmental factors such as location than by

tillage systems. Childs *et al.* (2001) on the other hand, reported that overtime, small-seeded annual broad-leaf weeds and perennial weeds become more prevalent in fields under conservation tillage. Considering a wide range of situation, Shrestha *et al.* (2002) concluded that long-term changes in weed flora are driven by an interaction of several factors such as tillage, environment, crop rotation, crop type and timing of weed management practices.

Dorado and Lopez-Fando (2006) pointed out that the main concern with the adoption of conservation tillage practices was potential weed management problems and the possibility of soil compaction especially in semiarid areas. Conservation tillage systems provide virtually no non-chemical alternatives for killing weeds after crop planting except smothering weed growth by more competitive crops, cover crops and intercrops (Shrestha *et al.*, 2006). As tillage both controls weeds and determines how well other weed management tactics can be carried out, the relationship between tillage (operations and systems) and weed control is quite complex. For example, effective broad-spectrum herbicides may wipe out susceptible weed species and it may lack controllability of some species, which would become more apparent with a different set of control tactics or in different crops or weather conditions (Dorado and Lopez-Fando, 2006; Philip *et al.*, 2002).

The increased herbicide reliance is increasingly becoming problematic because the declining development rate of new herbicides and the repeated use of few modes of action increase risks of herbicide tolerance (Darmency, 1996). As tillage is decreased, weed control can become a limiting factor in crop production (Buhler, 1992; Worsham and Lewis, 1985). Changes in tillage practices can affect weed population dynamics, including weed seed distribution and abundance in the soil seedbank (Buhler, 1992).

Soil tillage reduces weed numbers and species diversity but may increase germination of annual weed seed in the soil seedbank (Wrucke and Arnold, 1985). No-till systems typically have high populations of small-seeded annual weeds that remain on or near the soil surface (Clements *et al.*, 1996; Wrucke and Arnold, 1985).

2.6.2 Herbicides and tillage systems

Pre-emergence herbicides are meant to be applied prior to weed and crop emergence. Pre-emergent herbicides act upon weed seeds, seedlings or form a barrier in the soil to prevent weed seed germination or establishment. Pre-emergence herbicides are usually used to prevent weed seeds from establishing. Properly and timely application of pre-emergence herbicides can provide control for several months (Molin, 2004).

The benefits of pre-emergence herbicide application go beyond getting a head start on weed control. It improves yield; allows for greater flexibility of post-emergence herbicides; reduces early season competition between weeds and the crop; and aids in more efficient nitrogen management in crops, which can save money (Pollock, 2006). Molin (2004) reported reasons for pre-emergence herbicide failure which include: improper timing of application; application of herbicides to soil that already had weeds; improper herbicide calibration, application of herbicides with a narrow weed spectrum and disruption of chemical barrier; inadequate moisture in soils to be treated; and failure to read the manufacturer's instructions. Monsanto (1992) concluded that herbicides did not prevent weeds from germinating; instead they control weeds as they germinate within the chemical barrier.

Pollock (2006) proposed a number of measures that can help to reduce or prevent herbicide resistance. They include: several herbicide application timings and management

techniques such as pre-plant burndown treatments in conservation tillage, use of residual herbicides in conventional and no-tillage, and proper management of post-emergence herbicide applications, including glyphosate should be used. Monsanto (1992) suggested that post-emergent herbicides should be used on actively growing weeds. Gebhardt *et al.* (1985) suggested that in order to make conservation tillage economical and environmentally safe. The authors also advocated correct herbicide usage and proposed a number of issues that be considered such as: the effect of surface crop residues on herbicide adsorption, movement, persistence, and efficacy and on weed seed distribution, viability, and dormancy; the effect of tillage systems on the population dynamics of perennial and annual weed species; and (iii) the effect on weed control of new chemical, biological, and mechanical application technology. The study of Curran (1996) found that chemical weed control remained as an important pest management tactic in reduced-tillage agriculture but stressed that the choice of the type and control method to be used will be influenced by the tillage system. Chemical approaches are based on timing of herbicide application and include burndown, soil residual and post-emergence treatments (Curran, 1996).

2.6.3 Tillage system and weed seed bank

The weed seed bank is the sum of viable weed seeds produced on site and seed moved into an area. It also includes tubers, bulbs, rhizomes and other vegetative structures which assist with propagation of some of the serious perennial weeds (Ball, 1992; Dorado *et al.*, 1999). Weed seeds can reach the soil surface and become part of the soil seedbank through several avenues. The main source of weed seeds in the seedbank is from local matured weeds that set seed, production of new vegetative reproductive structures by perennial weeds, human activities, like cultivation and harvesting (Dorado *et al.*, 1999). Also weeds can be brought in fields with inputs such as manure, mulch, hay irrigation water and farm

machinery; or can be introduced by natural forces beyond the farm such as wind, flood water and migrating birds (Clements *et al.*, 1996).

Weed seeds have numerous fates after they are dispersed into a field. While a few of these weed seeds will germinate, emerge, grow and produce more seeds, a large proportion of them will germinate and die (also known as fatal germination), decay in the soil, or fall to predation by insects, birds or mammals (Wilson, 1988). Many weed seeds will remain dormant in the soil and not germinate under any set of environmental conditions. However, dormancy state is not permanent and weed seeds can change from a state of dormancy to non-dormancy, where they can germinate over a wide range of environmental conditions (Clements *et al.*, 1996; Wilson, 1988). Because dormancy can create future weed problems, weed scientists think of dormancy as a dispersal mechanism through time (Dorado *et al.*, 1999). Seed longevity in the soil depends on the interaction of many factors including the intrinsic dormancy of the seed population, the environmental conditions (such as light, temperature, moisture) and biological processes (including predation, allelopathy) (Ball, 1992; Wilson, 1988).

Although research has shown that agricultural weed seeds of some species may remain viable for several years, most weed seeds will either germinate or die shortly after being dispersed from the parent plant (Beckie *et al.*, 2005). In a six-year study conducted in Canada, Beckie *et al.* (2005) observed that when standard weed management practices were combined with weed seed shed prevention, weed patches expanded in size by 35%. However, when only standard weed management approaches were applied, weed patch expansion reached 330%.

Cardina *et al.* (1991) reported that soil tillage reduced weed numbers and species diversity but increased germination of annual weed seeds in the soil seedbank. The study done by Buhler and Daniel (1988) found that conventional tillage had greater velvetleaf (*Abutilon theophrasti* Medikus) densities than no-till, and no-till had greater giant foxtail (*Setaria faberi* Herrm.) densities than conventional tillage. Wrucke and Arnold (1985) also reported increased densities of grass species with reduction of tillage, while the density of common cocklebur (*Xanthium strumarium* L.) increased with tillage.

Refsell and Hartzler (2009) reported that tillage operations might have positive or negative effects on weed seeds in the soil seedbank as some weed seeds are exposed to predator and some are buried in soil. The number of emerging weeds could be lowered by: improving weed seed exposure to mice, birds and invertebrates; sustaining seed predator populations; collecting and removing weed seeds mechanically; extending the period of seed burial at unfavourable depths; creating soil conditions that enhance seed decay; enhancing fatal germination; preventing or delaying weed emergence; and suppressing weed growth and viable seed production (Refsell and Hartzler, 2009). Weed responses to tillage system vary with the location and the weed species (Derksen *et al.*, 1996). Perennial weeds, volunteer crops, and weeds whose seeds are dispersed by wind tend to become more problematic in zero-till systems (Blackshaw *et al.*, 1994; Derksen *et al.*, 1996). The response of annual grassy and broadleaved weeds depends more on location and other factors than on tillage system. The diversity of species within weed communities is of agronomic significance because of it is indicative of the response of weed species to soil management (Albrecht, 2003). Governments and nongovernmental organizations in German have begun promoting increased biodiversity in agricultural ecosystems, considering, among other things, the use of arable weeds as indicator organisms to evaluate management effects on wildlife diversity in arable fields (Albrecht, 2003).

Banting (1966) reported that in zero-till systems, weed seeds remain on the soil surface and the mortality of these seeds is higher than for seeds buried in the soil. Seed predators, such as mice and insects, feed on some of these seeds, preventing them from entering the soil seed bank. Burying weed seeds with tillage operations increases the number of weed seeds in the soil seedbank and may cause these seeds to persist longer than they would if they remained on the soil surface. Banting (1966) found that wild oat seeds buried below a depth of two inches remained viable longer than seeds on the soil surface. Gulden *et al.* (2003) found that canola seed lost during harvest could enter a state of secondary dormancy and persist for many years in the soil. The author also found that the number of persistent seeds found in conventional till plots were higher than in zero-till plots.

Tillage can also be used to deplete the weed seedbank in the soil. Jones and Medd (2000) reported that weed seedbank depletion could be accomplished by stimulating weed germination and emergence and then destroying weeds that have emerged. In another study, Olfert *et al.* (1991) reported that preventing weeds from producing seed, and collecting chaff might help to reduce additions of weed seed to the soil seedbank.

Therefore, since weeds have numerous seeds managing weeds in reduced-tillage systems may present a challenge. But successful growers anticipate potential problems through planning and field scouting, applying timely solutions, and using crop rotation to present alternative pest management strategies (Curran, 1996).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Layout of Experiments

Field experiments were conducted at the Tropical Pesticides Research Institute (TPRI) farm in Tengeru –Arusha. The site is located at 3⁰23' S 36⁰ 47' E and 1260 meters above sea level. Arusha region in general experiences two types of rainfall patterns: unimodal and bimodal. Karatu District enjoys unimodal rainfall which usually starts in November and ends in April. Other districts of Arumeru, Arusha, Monduli, Ngorongoro and Longido usually receive a bimodal rainfall pattern with short rains falling between October and end in December while the long rains start in February and end in June (URT, 1998). The short rains contribute 25% of total seasonal production. Long rains form the main season for cereal crops.

3.2 Land Preparation

Before land preparation, all experimental plots were laid out and glyphosate (N-(phosphonomethyl) glycine) herbicide was sprayed to the alley of the plots for clear demarcation of individual plots (Appendix 1). Dominant weed species and their number were recorded from all plots before imposition of tillage practices. Plots for conventional-tillage were cultivated by a hand hoe to break the soil and then harrowed before planting while those earmarked for conservation tillage were not cultivated but sprayed with glyphosate herbicide (Round up) was applied at the rate of 3 litres per ha two weeks before planting.

3.3 Plot Size, Experimental Design, Treatments and Layout

A Split-split plot experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Individual plots measured 3x4m and an alley of 1m was used to separate one plot from the other while 2m alley separated replicates (Appendix 1). In this study, the main plot factors were the two tillage practices, the conventional and conservation tillage. The sub-plot factors were cropping systems namely.

- (i) Maize sole crop (at a spacing of 75cm x 30 cm) which gave population of 44 444 plants per hectare,
- (ii) Bean sole crop (at a spacing of 50cm x 20 cm) which gave population of 100 000 plants per hectare,
- (iii) One bean row (at a bean spacing of 75 cm x 20cm) between two maize rows (at a maize spacing of 75cm x 30cm) which gave a total population of 111 110 plants per hectare,
- (iv) Two bean row (at a bean spacing of 50 cm x 20cm) between two maize rows (at a maize spacing of 75cm x 30cm) which gave a total population of 144 444 plants per hectare, and
- (v) Three bean row (at a bean spacing of 25 cm x 20cm) between two maize rows (at a maize spacing of 75cm x 30cm) which gave a total population of 244 444 plants per hectare.

Sub-sub plot factors were the imposed weed management systems: (i) Hand weeded once at 28 days after planting; (ii) Pre-emergence selective herbicide, Dual Gold (S-metolachlor), applied at the rate of 1.4 litres a.i per ha; (iii) Hand weeded twice at 14 and 28 days after planting; and (iv) No-weeding was done (Table 2).

In each plot, 5 maize rows with 10 plants per row were planted and data were collected from the three middle maize rows guided by one maize row on each side. The data was recorded from 4.05 m² harvest area. The total number of plots in this experiment was 120 (that is, two main plots x five sub plots x four sub-sub plots x three replicates (2x5x4x3=120)).

Table 2: Treatments

Main plot factor	Sub-plot factors	Sub-sub plot factors
Conservation tillage	Maize sole crop at a spacing of 75 cm x 30 cm (SM)	Hand weeded once at 28 days after planting (W1)
Conventional tillage	Bean sole crop at a spacing of 50 cm x 20 cm (SB)	Pre-emergence selective herbicide, Dual Gold, applied at the rate of 1.4 litres a.i per ha (W2)
	One bean row between two maize rows at a spacing of (75cm x 20cm) and (75cm x 30 cm) for bean and maize respectively (B1)	Hand weeded twice at 14 and 28 days after planting (W3)
	Two bean rows between two maize rows at a spacing of (50cm x 20 cm) and (75cm x 30 cm) for bean and maize respectively (B2)	No-weeding was done (W4)
	Three bean rows between two maize rows at a spacing of (25cm x 20cm) and (75cm x 30cm) for bean and maize respectively (B3).	

3.4 Planting Materials and Spacing

Maize variety Kilima was planted one seed per hole at the spacing of 75 x 30cm when in sole crop and when in intercropped with beans. Bean variety SUA 90 was planted two seeds per hole at spacing of 75 cm x 20cm, 50 cm x 20cm and at the spacing of 25 cm x

20cm in the intercrops while bean sole crop was planted at the spacing of 50 cm x 20cm. For intercrops, in some of the plots maize and beans were sown simultaneously while in others bean was sown 14days after maize planting. Gap filling was done two weeks after seed sowing to achieve the intended plant population (Table 3).

Table 3: Expected plant populations for maize and bean

	Maize spacing (m)	Maize population (plants ha ⁻¹)	Bean spacing (m)	Bean population (plants ha ⁻¹)	Total plant population per treatment
Maize sole crop (SM)	0.75 x 0.3	44 444	-	-	44 444
Beans sole crop (SB)	-	-	0.5x 0.2	100000	100 000
Single bean row between two maize rows (B1)	0.75 x 0.3	44 444	0.75x 0.2	66 666	111 110
Two bean rows between two maize rows (B2)	0.75 x 0.3	44 444	0.5 x 0.2	100 000	144 444
Three bean rows between two maize rows (B3)	0.75 x 0.3	44 444	0.25 x 0.2	200 000	244 444

3.5 Fertilizer Application

220 kg of Diammonium Phosphate per hectare was applied at planting only. Nitrogen fertilizer as urea was used to apply 60 kgN/ha in two split applications, with 50% of the total amount being applied at planting and the remainder when maize was about one meter high. Other management practices for production of maize and beans were done.

3.6 Supplemental Irrigation

Due to late onset of short rains, supplemental irrigation was applied after land preparation and then crops were sown. Another irrigation was done during tasselling, silking and at milk stage in order to supplement natural rainfall. In the long rains season, irrigation was not applied.

3.7 Weed Assessment Variables

The dominant weed species before land preparation was determined by counting all weeds and grouping them by their major groups (being either broad leaved, grasses or sedges) and then the percentage of each group calculated.

At the end of 14, 28, and 42 days after planting weeds were identified, counted and recorded by species from a 0.5m² quadrat randomly placed within the middle three harvest rows in each experimental plot. Weed counts were averaged and transformed (square root) to ensure homogeneity prior to data analysis. The weeds count by species were recorded and worked out separately at each counting interval.

The identified weed species were grouped into three categories namely grasses, sedges, broad leaved. Weeds of the different categories were collected from individual plot and weighed in the laboratory while fresh and after drying to a constant weight at 70°C to obtain their fresh and dry biomass respectively. Weed variables such as weed densities, weed frequencies, weed uniformities, mean field density, mean occurrence field density, and index of relative abundance of each weed species were determined using procedures described by Thomas, (1985) (Appendix 2). At each counting period the obtained weed count data was used to calculate the weed variable of that particular period (at 14, 28 and 42 days after planting).

3.8 Growth and Yield Variables of Maize and Beans

All data for both maize and beans were collected from plants in the middle of each experimental plot.

3.8.1 Growth and yield variables of maize

3.8.1.1 Days to 50% tasselling

Date on which about 50% of plants reached tasselling stage was recorded from the three middle rows in each plot and then days to tasselling were calculated as the difference between date of tasselling and date of emergence.

3.8.1.2 Days to 50% silking

Date on which about 50% of plants reached silking stage was recorded from the three middle rows in each plot and then days to silking were calculated as the difference between date of silking and date of emergence.

3.8.1.3 Leaf area index (LAI)

At silking, 4 plants were randomly harvested (destructively) from the three middle rows in each plot. Leaves were counted and then average was worked out. Length and width of the top, middle and bottom leaves of each plant was measured for calculating average leaf area. Then, LAI was calculated by using the following formula according to Williams (1946).

$$\text{LAI} = \frac{\text{Total leaf area of a crop}}{\text{Ground area occupied by the crop}} \dots\dots\dots(4)$$

3.8.1.4 Plant height

Plant height was recorded from the 10 plants selected from the three middle rows in each plot. Maize plant height was recorded by measuring the length of maize plant from the ground level to the tip of the tassel with the help of meter rod and the average height was calculated in cm.

3.8.1.5 Days to 50% physiological maturity

Complete loss of green colour from the ear sheaths and when the grain socket appeared black were used as criteria for physiological maturity. Days to physiological maturity was calculated as difference between date of physiological maturity and date of emergence (Ritchie and Hanway, 1982).

3.8.1.6 Number of ears (cobs) per plant

Number of plants and ears from each plot were counted and then ear number per plant was calculated.

3.8.1.7 Grain yield

Grain yield was recorded on per plot basis and then transformed into yield in tones per hectare.

3.8.1.8 Plant population

Plants from each plot were counted and then divided by the harvest area to obtain plant population per area.

3.8.1.9 Stover yield

Crops from harvestable area of each plot were harvested manually. Ears were detached from all plants, stalks were air dried and weighed to determine the stover yield in kg per plot, and then values were transformed into tones per hectare.

3.8.1.10 Harvest index (HI)

Harvest index (%) was calculated by using the following formula according to Bell *et al.* (1995).

$$HI = \left(\frac{\text{Economic yield (grain yield)}}{\text{Biological yield (grain yield + stover yield)}} \right) \times 100 \dots \dots \dots (5)$$

3.8.1.11 Land equivalent ratio (LER)

The Land Equivalent Ratio was used to test the productivity of the mixture according to Fisher (1977), as the sum of the fractions of the intercropped yields divided by the sole-crop yields. Although there are several alternatives for assessing yields under intercropping, LER is the only method that allows comparison of different intercropping situations (Waddington *et al.*, 1989).

$$LER = \frac{\text{Intercrop maize}}{\text{Sole maize}} + \frac{\text{Intercrop legume}}{\text{Sole legume}} \dots \dots \dots (6)$$

3.8.2 Growth and yield of beans

3.8.2.1 Plant height

Bean plant height was recorded by measuring the bean plant from the ground level to the tip of the longest leaf. Plant height was recorded from 10 plants randomly selected from each experimental unit with the help of meter rod and the average height was calculated in cm.

3.8.2.2 Days to 50% flowering

The actual number of days taken for half of the plants in each plot to have flowered was counted.

3.8.2.3 Days to 50% physiological maturity

Complete loss of green colour from the bean pods was used as criteria for bean physiological maturity. Days to physiological maturity of bean pods was calculated as the difference between the date of physiological maturity and date of emergence (Ritchie and Hanway, 1982).

3.8.2.4 Number of branches per plant

The number of branches per plant was determined by counting the number of branches from 10 plants selected at random, and then the total number of branches was divided by 10 to get average number of branches per plant.

3.8.2.5 Number of pods per plant

The number of pods per plant was determined by counting the number of pods (containing one or more seeds) from 10 pods selected at random, and then the total number of pods was divided by 10 to get average number of pods per plant.

3.8.2.6 Number of seeds per plant

The number of seeds per pod was determined by counting the number of seeds from 10 pods selected from three middle rows in each plot, and then the total number of seeds was divided by 10 to get average number of seeds per pod.

3.8.2.7 100 grain weight

Three sets of 100 seeds each were taken from the grain lot harvested from three middle rows in each plot, then weighed and averaged to get 100 grain weight.

3.8.2.8 Yield per hectare

The grain yield per plot (g) was transformed to tones per hectare.

3.9 Meteorological Data

Meteorological data were collected from the Tropical Pesticides Research Institute meteorological station. The collected data included rainfall and soil temperature. The total rainfall received during the 2010 short rains season (November, December, January, February and March) was 220.4 mm while the total rainfall received during the 2011 long rains season (April, May June, July and August) was 730.3 mm. (Fig. 1). This was low when compared with the total annual mean rainfall of the area of 1100 mm.

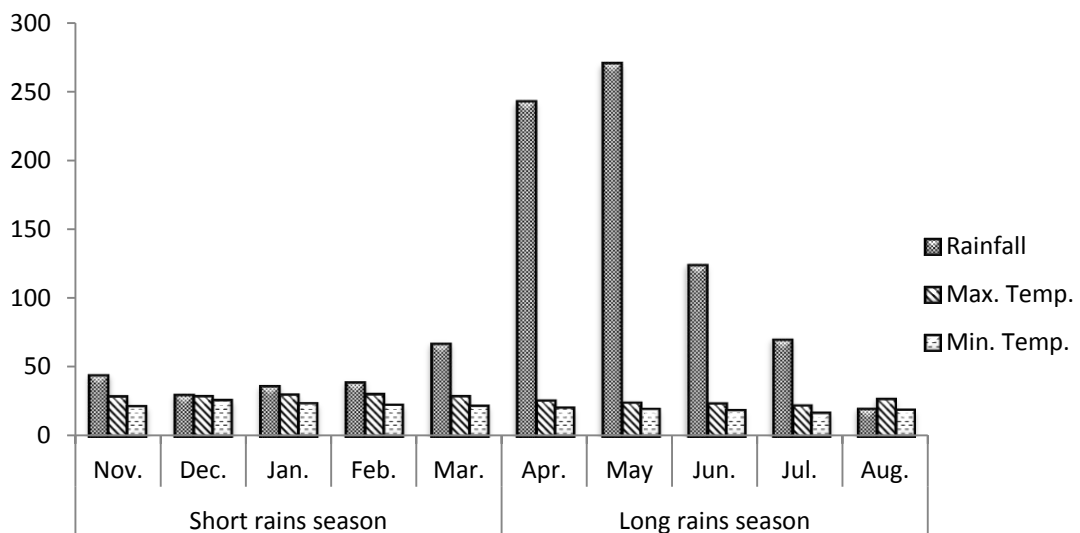


Figure 1: Weather data during 2010/11 cropping season

3.10 Occurrence of Other Pests

Rodents, insect pests and disease causing pathogen observed during the cropping seasons were recorded. The observed insect pests included crickets (*Gryllus assimilis*), stalk borers (*Ostrinia nubilalis*), white flies (*Bemisia species*), and maize aphids (*Rhopalosiphum maidis*). The dimethoate 4-EC (O, O-dimethyl methylcarbamoylmethyl (phosphorodithioate)) insecticide was sprayed after every 14 days for controlling aphids and white flies. The rate of application was 2.3L/ha for both seasons. Bean anthracnose and late blight diseases were controlled by using Dithane M-45 (Zinc and Manganese Ethylenebisdithiocarbamate) at the rate of 2.5kg/ha after every 7 days. The Sevin dust (1-naphthyl methylcarbamate) was applied in the crop holes during the evening for the control of crickets which were cutting the crops after seedling emergence once per week.

3.11 Data Analysis

Data analysis was done using Gen-Stat discovery 3rd edition software package (Buysse, 2007). Tukey's Honestly Significant Differences Test (THSDT) was used for mean separation.

CHAPTER FOUR

4.0 RESULTS

4.1 General Observations

4.1.1 Maize

During the short rains cropping season, the effect of cropping systems (maize and bean sole crops and different population of intercrops) was significant on leaf area index (LAI), cob length and grain yield. In the long rains cropping season, the effects of cropping system was significant only on LAI (Table 4 and 5).

The effect of weed management in the short rains season was significant on plant height, LAI, number of days to 50% silking and grain yield. In the long rains season the effects of weed management were significant on LAI, number of days to 50% silking and grain yield per hectare. The effects of tillage systems on all variables measured were insignificant in both seasons (Table 4 and 5).

Table 4: Analysis of variance for maize growth and yield variables in short rains cropping season (November 2010-March 2011)

Source of variation	DF	Plant height	LAI	50% tasselling	50% silking	50% maturity	Cobs/plant	Cob length	HI	Grain yield/ha	LER (maize)
Blocks	2	4766.3ns	10.1ns	108.9ns	72.4ns	103.6ns	0.04ns	68.9ns	0.4ns	4.4ns	0.2ns
Tillage systems	1	260.0ns	0.1ns	12.9ns	8.7ns	7.0ns	0.0ns	1.6ns	0.004ns	1.2ns	0.3ns
Main Plot Error	2	16170.5	28.0	122.5	74.1	102	0.2	33.6	0.05	4.8	0.2
Cropping system	3	3150.5ns	129.9**	30.8ns	18.9ns	19.5ns	0.3ns	82.0*	0.03ns	10.2*	1.2ns
Cropping * tillage	3	562.5ns	2.7ns	2.9ns	4.2ns	4.6ns	0.1ns	2.9ns	0.02ns	0.5ns	0.1ns
Subplot Error	12	1402.0	3.2	15.5	10.0	7.0	0.2	16.3	0.009	2.1	0.3
Weed management	3	10573.5***	27.7***	46.5*	25.8*	20.7ns	0.2ns	16.1ns	0.005ns	14.0***	0.5ns
Weed * Tillage	3	1103.3ns	2.1ns	7.9ns	5.2ns	0.5ns	0.2ns	6.3ns	0.01ns	1.3ns	0.1ns
Weed *cropping	9	2028.2ns	9.2***	31.02 *	19.8*	24.3*	0.0ns	10.9ns	0.9ns	6.7**	0.4ns
Weed*Cropping*Tillage	9	1473.77ns	3.1ns	12.0ns	8.4ns	11.7ns	0.1ns	6.8ns	0.001ns	0.84ns	0.14ns
Overall error	48	1019.91	1.7	13.5	8.9	10.2	0.1	6.5	0.01	1.76	0.56
Total	95										

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant;

DF=degree of freedom; LAI=Leaf Area Index; HI= Harvest Index; LER= Land Equivalent Ratio

Table 5: Analysis of variance for maize growth and yield variables in long rains cropping season (April 2011 – August 2011)

Source of variation	DF	Plant height	LAI	50% tasselling	50% silking	50% maturity	Cobs/plant	Cob length	HI	Grain yield/ha	LER (maize)
Blocks	2	5705.8ns	14.3ns	153.0ns	77.1ns	103.6ns	0.2ns	125.8ns	0.05ns	7.6ns	2.4ns
Tillage systems	1	1.0ns	0.2ns	24.0ns	7.0ns	7.0ns	0.5ns	4.2ns	0.01ns	13.8ns	0.8ns
Main Plot Error	2	10810.3	24.6	67.9	78.0	102.0	2.4	78.6	0.05	7.7	2.0
Cropping system	3	251.6ns	133.9**	25.2ns	19.3ns	19.5ns	0.2ns	1.5ns	0.03ns	3.0ns	0.2ns
Cropping * tillage	3	43134.7ns	8.2ns	11.5ns	4.2ns	4.6ns	0.2ns	11.2ns	0.01ns	2.3ns	0.2ns
Subplot Error	12	3594.6	14.7	14.2	9.7	7.0	0.2	17.2	0.009	3.3	0.7
Weed management	3	2787.3ns	13.6**	28.3ns	26.0*	20.7ns	0.4ns	9.0ns	0.005ns	11.8**	1.6ns
Weed * Tillage	3	793.1ns	0.6ns	9.7ns	4.7ns	10.5ns	0.1ns	4.1ns	0.01ns	5.8ns	4.5*
Weed *cropping	9	3015.7ns	6.0*	26.3*	19.9*	24.3*	0.1ns	13.7ns	0.01ns	6.0*	0.1ns
Weed * Cropping *											
Tillage	9	1882.5ns	1.0ns	13.6ns	8.70ns	11.7ns	0.1ns	11.5ns	0.001ns	0.8ns	1.0ns
Overall error	48	2861.9	2.4	12.3	8.7	10.2	0.2	19.7	0.011	2.68	1.3
Total	95										

**= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant; DF=degree of freedom;LAI=Leaf Area Index;

HI= Harvest Index; LER= Land Equivalent Ratio

During the short rains season, interaction between weed management and cropping system was significant on LAI, number of days to 50% silking, number of days to 50% physiological maturity and grain yield. During the long rains season the interaction between weed management and cropping system was significant on LAI, number of days to 50% tasselling, number of days to 50% silking, number of days to 50% physiological maturity and grain yield. The interaction among weed management and tillage systems, cropping system and tillage system; and that between weed management, cropping system and tillage system were not significant for all variables irrespective of the seasons.

4.1.2 Beans

In the short rains season, the effect of cropping system was significant on number of branches per plant, number of pods per plant, 100 seeds weight and yield per hectare. During the long rain season, the effects of cropping system was significant on plant height, number of branches per plant, number of pods per plant, number of seeds per pod, yield per ha, number of seeds per pod, and yield per hectare (Table 6 and 7).

Table 6: Analysis of variance for beans growth and yield variables in short rains cropping season(November 2010-March 2011)

Source of Variation	DF	Plant height	Branches/plant	Pods/plant	Seeds/pod	Pod length	100seeds wt	Grain yield/ha	LER (beans)
Blocks	2	628.5ns	0.04ns	6.2ns	3.5	8.6ns	6.6ns	0.7ns	0.12ns
Tillage systems	1	3.9ns	0.4ns	0.02ns	1.1	3.3ns	18.3ns	2.7ns	0.04ns
Main Plot Error	2	151.6	0.3	0.1	8.2	1.5	3.4	0.04	0.3
Cropping system	3	65.9ns	15.1***	29.4**	8.6	2.5ns	123.7**	1.9**	0.4ns
Cropping system * tillage system	3	10.2ns	0.4ns	1.0ns	1.0	1.2ns	6.4ns	0.1ns	0.1ns
Subplot Error	12	41.6	0.9	3.0	5.2	3.8	20.7	0.2	0.1
Weed management	3	231.4**	16.7***	37.6***	29.5***	3.1ns	87.7**	1.1***	1.0***
Weed * Tillage	3	41.9ns	0.5ns	0.3ns	9.2	4.9ns	15.2ns	0.1ns	0.2ns
Weed *cropping	9	27.3ns	2.0**	4.0ns	4.5	4.4*	34.1ns	0.3***	0.2ns
Weed * Cropping * Tillage	9	50.0ns	0.5ns	1.4ns	2.2	2.6ns	12.7ns	0.1ns	1.0ns
Overall error	48	44.8	0.5	2.3	4.2	2.0	17.0	0.1	0.1
Total	95								

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant; DF=degree of freedom;

LER= Land Equivalent Ratio

Table 7: Analysis of variance for beans growth and yield variables in long rains cropping season (April 2011 – August 2011)

Source of variation	DF	Plant height	Branches /plant	Pods/plant	Seeds/pod	Pod length	100seeds wt	Grain yield/ha	LER (beans)
Blocks	2	28.7ns	3.6ns	0.5ns	0.9ns	7.9ns	16.64ns	0.16ns	0.4ns
Tillage systems	1	0.4ns	0.8ns	0.003ns	3.4ns	4.7ns	4.6ns	1.0**	0.7ns
Main Plot Error	2	2.4	17.1	50.0	0.2	2.5	91.1	0.01	0.3
Cropping system	3	5.0ns	21.6*	37.0*	2.63*	5.7ns	12.0ns	0.7*	0.1ns
Cropping * tillage	3	11.0ns	1.2ns	1.0ns	0.4ns	3.9ns	8.3ns	0.1ns	0.2ns
Subplot Error	12	21.6	3.8	6.5	0.7	5.0	24.8	0.2	0.2
Weed management	3	273.6***	28.5***	69.5***	15.6***	1.0ns	49.8ns	2.6***	0.3ns
Weed * Tillage	3	27.0ns	1.2ns	8.6ns	1.2ns	11.9**	18.9ns	0.1ns	0.1ns
Weed *cropping	9	52.7*	2.3ns	5.7ns	1.3ns	1.5ns	15.4ns	0.2ns	0.1ns
Weed * Cropping * Tillage	9	3.8ns	2.0ns	3.5ns	1.07ns	2.5ns	11.8ns	0.2ns	0.1ns
Overall error	48	21.8	3.4	5.1	0.7	2.4	23.1	0.2	0.3
Total	95								

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant;

DF=degree of freedom; LER= Land Equivalent Ratio

The effect of weed management in short rains season was significant on plant height, number of branches per plant, number of pods per plant, number of seeds per pod, 100seeds weight, yield per hectare and LER. During the long rains season, the effects of weed management was also significant on plant height, number of branches per plant, number of pods per plant, number of seeds per pod, 100seeds weight and yield per hectare (Table 6 and 7).

The effects of tillage systems on all variables measured were insignificant in both seasons. During the short rains season, the interaction between weed management and cropping system was observed to be significant as far as the number of branches per plant, pod length and yield per hectare are concerned. On the other hand, during the long rains season, the interaction between weed management and cropping system was significant only on plant height while insignificant in other parameters measured (Table 6 and 7).

The interaction between weed management and tillage system; cropping system and tillage system; and the interaction between weed management, cropping system and tillage system were insignificant in all parameters measured in both seasons.

4.1.3 Weeds

In the short rains season, the effect of cropping system was significant on broad leaved fresh weed biomass at 28 and 42 days after planting; broad leaved dry weed biomass 14, 28 and 42 days after planting (Table 8 and 9).

Table 8: Analysis of variance for fresh weed biomasses in short rains cropping season (November 2010- March 2011)

Source of variation	DF	Fresh weed biomass					
		14 DAP		28 DAP		42 DAP	
		Broad-leaved	Grasses	Broad-leaved	Grasses	Broad-leaved	Grasses
Blocks	2	106.3ns	118.2ns	42.3ns	306.1ns	70.5ns	199.7ns
Tillage systems	1	165.7ns	51.0ns	64.8ns	12.0ns	0.3ns	65.5ns
Main Plot Error	2	39.7	647.8	39.9	419.8	42.7	459.6
Cropping system	3	20.4ns	44.7ns	199.6***	80.8ns	361.0ns	117.2ns
Cropping system * tillage system	3	23.0ns	79.4ns	62.8ns	61.0ns	60.6ns	225.6*
Subplot Error	12	18.9	43.5	21.2	42.6	28.8	64.8
Weed management	3	1045.5***	616.2***	741.0***	368.4***	1337.8***	510.3***
Weed * Tillage	3	32.6ns	29.4ns	6.3ns	49.2ns	136.7ns	77.9ns
Weed t *cropping	9	35.7ns	51.7ns	36.2	50.8ns	57.9ns	61.1ns
Weed * Cropping * Tillage	9	28.7ns	27.2ns	30.9ns	29.7ns	51.6ns	20.7ns
Overall error	48	29.6	43.9	31.4	59.7	54.3	77.3
Total	95						

***= Significant ($P \leq 0.001$);*= Significant ($P \leq 0.05$); ns=non-significant; DF=Degree Of Freedom;

DAP= Days after Planting

Table 9: Analysis of variance for dry weed biomasses in short rains cropping season (November 2010- March 2011)

Source of variation	DF	Dry weed biomass					
		14 DAP		28 DAP		42 DAP	
		Broad-leaved	Grasses	Broad-leaved	Grasses	Broad-leaved	Grasses
Blocks	2	8.7ns	21.9ns	41.8ns	45.1ns	23.4ns	209.7ns
Tillage systems	1	0.003ns	6.3ns	1.5ns	1.4ns	46.8ns	5.7ns
Main Plot Error	2	5.3	79.1	33.7	52.7	26.9	289.8
Cropping system	3	46.1***	18.1ns	84.5*	11.0ns	131.0***	65.4ns
Cropping system * tillage system	3	8.0ns	34.0*	5.1ns	9.1ns	42.5ns	42.8ns
Subplot Error	12	3.7	9.5	19.6ns	6.2	14.1	35.6
Weed management	3	172.2***	62.7***	78.3*	49.6**	478.1***	282.1**
Weed * Tillage	3	17.5ns	8.5ns	13.2ns	7.9ns	5.5ns	36.4ns
Weed *cropping	9	7.3ns	9.6ns	26.0ns	7.8ns	21.8ns	44.1ns
Weed * Cropping * Tillage	9	6.6ns	5.3ns	15.6ns	4.2ns	20.7ns	25.0ns
Overall error	48	7.0	11.0	26.9	8.5	21.3	47.2
Total	95						

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant; DF=Degree of Freedom; DAP=

Days after Planting

The effects of cropping system on fresh and dry weed biomass for sedges were insignificant in both seasons. On the other hand, the effect of weed management on fresh and dry weeds biomass in the short rains season was significant on broad leaved and grass biomasses at 14, 28 and 42 days after planting (Tables 8 and 9).

The interaction between cropping system and tillage system in the short rains season was significant on grass fresh weed biomass 42 days after planting and dry grass weed biomass 14 days after planting (Table 8 and 9).

During the long rains season, the effects of cropping system on fresh and dry biomass for both broad leaved and grass weeds were insignificant in both seasons (Tables 10 and 11).

Table 10: Analysis of variance for fresh weed biomasses in long rains cropping season of April 2011-August 2011

Source of variation	DF	Fresh weed biomass					
		14DAP		28DAP		42DAP	
		Broad-leaved	Grasses	Broad-leaved	Grasses	Broad-leaved	Grasses
Blocks	2	95.8ns	23.9ns	95.8ns	10.8ns	1.8ns	4.3ns
Tillage systems	1	123.9ns	83.8ns	123.8ns	56.6ns	35.7ns	22.9ns
Main Plot Error	2	14.5	55.6	14.5	28.0	6.9	1.9
Cropping system	3	13.8ns	9.5ns	13.8ns	5.9ns	5.0ns	3.12ns
Cropping system * tillage system	3	39.3ns	15.4ns	39.3ns	7.0ns	1.2ns	2.6ns
Subplot Error	12	28.6	16.5	28.6	7.5	6.6	5.5
Weed management	3	196.3**	10.8ns	155.7**	8.4ns	28.2**	8.9ns
Weed * Tillage	3	47.2ns	21.0ns	47.2ns	11.5ns	16.3*	6.4ns
Weed *cropping	9	18.6ns	16.0ns	18.6ns	9.1	9.6*	6.1ns
Weed * Cropping * Tillage	9	35.7ns	13.9ns	35.7ns	8.1ns	4.2ns	3.7ns
Overall error	48	29.8	22.1	27.8	12.7	4.8	4.8
Total	95						

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant; DF=Degree Of Freedom;

DAP= Days after Planting

Table 11: Analysis of variance for dry weed biomasses in long rains cropping season (April 2011-August 2011)

Source of variation	DF	Dry weed biomass					
		14DAP		28DAP		42DAP	
		Broad-leaved	Grasses	Broad-leaved	Grasses	Broad-leaved	Grasses
Blocks	2	5.3ns	1.7ns	11.3ns	1.2ns	7.5ns	0.4ns
Tillage systems	1	0.2ns	5.2ns	14.6ns	5.5ns	2.4ns	2.3ns
Main Plot Error	2	7.1	3.4	1.7	2.4	18.9	0.2
Cropping system	3	1.9ns	0.7ns	1.6ns	0.6ns	1.2ns	0.4ns
Cropping system * tillage system	3	2.0ns	1.0ns	4.6ns	0.7ns	1.0ns	0.3ns
Subplot Error	12	2.0	1.0	3.4	0.7	0.1	0.6
Weed management	3	15.4**	0.6ns	18.5**	0.6ns	0.8ns	1.0ns
Weed * Tillage	3	0.8ns	1.4ns	5.6ns	1.1ns	0.1ns	0.7ns
Weed * cropping	9	1.2ns	0.9ns	2.2ns	0.9ns	0.4ns	0.8ns
Weed * Cropping * Tillage	9	2.2ns	0.9ns	4.2ns	0.8ns	0.5ns	0.5ns
Overall error	48	1.3	1.4	3.5	1.2	0.5	0.6
Total	95						

***= Significant ($P \leq 0.001$); **= Significant ($P \leq 0.01$); *= Significant ($P \leq 0.05$); ns=non-significant;

DF=Degree Of Freedom

The effect of weed management on fresh and dry weed biomass in the long rains season was significant only in broad leaved biomasses in 14, 28 and 42 days after planting while the fresh and dry weed biomasses were insignificant at all durations of weed removal (Table 10 and 11).

During the long rains season, the interaction between cropping system and tillage system on fresh and dry weed biomass was insignificant (Table 10 and 11). The interaction of cropping system and tillage system on fresh and dry weed biomass for sedges were insignificant in both seasons. During short rains season, the interaction between weed management and tillage system was insignificant on all variables measured. During long rain season, interactions between weed management and tillage system was significant on broad leaved fresh weed biomass 42 days after planting but dry weed biomasses for both grasses and broad leaved weeds were insignificant in all variables measured. The interaction of weed management and tillage system on fresh and dry weed biomass for sedges were insignificant in long season.

During short rains season, the interaction between weed management and cropping system was insignificant in all treatment measured in the two seasons of the study. During the long rains season, interaction between weed management and cropping system was insignificant except on broad leaved fresh weed biomass 42 days after planting. The interaction between weed management, cropping system and tillage system for fresh and dry weed biomass was insignificant in all treatment measured in both seasons.

4.2 Effects of Bean Intercrops and Weeds in Maize-bean Intercrop Systems

4.2.1 Maize growth and development

4.2.1.1 Effect of bean population on maize growth and development

The lowest value of LAI among the intercrops was recorded when one bean row was planted between two maize rows (B1) (3.75 in long rains) while the highest LAI (7.91 in both short and long rains seasons) was recorded when three bean rows were planted between two maize rows (B3). Maize sole crops (SM) showed the lowest values of LAI (2.39 in short rains and 2.15 in long rains) compared with the intercrops in both seasons (Fig.2).

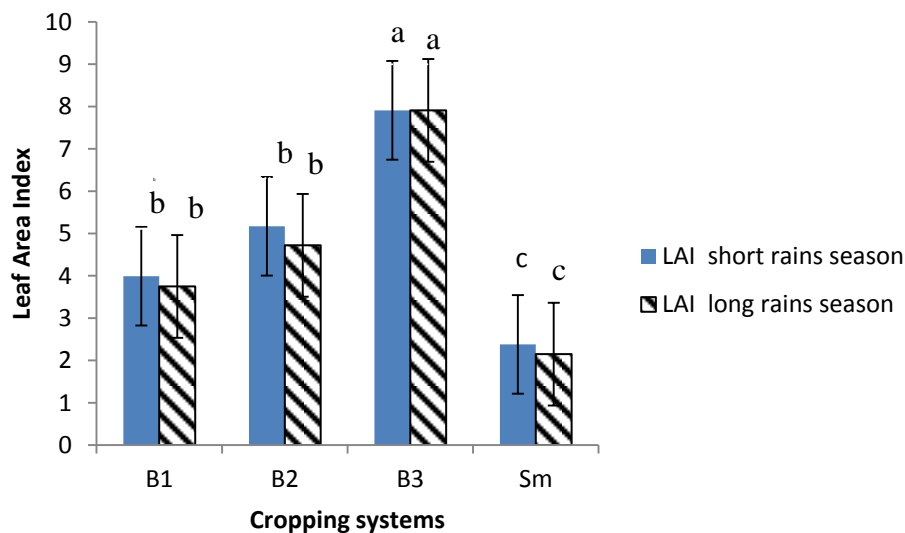


Figure 2: Effects of bean population on maize growth and development during short and long rain seasons

B1=One bean row between two maize rows; B2=Two bean rows between two maize rows; B3=Three bean rows between two maize rows; SM=Sole maize.

Bars followed by similar letter(s) are not significantly different from each other

4.2.1.2 Effect of weed management on maize growth and development

The influence of timing of intercropping of different bean populations on maize growth and development is presented in Fig.3, 4 and 5. The effects of weed management on LAI were statistically significant in both seasons. Among the different weed management practices used in this study, the largest values of LAI (6.68 in short rains and 5.52 long rains) was recorded when pre-emergence selective herbicide, Dual Gold, was applied at the rate of 1.4 litres a.i per ha, followed by hand weeding done at 28 days after planting (5.22 in short rains and 4.6 in long rains), followed by when hand weeding was done at 14 and 28 days after planting, while the lowest value of LAI (3.68 in short rains and 3.51 in long rains) was recorded when no-weeding was done in both seasons (Fig.3). The values of LAI did not differ significantly among seasons.

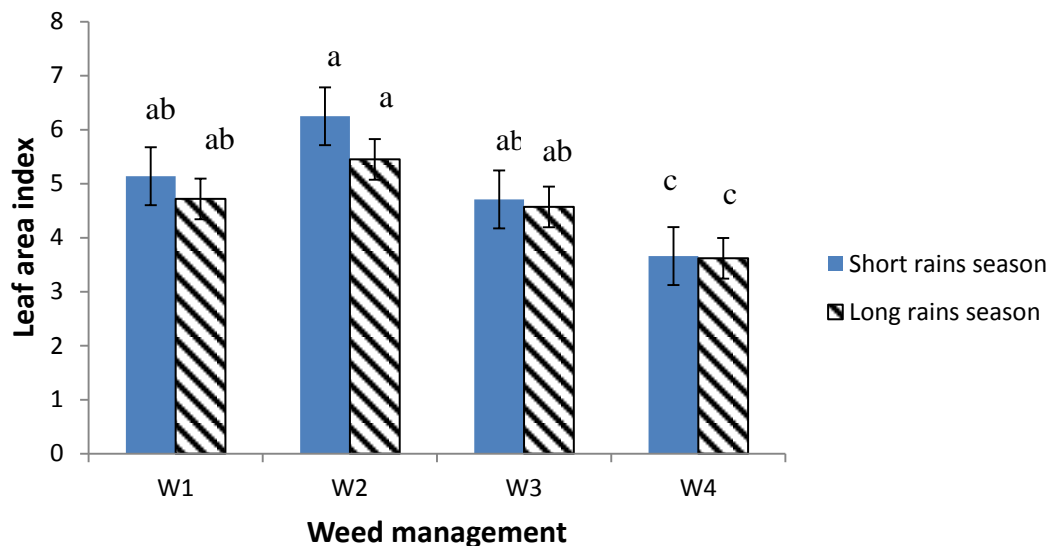


Figure 3: Effects of weed management on leaf area index in short and long rains cropping seasons

W1 = Hand weeded once at 28 days after planting; W2 = pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

Bars followed by similar letter(s) are not significantly different from each other

The effects of weeding methods on number of days to 50% tasselling and 50% silking differed significantly within the growing seasons (presented in Table 12 and 13). In 2010 short rains season, it was observed that when pre-emergence selective herbicide Dual gold was applied, maize took 71.33 and 82.75 days to attain 50% tasselling and silking respectively while weedy plots took the longest time (74.92 and 85.67 days to attain 50% tasselling and silking respectively) (Table 12). On the other hand, during 2011 long rains season, 73.75 and 85.75 days were taken to attain 50% tasselling and silking respectively when pre-emergence selective herbicide Dual gold was applied but when no weeding was done 76.67 and 88.67 days were taken to attain 50% tasselling and silking respectively in 2011 long rains season (Table 13). Generally, despite the type of weed management used, longer time was taken to reach 50% tasselling and silking than during 2011 long rains cropping season (Table 12) than in 2010 short rains cropping season (Table 13).

Table 12: Effects of weed management on duration to tasseling and silking during the short rain season (November 2010- March 2011)

Type of weed management	Duration to attain	
	50% tasseling	50% silking
W1	72.83	83.88
W2	71.33	82.75
W3	73.62	84.12
W4	74.92	85.67

W1 = Hand weeded once at 28 days after planting; W2 = pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

Table 13: Effects of weed management on duration to tasseling and silking during the long rain season(April 2011-August 2011)

Type of weed management	Duration to attain	
	50% tasseling	50% silking
W1	74.58	86.88
W2	73.75	85.75
W3	75.17	87.12
W4	76.67	88.67

W1 = Hand weeded once at 28 days after planting; W2 = pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

The effects of weeding methods on maize height at maturity were significantly different within and between the seasons (Fig. 3). Weed management did not show significant effects on plant heights where hand weeding was done at 28 days after planting; when pre-emergence selective herbicide Dual gold was applied; and when hand weeding was done twice at 14 and 28 days after planting during the short rains cropping season except for unweeded plots which showed shorter plants (146.7 cm). During the long rains season, weed management did not show a significant effects on plant height between hand weeding done at 28 days after planting (188.5 cm), when pre-emergence selective herbicide (Dual gold) applied (193.5 cm) and when hand weeding was done at 14 and 28 days after planting (178 cm) but they differ with weedy plots (179.1 cm) (Fig. 4).

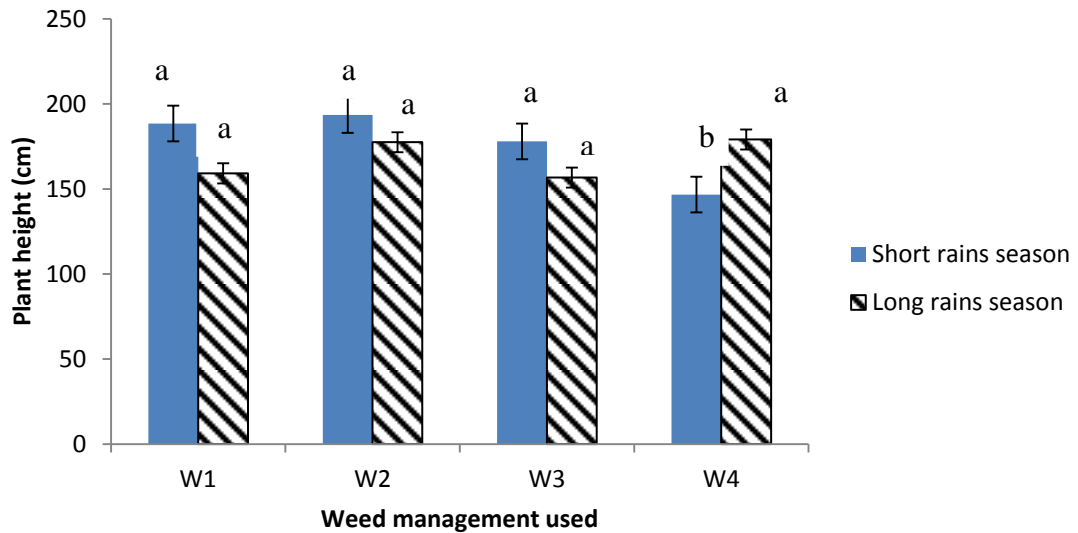


Figure 4: Effects of weed management on plant height in short and long rains cropping seasons

W1 = Hand weeded once at 28 days after planting; W2 = pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

Bars followed by similar letter(s) are not significantly different from each other.

Results of effects of bean population and weed management on LAI are shown in Table 14 and 15. LAI was highly significant and increased with increasing bean population in all weed management methods practiced (Table 14 and 15). In all bean populations, pre-emergence selective herbicide(Dual gold) gave greater LAI (11.15 in short rains and 10.02in long rains)than either when weeding was done at 28 days after planting orwhen hand weeded twice at 14 and 28 days after plantingwhile plots without weeding gave lowest LAI (1.53 in short rains and 1.63 in long rains).Among the intercrop, larger LAI were observed when three bean rows were planted between two maize rows and pre-emergence selective herbicide(Dual Gold)was applied (B3W2) while the lowest was observed where one bean row was planted between two maize rows and without being weeded (BIW4) (Table 14 and 15).

Table 14: Effect of bean population and weed management on LAI during short rain season (November 2010- March 2011)

		LAI			
		B1	B2	B3	SM
Weed management	Bean population				
	W1	3.81	5.12	8.21	3.16
	W2	4.35	6.55	11.15	2.17
	W3	4.47	5.13	7.67	2.66
	W4	3.31	3.68	4.62	1.53

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

B1=One bean row between two maize rows; B2= Two bean rows between two maize rows; B3=Three bean rows between two maize rows; SM= Sole maize.

Table 15: Effect of bean population and weed management on LAI during long rain season (April 2011-August 2011)

		LAI			
		B1	B2	B3	SM
Weed management	Bean population				
	W1	3.35	4.96	8.01	2.58
	W2	4.04	5.63	10.02	2.13
	W3	4.25	4.34	8.04	2.25
	W4	3.34	3.94	4.97	1.63

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

B1=One bean row between two maize rows; B2= Two bean rows between two maize rows; B3=Three bean rows between two maize rows; SM= sole maize.

The effects of bean population and weed management on duration for attaining 50% tasselling, silking and physiological maturity are presented in Fig.5. When two bean rows planted between two maize rows and pre-emergence selective herbicide, Dual Gold applied, it gave significantly shorter time to attain 50% tasselling, silking and physiological maturity than the other cropping systems despite their weeding methods used. Although three bean rows between two maize rows gave greater LAI, its maturity was relatively delayed compared with one bean row between two maize rows and two bean rows between two maize rows. In all bean populations used to intercrop maize, plots without weeding was observed to have taken longer duration to attain 50% tasselling, silking and physiological maturity (Fig.5).

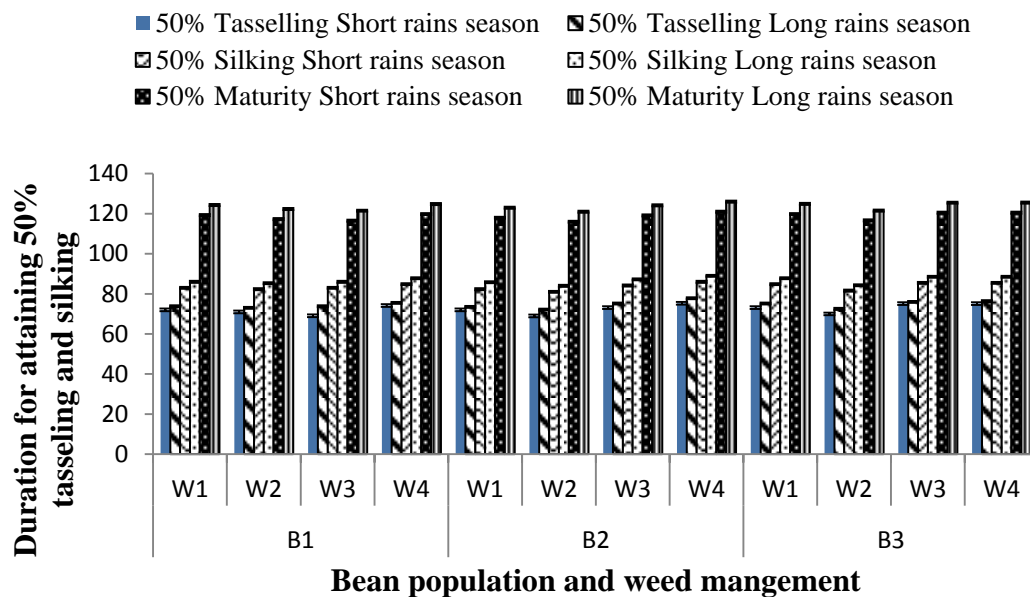


Figure 5: Days to 50% tasselling, silking and physiological maturity as affected by interaction between bean population and weed management

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. B1=One bean row between two maize rows; B2= two bean rows between two maize rows; B3=three bean rows between two maize rows.

When the error bars on bar charts do not overlap, the significant differences exists among the means; and if they do overlap they are not significantly different

4.2.2 Maize yield and yield components

4.2.2.1 Effect of bean population on maize yield and yield components

The data showing the effects of bean population on maize yield and yield components are presented in Table 16. The results showed that bean population had significant effects on maize yield such as cob length, and yield per ha in short rains season (Table 16). For the long rains season, bean population had insignificant effects on all variables measured. Among the intercrops, two bean rows planted between two maize rows gave highest cob length (17.87 cm) and maize yield (4.68 t/ha) than either three bean rows between two maize rows or one bean row planted between two maize rows. On the other hand, maize sole crop showed the shortest cob (13.98 cm) which eventually resulted into low yield per ha (3.27 t/ha).

Table 16: Effects of intercropping on maize yield and yield components in short rains season (November 2010- March 2011)

Cropping system	B1	B2	B3	Sole maize	Mean	SE	CV (%)
Cob length (cm)	17.27a	17.87a	17.79a	13.98b	16.72	2.73	16.30
Yield/ha (t)	4.49a	4.68a	4.51a	3.27b	4.24	1.06	25.10

Mean values in the same row followed by the same letter do not differ significantly at $P \leq 0.05$ using Tukey's Honestly Significant Differences Test (THSDT)

B1=One bean row between two maize rows; B2= two bean rows between two maize rows; B3=three bean rows between two maize rows

4.2.2.2 Effect of weed management on maize yield and yield components

The results in Table 17, shows the effects of weed management on maize yield and yield components. The effects of weed management methods on maize yield variables were

significant in both seasons (Table 17). Application of selective herbicide (Dual gold) resulted in significantly higher maize yield (4.79 and 4.75 t/ha in short and long rains seasons respectively) compared with the other treatments. The unweeded plots gave the lowest maize yield (3.16 and 3.06 t in short and long rains seasons respectively). The pre-emergence selective herbicide (Dual Gold) application was associated with vigorous and higher yield than any other treatments in this study. There were no significant differences in maize yield from the plots weeded twice at 14 and 28 days after planting and those weeded once at 28 days at planting.

Table 17: Effects of weed management on maize yield and yield components in short and long rains seasons (2010/11)

Cropping system	W1	W2	W3	W4	Mean	SE	CV (%)
Yield/ha in S1(t)	4.77a	4.79a	4.24a	3.16b	4.24	1.06	25.10
Yield/ha in S2 (t)	3.64ab	4.75a	3.86ab	3.06b	3.83	1.49	38.90

Mean values in the same row followed by the same letter do not differ significantly at ($P \leq 0.05$) using Tukey's Honestly Significant Differences Test (THSDT).

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres/ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

S1= 2010 short rains season, S2= 2011 long rains season

4.2.2.3 Interactive treatment effects on maize yield and yield components

4.2.2.3.1 Interactive effects of tillage system and weed management on maize yield and yield components in 2011 long rains season

The results indicated that there was a significant ($P \leq 0.05$) interaction between tillage and weed management on land equivalent ratio (LER) in long rains season (Fig.6). For long rains season, conventional tillage and application of pre-emergence selective herbicide Dual gold resulted in a significantly higher (2.49) land equivalent ratio relative to the other

treatments. The conservation tillage and unweeded plots showed the lowest (0.87) LER compared with the other treatments. Generally, the conventional tillage system showed high values of LER in all weed management practices used when compared with its counterpart conservation tillage system (Fig. 6).

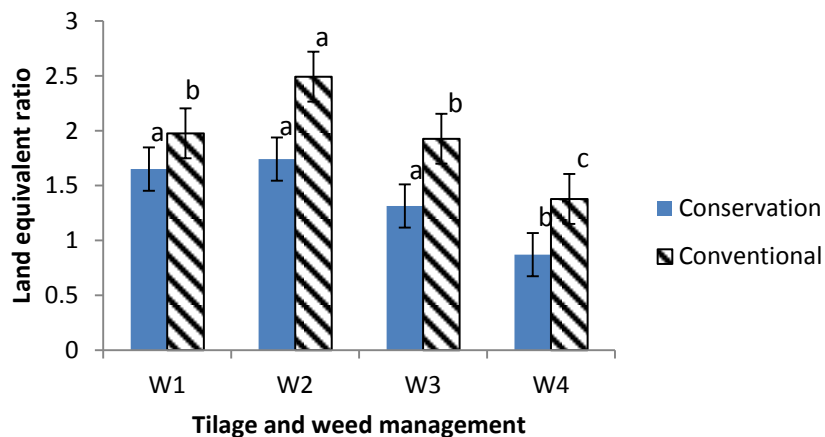


Figure 6: LER as affected by interaction between tillage system and weed management in 2011 long rains season

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres/ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. Bars followed by similar letter(s) are not significantly different from each other

4.2.2.3.2 Interactive effects of bean population and weed management

Significant differences existed in interaction of bean population and weed management on maize yield per ha in both seasons (Fig.7). In the 2010 short rains season, the two bean row planted between two maize rows and application of pre-emergence selective herbicide Dual Gold was gave significantly higher maize yield (5.52 t/ha) while the lowest maize yield (2.64 t/ha) was recorded in the plots where three bean rows was planted within two maize rows without weeding. In the 2011 long rains season, the two bean row planted

between two maize rows and weeded twice at 14 and 28 days after planting gave significantly higher maize yield (5.12 t/ha) compared with other treatments applied.

On average, all bean populations combined with pre-emergence selective herbicide, Dual gold applied, showed higher maize yield than other weed management techniques used. And also 2010 short rains season yielded higher than long rains season regardless of the bean population (Fig. 7).

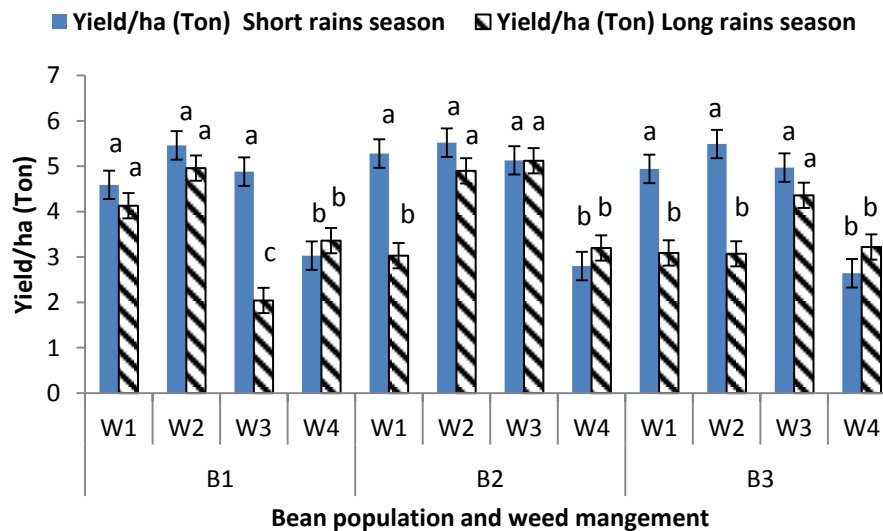


Figure 7: Maize yield as affected by interaction between bean population and weed management

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. B1=One bean row between two maize rows; B2= Two bean rows between two maize rows; B3=Three bean rows between two maize rows. Bars followed by similar letter(s) are not significantly different from each other

4.3 Weed Occurrence and Severity

4.3.1 Effects of cropping system on fresh and dry weed biomasses

4.3.1.1 Effects of cropping system on fresh weed biomass

The effects of cropping systems on broad leaved fresh weed biomass measured 28 and 42 days after planting were only significantly different in the short rains cropping season. The highest broad leaf fresh biomass was found in sole bean, sole maize, followed by one bean row between two maize rows, two bean rows between two maize rows and lowest in three bean rows between two maize rows (Fig.8).

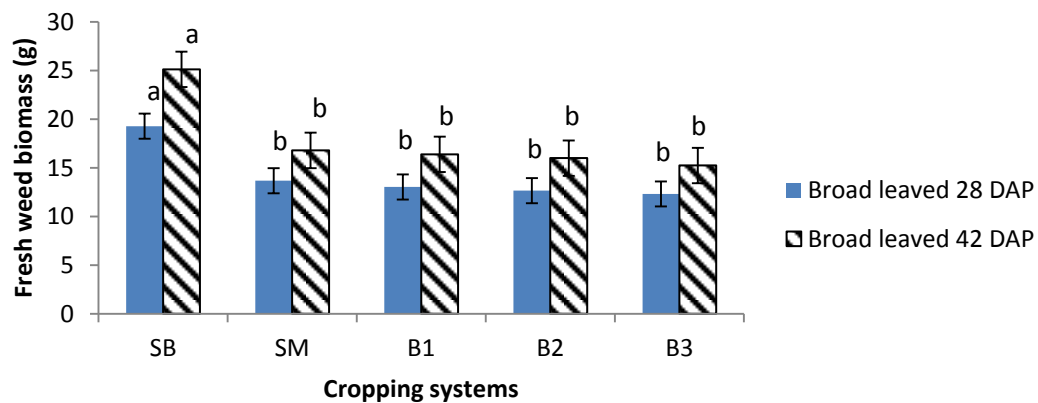


Figure 8: Fresh weed biomass as affected by cropping system

B1=1 bean row between 2 maize rows; B2=2 bean rows between 2 maize rows;

B3=3 bean rows between 2 maize rows; SM=sole maize; SB= sole bean.

Bars followed by similar letter(s) are not significantly different from each other

4.3.1.2 Effects of cropping systems on dry weed biomass

The effects of cropping systems on broad leaved dry weed biomass measured 14 and 28 days after planting were significantly different in short rains season. Regardless of time of weed removal, the highest broad leaved dry weed biomass were found in sole bean, followed by one bean row between two maize rows, sole maize, two bean rows between two maize rows and the lowest in three bean rows between two maize rows (Table 18).

Table 18: Effects of cropping system on broad leaf dry weed biomass in short rain cropping season(November 2010- March 2011)

Weed management	Broad leaved dry weed biomass	
	14 Days After Planting	28 Days After Planting
B1	6.68b	13.04b
B2	6.11b	12.66b
B3	6.05b	12.33b
SM	6.12b	13.04b
SB	9.09a	19.28a
Mean	6.81	14.07
SE	2.62	6.07
CV (%)	39.0	42.7

Mean values in the same column followed by the same letter do not differ significantly at ($P \leq 0.05$) using Tukey's Honestly Differences Significant Test (THSDT). B1=One bean row between two maize rows; B2=Two bean rows between two maize rows; B=Three bean rows between two maize rows; SM=sole maize; SB=sole bean

4.3.2 Effects of weeding methods on fresh and dry weed biomass

4.3.2.1 Effects of weeding methods on fresh weed biomass

The effects of weed management on grasses and broad leaved fresh weed biomass measured at 14, 28 and 42 days after planting were all significant in short rains season (Table 19) while in long rains season only broad leaved biomass was significant at 14, 28 and 42 days after planting (Table 20). In both seasons, the broad leaved and grasses fresh weed biomass were highest in unweeded plots while the lowest biomass was recorded

in plot received pre-emergence selective herbicide (Dual Gold) despite their time of weed removal (either 14, 28 or 42 days after planting).

Table 19: Effects of weed management on grasses and broad leaved fresh weed biomass in the short rains cropping season (November 2010- March 2011)

Weed management	14 Days After Planting		28 Days After Planting		42 Days After Planting	
	Broad leaved	Grass	Broad leaved	Grass	Broad leaved	Grass
W1	14.71a	11.01ab	11.83b	10.21b	15.91b	10.51b
W2	3.95b	2.92c	10.68b	8.65b	14.71b	10.15b
W3	15.37a	7.45b	12.73b	9.03b	14.82b	10.21b
W4	16.81a	13.32a	21.54a	16.18a	28.46a	18.53a
Mean	12.71	8.68	14.20	11.08	18.48	12.45
SE	5.04	6.61	6.06	6.42	7.30	7.85
CV (%)	39.6	76.2	42.7	58.3	39.5	63.5

Mean values in the same column followed by the same letter do not differ significantly at ($P \leq 0.05$) using Tukey's Honestly Significant Differences Test (THSDT). W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

Table 20: Effects of weed management on broad leaved fresh weed biomass in the long rains cropping season(April 2011-August 2011)

Weed management	14 Days After Planting	28 Days After Planting	42 Days After Planting
W1	15.39b	14.96ab	16.17b
W2	17.88ab	12.40b	16.16b
W3	16.39b	14.53ab	16.78ab
W4	21.24a	17.93a	18.22a
Mean	17.73	14.96	16.83
SE	6.39	5.21	2.10
CV (%)	36.0	34.8	12.4

Mean values in the same column followed by the same letter do not differ significantly at ($P \leq 0.05$) using Tukey's Honestly Significant Differences Test (THSDT). W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done.

4.3.2.2 Effects of weeding methods on dry weed biomass

The effects of weed management on broad leaved and grass weeds dry biomass measured at 14, 28 and 42 days after planting were significantly different in short rains season but the dry weed biomass were significantly different only in broad leaved at 14 and 28 days after planting in long rains season (Fig.9). Unweeded plots showed greater values of broad leaved and grasses dry weed biomass while the lowest biomass were recorded in when pre-emergence selective herbicide (Dual Gold) was applied regardless of their time of weed removal (either 14, 28 or 42 days after planting) and the sampling season. These results indicated that the longer the weed removal was delayed, the higher the weed biomass.

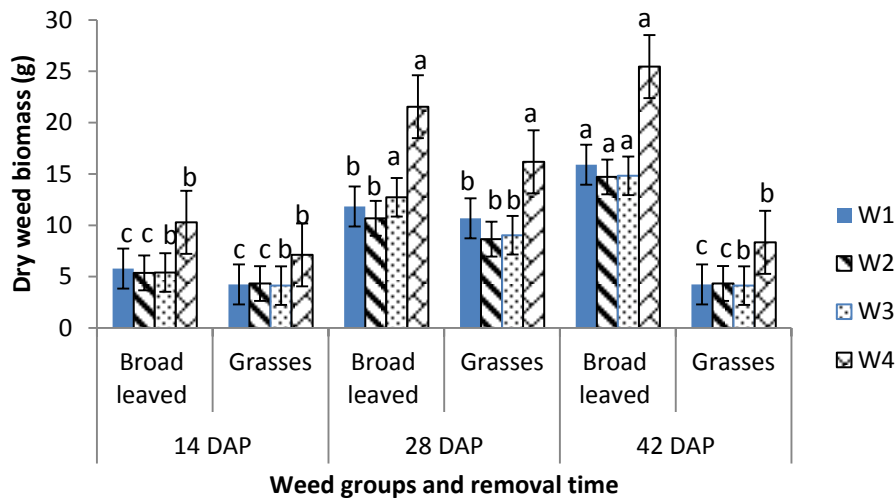


Figure 9: Effects of weed management on grasses and broad leaved fresh weed biomass in short rains cropping season

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. Bars followed by similar letter(s) are not significantly different from each other

4.3.3 Interactive effects

4.3.3.1 Interactive effects between tillage and weed management fresh weed biomass

The effects of interactions of tillage and weed management on fresh weed biomass were significant on broad leaved biomass at 42 days after planting in both tillage systems in long rains cropping season. When unweeded, all tillage systems yielded higher broad leaved fresh weed biomass than other weeding methods used. The highest broad leaved fresh weed biomass was observed in conservation tillage under weedy condition while the lowest broad leaved biomass was recorded in conventional tillage when pre-emergence selective herbicide Dual Gold was applied. The conservation tillage gave higher

broad leaf biomass than conventional tillage system regardless of weeding management practiced (Fig.10).

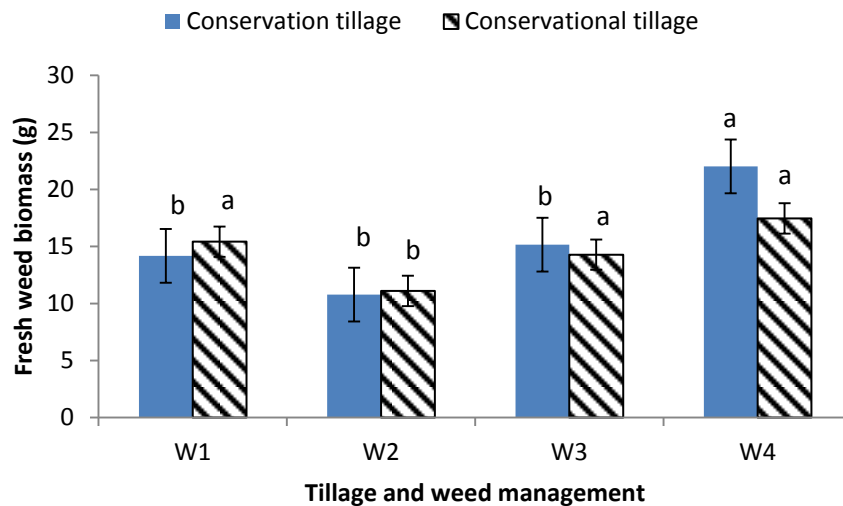


Figure 10: Broad leaf fresh weed biomass as affected by interactions of tillage and weed management during long rain cropping season

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres.a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. Bars followed by similar letter(s) are not significantly different from each other

4.3.3.2 Interactive effects between bean population and weed management fresh weed biomass

The effects of interactions between crop stand/bean population and weed management on fresh weed biomass was only significant at 42 days after planting broad leaved (Fig. 11). The highest broad leaved fresh weed biomass were found in sole bean, followed by sole maize, one bean row between two maize rows, two bean rows between two maize rows and three bean rows between two maize rows in combination with different weeding practiced (Fig.11).

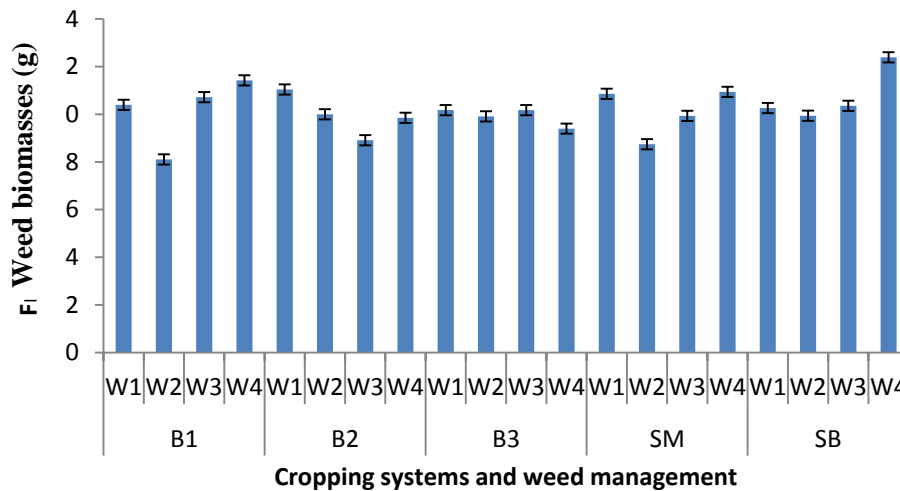


Figure 11: Broad leaved fresh weed biomass as affected by interactions of cropping systems and weed management during long rain cropping season

W1 = Hand weeded once at 28 days after planting; W2 = Pre-emergence selective herbicide Dual gold applied at the rate of 1.4 litres a.i per ha; W3 = Hand weeded twice at 14 and 28 days after planting; W4 = No weeding was done. B1= one bean row between two maize rows; B2=two bean rows between two maize rows; B3= three bean rows between two maize rows; SM=sole maize; SB=sole bean.

When the error bars on bar charts do not overlap, the significant differences exists among the means; and if they do overlap they are not significantly different

4.4 Weed Species Composition under Conventional and Conservation Tillage Systems in Maize-bean Intercrop

Before land preparation and imposition of tillage systems the area was dominated by the broad leaved weeds (broad leaved (81.63 %), grasses (16.33%), and sedges (2.04%). The calculation of weed density (D), frequency (F), field uniformity (FU) and index of relative abundances (RA) of the weed species were used to determine the dominant weed species

during the cropping season. The higher the relative abundance of a weed species, the dominant the species it became. Before imposition of tillage systems the dominant weed species in the experimental area were: couch grass (*Cynodondactylon*), flax-leaf fleabane (*Conyzabonariensis*), blackjack (*Bidenspilosa*), hairy spurge (*Euphorbia hirta*), and Mexican poppy (*Argemonemexicana*) and goatweed (*Ageratum conyzoides*).

Weed species composition changed from those observed before land preparation in different tillage system in both seasons. The dominant weed species prior and after imposition of tillage systems and their major groups during the cropping systems are shown in (Table 21).

The most dominant weed species (based on their relative abundances) during the 2010 short rains season under conventional tillage 14 days after planting were marsh grass (*Echinochloacolona*), painted euphorbia (*Euphorbia heterophylla*) and blackjack with the relative abundance of 40.95, 29.16 and 23.58 respectively (Appendix 6). On the other hand, under conservation tillage the most dominant weed species 14 days after planting were: blackjack, painted euphorbia and wandering jew with the relative abundance of 80.82, 56.32 and 38.77 respectively (Appendix 7). In the 2011 long rains seasons the dominant weed species under conventional tillage 14 days after planting were blackjack, painted euphorbia and purple nutsedge with the relative abundances of 58.50, 58.19 and 33.93 respectively (Appendix 6). On the other hand, under conservation tillage the most dominant weed species 14 days after planting were: marsh grass, painted euphorbia and purple nutsedge with the relative abundances of 54.00, 32.89 and 20.03 respectively (Appendix 7).

**Table 21: Classification of dominant weed species before treatment application
(listed in order of dominancy based on their relative abundances)**

Dominant weeds in short rains season	Group	Dominant weeds in long rains season	Group
Couch grass	G	Blackjack	B
Flax-leaf fleabane	B	Marsh grass	G
Blackjack	B	Gallant soldier	B
Hairy spurge	B	Wandering jew	B
Hairy crabgrass	G	Purple nutsedge	G
Tropical richardia	B	Painted euphorbia	B
Mexican poppy	B	Hairy crabgrass	G
Wild lettuce	B	Purslane	B
Coatbuttons	B	Thorn apple	B
Purple nutsedge	S	Hairy spurge	B

B= Broadleaved; G=Grass; S=Sedge;

In the 2010 short rains season the most dominant weed species under conventional tillage 28 days after planting were annual weeds such as marsh grass, blackjack and gallant soldier with the relative abundances of 41.59, 32.77 and 28.90 respectively (Appendix 6) while the most dominant weed species under conservation tillage 28 days after planting were blackjack, gallant soldier and painted euphorbia with the relative abundances of 99.19, 52.12 and 46.18 (Appendix 7). On the other hand, in the 2011 long rains season the most dominant weed species under conventional tillage 28 days after planting were weeds such as blackjack, gallant soldier and painted euphorbia with the relative abundances of 78.02, 49.39 and 45.46 (Appendix 6) while the most dominant weed species under conservation tillage 28 days after planting were marsh grass, blackjack and painted euphorbia with the relative abundances of 56.39, 43.26 and 41.08 respectively (Appendix 7).

The marsh grass, blackjack, and gallant soldier were the most dominant weed species during the 2010 short rains season under conventional tillage 42 days after planting with the relative abundances of 41.01, 40.21 and 32.91 respectively (Appendix 6). The most dominant weed species under conservation tillage 42 days after planting were blackjack, purple nutsedge and Mexican poppy with the relative abundances of 45.22, 32.38 and 32.58 respectively (Appendix 7). The blackjack, painted euphorbia and wandering jew were the most dominant weed species during the 2011 long rains season under conventional tillage 42 days after planting with the relative abundances of 60.03, 44.59 and 28.91 respectively (Appendix 6). The most dominant weed species under conservation tillage 42 days after planting were blackjack, marsh grass and gallant soldier with the relative abundances of 60.51, 46.48 and 34.24 respectively (Appendix 7).

Some weed species which were not present before imposition of conventional tillage appeared during the cropping seasons. These included marsh grass, blackjack, purslane (*Portulaca oleracea*), apple of Peru (*Nicandra physaloides*), gallant soldier, abyssinian finger grass, thorn apple (*Datura stramonium*), Mexican marigold (*Tagetes minuta*) and signal grass (*Urochloa panicoides*) (Appendix 4).

The newly appeared weed species which were not present before imposition of conservation tillage included marsh grass, cosmos (*Bidens formosa*), thunberg's amaranth (*Amaranthus thunbergii*), spiny sida (*Sida alba*), purslane, thorn apple and Mexican marigold (Appendix 5).

Weed species such as wild lettuce (*Lactuca capensis*), African finger millet (*Eleusine coracana*), scotch thistle (*Cirsium vulgare*), pennywort (*Centella asiatica*),

pepper cress(*Lepidium africanum*), East Indian globe thistle(*Sphaeranthus africanus*), rattlepods(*Crotalaria striata*), creeping indigo(*Indigofera spicata*), lantana(*Lantana camara*), Natal redtop(*Melinis repens*), spiny sida, wild jute(*Corchorus trilocularis*), creeping sorrel(*Oxalis corniculata*), and sow thistle(*Sonchus oleraceus*) which were observed before land preparation disappeared during the cropping seasons (Appendix 4 and 5).

On the other hand some weed species such as punarnava (*Boerhavia diffusa*), signalgrass, scotch thistle, pennywort, pepper cress, prickly malvastrum(*Malvastrum coromandelianum*), creeping indigo, Mexican poppy, late weed(*Trichodesma zeylenicum*), wild jute, creeping sorrel, cogon grass(*Imperata cylindrica*), and crowfoot grass(*Eleusine indica*) which were not present before imposition of conservation tillage appeared during the cropping season (Appendix 5).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of Intercropping on Maize Growth and Development

5.1.1 Maize growth and development

The results from the study showed that two bean rows planted between two maize rows (100 000plants (bean) per ha (spacing of 50cm x 20cm) gave vigorous,taller, healthy maize plants compared to other populations such as one bean row planted between two maize rows (66666plants per ha(75cm x 20cm)) and three bean rows planted between two maize rows (200000plants per ha (25cm x 20cm) and the maize sole crop. From these results it was evident that maize growth was affected by both high and low plant densities. The maize growth in high densities faced high competition due to overcrowding leading to slow growth rate and also and when planted in low density, the completion for growth resources in minimized thus high growth. These results are similar to those of Molatudi and Mariga (2012) who reported that too low plant densities limit the potential yield, and too high plant densities lead to increased stress on the plants, which also decrease the yield.

The application of pre-emergence herbicide (Dual Gold) significantly suppressed weeds than other weed management practiced in all bean populations and tillage used in both seasons. It gave taller and vigorously growing plants with large LAI (11.15 in short rains and 10.02 in long rains), and less number of days to attain 50% tasselling (71.33 and 73.75days in short and long rains season respectively), silking (82.75 and 85.75 days in

short and long rains season respectively) and maturity when compared to the other weeding methods. In contrast, weedy plots had the lowest LAI (3.66 in short rains and 3.62 in long rains); shorter plants, and took longest time to attain 50% tasselling, 50% silking and 50% physiological maturity in both seasons. This could be due to the fact that the application of herbicide, Dual gold, killed the weeds at early stages of crop growth and development, which resulted into less competition for growth resources and reduced germination of weed seeds. These results are similar to those of Ransom *et al.*, (1997) who reported that yield advantages of successful intercropping systems were related to minimized interspecific competition for light, water and nutrients.

LAI increased with increasing bean population despite the tillage systems in both seasons among the intercrops. Larger values of LAI were observed when bean population of 200000 plants per ha and pre-emergence herbicide were applied while the lowest was found where bean population of 66666 plants per ha without weeding. The higher values of LAI in intercrops have been attributed to reduced competition between crops and weeds that stimulated maize leaf growth. Gardiner and Gacker (2003) concluded in their study that the larger the LAI the greater the light interception. It is evident from data that interactive effects and individual effects of row spacing and weed competition durations on LAI of maize were significant during both seasons of study.

The longer duration taken by weedy plots to acquire 50% tasselling, silking and physiological maturity was due to delayed removal of weeds from the crops. Silking time decreased with decreasing duration of weed competition and increased with delaying weeding as previously reported by Bergamaschi *et al.* (2004). Similarly, Sibuga and Bandeen (1978) found that delayed removal of weeds caused an increase in the days to flowering and maturity and a decrease in crop yield. Also, among the intercrops used, bean

population of 200000plants per hawasobserved to delayattaining 50% tasselling, (75.17days), 50% silking (86.0 days) and 50% physiological maturity (120.5 days) while the population of 100000plants per ha took the shortest time of 69.0, 82.3, 116.5 days for attaining 50% tasselling, silking and physiological maturity. The longer time taken by plants to attain 50% tasseling in the bean population of 200000plants per hawas due to the closer spacing, which caused intense interspecific-competition among maize, beans and weeds for growth resources such as nutrients, water and light energy when compared with bean population of 66 666 plants per hectare in wider spacing wasused. These results are similar to those of Hamid and Nasab (2001) who reported that silking was delayed in higher planting density. This suggests that dense planting density might have slightly reduced the rate of plant development because of greater competition.

5.1.2 Maize yield and yield components

The results from this study have indicated that maize insole crop resulted in significantly less yield per ha, number of cobs per plant and shorter cobs whencompared to intercrops. The low yield in sole maize could be due to shorter cob and less number of cobs than the intercrops. Two bean rows between two maize rows (100 000bean population) resulted into increased maize yield per ha, number of cobs per plant and longer cobs in both seasons relative tothe other intercrops. From these results it was evident that the intercrop yields were higher than those of sole crops. These results are similar to those reported byMuoneke *et al.* (2007) where it was reported that high competition for available nutrients, especially under sole crop and presence of weeds reduced grain yield. This could be due to the fact that cereals mixed with legumes have many advantages in terms of growth and some other agronomical properties (Putnam *et al.*, 1986; and Kutuet *al.*, 2009). This may bedue to reduced competition and increased complementarity effects of the crop varieties used (Kutuet *al.*, 2009).

On the other hand, among the intercrops, the three bean rows between two maize rows (200 000 bean population) and the one bean row between two maize rows (66 666 bean population) gave less yields under conservation and conventional tillage, respectively, in both seasons. This could be due to increased inter- and intra-specific competition for nutrients, moisture and light due to higher plant densities especially with three bean rows between two maize rows. These results are similar to those of Molatudi and Mariga (2012) who reported that too low plant densities limited the potential yield, and too high plant densities led to increased stress on the plants, which also decreased the yield.

5.2 Effects of Intercropping on Weed Occurrence and Severity

5.2.1 Weed biomass

The results indicated that effects of cropping systems on broad leaved fresh and dry weed biomass measured 28 and 42 days after planting were significant different at $P \leq 0.05$ in the short rains season with the highest broad leaf fresh biomass found in bean sole, followed by one bean row between two maize rows, maize sole, two bean rows between two maize rows and lowest biomass in three bean rows between two maize rows. The higher biomass in bean sole could be due to the intraspecific competition for growth resources. Oljaca *et al.* (2000) reported that intraspecific competition was more intense than interspecific competition. The broad leaved weed biomass absorbs a lot of water from the soil than the grassy weeds thus their effects in the crop field are also high. The cause of the observed weed suppression in intercrops was that the intercrops captured more light than the sole crops, due to the different growth habits and heights of the intercrops (Szumigalski, 2005).

The un-weeded plots yielded highest weed broad leaved biomass while the lowest biomass were recorded in where pre-emergence selective herbicide Dual gold was applied

regardless of their time of weed removal (either 14, 28 or 42 days after planting). The higher fresh grass biomass in the weedy check than in pre-emergence herbicide applied plots might be due to intense competition between the crops and weeds in the weedy check where weeding was not done. Pre-emergence herbicide such as Dual gold, acts by preventing weeds from emerging or establishing especially the annual grasses and broadleaf weeds (Pollock, 2006).

The significant differences observed on fresh broad leaf biomass at 42 days after planting in both tillage systems during long rains cropping season indicated that, tillage systems were capable of controlling weeds effectively during the first four weeks after planting but later than that, weeds need to be controlled. The highest broad leaf fresh weed biomass was observed when conservation tillage was combined with maize sown 14 days earlier than beans and without weeding while the lowest broad leaf biomass were recorded in conventional tillage when maize was sown 14 days earlier than beans and pre-emergence selective herbicide (Dual gold) was applied. In general, conservation tillage gave higher broad leaf biomass than conventional tillage system regardless of weeding management practiced. The highest weed biomass in conventional tillage was due to the fact that conventional tillage moves the weed seeds up or down the soil profile; those which moved down the soil profile fail to germinate, and those exposed to the surface can be exposed to predators or to desiccation and die, resulting into low fresh and dry grassy biomass during the short rains cropping season. Froud-Williams (1984) reported that tillage moved seeds up or down in the soil profile, and changed soil conditions, which promoted either germination or dormancy. The interactive effects between plant population and weed management on fresh weed biomass at 42 days after planting indicated that the weed biomass were in the order of (from the highest to lowest biomass) sole bean, sole maize, one bean row between two maize rows, two bean rows between two maize rows and three

bean rows between two maize rows regardless of weed management practiced. In the study of barley-pea intercrop, Liebman and Dyck(1993) found that barley-pea intercrops had fewer weeds than pea grown as a sole crop.

The results indicated that the maize sown 14days earlier than beans and pre-emergence selective herbicide (Dual gold)applied controlled weeds in more efficient way than other weeding methods and this could be due to less interference between crops and weeds in early stages of crop development. Crop plants and weeds interfere with growth activities of each other to a varying degree and compete for moisture, mineral nutrients, and light and hinder harvest operations (Maqboolet *al.*, 2006).

5.2.2 Weed species composition under conventional and conservation tillage system in maize-bean intercrop

Before land preparation and imposition of tillage systems the area was dominated by the mixture of broad leaved weeds (81.63 %), grasses (16.33%), and sedges (2.04%). The most dominant weed species before land preparation and imposition of tillage systems in the experimental area were couch grass, flax-leaf fleabane, blackjack, hairy spurge, Mexican poppy, and goatweed. Most of these weeds were of broad leaf types and perennials. The results of weed species composition in this study indicated that weed seed bank is dynamic because species changed from those observed before land preparation in different tillage system in both seasons.

The most dominant weed species under conventional tillage were annual weeds such as marsh grass, painted euphorbia, blackjack, gallant soldier,red amaranths, and wandering jewwhich is biannual. The presence of annual weeds could be due to soil disturbances during tillage operation such land preparation and weeding. The annual weeds are well adapted to succeed in highly unstable and unpredictable environments brought about by

frequent tillage, drought, or other disturbance as speculated by ATTRA, (2003). These results are similar to those of Ortega (1991) who reported that the higher the soil is disturbed the higher would be the weed seed bank. Furthermore, Buhler (1995) reported that the presence of light during soil cultivation stimulated weed germination in fields.

The majority of the observed weed species under conventional tillage were dicot annual weeds. These results are similar to those of Cussans (1976) who reported an increase of some dicot weeds under conventional tillage.

Some weed species such as marsh grass, cosmos, purslane, apple of Peru, gallant soldier, abyssinian finger grass, thorn apple, Mexican marigold and signal grass which were not present before imposition of conventional tillage appeared during the cropping seasons under conventional tillage systems. On the other hand some weed species such as cogon grass, crowfoot grass, scotch thistle, pennywort, pepper cress, East Indian globe thistle, rattlepods, creeping indigo, lantana, Natal redtop, spiny sida, wild jute, creeping sorrel, and sow thistle which were observed before land preparation disappeared during the cropping seasons. These results indicated that some weed seeds which were below the soil profile were moved up the profile and the vice versa is true for the emerged weed species. These results are similar to those of Ortega (1991) who reported that cultivated soils have larger seed bank when frequently cultivated and the higher the soil is disturbed the higher the weed seed bank (more the species). Derksen *et al.* (1993) suggested that changes in weed communities were influenced more by environmental factors such as location than by tillage systems. Childs *et al.* (2001) however, reported that overtime, small-seeded annual broad-leaf weeds and perennial weeds become more prevalent in fields under conservation tillage.

The appearance of Marsh grass weed only during the short rains season could be due to the weed emergence periodicity or their seeds being under the dormancy period during the long rains season. The influence of tillage system on weed emergence periodicity is likely due to the influence of tillage (Bullied *et al.*, 2003). Begumet *al.* (2006) reported weed emergence to be influenced by soil disturbance, temperature, rainfall, soil moisture and radiant energy.

Blackjack, painted euphorbia, red amaranths, wandering jew, gallant soldier and abyssinian finger grass were the most dominant weed species under conservation tillage. These weed species observed were all dicots annual weeds except wandering jew which is biannual and abyssinian finger grass which is a perennial grass weed. Considering a wide range of situation, Shrestha *et al.* (2002) concluded that long-term changes in weed flora are driven by an interaction of several factors such as tillage, environment, crop rotation, crop type and timing of weed management practices.

The weed species such as marsh grass, cosmos, red pigweed, spiny sida, purslane, thorn apple, Mexican marigold which were not present before land preparation appeared under conservation tillage during the cropping while weed species such as punarnava, signalgrass, scotchthistle, pennywort, pepper cress, prickly malvastrum, creeping indigo, Mexican poppy, late weed, wild jute, creeping sorrel, cogon grass, crowfoot grass which were not present before imposition of tillage system appeared under conservation tillage during the cropping season. These results indicated that the appeared weeds were brought up the soil profile by the conservation tillage. These results are similar to those by Forcella and Lindstrom, (1988) who reported that conservation tillage is important for drawing weed seeds to the surface for easy management.

The lost weed species were killed by broad spectrum glyphosate herbicides, during land preparation and during application of pre-emergence herbicide (Dual gold). Glyphosate herbicide moves throughout the plant and control the growing shoot and roots, and thus providing long term control of a wide range of species from annual to perennial grasses and broad leaves, invasive species that are spreading in agricultural, non-crop, amenity and industrial land uses, aquatic uses as well as weeds resistant to selective products in arable land(Monsanto, 1992). Weed seeds stimulated by tillage to either emerge or die, depending on depth at which germination occurs, and whether current growing conditions are favorable. Generally, tillage hastens the decline in numbers of viable dormant weed seeds remaining in the soil.

Weed species such as signalgrass, gallant soldier, rattlepods and East Indian globe thistle which was available before imposition of tillage systems did not appear in conservation but it appear in conventional tillage only. Weed shifts have occurred in response to changes in tillage, irrigation, fertility, crop rotation, and herbicide use practices (Buhler, 1995).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

This study has shown that

- i. Two bean rows planted between two maize rows gave vigorous, taller, healthy maize plants compared to other populations used and the sole maize. It also gave lower weed biomass than the rest bean populations and sole maize regardless of tillage and weeding method.
- ii. Application of pre-emergence herbicide (Dual Gold) 14 days before sowing beans was the best weed management option under all bean populations and tillage systems irrespective of cropping season. It outperformed the rest of the weeding method tested in this study.
- iii. Irrespective of the growing season, sole maize treatment gave the lowest LAI regardless of the weeding method practiced and it was associated with the maize grain yield.
- iv. Among the intercrops, three bean rows between two maize rows and one bean row between two maize rows gave the lowest maize yields under conservation and conventional tillage, respectively in both seasons.
- v. Application of pre-emergence selective herbicide, Dual gold, in maize sown 14 days earlier than beans gave lowest broad leaf biomass while the weedy plots gave highest broad leaf biomass regardless of their time of weed removal. The

interactive effects between plant population and weed management on fresh weed biomass indicated that the weed biomass were in the order of (from the highest to lowest biomass) sole bean, sole maize, one bean row between two maize rows, two bean rows between two maize rows and three bean rows between two maize rows regardless of weeding practiced.

6.2 Recommendation

A number of results obtained in this study particularly those related to influence of bean population and weeding treatments could not be explained in specificity with regard to what led to such results. A recommendation to do further detailed studies to show specific contribution of the influencing factor is very much needed.

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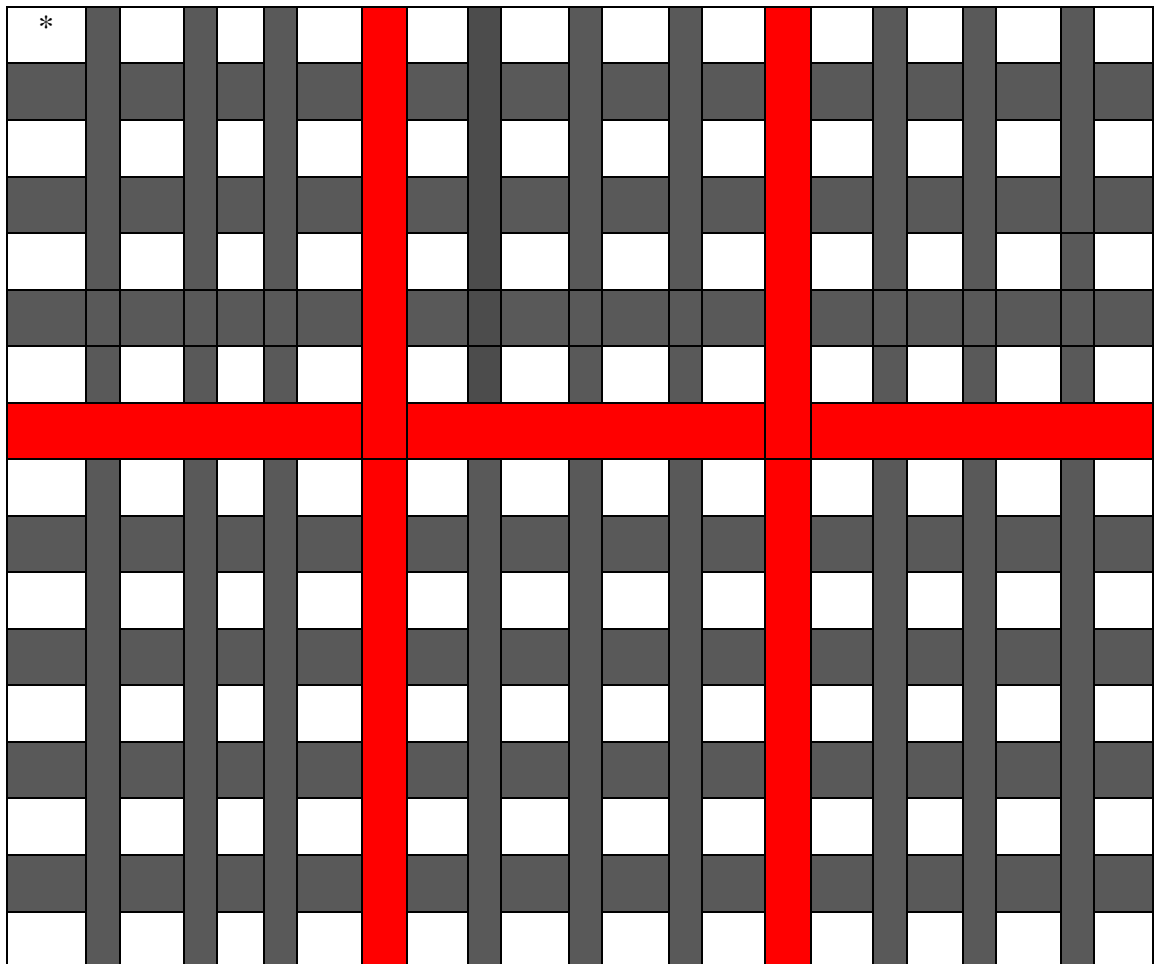
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APPENDICES

Appendix 1: A plot layout



- Key
- * represents a sub-sub plot size with 4m x 3m
 - Red colour indicates the path of 2m which separates one replication from another and one tillage practice to another.
 - Black colour indicates the path of 1m which separates one sub-plot factor treatments and sub-sub plot factors from each other.

Appendix 2: Weed Variables

1. Weed density (D):

The density (D) of each species in a field will be calculated by summing the number of plants in all quadrants and dividing by the area of the quadrants (Thomas, 1985).

$$D_{ki} = \sum Z_j / A_i$$

Whereby:

D_{ki} is density (in numbers m^{-2}) of species k in field i,

Z_j is the number of plants of a species in quadrant j, and

A_i is the area in m^2 of 4 quadrants in field i.

2. Weed frequency (F):

Frequency (F) will be calculated as the percentage of the total number of fields surveyed in which a species occurred in at least in one quadrant (Thomas, 1985).

$$F_k = \frac{\sum_{i=1}^n Y_i}{n} \times 100$$

Whereby:

F_k is the frequency for species k,

Y_i is the presence (1) or absence (0) of species k in field i, and

n is the number of fields surveyed.

3. Weed field uniformity (FU):

Field uniformity (FU) will be calculated as the percentage of the total number of quadrants sampled in which a species occurred (Thomas, 1985).

$$FU_k = \sum \sum X_{ij} * 100 / n$$

Whereby:

\mathbf{Fu}_k is the field uniformity for species k,

\mathbf{X}_{ij} is the presence (1) or absence (0) of species k in quadrat j in field i, and

\mathbf{n} is the number of fields surveyed.

4. Weeds mean density (MFD):

Mean field density (MFD) is the mean number of plants m^{-2} for each species averaged over all fields sampled (Thomas, 1985).

$$MFD_k = \frac{\sum_1^n D_{ki}}{n}$$

Whereby:

\mathbf{MFD}_k is the mean field density of species k,

\mathbf{D}_{ki} is the density (in numbers m^{-2}) of species k in field i, and

\mathbf{n} is the number of fields surveyed.

1. Weed mean occurrence field density (MOFD):

Mean occurrence field density (MOFD) was the mean number of plants m^{-2} for a weed species averaged over only the fields in which that species occurred (Thomas, 1985).

$$MOFD_k = \frac{\sum_1^n D_{ki}}{n - a}$$

Whereby:

\mathbf{MOFD}_k is the mean occurrence density of species k,

\mathbf{D}_{ki} is the density (in numbers m^{-2}) of species k in field i,

\mathbf{n} is the number of fields surveyed, and

\mathbf{a} is the number of fields from which species k is absent.

6. Index of Relative abundance (RA):

Relative abundance (RA) is the sum of relative frequency (RF), relative field uniformity (RFU), and relative mean field density (RMFD) for each particular weed species (Thomas, 1985).

$$RA_k = RF_k + RFU_k + RMFD_k$$

Whereby:

RF_k = frequency value of species k / Sum of the frequencies for all species x 100

RU_k = Uniformity value of species k / Sum of the uniformities for all species x 100

RMFD_k = MFD value of species k / Sum of the MFD for all species x 100

Appendix 3: Classification of dominant weed species before and after treatment application (listed in order of dominance)during the 2010 short and 2011 long rains seasons

Time	Dominant weeds in S1	Group	Dominant weeds in S2	Group
Weed species composition Before land preparation	Couch grass	G	Blackjack	B
	Flax-leaf fleabane	B	Marsh grass	G
	Blackjack	B	Galant soldier	B
	Hairy spurge	B	Wandering jew	B
	Hairy crabgrass	G	Purple nutsedge	G
	Tropical richardia	B	Painted euphorbia	B
	Mexican poppy	B	Hairy crabgrass	G
	Wild lettuce	B	Purslane	B
	Coat buttons	B	Thorn apple	B
	Purple nutsedge	S	Hairy spurge	B
Weed species name 14 Days After Planting	Marsh grass	G	Blackjack	B
	Blackjack	B	Painted euphorbia	B
	Painted euphorbia	B	Purple nutsedge	S
	Purple nutsedge	S	Wandering jew	B
	Wandering jew	B	Flax-leaf fleabane	B
	Galant soldier	B	Thorn apple	B
	Thorn apple	B	Puncture vine	B
	Puncture vine	B	Purslane	B
	Purslane	B	Red garden sorrel	B
Red garden sorrel	B	Hairy spurge	B	
Weed species name 28 Days After Planting	Marsh grass	G	Blackjack	B
	Blackjack	B	Painted euphorbia	B
	Painted euphorbia	B	Galant soldier	B
	Galant soldier	B	Wandering jew	B
	Wandering jew	B	Purple nutsedge	S
	Purple nutsedge	S	Hairy crabgrass	G
	Hairy crabgrass	G	Chickweed	B
	Purslane	B	Purslane	B
Tropical richardia	B	Tropical richardia	B	
Couch grass	G	Couch grass	G	
Weed species name 42 Days After Planting	Blackjack	B	Blackjack	B
	Marsh grass	G	Galant soldier	B
	Galant soldier	B	Wandering jew	B
	Wandering jew	B	Purple nutsedge	S
	Purple nutsedge	S	Painted euphorbia	B
	Painted euphorbia	B	Tropical richardia	B
	Hairy crabgrass	G	Hairy crabgrass	G
	Purslane	B	Purslane	B
Thorn apple	B	Thorn apple	B	
Hairy spurge	B	Hairy spurge	B	

B= Broadleaved; G=Grass; S=Sedge; S1= Short rain season; S2=Long rain season

**Appendix 4: Weed species and composition under conventional tillage systems during
the 2010 short and 2011 long rains seasons**

Weed species name	Before land preparati on	Conventional tillage in S1			Conventional tillage in S2		
		14DAP	28DAP	42DAP	14DAP	28DAP	42DAP
Purple nutsedge	v	v	v	v	v	v	v
Couch grass	v	v	v	v	v	v	v
Egyptian crowfoot	v	v	v	v	x	x	x
Cogon grass	v	x	x	x	x	x	x
Crowfoot grass	v	x	x	x	x	x	x
Sticky bristle grass	v	v	v	v	v	v	v
Hairy crabgrass	v	v	v	v	v	v	v
Abyssinian finger grass	v	x	v	v	v	v	x
Marsh grass	x	v	v	v	v	x	v
Blackjack	v	v	v	v	v	v	v
Cosmos	x	v	v	v	v	v	v
Painted euphorbia	v	v	v	v	v	v	v
Hairy spurge	v	v	v	v	v	v	v
Red amaranth	v	v	v	x	v	v	v
Thorny amaranth	v	v	v	v	v	v	v
Slender amaranth	v	v	v	v	v	v	v
Thunberg's amaranth	x	v	x	x	x	x	x
Wandering jew	v	v	v	v	v	v	v
Tropical richardia	v	v	v	v	v	v	v
Flax-leaf fleabane	v	v	v	x	x	v	x
Sow thistle	v	x	x	x	x	x	x
Red garden sorrel	v	v	v	v	v	v	v
Creeping sorrel	v	x	x	x	x	x	x
Wild jute	v	x	x	x	x	x	x
Cattle bush	v	x	x	x	x	v	v
Spiny sida	v	x	x	x	x	x	x
Apple of Peru	v	v	x	v	x	v	x
Natal red-top	v	x	x	x	x	x	x
Mexican poppy	v	v	x	v	v	v	v
Lantana	v	x	x	x	x	x	x
Puncture vine	v	v	v	v	v	v	v
African turnip weed	v	v	v	v	v	v	v
Creeping indigo	v	x	x	x	x	x	x
Punanrnava	v	x	x	x	x	x	x

Prickly malvastrum	v	v	x	x	x	x	x
Rattlepods	v	x	x	x	x	x	x
East Indian globe thistle	v	x	x	x	x	x	x
Pepper cress	v	x	x	x	x	x	x
Pennywort	v	x	x	x	x	x	x
Goat weed	v	v	v	v	x	v	v
Coat buttons	v	v	v	v	x	x	x
Wild lettuce	v	v	v	v	x	v	v
Scotch thistle	v	x	x	x	x	x	x
Galant soldier	x	v	v	v	v	v	v
Purslane	x	v	v	v	x	x	x
Thorn apple	x	x	v	v	v	v	v
Mexican marigold	x	x	v	x	x	x	x
Signal grass	x	x	v	x	x	x	x

S1=Short rain season; S2= Long rain season; v= Weed species present; x= Weed species

absent;

**Appendix 5: Weed species and composition under conservation tillage systems
during the 2010 short and 2011 long rains seasons**

Weed species name	Before land preparation	Conservation tillage in S1			Conservation tillage in S2		
		14DAP	28DAP	42DAP	14DAP	28DAP	42DAP
Purple nutsedge	v	v	v	v	v	v	v
Couch grass	v	v	v	v	v	v	v
Egyptian crowfoot	v	x	x	x	x	x	x
Cogon grass	v	x	x	x	x	x	x
Crowfoot grass	v	x	x	x	x	x	x
Sticky bristle grass	v	v	v	v	v	v	v
Hairy crabgrass	v	v	v	v	v	v	v
Abyssinian finger grass	v	v	v	x	v	v	v
Marsh grass	x	v	x	v	v	x	v
Blackjack	v	v	v	v	v	v	v
Cosmos	x	v	v	v	v	v	v
Painted euphobia	v	v	v	v	v	v	v
Hairy spurge	v	v	v	v	v	v	v
Red amaranth	v	v	v	v	x	v	v
Thorny amaranth	v	v	v	v	v	v	v
Slender amaranth	v	v	v	v	x	v	v
Wandering jew	v	v	v	v	v	v	v
Tropical richardia	v	v	v	v	v	v	v
Flax-leaf fleabane	v	x	v	x	x	x	x
Sow thistle	v	x	x	x	x	x	x
Red garden sorrel	v	v	v	v	v	v	v
Creeping sorrel	v	x	x	x	x	x	x
Wild jute	v	x	x	x	x	x	x
Cattle bush	v	x	v	v	x	v	v
Spiny sida	v	x	x	x	x	x	x
Apple of Peru	v	x	v	x	x	v	x
Natal red-top	v	x	x	x	x	x	x
Mexican poppy	v	v	v	v	v	v	v
Lantana	v	x	x	x	x	x	x
Puncture vine	v	v	v	v	v	v	v
African turnip weed	v	v	v	v	v	v	v
Creeping indigo	v	x	x	x	x	x	x
Punanrnava	v	x	x	x	x	x	x
Prickly malvastrum	v	x	x	x	x	x	x

Rattlepods	v	x	x	x	x	x	x
East Indian globe thistle	v	x	x	x	x	x	x
Pepper cress	v	x	x	x	x	x	x
Pennywort	v	x	x	x	x	x	x
Goatweed	v	x	v	v	x	v	v
Coat buttons	v	x	x	x	x	x	x
Wild lettuce	v	x	v	v	x	v	x
Scotch thistle	v	x	x	x	x	x	x
Galant soldier	x	v	v	v	v	v	v
Thorn apple	x	v	v	v	v	v	v

S1 = Short rain season; S2 = Long rain season; DAP = days after planting; v= Weed species present; x= Weed species absent;

Appendix 6: Weed assessment variables under conventional tillage system in 2010 short and 2011 long rains seasons (based on relative abundances of each weed species observed)

Weed species name	Weed relative abundances under Conventional tillage in S1				Weed relative abundances under Conventional tillage in S2			
	Before land prep.	14DAP	28DAP	42DAP	Before land prep.	14DAP	28DAP	42DAP
Purple nutsedge	9.23	22.79	22.25	23.30	23.30	33.93	3.27	27.55
Couch grass	39.69	13.29	14.96	10.80	10.80	5.29	4.20	6.64
Egyptian crowfoot	9.23	1.06	8.87	1.54	1.54	0	0	0
Cogon grass	2.77	0.00	0	0	0	0	0	0
Crowfoot grass	2.77	0	0	0	0	0	0	0
Sticky bristle grass	2.77	13.29	12.93	12.29	12.29	7.15	1.85	5.03
Hairy crabgrass	2.77	4.77	14.31	18.27	18.27	6.09	6.84	7.43
Abyssinian finger grass	0	0	4.16	4.34	4.34	8.34	9.50	0
Marsh grass	0	40.95	41.59	41.01	41.01	3.27	0	5.20
Blackjack	34.15	23.58	32.77	40.21	40.21	58.50	78.02	60.03
Cosmos	0	4.75	2.73	6.38	6.38	3.68	7.58	1.59
Painted euphorbia	1.85	29.16	28.09	23.01	23.01	58.19	45.46	44.59
Hairy spurge	27.69	12.49	11.32	10.55	10.55	4.39	2.32	7.65
Red amaranth	0	3.44	1.02	0	0	2.51	5.38	0.68
Thorny amaranth	7.38	2.00	4.00	2.46	2.46	2.01	1.39	4.26
Slender amaranth	4.62	6.55	3.03	1.45	1.45	0.72	3.60	1.23
Thunberg's amaranth	0	5.07	0	0	0	0	0	0
Wandering jew	1.85	21.62	25.01	22.07	22.07	31.57	15.60	28.91
Tropical richardia	13.85	1.78	11.19	6.93	6.93	12.07	13.13	8.56
Flax-leaf fleabane	28.62	4.17	0.51	0	0	0	0.74	0
Sow thistle	6.46	0	0	0	0	0	0	0
Red garden sorrel	2.77	9.11	6.21	5.06	5.06	10.75	7.24	8.84
Creeping sorrel	1.85	0	0	0	0	0	0	0
Wild jute	0.92	0	0	0	0	0	0	0
Cattle bush	4.62	0	0	0	0	0	9.08	6.61
Spiny sida	6.46	0	0	0	0	0	0	0
Apple of Peru	0	0.50	0	0.47	0.47	0	2.77	0
Natal red-top	0.92	0	0	0	0	0	0	0
Mexican poppy	16.62	0.48	0	0.98	0.98	7.53	3.50	14.98
Lantana	3.69	0	0	0	0	0	0	0
Puncture vine	0.92	16.70	6.19	5.43	5.43	5.01	4.22	4.48

African turnip weed	3.69	12.32	2.52	4.90	4.90	5.24	4.20	3.65
Creeping indigo	1.85	0	0	0	0	0	0	0
Punanrnava	0	0	0	0	0	0	0	0
Prickly malvastrum	2.77	3.31	0	0	0	0	0	0
Rattlepods	0.92	0	0	0	0	0	0	0
East Indian globe thistle	3.69	0	0	0	0	0	0	0
Pepper cress	7.38	0	0	0	0	0	0	0
Pennywort	4.62	0	0	0	0	0	0	0
Goatweed	16.62	1.11	1.62	3.52	3.52	0	10.62	16.21
Coat buttons	9.23	0.55	0.49	0	0	0	0	0
Wild lettuce	10.15	1.41	0	1.42	1.42	0	5.05	3.11
Scotch thistle	4.62	0	0	0	0	0	0	0
Galant soldier	0	13.22	28.90	32.91	32.91	30.83	49.39	21.58
Purslane	0	10.25	14.25	7.19	7.19	0	0	0
Thorn apple	0	0	6.64	9.96	9.96	2.91	5.04	8.84
Mexican marigold	0	0	0.53	0	0	0	0	0
Signal grass	0	0	1.20	0	0	0	0	0

S1= Short rain season; S2= Long rain season; DAP= Days after Planting

Appendix 7: Weed assessment variables under conservation tillage system in 2010 short and 2011 long rains seasons(based on relative abundances of each weed species observed)

Weed species name	Weed relative abundances under Conservation tillage in S1				Weed relative abundances under Conservation tillage in S2			
	Before land prep.	14DAP	28DAP	42DA P	Before land prep.	14DA P	28DA P	42DAP
Purple nutsedge	22.05	17.97	3.81	32.58	3.17	20.03	22.91	22.05
Couch grass	2.88	0.85	0.73	6.46	60.57	3.95	4.16	2.88
Egyptian crowfoot	3.00	0	0	0	2.85	0.59	0.54	3.00
Cogon grass	0	0	0	0	1.14	0	0	0
Crowfoot grass	0	0	0	0	2.85	0	0	0
Sticky bristle grass	3.33	1.54	1.45	4.48	0.57	4.44	2.30	3.33
Hairy crabgrass	13.26	1.60	3.06	4.80	18.81	2.25	9.91	13.26
Abyssinian finger grass	0	2.54	1.66	2.51	4.56	0	0	0
Marsh grass	46.48	5.37	0	4.84	0	54.00	56.39	46.48
Blackjack	60.51	80.82	99.19	45.22	16.65	41.60	43.26	60.51
Cosmos	3.47	0.79	2.11	1.43	0	1.21	0.52	3.47
Painted euphorbia	21.00	56.32	46.18	22.99	0.57	32.89	41.08	21.00
Hairy spurge	5.44	4.65	2.12	5.79	13.73	5.75	6.34	5.44
Red amaranth	0	0	3.45	2.13	0.57	0	0	0
Thorny amaranth	3.39	1.45	1.38	0.62	3.99	1.19	3.10	3.39
Slender amaranth	0.49	0	2.85	0.69	2.28	1.19	3.72	0.49
Thunberg's amaranth	0	0	0	0	0	3.40	0	0
Wandering jew	27.63	38.77	12.73	30.84	3.42	19.31	30.09	27.63
Tropical richardia	3.06	6.24	6.44	7.05	6.86	3.40	8.41	3.06
Flax-leaf fleabane	1.01	0	0	0	28.72	6.28	2.57	1.01
Sow thistle	0.48	0	0	0	2.86	1.69	0.55	0.48
Red garden sorrel	8.04	16.14	12.48	7.41	3.99	12.14	8.15	8.04
Creeping sorrel	0	0	0	0	0.57	0	0	0
Wild jute	0	0	0	0	0.57	0	0	0
Cattle bush	0	0	0.71	10.43	3.99	0	0	0
Apple of Peru	2.89	0	6.97	0	1.14	2.26	1.03	2.89
Natal red-top	0	0	0	0	2.85	0	0	0
Mexican poppy	0	12.37	6.33	32.38	5.13	0	0	0
Lantana	0	0	0	0	1.71	0	0	0
Puncture vine	7.44	9.06	4.21	3.91	0.57	17.52	6.86	7.44

African turnip weed	3.39	2.97	7.82	3.33	1.14	4.22	2.22	3.39
Creeping indigo	0	0	0	0	2.28	0	0	0
Punanrnava	0	0	0	0	2.28	0	0	0
Prickly malvastrum	0	0	0	0	0.57	0	0	0
Pepper cress	0	0	0	0	4.56	0	0	0
Pennywort	0	0	0	0	6.27	0	0	0
Goatweed	4.53	0	13.49	16.22	10.88	1.29	1.13	4.53
Coat buttons	0	0	0	0	4.00	1.30	0.52	0
Wild lettuce	2.41	0	5.03	0	6.84	2.24	1.03	2.41
Scotch thistle	0	0	0	0	3.42	0	0	0
Galant soldier	34.24	35.07	52.12	18.93	0	25.09	28.56	34.24
Purslane	12.11	0	0	0	0	15.63	8.46	12.11
Thorn apple	6.98	5.48	3.68	6.32	0	15.22	6.20	6.98

S1= Short rain season; S2= Long rain season; DAP= Days after Planting