AGRONOMIC PERFORMANCE OF MAIZE (*Zea mays* L.) UNDER DIFFERENT WEED MANAGEMENT REGIMES

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Assessment of the agronomic performance of maize (*Zea mays* L.) under different weed management regimes

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DECLARATION

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

Signature: ………………………………… Date: ……………………………..

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

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DEDICATION

This work is dedicated to my husband, Alex, children Florence and Ashbel, nephew Eric and mother, Priscilla, who helped me greatly through moral support and encouragement to complete the study. God bless them abundantly.

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LIST OF ABBREVIATIONS/ACRONYMS

JKUAT	Jomo Kenyatta University of Agriculture and Technology
ANOVA	Analysis of Variance
DAP	Days After Planting
RCBD	Randomized Complete Block Design
WCE	Weed Control Efficiency
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
IITA	International Institute for Tropical Agriculture
VASAT	Virtual Academy for the Semi Arid Tropics
FAR	Foundation for Arable Research
2, 4-D	2, 4-D-Dichlorophenyl acetic acid
MCPA	2-Methyl-4- Chlorophenoxyacetic Acid
IWM	Integrated Weed Management
DWC	Dry weight of weeds from control plot
DWT	Dry weight of weeds from treated plot
RD	Research field dry season
RW	Research field wet season
MD	Maize field dry season
MW	Maize field wet season
VD	Vegetable field dry season
VW	Vegetable field wet season
ARD	Average relative density
ARA	Average relative abundance

ARF	Average relative frequency

ABSTRACT

Weed management constitutes a major operation and cost in maize production. Three field experiments were conducted in the arable cropping fields of Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja, Kenya from August 2015 to August 2016 to assess the composition and diversity of weed plants, determine the effect of different weed management practices on weed growth and agronomic performance of maize, and identify the most cost effective weed management option in arable cropping fields. In order to assess the composition and diversity of weed plants, weeds were sampled for two seasons during the fallow phase from three arable cropping fields each measuring about 4 ha and having different cropping histories. Each field was stratified into equal sized plots from which 3 plots were surveyed for weeds using 5 randomly distributed quadrats measuring 0.5m x 0.5m. All weeds within each quadrat were counted and segregated into different species. Weed plants composition was determined by relative abundance, relative density and relative frequency between fields. A total of 28 weed plant species representing 11 families were recorded. Broad leaved weeds (18) were more abundant than grasses (8) and sedges (2).Shannon index for weed diversity was higher in crop research field(Wet season 2.427; Dry season 2.524) compared to maize (Wet season 2.381; Dry season 2.118)and vegetable fields (Wet season 2.05; Dry season 1.862).Wet season increased species richness than dry season by 20% in Crop research field, 36% in Maize field and 21% in Vegetable field. Kruskal-wallis H test results indicate that there was no significant effect of arable cropping system on mean abundance of weeds, H (2) = 2.263, P= 0.322. However, there was high significant effect of season on weed mean abundances, H (1) = 14.173, P= 0.000. To determine the effect of different weed management treatments on weed growth and agronomic performance of maize and to identify the most cost effective weed management option, twelve weed management treatments involving a combination of hand weeding, pre-emergence and/or post-emergence herbicides were applied at 1, 25 and 50 days after planting (DAP); including a weedy check. Treatments were laid out in a RCBD and replicated thrice. Data on dry matter of weeds from different plots was used to calculate weed control efficiency (WCE) and data on maize grain, stover yield, cost of inputs and sale income used to perform gross margin analysis. Results indicated no significant difference for agronomic traits in 2015 growth season. In the 2016 season however, weed density, weed dry weight, cob length and kernels/row were significantly different among treatments. T1 (weedy check) recorded the highest weed density (193.33 g/m^2) and T12 (post emergence herbicide at 25 and 50 DAP) the least (6.4 g/m^2). Thus, the lowest and highest WCE were recorded in T1 (0%) and T12 (98.1%), respectively. Combined analysis indicated significant seasonal effect for all agronomic traits studied except number of kernels/ row and 100 kernels weight. T6 (hand weeding and post emergence herbicide application at 25 and 50 DAP respectively) produced the highest grain yield (3373Kg/ha) and T1 the least (2394 Kg/ha). The 2016 season gave higher mean values than 2015 for traits studied. On both grain and stover yield, T10 (post-emergence herbicide application at 25 DAP) had highest gross margin (Ksh124, 407) (1244.07 US$) and T5 (two hand weedings at 25 and 50 DAP) lowest (Ksh64, 837.60) (648.4 US$). The results further showed that T6was the most effective weed management option while T10 was the most cost effective treatment.T10 gave the highest gross margin and achieved fairly good grain and Stover yield. Therefore, on the basis of this study T10 may be used by the smallholder farmers for controlling weeds in maize with fairly good yield and economic returns.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Maize accounts for about 50-60% of Kenya's cereal production, and is a major staple food to a large proportion of the population (Onono *et al.,* 2013; Ranum et *al.,* 2014). The crop is produced under diverse environmental conditions (Arif *et al.,* 2012). According to the country's Ministry of Agriculture (2013), the crop's production and productivity is constrained by several biotic and abiotic factors in addition to poor crop management practices. Further, studies by Sulewska *et al.,* (2012); Ndwiga *et al.,* (2013) and Saudy (2013) show that, poor crop management practices notably inadequate weed control, especially at initial crop growth stage, results in drastic reduction of maize yield in the range of 50- 90%. Weeds reduce maize yields by competing for light, nutrients, water and carbon dioxide and consequently interfere with the normal growth of crops. Larbi *et al.,* (2013) reported that weed interference not only results in crop losses but also increases insect pest damage, harvesting difficulties, crop contamination and increase the cost of crop production. Economic damage to crop production from weeds outweighs the more incidental damage inflicted by other biotic factors such as insect pests, rodents and diseases. According to Tesfay *et al.,* (2014), weeds impose a yield loss potential of 37%, which is higher than that due to insect pests (18%), fungal and bacterial pathogens (16%) and viruses (2%).

The common weed species of maize fields in Kenya are *striga sp*. which is a parasitic weed in western parts of Kenya (Ndwiga*et al.,* 2013; Kamara, 2013), *Amaranthus sp* (pig weed), *Bidens pilosa* (black jack), *Galinsoga parviflora* (gallant soldier), *Setaria verticillata* (love grass), *Commelina benghalensis* (wondering jew), *Oxalis latifolia* (oxalis), *Cyperus esculentus* (nut grass) and *Sorghum bicolor* (johnsons grass). The types, numbers and frequencies of weed species infesting maize fields are determined by different soil characteristics, climatic conditions and cultural practices across the country and thus influence the diversity and predominant weeds in different arable fields (Aluko *et al.,* 2015). According to Gianessi and

Williams, (2011) weeds grow vigorously and their nutrient requirements are often greater than that of the crop plants. Broadleaved weeds and grasses dominate the weed spectrum, whereas sedges are minor.

Several weed management measures are available for use by maize farmers. They include physical (hand and mechanical removal), cultural such as crop rotation, sowing period, cover cropping, mulching, crop competition, flooding, cleaning of harvesting equipment and machinery; and chemical measures either singly or in various combinations. According to investigations carried out by Gianessi (2009) and Abouziena *et al.*, (2013), hand weeding when done on time, and for 2 to 3 times, is the most effective method of controlling weeds in maize fields. However, hand weeding is time-consuming and labourious. Moreover, manual labour may not be readily available when needed, especially during peak weeding periods. In most cases, the farmers end up weeding their crops late. According to Micheni *et al.*, (2014), shortage of labour early in the season results in delayed weeding and subsequent yield losses of 15–90% due to weed competition. This implies that the use of herbicides is going to be increasingly important in the country.

According to Zaremohazabieh and Ghadiri (2011); Wilson and Sbatella (2014); Hossain (2015) reports, herbicide application is an efficient way of checking weed infestation in crop fields since it is less expensive than hand weeding. Further, Micheni *et al.*, (2014) showed that herbicides were more effective in controlling weeds than hand weeding. Determination of the most efficient and cost effective weed management option from a combination of hand weeding and herbicides would be desirable to realize sustainable maize production among the smallholder farmers.

1.2 Statement of the problem

Weeds constitute an essential component of the pest complex in Kenyan arable cropping fields, and hence are an important biotic constraint on maize production (Ndam *et al.*, 2014).Weeds compete with maize for essential resources and act as alternate hosts of other pests and pathogens therefore, lower production (Ndam *et al.*,2014). Weeds are also destructive as a result of their allelopathic and persistent attributes (Zaman *et al.*, 2011). Thus, weeds infestation increases the cost of production and reduces the market value of crops (Larbi *et al.,* 2013; Nyamwamu, *et al.*, 2017). Losses caused by weeds exceed the losses from any other category of biotic factors (Habimana *et al*., 2014). However, information on weed diversity in arable cropping fields is limited (Mwangi, 2016). Therefore, this study will investigate the composition and variation of weed plants in arable cropping fields.

Maize production is constrained among other factors by poor crop management, particularly insufficient weed control (Shaba *et al.,* 2015). Weeds which emerge during the first 50 days after planting are known to endanger yields more than those appearing later (Iyagba, 2010). Weed competition in maize leads to 25 to 80% decline in yield (Nyaga, 2012; Sulewska *et al.,* 2012). Therefore, inadequate weed control presents a major management problem in maize farmers' fields. Farmers control weeds by physical (manual and mechanical), cultural, and chemical measures either singly or in combination (Varga *et al.*, 2011).Traditionally, hand weeding was the most common weed control practice in smallholder farm (Varga *et al.,* 2011). It was cheap, readily available and reliable. However, a large number of hours (300-400 hours per hectare) of hand weeding are undertaken. Hand weeding alone accounts for 40-54% of the total labour input in maize farming (Gianessi and Williams, 2011). Manual labour (hand weeding) may not be available when needed especially during peak weeding periods. In most cases, maize farmers are unable to do their weeding on time due to limitations on family labour. Therefore, hand weeding, in Kenya, is no longer easily available and reliable and is getting expensive (Tesfay and Mulugeta, 2014) due to rural-urban migration; small family size and increased educational opportunities of the young adults aged 18-34 years, who are about 25% of the population (Hossain, 2015). Limitations on family labour results in delayed weeding and increased duration for weed crop competition therefore, loss of the maize yields (Mwangi, 2016). Thus, it will not be promising and cost-effective to continue using hand weeding for Kenyan agriculture. Herbicide application has been proposed as an efficient and economical option of checking weed infestation on smallholder farmers' maize fields since it is less expensive than the hiring of labour for hand weeding (Micheni *et al.,* 2014). According to Nadeem *et al.*, (2010), herbicide application can improve weed control efficiency and increase maize yield by 77 to 96 % than the weedy check. However, there is limited information on how the recommended herbicides could be utilized either singly or in combination for management of weeds in maize fields in Kenya.

1.3 Justification of the study

Decline in maize yield due to poor weed management methods translates into hunger and reduction of the farmers' incomes. This has adverse effects on a country's development budget because money needed for development may have to be used for importation of maize to supplement local deficit. Many studies investigated the effects of chemical and hand weeding methods on weed control and grain yield in maize. Dass*et al.*, 2012; Shaba *et al.*,2015; Mwangi, 2016; Mohamed *et al.*, 2020 observed that timely and efficient weeding in maize production are particularly essential during the first 25 to 50 days after planting if maximum weed control and increased yield at reduced cost are to be achieved. Weed competition between the first 10 to 30-40 days from planting time can reduce maize yields by 70% to total crop failure when farmers fail to weed at optimal times (Anorvey, 2011; Gomaa *et al.*, 2011; FAR, 2013). Due to inability to control weeds through hand weeding, because of unavailability of good quality and quantity of manual labour on time and the high cost involved, hand weeding is no longer considered sustainable for Kenyan agriculture. Chemical weed control is an important option that needs to be investigated. According to Kamara, (2013), careful use of herbicides in maize is believed to be a better option to hand weeding since it is cheaper, faster, efficient and cost effective. Selective herbicide products that have been used do not have any phytotocixity on the crop and do not cause adverse effects on human health and livestock. Recently, the wide-spread use of herbicides has made a significant contribution to the green revolution in agriculture (Ali *et al.*, 2012).

Understanding weed plants present in a crop field is important in that it affects timing of herbicide application, best herbicide selection and the effective weed management strategy (Nkoa *et al*., 2015; Christy, 2017; Nyamwamu *et al.*, 2019). Therefore, there is need to investigate weed plants composition and variation in arable cropping fields and evaluate weed management options in order to determine the most efficient, cost effective and more pleasing method to smallholder maize farmers in order to cater for their needs, the community and nation at large thus, increasing food security in Kenya (Colglazier, 2015).

1.4 Objectives of the study

The main objective of the study was to determine the most efficient and cost effective method of managing weeds in maize production amongst the practices used by farmers. The specific objectives of the study were;

1. To investigate the composition and variation of weed plants in arable cropping system crop fields in Juja,

2. To assess the effect of different weed management practices on weed growth and agronomic performance of maize in an arable cropping system,

3. To determine cost effectiveness (economic benefits) of different weed management regimes in maize fields.

1.5 Test hypotheses

1. Weed plants abundance is not variable between arable cropping system crop fields in Juja.

2. Different weed management practices have no effect on weed growth and agronomic performance of maize in an arable cropping system.

3. Different weed management regimes in maize fields are not cost effective.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of maize

Maize is an old-established cultivated plant in America in Columbus' time. The origin of maize plant is not clear because it does not occur in the wild form, although in Mexico a closely related grass, teosinite (*Euchlena mexicana*) grows, which hybridizes freely with *Zea* (Ranum *et al.,* 2014). So, it has been suggested that modern maize is either of hybrid origin or a derivative of teosinte. Maize pollen has been identified in excavations in Mexico City dating back some 80 000 years. Mexico or Central America is believed to be the earliest centre of cultivation of maize (Jhala *et al.*, 2014; Nyaga, 2012). Initially maize was a very much smaller plant closer to teosinte than it is today (Appah, 2012). The spread of maize from its center of origin in Mexico to various parts of the world has been remarkable and rapid with respect to its evolution as a cultivated plant and as a variety of food products. The inhabitants of several indigenous tribes in Central America and Mexico brought the plant to other regions of Latin America, the Caribbean, and then to the United States and Canada. European explorers took maize to Europe and later traders took maize to Asia and Africa in the 16th century (Ranum *et al.,* 2014). Maize was reported for the first time in West Africa in 1498, six years after Columbus discovered the West Indies. United States of America is currently the largest producer of maize followed by China, Brazil, Russia and Europe (FAOSTAT, 2011). Africa is a minor producer of maize accounting for only 7% of global maize production and the largest African producer is Nigeria followed by South Africa (IITA, 2009).

2.2 Uses of maize

Maize is a multipurpose crop used as human food, animals and poultry feed (Anorvey, 2011). It also produces raw materials for starch industry and other products (Ali *et al.,* 2012; Shaba *et al.,* 2015). Economically the most important product of maize is the grain. The grain endosperm is starchy and is a valuable source of starch (71.8%) and oil (4.5%) (Anees *et al.*, 2008), carbohydrate, protein

(10.4%), fiber (3%), moisture (11%), iron, vitamin B, and minerals like Calcium, Phosphorous, Sulphur and small amounts of sodium (Hamayun, 2003; Ranum *et al.*, 2014). Maize-based products are used in a wide range of foods. Africans consume maize as a starchy base in a wide variety of porridges commonly eaten as a breakfast meal and weaning food for children. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled (Anorvey, 2011). Corn flour is a source of starch, syrup and glucose. Maize grains are fermented to produce alcohol. Corn oil is rich in essential fatty acids and is used widely as a salad and cooking oil (Smale *et al*., 2011). Grains and by-products from processing of maize are used as animal feedstuff. Maize can also be grown as a forage crop. Fodder maize is cut at an immature reproductive stage and is either fed to animals in the fresh state or after being ensiled as silage (Nyaga, 2012). It can also be cut at maturity stage as stover or conserved as standing forage for dry season livestock feeding. Responding to its multiple uses, the demand for maize is constantly increasing in the global market (Anees *et al.,* 2008).

2.3 The Biology of maize (*Zea mays* L.) plant/ Physiology of Maize

Maize (*Zea mays* L.) is a tall annual grass belonging to the family Gramineae (Mwangi, 2016) and small highly specialized tribe called the Maydeae. Maize plant is a stout, thick, solid, single stem that is supported by prop roots. The vegetative growth parameters are the roots, stem and leaves. Maize has shallow roots and therefore susceptible to low soil moisture content. Adequate nutrition and soil moisture are crucial at the critical stages of growth for maximum yield and quality (Maqsood *et al*., 2012; Hussain *et al*., 2015). Weed competition in these stages affect maize with severe consequences when soil moisture is inadequate (Abdin *et al*., 2000). Its leaves are large, broad and smooth with a conspicuous midrib. A single leaf extends from nodes at an alternating pattern. Maize shows a wide range of variation, from early dwarf forms of 1.5 m high with about twelve leaves on the main shoot and maturing in about 90 days, to forms 4 m high with about 25 leaves and a growing season of 190 days depending on the genotype and the climate (Khan *et al.*, 2012). The first 5-7 leaves drop off at an early stage while last leaves emerge shortly before tasseling. Maize shows vigorous growth and high yields which are attributed to the C_4 pathway of photosynthesis of the plant (Abouziena *et al.*, 2013; Mwangi, 2016). Maize is a monoecious plant bearing separate male and female inflorescences on the same plant. According to Khan *et al.*, 2012, the terminal panicle bears only male flowers that are known as the tassel. The panicle branches are long and bear closely- spaced short-stalked pairs of spikelets. Each spikelet consists of a pair of glumes enclosing two male florets, each with lemma and palea, loducules and three stamens (anthers) that are yellow, green or purple. The male florets open widely to shed mature pollen that is cross pollinated by wind to the female inflorescences, the ear (cob). The ear occurs in the axil of some leaves in the mid region of the stem. The cob is tightly packed with modified bladeless leaves forming the husk that serves to protect the female inflorescence. The styles are greatly conspicuous because of their great length. They extend from each ovary to above the top of the cob from which they protrude as bundle of threads called the silk (Belfield & Brown, 2008).

Pollen grains settle on the stigmatic surfaces of the silks. On fertilization grains develop. Cobs mature inside the husks, thus there is no seed dispersal unlike other grasses. This explains the fact that maize is not known as a wild plant. At physiological maturity, the husks dry and become papery. A mature cob exposes rows of naked caryopsis (Belfield & Brown, 2008). Ear size varies; with an even number of rows 8 to 28 (commonly 12-18) rows of grains on the cob, about 20 -70 grains in each row up the length of the cob. The grains are regularly arranged in an even number of rows. Maize grain is a kernel of hard and one-sided fruit called a caryopsis. The caryopsis is usually large from about 8-18 mm long. The kernel consists of pericarp, endosperm and embryo. The pericarp is a protective outer layer derived from maternal tissue while endosperm constitutes the major portion of the kernel which serves as energy reserve for the growing seedling. It is composed of about 88% starch and 8% protein. As soon as the seed imbibes water, the aleurone layer releases enzymes which digest the endosperm starch into sugar thereby providing energy for seedling growth. Embryo forms the radical and plumule, the radical develops into roots while the plumule grows to form the vegetative part (Appah, 2012).

2.4 Types of maize

Maize kernels can be different colors ranging from white to yellow to red to black. Most of the maize grown in the United States is yellow, whereas people in Africa, Central America, and the southern United States prefer white maize (Ranum *et al.,* 2014). The structure and composition of the endosperm varies in different forms of maize grains hence different kernel (seeds) types of have been developed by the plant breeders. Different types of kernels include dent, flint, waxy, flour, sweet, pop and Indian corn. According to Ranum *et al.,* 2014, Flint corn has a hard endosperm and little shrinkage at maturity. The grain is rounded and opalescent in appearance. Dent corn has similar characteristics as flint corn but has an indented shape. Flint and dent corns store well and are the most important types grown for grain. Flour corn endosperm is soft and floury. Waxy corn produces a waxy endosperm which on milling gives a flour resembling tapioca that is normally obtained from the roots of cassava. The whole of the starch consists of amylopectin that can be milled to give a starch forming stable jel, used in preparation of some processed foods and manufacture of a tapioca substitute. Pop corn has small, pointed grains whose hard endosperm expands rapidly on heating, making the grain to burst open turning the endosperm inside out to give a product which is eaten whole, without milling. Sweet corn is grown as a vegetable in its immature stage. The endosperm of this corn is improved to be soft and sugary for sometime enabling the crop to be harvested and sold before starch is formed. The mature grain is shriveled in appearance hence, can only be used as a seed (Jhala *et al.,* 2014).

2.5 Ecological requirements of maize

Maize needs a regular supply of water and suffers badly in times of drought. It requires rainfall of about 600-1,200mm per annum and this must be well distributed throughout the year (Belfield & Brown, 2008). During the silk appearance and pollen shedding growth stage, demand for nutrients and water is high. Availability of soil moisture at the time of tasseling is essential for the production of high yield (Anorvey, 2011). Maize is very high yielding and well adapted to grow in warm climates. Maize is not adapted to the cooler parts of the temperate zone. Germination occurs within 4-6 days after planting when the soil temperature is (10 -20)^{0}C.

Seedling growth below 13^0C is very slow (Anorvey, 2011). After seedling emergence, high soil and air temperatures accelerate leaf initiation. It has C_4 metabolic pathway and is photosynthetically highly efficient in conditions of high temperature and high light intensity (Belfield and Brown, 2008). If conditions are unfavourable, the grains towards the apex of the cob remain undeveloped. In temperate regions it can only be grown as a forage crop since grains will not form (Anorvey, 2011). Maize requires an average temperature of 13-40°C and does not grow at higher temperatures. The optimum temperature for maize growth ranges from 18-32°C (Belfield and Brown, 2008). The aspect of light that influences maize growth substantially is the amount of light (intensity) received during the growth period. No other crop utilizes sunlight more effectively than maize, and its yield per ha is the highest of all grain crops. Maize requires a lot of clear sunshine. Maize can be grown without additional irrigation in areas receiving about 600 mm of well distributed rainfall. Maize grows best in well drained, well-aerated, deep loams or silty loams with high to moderate organic matter and nutrient content. The crop is susceptible to water-logging (Anorvey, 2011). Soil pHranging between 6.5 and 7.5 is best for maize production (Belfield and Brown, 2008).

2.6 Sowing of Maize

Maize seeds are sown at stake usually in rows for maximum plant population density. The inter-rows range from 70-90 cm apart while intra-rows range 23-30cm depending on the variety and seed rate. The seeds are sown at 2 seeds per hill but it could be sown up to 3 or 4 and later thinned to 2 seedlings per hill. The population then varies from 15,000 to 90,000 plants/ha (Appah, 2012). Sowing can be done with a planter, machete or dibber. To obtain uniform germination, sowing depth of maize varies from 5 to 10 cm, depending on the soil type and the moisture content in the soil.

2.7 Maize yield loss due to weed infestation

Worldwide maize production is hampered up to 40% by competition from weeds which are the most important pest group of this crop (Tesfay *et al.*, 2014). Maize and weeds interaction sets an environment of direct competition for limited plant growth resources (Nyaga, 2012). However, weed plants are capable of heavy nutrient absorption and accumulation thereby, reducing the expected yield and quality of maize crop. The effect of the competition depends on crop growth stage, weed species present, weed abundance, nutrition and water status of the soil. Naher, *et al.,* (2020) observed that a wide range of weed plants invade maize crop. The taller and more numerous the weed plants are in relation to the crop, the stronger is the competition. Furthermore, high weed incidence smothers maize plants at an early delicate stage of growth and development. Likewise, Shrestha1 *et al.,* (2019) found that third to sixth week after emergence of maize, the growth period is very sensitive to weed infestation due to narrower canopy which could not suppress excessive weed growth. If at early growth stages maize plants fail to get optimal levels of nutrients and water, the rate of photosynthesis and accumulation of carbohydrates slows down thus, the plants remain stunted and unproductive (Munialo, 2020).Abouziena, (2013) weed competition caused a significant reduction in the value of plant height, cob length, kernels per row, kernel weight and, consequently, stover and grain weight per unit area.

According to Munialo (2020), weed plants affect maize crop indirectly thereby, reducing the anticipated yield and quality of maize crop. Delayed weeding results in weed overgrowth which makes weeding more difficult and more often, weed plants resist the action of herbicides. Some weeds are alternate hosts to maize plants pests and diseases. Therefore, heavy weed infestation increases incidences of pests and diseases in maize plantations which lower maize production. Some weeds produce allelopathic chemicals and due to weeds genetic diversity and ability to adapt they take advantage of conditions created by crop production systems. Therefore, timing weed control in maize fields constitutes a major factor in determining grain and stover yield (Beckert *et al.,* 2011). According to Tesfay *et al.,* (2014), early weed control practices in maize resulted in 77 to 96.7% higher grain and stover yield than no weeding. Due to scarcity, higher time consumption and higher labour cost for hand weeding, chemical methods have come in common practice as easier, economic and effective method of weed control at present situation (Shrestha1 *et al.,* 2019).

2.8 Weed management options in maize production

For long term management weeds should be controlled as early as possible and before they produce seeds. The main weed management methods can be classified into various categories including preventative control, physical (manual cultivations and mechanized cultivation), cultural methods, biological control, use of herbicides and Integrated Weed Management (IWM) (Nyaga, 2012; Shaba *et al.,* 2015).None of the weed control methods alone is suitable under all conditions (Shrestha1 *et al.*, 2019).

Preventive control

According to FAR, (2013), weeds must be prevented from entering a field and should not be allowed to increase in population. Preventive control of weeds includes all actions taken to prevent the introduction of new or additional weed populations, reducing the overall emergence and propagation of weeds in the field and spread of unwanted plants (Palou *et al.,* 2008; Sims *et al*., 2018).The success of a preventive program varies according to the weed species, the amount and the persistence of the effort that it dedicates to prevention (Shrestha1 *et al.*, 2019). Preventive control is achieved through use of weed free seeds, use of well decomposed organic manure, cleaning of all the farm implements and machinery properly after their use in infested areas and before using in clean areas, keeping farm fences, roads and bunds free from weeds, preventing weeds from producing seeds, prohibiting domestic animals from transferring weed seeds to clean fields, killing the weeds on irrigation and drainage channels, avoidance of use of sand or soil from weed infested area amongst others (Shrestha1 *et al.*, 2019). To prevent serious invasion and establishment of perennial weeds and sedges, early suitable methods of control must be employed. Prevention methods are more efficient and cost-effective to save the crop and yield from weed infestation. Some safe measures like soil solarization (Candidoa *et al.*, 2011), stale seed bed technique and robotic system (Perez-Ruiz *et al.,* 2012) could be used as more effective methods for prevention of weed infestation in maize crop.

Manual cultivation

Manual cultivation makes use of simple hand tools to physically eradicate weeds. It entails deep, dry-season cultivations through hand digging (hand weeding), hand pulling and cutting. Hand pulling, cutting, slashing and mowing play a role in minimum (conservation) tillage to prevent soil erosion. Manual weeding is the predominant method of weed control used by smallholder farms (Damian, 2011). Abouziena *et al.,* (2013) reported that hand weeding works best when done 2 to 3 times before the crop matures. It gives the best control of weed plants and increases maize yield up to 74.5 %. However, high labour cost, time-consumption, hard to operate in tough soil conditions and high cost involved are some disadvantages of using hand weeding (Saudy, 2013). Family labour may not also be available when needed especially during peak weeding periods due to small family size and youth migration to urban areas (Hossain, 2015; Gianessi and Williams, 2011). The scarcity of labour at the peak time and the concurrent rise in the cost of labour makes timely removal of weeds by hand weeding difficult and uneconomical (Abouziena *et al.,* 2013).

Mechanized cultivation

Mechanized cultivation involves ploughing and harrowing. Ploughing makes use of tractor- mounted ploughs for cultivation which include disc and mouldboard ploughs. Ploughing burries weed plants and many weed seeds, beneath an inverted furrow however, it also brings other seeds back to the surface, where they can germinate (FAR, 2013). Therefore, repeated ploughing only changes the weed population, but does not control weeds in the long term (Sims *et al*., 2018).It should be done as soon as possible after the previous crop has been harvested. Harrowing makes use of harrows and should follow shortly before planting to get a weed-free seedbed of good tilth. Maize farmers can use the inter-row weeders to manage weeds up until the maize crop is one meter high (Jhala *et al.,* 2014).

Mechanized cultivation is usually ineffective against rhizomes, stolons, tubers and bulbs. Machinery can only be used to expose these propagules to extended periods of sun heat for desiccation. According to Jemison, (2007), machineries are faster, but on the other hand they are expensive and unavailable for the poor small-scale farmers. High costs of farm machineries have affected the quality and timeliness of farm operations such as the land preparation in the key maize production zones. This has forced farmers to reduce the quality of seedbed preparation which has adversely affected maize yields and hence cause an increase in production costs per unit production.

Cultural practices

Cultural practices are farming practices, also known as indirect control measures that involve agronomic practices (Sampaio *et al.,* 2015). Such practices include; choice of cultivar, crop rotation, sowing period, cover cropping, mulching, crop, flooding, destruction or burning of freshly shed viable weed seeds and nutrient management, among other practices designed to promote the competitive ability of crops (Sanyal *et al.,* 2008; Nyaga, 2012). A diverse crop rotation is one of the most effective practices in the management of weed density (Melander, 2008). Weed species are typically associated with crops, and crop rotations determine the specific weed population over time (Jemison, 2007). Other weed species resemble the main crop, For example, Johnson's grass (*Sorghum bicolor*) almost resembles maize plant when it is young. So, crop rotation with broad-leafed crops like groundnuts may help to identify and destroy the weeds. However, various research reports suggest that none of the currently available cultural techniques provide an adequate level of weed control when used alone (Jhala *et al.,* 2014). Therefore, they should be used in carefully planned combinations as they are extremely effective control measures of controlling weeds (Jemison, 2007).

Biological weed control

Biological weed control exploits ecological relationships, using herbivory (insects or grazing animals) and disease-host relationships to limit weed growth. Biological weed control takes three main forms including conservation, inoculation and inundation. Conservation biocontrol conserves habitat for beneficial organisms including those that damage weeds. Inoculation biocontrol involves introduction of a relatively small number of beneficial organisms to damage a target weed species.

Inundation biocontrol introduces large numbers of beneficial organisms with the goal of quick control (Dedecker, 2012).

Direct application of biological weed control methods is complex and risky. This requires that potential biological control agents to be thoroughly evaluated prior to introduction to minimize bad impacts on non-target species. Also, field efficacy of biological weed control is often partial and hence adoption of biocontrol remains limited even when biocontrol agents targeting weed species have proven effective in trials. Therefore, this makes biological weed control simply to be rejected by the farmers (Lamine, 2011; Puente *et al.,* 2011).

Chemical method

Chemical method involves the use of selective herbicides in crop production to control, suppress or kill weeds by interrupting normal plant growth processes without affecting the crop (Beckert *et al.,* 2011). With rising costs and scarcity of labour for hand weeding, farmers are largely adopting use of herbicides although its full potential has not been realized. Chemical method of weeding is very easy, flexible and cheaper than using tedious, time- consuming and costly labour for hand weeding (Shrestha1 *et al.,* 2019).Herbicides contribute effectively and profitably to weed control in saving labour and labour cost necessary for weed control practices (Anees *et al.,* 2008). It has also played a role in environmental protection, reduced soil erosion, saved energy and increased maize production. Zvonko, (2007) reported that use of herbicides for weed control reduces hand weeding labour requirements for maize production which has become scarce and expensive in many parts of the world. Herbicides also reduce seasonal variation in labour and the total labour needed for hand weeding. According to Zaremohazabieh and Ghadiri, (2011) study, all herbicides treatments improved maize grain yields compared to the weedy check. Maize yields in the weedy checks were reduced by approximately 77%. According to FAR, (2013) results showed that grain yields for the non-herbicide treatment averaged 39 % of the yields.

Herbicides are classified based on the mode of action, placement method, time of application or the type of vegetation controlled (selectivity) (Ferguson, 2008;

Nadeem *et al.,* 2010). According to Christy, (2017), chemical control of weeds can be obtained with either selective, non-selective, contact, systemic, pre-emergemence or post-emergemence herbicides applications. Selective herbicide kills some plant species, but does not damage others. For example, atrazine and alachlor are used for control of annual weeds in maize. Also 2, 4-D plus MCPA are applied as post-emergence for controlling broadleaved weeds in maize (Zaremohazabieh and Ghadiri, 2011). Nonselective herbicide generally kills all plant species hence also referred to as broad spectrum herbicide. They must be applied in absence of desirable plants. Non-selective herbicides such as glyphosate (Round up) or dalapon ensure a clean seedbed free from problematic weeds such as perennial grasses and sedges during planting. Currently foramsulfuron and rimsulfuron are among the newly released broad spectrum sulfonylurea herbicides for weed management in maize (Zaremohazabieh and Ghadiri, 2011). Postemergence herbicides are compounds applied to thefoliage of weeds. They may burn offthe aboveground parts of weeds(contact herbicides) or they may betranslocated throughout the plantsand kill the growing points (systemicherbicides) (Christy, 2017).According to Ferguson, (2008), contact herbicide must be applied directly to weeds since it destroys only the plant tissue touched by the chemical. It causes localized injury to plant tissue. Usually exhibit acute effects and is fast acting. It does not readily translocate therefore, effective for annual weeds. It is usually ineffective for perennials because no translocation to underground reproductive organs. Contact foliage-applied herbicides, such as paraquat (Gramoxone), bromoxynil (Buctril), carfentrazone (Aim), Diquat, and oxyfluorfen (Goal), are usually less affected by drought stress than the translocated herbicides, such as 2,4-D, glyphosate (Roundup, others), dicamba (Banvel, Clarity), clopyralid (Stinger, Lontrel), fluroxypyr (Starane), triclopyr (Garlon), and combinations. Systemic (translocated) herbicide is absorbed and moves throughout the living portion of the weedy plant. It readily translocates in plant tissue and usually is slow acting. Therefore, systemic herbicides are mostly effective on perennial because of translocation to underground organs for example, Roundup. Post-emergence herbicides such as Roundup (Ferguson, 2008) and 2, 4-D Amine are applied to weeds during the growing season (Gianessi & Williams, 2011). Pre-emergence herbicide is applied after planting, but prior to crop and weed emergence to kill the germinating weed seeds from a field (Christy, 2017). Pre-emergence herbicide provides weed control during the critical period for the crop, from emergence to canopy closure (FAR, 2013). Overhead irrigation is required following a pre-emergence herbicide application to move the herbicide into the soil, making it available for absorption by the emerging weeds. The most common combination of pre-emergence herbicides is a mixture of atrazine or terbuthylazine, for broadleaf weed control and chloroacetanilide such as alachlor, metalochlor and acetochlor for the control of grass weeds (Sims *et al.*, (2018). Jemison, (2007) reported that combination of pre-emergence and post-emergence weed management strategy is generally the most expensive weed management program. Nevertheless, a single pre-emergence or post-emergence application program is sufficient. Similarly, Pannacci and Onofri, (2016) reported that early post-emergence treatments should be suggested if the pre-emergence treatments were not carried out. Furthermore, treatments of either pre-emergence or early post-emergence have the advantage of avoiding the competition in the first part of the growth cycle of maize, favouring maize growth and productivity at a reduced cost.

Integrated weed management (IWM)

Integrated weed management (IWM) is a broad term covering many different methods that can be combined and applied in various ways to the growing crop to prevent and manage weed populations (Jhala *et al.,* 2014 and Belfield and Brown 2008). According to the study reported by fact sheet, (Melander, 2008) Integrated weed management (IWM) strategy is practical and reasonably cost-effective. IWM is based on combinations of non-chemical and chemical weed control methods. According to Belfield and Brown (2008), IWM includes combination of any two or more of the various techniques such as diversified cover cropping and crop rotations, inter-row cultivation, pre-emergence application, band-spraying or broad-spraying at reduced doses. Plants (crops) that release chemical substances that suppress weed growth are also used in crop rotation programmes to control weeds through allelopathy (Ndwiga *et al.,* 2013). Eradication of the target weed is not possible by allelopathy as the agent only survives in the presence of the host, but it is possible to achieve stable, low populations after several years. IWM is one of the sustainable forms of weed control and management system that gives durable results as well as conserving the environment too (Harker *et al.,* 2012; Shaner, 2014; Liebman *et al.,* 2016). Sole use of any control method cannot give satisfactory result. So, proper combination of different methods is required for sustainable control and management of weeds and increased crop yield.

CHAPTER THREE

WEED PLANTS COMPOSITION AND VARIATION IN ARABLE CROPPING SYSTEM CROP FIELDS

3.1 Introduction

Weed plants compete with maize crop for essential resources, some release toxins that inhibit crop growth and development (Zaman *et al.,*2011), others harbour insects or diseases that attack maize crop, interfere with harvesting operations, and at times contaminate maize grains with weed seeds or other plant parts (Ndam *et al.,* 2014). Therefore, weeds lower maize production and increase the cost of production (Nyamwamu *et al.,* 2017). Cost-effective crop production depends on effective weed control (Christy, 2017). Dekker, (1997) reported that crops lack diversity and leave unused resources in arable fields. Weeds possess diversity that allows them to exploit these opportunities hence will always succeed. Weed diversity allows for exploitation of new and diverse opportunities as they occur in arable cropping system fields (Nkoa *et al.,* 2015). Therefore, despite centuries of eradication efforts, weed communities remain viable across the arable cropping system fields. According to Wortman *et al.,* (2010), many weed species produce large quantities of viable seeds making them to establish rapidly in the field and therefore, weed management is consistently a top priority among farmers. Use of inefficient and ineffective weed management practices have caused major changes in the composition and weed species diversity in arable cropping fields (Puricelli *et al.,* 2012). In smallholder farms, poor weed control practices have been promoted by shortage of good quality and quantity of labour during the peak weeding seasons (Hossain, 2015). This has motivated some farmers to resort to chemical weed management options.

Often there is a mismatch between weed control measures and the type of weeds actually present in a field which leads to ineffective control and ultimately more cost to the farmer. Understanding whether a weed is an annual or a perennial helps to inform long term weed management strategies (Nyamwamu *et al.,* 2017). Knowing when a weed emerges can affect timing of herbicide application and also the method of weed management. Dhole *et al.,* (2013) in their study, have suggested that understanding weed biology improves the likelihood of good weed control with reduced cost, energy inputs and time. Therefore, to apply the most effective weed management option, farmers must correctly identify and appreciate the economic importance of weeds. Sustainable weed management methods demand that farmers understand weed composition and diversity so that an effective weed management program can be developed to either reduce weed opportunities, or to avoid the economic crop losses resulting from them (Christy, 2017). Information on weed diversity in arable cropping system fields is limited. The objective of this component of the study was to investigate the composition and diversity (variation) of weed plants in arable cropping system fields. Information obtained from the study will guide the farmer in making an informed choice on the best weed management strategy.

3.2 Materials and methods

3.2.1 Study site

The study was conducted in JKUAT farm, where fields that are commonly used for arable crop production are located (Figure 3.1). JKUAT is located in Juja, 36 km North-East of Nairobi along the Thika-Nairobi Highway. According to Kenya Meteorological Department, Nairobi, (2016), Juja lies between latitudes 3° 35" and 1°45" south of the equator and longitudes 36º 35" and 37º 25" East. Juja is located in the upper midland zone 4 which is semi- humid to semi-arid, with an altitude of 1530 meters above sea level with a mean annual temperature of 20ºC and mean maximum temperature of 30ºC. The area receives annual rainfall of 600mm-856mm with a bimodal distribution with peaks in April (long rain season) and November (short rain season).The area has three types of soils which are shallow clay soils over trachytic tuff, very shallow sandy clay soils over murram and deep clay soils (vertisols) (Wanjogu and Kamoni, 1986).

Weed survey study was carried out in three arable cropping fields located in JKUAT farm, namely crop research field (R) (Block A), maize field (M) (Block B) and vegetable field (V) (Block C), based on the preceding crop(s) and crop -specific cultural practices during the fallow phase. Each arable cropping field measured about 4 hectares and varied in weed plants composition and diversity. The crop research field is dominated, with sandy clay loam soil and is grown with different crops, in separate plots for research purposes. These included maize, pawpaw, mango, beans, egg plant, African night shade, Amaranthus species, kales, spinach and flower crop species. Maize field (block B) was grown with maize in a field with sandy clay soil. In the vegetable field, with sandy clay soil, kales and spinach were the common crop plants. All the crops were planted over a period of about three years (six seasons). This is according to the information on cropping history of the fields given by the JKUAT farm manager.

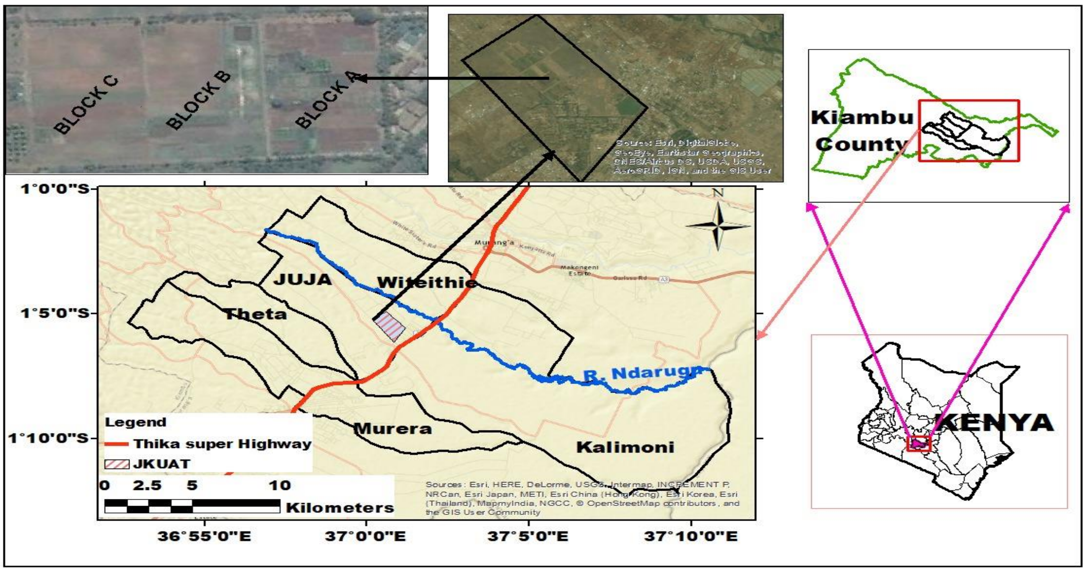

Figure 3.1: Map showing location of the study site

(Source: Authors developed using ArcMap 10.5, and ILRI datasets)

Key: Block A = Crop research field (R), Block B=Maize field (M), Block C=Vegetable field (V)

3.3 Study design

3.3.1.1Sampling and data collection

Stratified random sampling pattern (Cochran, 1977; Nkoa *et al.*, 2015; Assefa, 2019) is a technique in which each arable cropping field was first divided (stratified) into relatively homogeneous, non-overlapping equal sized sub plots called strata, each measuring 20m x 10m. A stratified random sampling procedure was used to select three study plots (strata) randomly after stratifying the field for data collection. Where sub plots were not clear, strata boundaries were created in order to carry out weed survey. Plots near the road and farming structures like screen houses were avoided. In each study plot (stratum), a quadrat measuring 0.5 m x 0.5 m was randomly thrown and all the weed plants present identified to species level, counted and recorded for subsequent data entry and analysis. This was repeated for five times in each study plot to give the abundance or population of plants sampled. An accurate estimate of the whole population was then obtained by combining estimates of individual strata.

Sampling was carried out in two seasons, the dry season during short rain season in the month of December, 2015 and wet season during the long rain season in May, 2016. This sampling time was chosen because most of the weeds were well established. For this study, experience gained from previous studies on weed diversity (Mwangi, 2016; Nyamwamu *et al.*, 2017) was used to identify and classify common weeds. During data collection for unknown weed species, the unfamiliar weeds were given code numbers and collected for further identification using the help of books which contain illustrations and descriptions of East African weeds (Terry and Michieka 1987; Ivens, 1993). Data for the two survey seasons and for each cropping field were summarized using five quantitative measures. These were relative abundance, absolute density, relative density, absolute Frequency and relative frequency which were computed for each weed species using the method of Thomas (1985).

3.3.2 Data analysis

3.3.2.1 Weed plant composition

The total number of individual plants recorded was summed for each quadrat, then for each plot and the whole field to give the abundance or population of plants sampled. Plants were then categorized by their taxonomic families to identify occurrence level of different plant families. According to Nkoa *et al*., (2015), abundance provides quantitative information (number of individuals) of the weed species present in each crop field. It describes the species' success in terms of numbers. There are several different methods of measuring weed plants abundance depending upon the type of species, the habitat (field), the objectives of the study, and the financial status of the research team. Abundance can be described as a measure of the number or frequency of individuals in an area. Therefore, density and frequency are the two simplest and most accepted methods of measuring abundance. Density measures the number of individuals weed species per unit area (weed plants/ m^2), whereas frequency is the proportion of sampling units (quadrats) that contains the species. Thus, relative values of density, abundance and frequency of weed species were computed to determine the composition of weed species in terms of the most dominant, abundant and frequent in the crop research field, maize field and vegetable field during the dry (short rain season) and wet seasons (long rain season)by applying the following formulas (Thomas, 1985; Arpana, 2013; Nyamwamu *et al.*, 2017):

(i) The relative abundance of each weed plant species per block as;
RA = abundance of individual species / abundance of all species *100

(ii) Absolute frequency of weed plant species as;
AF = number of quadrats where a species was observed in a block / total number of quadrats sampled

(iii) Relative frequency: Frequency of a given species divided by the total frequencies of all the sampled species*100

(iv) Absolute density: The total number of individuals tallied for a given species divided by the total area of the measured plots (plants per m^2).

(v) Relative density: Density (plants per m^2) of a given species divided by the total densities of all the sampled species*100

3.2.3.2 Weed plant species diversity

Shannon diversity index (H')

Diversity measures the qualitative while abundance measures the quantitative significance of a weed species in its habitat (Puricelli *et al.,* 2012; Romero *et al.*, 2012). Typical values of Shannon (diversity) index are generally between 1.5 and 3.5 in most ecological studies, and is rarely greater than 4.0 (Nyamwamu *et al.,* 2019).

Higher values of the diversity index obtained imply greater weed species diversity. According to Stirling and Wilsey, (2001) diversity is measured with a standardized index of species abundance (evenness) that is typically on a scale ranging from near 0 to 1 where; zero indicates low evenness and one indicates equal abundance of all species. Evenness provides information on whether a community is dominated by one or more species or whether the species within the community are represented by approximately equal numbers (Booth *et al.,* 2010; Nkoa *et al.,* 2015). Parameters for weed species composition provided a basis for calculating the Shannon-Weaver indices of species diversity (H'), species richness (S) and evenness (E) (Jastrzebska *et al.,* 2013). The following species diversity measures were computed;

(i) Weed plant species richness (S) was derived as the total count of different types of plant species observed in all the quadrats for each study field based on Stirling and Wilsey, (2001) method.

(ii) The weed species diversity characterization was analyzed using the Shannon index combining both species richness and evenness. A Shannon-Weaver index (H') was performed in order to estimate and compare species diversity of the three arable cropping systems; research field, maize field and vegetable field in dry and wet seasons. It was calculated using the following formula,

$H' = -\sum (pi * \ln pi)$, based on Shannon and Weaver, (1963) method

where:

H' = Shannon diversity index;

pi= proportional abundance of the i^{th} species, i.e. proportion of each plant species in the sample.

(iii) Evenness(E)

This was calculated as $E = H' / \ln (S)$, Where:

E= evenness index, H'= diversity index, In= natural logarithm, S= species richness

3.2.3.3 Statistical Analysis

The two-way analysis of variance (ANOVA) (Gomez and Gomez, 1983) was done using data of total abundance. A two-way ANOVA was used to examine the effect of fields (crop research, maize and vegetables fields) and seasons (dry season during short rains and wet season during the long rains season) on weed plants abundance and variation in arable cropping system crop fields. Data for the individual weed species abundance per throw for the five throws were used to give the average weed species per plot for every field and season. Summary of the average weed species abundance per plot in each field and season were transformed based on square root transformation using formula$\sqrt{(x + 0.5)}$ (Chandel, 1984) to have normal distribution of the data. All the data were subjected to the two-way analysis of variance (ANOVA) at $P < 0.05$ level of significance using Gen Stat software 14th edition, to statistically test the hypothesis that weed plants abundance is not variable between arable cropping system crop fields in Juja.

Weed species (13) with patchy growth, runners and tillers were excluded from the ANOVA test since they were difficult to quantify. These included *Acanthospermum hispindum* (patchy), *Ageratum conyzoides* (patchy), *Commelina benghalensis* (runners), *Conyza bonariensis* (patchy), *Cynodon plectostachyus* (patchy), *Cyperus rotundus* (patchy), *Datura stramonium* (patchy), *Digtaria scaralum* (patchy/ runner), *Eleusine indica* (patchy), *Eleusine coracona* (many tillers), *Eragrostis tenuifolia* (many tillers), *Setaria pumila* (patchy) and *Setaria verticillata* (many tillers). The ANOVA results were used to determine if significant differences existed between the fields and seasons and if there were any field-season interaction effects on weed species mean abundance. Existence of significant differences of weed plants between the fields and seasons is an indication that weeds are not found all over the plots (patchy weeds). Existence of non significant differences of weed plants between the fields and seasons is an indication that weeds are found all over the plots (uniformly spread). Fisher's LSD test was used to analyze the pattern of significant difference between fields and seasons after rejecting the null hypothesis as a result of hypothesis test results ($P < 0.05$). Using LSD values it was possible to make direct comparisons between weed species abundance from two individual fields or seasons.

Where weed plants are significantly different in fields and seasons, their mean abundance differences are greater than the LSD values, so weeds are not found in the two fields/ seasons. If weed plants were not significantly different in fields and seasons, their mean abundance differences are less than the LSD values, so weeds are found all over in the two fields/ seasons. Coefficient of variation (CV %) was used to determine the variability of individual weed species in the crop fields where they occurred. High CV was an indication that weed species were not uniformly distributed (patchiness) and low CV showed that weeds were uniformly distributed (evenness) where they occurred.

3.3 Results

3.3.1 Soil chemical and physical characteristics at the survey crop fields

Soil chemical and physical characteristics of the fields are presented in Table 3.1.Soil samples were taken from 0-20cm depth for fertility nutrient status analysis. The textural class of the soils was sandy-clay loam in crop research field to sandy clay in both maize and vegetable fields while the pH was slightly acidic and within the optimum range (5.5-6.8) in crop research field and maize field but acidic in the vegetable field. Moisture content (%) was below the optimal range in all fields but highest in the crop research field.

The levels of exchangeable potassium (Meq/100g), Ec and bulk density were within optimal levels of most soils in Kenya. Exchangeable magnesium in crop research field was within the optimal range while in maize and vegetable fields it was below optimum. Exchangeable nitrogen for all the crop fields was below the optimal range. Exchangeable calcium was high in research field whereas in maize and vegetable fields it was below the optimum range. Available phosphorous in research field was the highest and above optimum range while in maize and vegetable fields it was below required levels. Generally the soil nutrients and moisture content were at slightly higher level in crop research field than in maize and vegetable fields.

Table 3.1: Soil chemical and physical characteristics of the arable cropping system fields; of crop research field, maize field and vegetable field, measured during two seasons in 2016

Soil characteristics	Crop research field(R)	Maize field (M)	Vegetable field (V)	Optimal range
pH H_2O (2:5 water)	6.11	6.2	5.4	5.5-6.8
Ec H_2O 2:5 (dS/m)	0.036	0.011	0.3	<0.8dS/m
ExchangeableNitrogen (Meq/100g)	0.15	0.02	0.01	>0.25%
Exchangeable Potassium (Meq/100g)	1.11	0.13	0.15	0 -2%
ExchangeableMagnesium (Meq/100g)	2.02	0.1	0.23	1-4%
ExchangeableCalcium (Meq/100g)	21.35	2.3	2	4-11%
Available P_2O_5 mg/kg by Truog	314	100	120	200 – 300
Bulk density(g/cm3)	1.1	1.03	1.1	<1.1
Moisture content (%)	5.47	4.52	5.03	10-20%
Textural class	Sandy Clay loam	Sandy clay	Sandy clay	

3.3.2 Weather conditions at the site in dry season /short rain season (December 2015) and wet season /long rain season (May 2016)

Figure 3.2a and 3.2b show the monthly mean air temperature and total monthly rainfall (mm) for dry season /short rain season (December 2015) and wet season /long rain season (May 2016) cropping season, respectively.

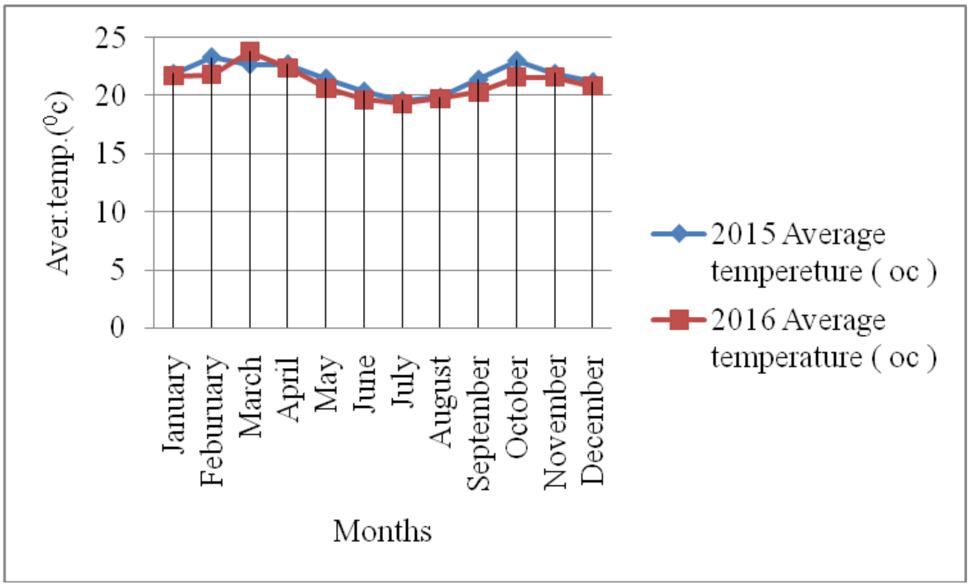

Figure 3.2a: Average air temperature (^{0}C) for year 2015 and 2016 from January to December

{Source: NASA power (National Aeronautics and Space Administration); Agromet data; coordinates Latitude -1.110, Longitude 37.011; Weather data for Juja (JKUAT farm), Thika Sub-County, (2016)}.

Note: *Average air temperature (^{0}C) for the seasons/ months and the survey date when the experiments were conducted is:

(i) Dry season /short rain season (August 2015-December 2015) (December 2015) = 21.5 ^{0}c Wet season /long rain season (April 2016 –August 2016) (May 2016) = 0.3^{0}c

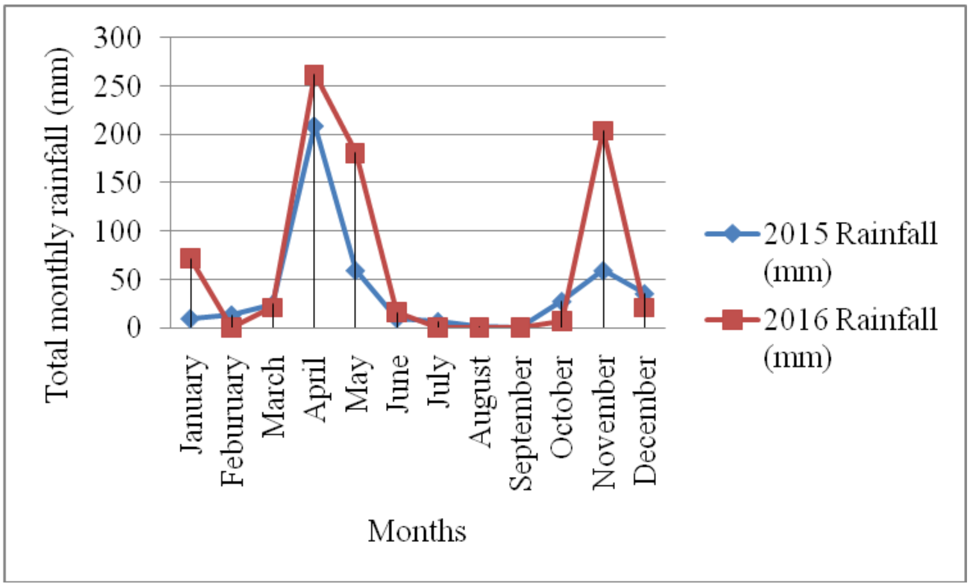

Figure 3.2b: Total monthly rainfall (mm) for year 2015 and 2016 from January to December {Source: JKUAT Farm Weather Station, (2015-2016)}

Note: * The total rainfall (mm) for the seasons/ months and the survey date when the experiments were conducted is:

(i) Dry season /short rain season (August 2015-December 2015) (December, 2015) = 123.4 mm;

(ii) Wet season /long rain season (April 2016 –August 2016) (May, 2016) = 459 mm

3.3.3 Weed plant species composition

3.3.3.1 Weed plants taxonomic families

In total, 28 weed plant species belonging to 11 families were identified and recorded from the study area (Table 3.2). Broadleaved weed species (18) belonged to 9 families, grass species (8) and sedges (2) each belonged to 1 family. Asteraceae and gramineae/poaceae families were the most dominant each with 28.6 percent contribution of plant families followed by solanaceae (10.7%), cyperaceae (7.1%) and the rest of the families each with 3.8 % contribution of the weed flora.

Table 3.2: The plant family's representation of the observed weed plant species and the occurrence level in the surveyed crop fields

Plant morphology	Plant family name	Percent contribution of plant families	Common name	Scientific name	Growth cycle
Broad leaved	Asteraceae	28.57%	Black jack	*Bidens pilosa*	Annual
			Dwarf marigold	*Schkuhria pinnata*	Annual
			Fleabane	*Conyza bonariensis*	Annual
			Gallant soldier	*Galinsoga parviflora*	Annual
			Goat weed	*Ageratum conyzoides*	Annual
			Mexican marigold	*Tagetes minuta*	Annual
			Sowthistle	*Sonchus oleraceus*	Annual
			Starrbur	*Acanthospermum hispindum*	Annual
	Euphorbiaceae	3.57%	Asthma weed	*Euphorbia hirta*	Annual
	Solanaceae	10.71%	Black night shade	*Solanum nigrum*	Annual
			Chinese lantern	*Nicandra physalodes*	Annual
			Thorn apple	*Datura stramonium*	Annual
	Brassicaceae	3.57%	Rape seed	*Brassica napus*	Annual
	Acanthaceae	3.57%	Climbing Asystasia	*Asystasia schimperi*	Annual
	Polygonaceae	3.57%	Double thorn	*Oxygonum sinuatum*	Annual
	Oxalidaceae	3.57%	Oxalis	*Oxalis latifolia*	Perennial
	Amaranthaceae	3.57%	Pig weed	*Amaranthus SP.*	Annual
	Commelinaceae	3.57%	Wondering jew	*Commelina benghalensis*	Perennial
Grasses	Gramineae	28.57%	Couch grass	*Digtaria scaralum*	Perennial
			Elastic grass	*Eragrostis tenuifolia*	Annual
			Goose grass	*Eleusine indica*	Annual
			Wild finger millet	*Eleusine coracona*	Annual
			Johnson grass	*Sorghum bicolor*	Perennial
			Love grass	*Setaria verticillata*	Perennial
			Star grass	*Cynodon plectostachyus*	Perennial
			Yellow foxtail	*Setaria pumila*	Annual
Sedges	Cyperaceae	7.14%	Nut grass	*Cyperus esculentus*	Perennial
			Nut sedge	*Cyperus rotundus*	Perennial

3.3.3.2 Relative weed plant density

According to the relative mean density (Table 3.3), the five most dominant weed species in the crop fields were *Schkuhria pinnata* (14.53%), *Bidens pilosa* (12.88%), *Galinsoga parviflora* (9.39%), *Asystasia schimperi* (7.41 %) and *Euphorbia hirta*

(6.85%). The five least dominant were *Cyperus rotundus* (0.26%), *Acanthospermum hispindum* (0.11%), *Conyza bonariensis* (0.11%), *Cynodon plectostachyus* (0.1%) and *Datura stramonium* (0.06%).The dominant weed species by the type of fields and season were; Research field during dry season (RD), *Cyperus esculentus* (18.7 %), Research field during the wet season (RW), *Amaranthu ssp* (16.99),Maize field during the dry seaso (MD), *Biden spilosa* (23.2%), Maize field during the wet season (MW) were *Bidens pilosa* (18.2 %), Vegetable field during the dry season (MD), *Schkuhria pinnata* (28 %) and Vegetable field during the wet season (VW), *Schkuhria pinnata* (34.6%).

3.3.3.3 Relative abundance

According to the average relative abundance (Table 3.3) the five most abundant weed species in the crop fields were *Bidens pilosa* (17.6%), *Schkuhria pinnata* (16.1%), *Galinsoga parviflora* (11.3%), *Euphorbia hirta* (7.7%) and *Asystasia schimperi* (6.5%).The least abundant were *Conyza bonariensis* (0.1%), *Brassica napus* (0.1%), *Cynodon plectostachyus* (0.06%), *Acanthospermum hispindum* (0.04%) and *Datura stramonium* (0.02%). The most abundant weed species by the type of fields and season were; RD, *Cyperus esculentus* (16 %), RW, *Galinsoga parviflora* (19 %), MD, *Bidens pilosa* (33%), MW were *Bidens pilosa* (27 %), VD, *Schkuhria pinnata* (34 %) and VW, *Schkuhria pinnata* (42%).

3.3.3.4 Relative frequency

The five most frequent weed species in the crop fields were *Bidens pilosa* (10.29 %), *Euphorbia hirta* (9.34 %), *Galinsoga parviflora* (8.91%), *Commelina benghalensis* (8.43%) and *Schkuhria pinnata* (8.35 %).The least frequent weed species in the crop fields were *Cynodonpl ectostachyus* (0.4 %), *Conyza bonariensis* (0.36 %), *Cyperus rotundus* (0.29%), *Acanthospermum hispindum (*0.15%), and *Datura stramonium* (0.07%) (Table 3.3). The most frequent weed species by the type of fields and season were; RD, *Commelina benghalensis* (12 %), RW, *Bidens pilosa* and *Galinsoga parviflora* (11 %), MD, *Bidens pilosa* and *Euphorbia hirta* (11%), MW were *Bidens pilosa* and *Galinsoga parviflora* (13 %), VD, *Bidens pilosa* and *Euphorbia hirta* (13 %) and VW, *Schkuhria pinnata* (16 %).

Table 3.3:Relative density, relative abundance and relative frequency of weed plants of crop research field (R), maize field (M) and vegetable field (V) in dry/ short rain season (D) (December 2015) and wet/ long rain season (W) (May 2016).

	Relative density (RD)(%)							Relative Abundance (RA)(%)							Relative Frequency (RF)(%)						
Weed species	RD	R W	MD	MW	VD	VW	A.RD	RD	RW	MD	MW	VD	VW	A.RA	RD	RW	MD	MW	VD	VW	A.RF
Schkuhria pinnata	2.2	0.7	10	12	28	35	14.53	1.7	0.7	8.9	9.5	34	41.62	16.14	4.9	1.3	9.9	6.9	11	16	8.353
Bidens pilosa	1.2	7.8	23	18	19	7.4	12.88	0.8	12	33	27	27	6.589	17.67	2.4	11	11	13	13	11	10.29
Galinsoga parviflora	1.6	15	14	13	5.7	6.8	9.391	1.6	19	19	17	4.5	6.123	11.35	3.7	11	9.9	13	7.1	9.5	8.908
Asystasia schimperi	10	12	6.4	3.8	5.6	6.6	7.406	9.5	13	2.9	2.5	3.3	7.91	6.515	9.8	9.2	6.6	4.5	4.3	11	7.626
Euphorbia hirta	7.2	5.3	7.6	7.9	2.9	10	6.846	11	4.4	8.4	9.1	2.9	10.99	7.75	7.3	6.6	11	9.9	13	8.3	9.335
Cyperus esculentus	19	2.7	6.8	3.5	7.5	1.8	6.829	16	2.3	4.6	4.4	5.8	1.554	5.758	4.9	2.2	4.4	4.7	10	4.8	5.165
Amaranthus SP.	3.7	17	2.7	5.9	5.3	2.3	6.148	2.3	14	2.6	6.3	2	0.975	4.714	2.4	7.5	6.6	9.6	5.7	3.5	5.884
Commelina benghalensis	8.6	5.3	2.1	3.7	3.6	4.1	4.563	10	3.5	1.4	2.3	2.9	2.747	3.848	12	5.3	7.7	6.5	11	7.5	8.426
Oxalis latifolia	1.2	9.4	2.6	7.6	0.6	5.5	4.472	1.2	12	3.8	8.6	0.4	4.131	5.056	3.7	10	5.5	8	2.9	6	6.005
Nicandra physalodes	6.1	0.3	6.6	0.7	4.6	0	3.053	7.8	0.2	2.4	0.7	4	0	2.514	9.8	0.9	4.4	1.5	8.6	0	4.178
Oxygonum sinuatum	14	1.5	0	2	0	0.8	2.98	13	0.9	2.4	1.2	0	0.209	2.889	9.8	3.1	7.7	4.1	0	1.2	4.296
Ageratum conyzoides	0.6	0	0	0	15	0	2.602	0.2	0	0	0	12	0	2.032	1.2	0	0	0	7.1	0	1.394
Setaria verticillata	0	3.6	2.5	1.3	0.6	7.3	2.561	0	2.7	2.2	0.7	0.4	8.209	2.36	0	4.8	6.6	2.9	2.9	6.7	3.969
Digtaria scaralum	0	0	2	6.7	0	5.7	2.405	0	0	0	2.2	0	2.555	0.795	0	0	0	1.1	0	2.3	0.572
Eleusine indica	0	1	12	0	0	0	2.133	0	0.7	7.9	0	0	0	1.436	0	0.9	5.5	0	0	0	1.063
Eragrostis tenuifolia	4	4	0	3.3	0	0.7	2.009	2.5	5.3	0	3.2	0	0.541	1.926	2.4	3.5	0	3.3	0	2.9	2.02
Sonchus oleraceus	1.2	2.6	0	2.8	0	5.1	1.933	0.4	2.4	0	2.2	0	5.544	1.757	1.2	5.7	0	6.4	0	7.8	3.525
Sorghum bicolor	5.2	2.7	0	1.3	0.6	0	1.623	2.5	2.2	0	0.7	0.2	0	0.937	3.7	5.7	0	1.8	1.4	0	2.103
Eleusine coracona	3.9	2.4	1.2	1.1	0	0.4	1.504	6.2	1.2	0.6	0.3	0	0.101	1.388	6.1	3.1	3.3	0.4	0	0.5	2.217
Tagetes minuta	0	2.5	0	5.1	0	0.1	1.286	0	1	0	1.5	0	0.034	0.422	0	2.2	0	1.5	0	0.5	0.695
Setaria pumila	7.6	0	0	0	0	0	1.26	12	0	0	0	0	0	2.003	6.1	0	0	0	0	0	1.016
Solanum nigrum	2.1	0.3	0	0.5	0	0.7	0.622	1.4	0.1	0	0.3	0	0.169	0.324	4.9	0.4	0	0.7	0	0.5	1.088
Erucastrum arabicum	0.6	0.7	0	0	0.6	0	0.315	0.2	0.2	0	0	0.2	0	0.1	1.2	0.9	0	0	1.4	0	0.589
Cyperus rotundus	0	1.6	0	0	0	0	0.262	0	0.9	0	0	0	0	0.148	0	1.7	0	0	0	0	0.29
Acanthospermum hispindum	0	0.7	0	0	0	0	0.115	0	0.2	0	0	0	0	0.038	0	0.9	0	0	0	0	0.147
Conyza bonariensis	0	0.7	0	0	0	0	0.109	0	0.6	0	0	0	0	0.104	0	2.2	0	0	0	0	0.362
Cynodon plectostachyus	0.6	0	0	0	0	0	0.102	0.4	0	0	0	0	0	0.065	2.4	0	0	0	0	0	0.407
Datura stramonium	0	0.3	0	0	0	0	0.057	0	0.1	0	0	0	0	0.019	0	0.4	0	0	0	0	0.074
RICHNESS	20	24	14	19	14	17		20	24	14	19	14	17		20	24	14	19	14	17	

Key: (RD=Research field dry season, RW=Research field wet season, MD= Maize field dry season, MW= Maize field wet season, VD= Vegetable field dry season, VW= Vegetable field wet season, ARD = Average relative density, ARA=Average relative abundance, ARF= Average relative frequency) {n=15}.

3.3.4 Weed species ecological variation

Table 3.4 shows that, diversity index (H') of the weed plants in the crop fields ranged from1.862 (lowest weed species diversity/ variation) to 2.524 (greatest weed speciesdiversity/ variation), species evenness (E) ranged from 0.706 (lowest species evenness, an indication that weed species were not uniformly distributed (patchiness) where they occurred) to 0.843 (highest species evenness, showing that weeds were uniformly distributed (evenness) where they occurred) and species richness (S) ranged from 14 (smallest total count of different types of weed plant species) to 24 (highest total count of different types of weed plant species). Shannon index for weed diversity, evenness and richness were higher in crop research field (R) (Wet season 2.427; Dry season 2.524) compared to maize (M) (Wet season2.381; Dry season 2.118) and vegetable (V) fields (Wet season 2.05; Dry season 1.862). Wet season (long rains) increased species richness than dry season (short rains) by 20% in Crop research field, 36% in Maize field and 21% in Vegetable field. Overall mean abundance was highest in the vegetable field in the wet season/ long rains season (65.26).

Table 3.4: Diversity, species richness and evenness of weed plants in the arable cropping fields of crop research field (R), maize field (M) and vegetable field (V) in the dry (short rains) and wet (long rains) seasons

Crop Fields		Dry season (Short rain season) (December 2015)	Wet season (Long rain season) (May 2016)
Crop research field (R)	Mean abundance	35.5	33.2
	Diversity Index (H')	2.524	2.427
	Richness (S)	20	24
	Evenness (E)	0.843	0.764
Maize field (M)	Mean abundance	47.86	43.63
	Diversity Index (H')	2.118	2.381
	Richness (S)	14	19
	Evenness (E)	0.803	0.809
Vegetable field (V)	Mean abundance	36.67	65.26
	Diversity Index (H')	1.862	2.05
	Richness(S)	14	17
	Evenness (E)	0.706	0.724

Kruskal-wallis H test results indicate that there was no significant effect of arable cropping system on mean abundance of weeds, H (2) = 2.263, P= 0.322. However, there was high significant effect of season on weed mean abundances, H (1) = 14.173, P= 0.000.

Weed species variation

The ANOVA results (Table 3.5) showed that none of the weed species showed significant differences (P > 0 .05) in field- season interaction. The mean abundance of *Schkuhria pinnata* and *Sorghum bicolor* species were significant (P < 0.05) between the fields. *Nicandra physalodes, Oxalis latifolia* and *Sonchus oleraceus* showed significant differences between the wet and dry seasons. The rest of the sampled weed species were found to be non- significant (P > 0.05) between the fields and seasons. *Bidens pilosa* recorded the highest coefficient of variation (CV) of 34 %

while *Brassica napus* recorded the lowest CV of 1.5 %. According to the analysis of this field experiment, the test hypothesis as stated 'weed plants abundance is not variable between arable cropping system crop fields in Juja' is rejected since some weed species means were statistically significant between the fields and seasons although there was no any kind of interaction between the fields and seasons,.

Table 3.5: The effects of arable cropping fields, seasons and field- season interaction on mean abundance and variation of weed species

Weed species	Fields		Seasons		Field-Season interaction		CV %
Amaranthus Sp.	0.166	NS	0.123	NS	0.11	NS	6.8
Asystasia schimperi	0.176	NS	0.417	NS	0.456	NS	17.4
Bidens pilosa	0.134	NS	0.816	NS	0.466	NS	34
Cyperus esculentus	0.936	NS	0.293	NS	0.691	NS	33.4
Brassica napus	0.337	NS	0.564	NS	0.677	NS	1.5
Euphorbia hirta	0.293	NS	0.153	NS	0.051	NS	27.3
Galinsoga parviflora	0.218	NS	0.124	NS	0.3	NS	24.7
Nicandra physalodes	0.762	NS	0.009	S	0.531	NS	27.3
Oxalis latifolia	0.896	NS	0.032	S	0.719	NS	9.9
Oxygonum sinuatum	0.062	NS	0.081	NS	0.124	NS	3.4
Schkuhria pinnata	0.005	S	0.443	NS	0.302	NS	17.9
Solanum nigrum	0.467	NS	0.861	NS	0.108	NS	8.9
Sonchus oleraceus	0.328	NS	<.001	S	0.231	NS	4.6
Sorghum bicolor	0.024	S	0.687	NS	0.595	NS	8.2
Tagetes minuta	0.384	NS	0.055	NS	0.384	NS	11.8

NS=Not significant, S=Significant, CV=Coefficient Variation

The findings of Table 3.6 showed that *Sorghum bicolor* weed species was significantly different between research and maize fields and, research field and vegetable field but not significant between maize and vegetable fields. *Oxygonum sinuatum* was significantly different between research field and vegetable field. *Schkuhria pinnata* was significantly different between research and vegetable fields and, maize and vegetable field but non significant between research and maize fields. *Nicandra physalodes, Oxalis latifolia* and *Sonchusoleraceus* weed species were significantly different between dry and wet seasons.

Nicandra physalodes, Oxygonum sinuatum and *Sonchus oleraceus* weed species were significantly different between dry and wet seasons in research field. *Sonchus oleraceus* weed was significantly different between dry and wet seasons in maize field. *Euphorbia hirta* and *Sonchus oleraceus* were significantly different between dry and wet seasons in vegetable field.

Table 3.6: Comparisons between weed species mean abundance between the arable cropping fields and seasons

Weed species	R	M	V	LSD	R&M	R&V	M&V	D	W	LSD	D&W	LSD	RD	RW		MD	MW		VD	VW	
Amaranthus sp	1.7	1.4	1	0.688	NS	NS	NS	1.1	1.6	0.562	NS	0.974	1.1	1.6	NS	1.2	1.5	NS	1.1	0.9	NS
Asystasia schimperi	1.9	1.2	1.5	0.77	NS	NS	NS	1.4	1.7	0.629	NS	1.089	1.7	2.1	NS	1.4	1.1	NS	1.2	1.7	NS
Bidens pilosa	1.5	3.1	2.6	1.687	NS	NS	NS	2.3	2.5	1.377	NS	2.385	0.9	2.1	NS	3.3	3	NS	2.8	2.3	NS
Cyperus esculentus	1.5	1.3	1.5	1.081	NS	NS	NS	1.7	1.2	0.883	NS	1.529	2	1.1	NS	1.5	1.2	NS	1.5	1.4	NS
Erucastrum arabicum	0.8	0.7	0.7	0.063	NS	NS	NS	0.7	0.7	0.052	NS	0.089	0.8	0.8	NS	0.7	0.7	NS	0.8	0.7	NS
Euphorbia hirta	1.5	1.9	2.3	1	NS	NS	NS	1.6	2.2	0.817	NS	1.414	1.6	1.4	NS	2	1.9	NS	1.2	3.3	S
Galinsoga parviflora	1.8	2.7	1.8	1.214	NS	NS	NS	1.7	2.4	0.991	NS	1.717	1	2.6	NS	2.8	2.6	NS	1.4	2.2	NS
Nicandra physalodes	1.2	1.1	1	0.52	NS	NS	NS	1.4	0.8	0.424	S	0.735	1.6	0.8	S	1.2	0.9	NS	1.3	0.7	NS
Oxalis latifolia	1.5	1.5	1.3	1.039	NS	NS	NS	1	1.9	0.849	S	1.47	0.9	2.1	NS	1.3	1.8	NS	0.8	1.9	NS
Oxygonum sinuatum	1.5	1.1	0.7	0.623	NS	S	NS	1.3	0.9	0.509	NS	0.882	2.1	0.9	S	1.2	1	NS	0.7	0.8	NS
Schkuhria pinnata	0.9	2	3.9	1.57	NS	S	S	2.1	2.5	1.282	NS	2.22	1	0.8	NS	2.1	1.9	NS	3	4.8	NS
Solanum nigrum	0.9	0.8	0.8	0.179	NS	NS	NS	0.8	0.8	0.146	NS	0.252	1	0.7	NS	0.7	0.8	NS	0.7	0.8	NS
Sonchus oleraceus	1	0.9	1.1	0.263	NS	NS	NS	0.8	1.3	0.215	S	0.372	0.8	1.2	S	0.7	1.1	S	0.7	1.5	S
Sorghum bicolor	1.1	0.8	0.7	0.271	S	S	NS	0.9	0.9	0.221	NS	0.383	1.1	1.1	NS	0.7	0.9	NS	0.8	0.7	NS
Tagetes minuta	0.8	0.9	0.7	0.242	NS	NS	NS	0.7	0.9	0.198	NS	0.343	0.8	0.9	NS	0.7	1	NS	0.7	0.7	NS

NS= Not significant, S= Significant, LSD= Least significant difference, R=Crop research field, M=Maize field, V=Vegetable field, D=Dry season, W=Wet season, RD= Research field dry season, RW= Research field wet season, MD= Maize field dry season, MW=Maize field wet season, VD= Vegetable field dry season and VW= Vegetable field wet season.

3.4 Discussion

3.4.1 Weed plant species composition and cultural practices

In total, 28 weed plant species belonging to 11 families were identified and recorded from the surveyed area. Broadleaved weed species (18) belonged to 9 families, grass species (8) and sedges (2) each belonged to 1 family. Similarly, Mwangi, (2016) study conducted in Makueni County demonstrated that maize fields were infested heavily by 28 different weed species; belonging to broadleaved (18), grasses (8), sedge (1) and one parasitic weed. Further, Nyamwamu *et al.,* 2019 survey conducted in Kisii Central Sub County showed that a total of 24 weed species belonging to 12 families were recorded in the arable cropping farms and family Asteraceae dominated with 6 species followed by family Solanaceae with 5 species and family Poaceae had 3 species. In our study, Asteraceae and Gramineae families dominated. Annual species were more than perennial, broadleaved were more prevalent than narrow-leaved species. Correspondingly, Hossain *et al.,* (2010) in survey and documentation of weed flora in the farm of wheat research centre conducted in Dinajpur, Bangladesh, observed that annual species were more prevalent than perennials, broadleaved were more than grasses and sedges, and gramineae was the most common family. It is evident from the results that different crop fields and seasons supported different weed flora not only in terms of number of weed species but also in terms of relative mean density, relative abundance and relative frequency. Weeds are primarily linked to field and season, unlike pests and diseases, which are mainly associated with specific crops. However, in our study weed plants composition was mainly influenced by the type of preceding crop, crop- specific cultural practices and season and seasonal weather variations.

The type of preceding crops contributed greatly to changes in weed flora composition. Annual crops increase annual weeds and decrease perennial species whereas perennial crops increase perennial weeds (Necajeva *et al.,* 2015). Vigorous crops are heavy feeders and form a thick canopy which smothers weeds and prevents emergence of new ones thus, encourage dominance of the best adapted (Aluko *et al.,* 2015). Research field supported different weed communities in wet and dry seasons in association to different preceding research crops in different plots. Thus, *Amaranthus spp,* an annual weed occurred in association to *Amaranthus spp* vegetable crop which was previously grown as a research crop in some of the research plots and therefore, dominated in wet season. *Cyperus esculentus* a perennial weed dominated in plots with perennial and long growth cycle research crops such as kales and maize in dry seasons. Increased species richness in crop research field was in relation to occurrence of *Setaria pumila, Cyperus rotundus, Acanthospermum hispindum, Conyza bonariensis, Cynodon plectostachyus and Datura stramonium* species which were not found in maize and vegetable fields.

Aluko *et al.* (2015) observed that vigorous crops are heavy feeders and form a thick canopy which smothers weeds and prevents emergence of new ones thus, encourage dominance of the best adapted weed species. Similarly in our study, vigorous tall maize plants formed a thick canopy which smothered weeds resulting to high relative density, high relative abundance and high relative frequency of the best adopted dominating *Bidens pilosa* species in maize field in both dry and wet seasons. In the same way, Ndam*et al.,* (2014) in their study on weed diversity in maize fields conducted in South Western Cameroon observed that, *Bidens pilosa* weed thrived well even under heavy shading from the maize crop.

Leafy spinach and kales are basically short cover crops and heavy feeders thus smothered most of the weed species in vegetable field. However, the best adapted *Schkuhria pinnata* species over dominated in both seasons as shown by its significantly high relative density, relative abundance and relative frequency. Similarly, Agbede *et al.,* (2009) observed that the most adapted weeds domineered in the field as a result of successfully competing with the less adaptable weed species.

Crop- specific cultural practices including pre-planting and regular cultivations showed great impact on weed composition. Lososova *et al,* (2004) reported that crop plants and crop-specific practices affect weed composition to a lesser, but still significant extent. Pre-planting cultivations can affect weed presence. Thus, grasses are favoured by non-inversion tillage, whereas broad-leaved weeds are favoured by ploughing (Puricelli *et al.,* 2012). Regular cultivation increases annual weeds and decreases perennial weeds and vice versa. Therefore, ploughing and regular cultivation may have increased annual broadleaved weeds in research field. Nevertheless, abandonment and slashing in perennial orchard plots in research field contributed to occurrence of perennial broadleaved (*Commelina benghalensis*) and grass (*Sorghum bicolor*) species. Therefore, different species in research field occurred in more or less equal relative density, relative abundance and relative frequency giving no room for dominance of a particular species. Similarly, Necajeva *et al.,* (2015) in their study on factors influencing weed species diversity in Southeastern part of Latvia reported that abandonment of land causes reduction of rare weed species encouraging more diverse weed vegetation.

Ploughing and regular cultivation encouraged more annual broadleaved weeds in maize field in both seasons. In vegetable field, despite ploughing and regular cultivation between harvests, trampling of land during harvesting operations may have attributed to annual broadleaved weeds, over dominance and decreased species richness. Fried *et al.,* (2008); Pinke *et al.,* (2009) observed that, management regime is one of the most important variable influencing the species composition of weed vegetation.

Season and seasonal weather variations greatly influenced weed composition in that wet season (long rain season) contained a very different selection of weed species to a dry one (short rain season). Temperature and rainfall variations are associated with differences in species emergence times and, growth and development of annual weeds (Lososova *et al.,* 2004; Puricelli *et al.,* 2012). 2016 wet (long rain) season experienced slightly lower average air temperature (^{0}C) and higher rainfall (mm) than 2015 dry (short rain) season. Species richness increases with increase in rainfall (optimal soil moisture). Thus, higher species richness in wet season can be associated to higher amount of available water which favoured establishment and growth of weed plants than in dry season (short rainy season) (Suzart de Albuquerque *et al.,* 2010).

3.4.2 Weed variation in arable cropping system crop fields

Relative abundance of weed species, soil resources and the level of competition influenced the variation of weed species in crop fields. Relative abundance of weed species in a community directly affects diversity. Relative abundance of species is mainly influenced by the level of competition for resources and species richness. Frequency is a good indicator of the spatial distribution of weed species within a sampled area. Estimates of frequency are more dependent on the size of the quadrat where small quadrats result in many species having frequencies of zero percent (Nkoa *et al.,* (2015). The quadrats in this study were of small size, 50 cm * 50 cm, and this could explain the many cases of species having frequencies of zero percent. Weed diversity has been shown to depend on several edaphic factors (Necajeva *et al.,* 2015). More soil resources and favourable soil structure in crop research field created a strong competitive environment for any dominance of invasive weed. Thus, decreased species relative abundance and field mean abundance, increased species richness and evenness and formed a more diversified crop research field. Similarly, Stirling and Wilsey, (2001) reported that a diverse community maintains high species richness and evenness. Similarly, Otto *et al.,* (2012), reported that different species in a diverse field are likely to utilize available resources more efficiently thus creating a strong competitive environment for any invasive species to grow vigorously.

Limited resources in maize field increased the level of a single- weed species competition. Therefore, a single- weed species dominated and fairly increased its relative abundance and field mean abundance; decreased species richness and evenness thus formed a less diverse community. In vegetable field, unavailability of resources due to poor and a more acidic soil resulted to stiff competition for resources hence single- species over dominance as shown by its very high relative abundance, very high field mean abundance, decreased species richness and evenness therefore formed a less diverse community. Fried *et al.,* (2008); Climanova and Lososova, (2009); Pinke *et al.,* (2009) and Pal *et al.,* (2013) observed that soil pH is one of the most important factors explaining species assemblages. Poor evenness and low diversity indices in a highly populated community could be explained by one best adapted weed species over dominating due to stiff competition for resources (Stirling and Wilsey, 2001).

Significant field effects on mean abundance of *Schkuhria pinnata* and *Sorghum bicolor* species were attributed to the differences in soil characteristics; and significant season effects on *Nicandra physalodes, Oxalis latifolia*and *Sonchus oleraceus* species due to season and seasonal weather variations. The results also revealed bordering effects for *Oxygonum sinuatum* between research and maize fields, and *Schkuhria pinnata* between vegetable and maize fields. Possibly due to excellent weed seeds dispersal by wind, workers and tillage equipment to the adjacent fields. Single species over dominance and unevenness was a unique feature in vegetable field as shown by significant mean abundance of *Schkuhria pinnata* species due to stiff competition for resources. *Nicandra physalodes* was favoured by the dry season while *Oxalis latifolia* and *Sonchus oleraceus* species were favoured by the wet season.

The distribution of weed plants was the same across all crop fields as measured by H statistic (P = 0.322). The null hypothesis that weeds plants abundance is not variable between arable cropping system crops fields in Juja was upheld. However, the distribution of the weed plants was not the same across the dry and wet seasons as suggested by Kruskal-Wallis H test results. Weed variation was mainly influenced by season and seasonal weather variations. 2016 wet season (long rain season) experienced higher rainfall (mm) than 2015 dry (short rain season) season. Wet season increased species richness than dry season by 20% in Crop research field, 36% in Maize field and 21% in Vegetable field. Thus, higher species richness in wet season (long rain season) could be associated to higher amount of available water in the soil due to higher rainfall. Weed species richness increases with increase in rainfall (optimal soil moisture). Suzart de Albuquerque *et al.* (2010) found that weed plant species richness can be well predicted by water availability. Likewise, according to Lososova*et al.*, (2004); Pal *et al.*, (2013) seasonal changes and moisture availability can result in striking differences between weed communities and species richness. Therefore, during the dry season *Ageratum conyzoides, Setaria pumila* and *Cynodon plectostachyus* (research field), *Eleusine indica* (maize field) and *Nicandra physalodes, Sorghum bicolor* and *Erucastrum arabicum* (vegetable field) were observed; and in wet season additional species including; *Setaria verticillata, Eleusine indica, Tagetes minuta, Cyperus rotundus, Acanthospermum hispindum, Conyza bonariensis* and *Datura stramonium* (research field), *Eragrostis tenuifolia, Sonchusoleraceus, Sorghum bicolor, Tagetesminuta* and *Solanumnigrum* (maize field) and *Oxygonum sinuatum, Digtaria scaralum, Eragrostis tenuifolia, Sonchus oleraceus, Eleusine coracona, Tagetes minuta* and *Solanum nigrum* (vegetable field) species were observed.

3.5 Conclusion

Results from this study indicated that twenty eight weed species which belonged to 11 families were identified. Compositae and Gramineae families are dominant ones. The most abundant weed species were the broadleaved annual weeds. Perennial grass weed species were fewer in the fields. The five most dominant species were *Schkuhria pinnata, Galinsoga parviflora, Euphorbia hirta, Bidens pilosa* and *Asystasia schimperi*. The least dominant species were *Cyperus rotundus, Acanthospermum hispindum, Datura stramonium, Conyza bonariensis* and *Cynodon plectostachyus.* The population of weed species in the surveyed crop fields and seasons varied. Wet season increased species richness than dry season. Weed plants diversity was higher in crop research field than in maize field and vegetable field. The differences in weed plants abundance and variability in arable cropping fields was mainly influenced by season and seasonal weather variations.

Results obtained from this study would be useful in developing a long term cost effective weed management strategy for arable cropping small scale farmers.

CHAPTER FOUR

EFFECT OF DIFFERENT WEED MANAGEMENT PRACTICES ON WEED GROWTH AND AGRONOMIC PERFORMANCE OF MAIZE IN AN ARABLE CROPPING SYSTEM

4.1 Introduction

Weed control in maize fields constitutes a major factor in determining grain yields (Beckert *et al.,* 2011). Anees *et al.,* (2008) attributed maize yield losses ranging from 50% to 90% to weed competition with crop for nutrients, soil moisture, light and space. Main weed control techniques in maize include preventative control, physical (manual cultivations and mechanized cultivation), biological control methods, cultural methods such as crop rotation, sowing period, cover cropping, mulching, crop competition, flooding, cleaning of harvesting equipment and machinery and use of herbicides and Integrated Weed Management (IWM). *Striga* damages in maize can be reduced by growing varieties that are tolerant of or resistant to *Striga* or by planting trap crops such as varieties of groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*), and sesame (*Sesamum indicum*) that stimulate the *Striga* seeds to germinate without providing a viable host **(**Ndwiga*et al.,* 2013; Kamara, 2013).Research studies have proofed that none of the weed control methods alone is best under all conditions **(**Kamara, 2013). So, there is a need to make a comparative study of different weed management options in maize and to develop a weed management approach, which is efficient, cost effective and environmentally safe (Riaz *et al.,* 2007). For long term management, controlling weeds before they produce new seeds is critical. According to Micheni *et al.,* (2014); Hossain, (2015) and Shaba *et al.,* (2015) herbicide application is an efficient way of controlling weeds in crop fields since it is less expensive than hand weeding. The objectives of this study component were to assess the effect of different weed management regimes on 1) weed growth, and 2) agronomic performance of maize.

4.2 Materials and methods

4.2.1 Study site

The study site was as indicated in section 3.2.1.The trial was planted in crop research field (block A) (Figure 3.1) with sandy clay loam soils.

4.2.2 Experimental design and treatments

The study comprised of two experiments: Experiment I which was conducted in 2015 and constituted of nine treatments with four replicates making a total of 36 plots (Table 4.1) and Experiment II conducted in 2016 and constituted of twelve treatments, with each treatment replicated three times making a total of 36 plots (Table 4.2). The experimental design was a randomized complete block design (RCBD).

Table 4.1: Weed management treatments applied in experiment I

Treatments	Weed management treatments 1 day after planting	25 Days after planting	50 Days after planting
	(DAP)	(DAP)	(DAP)
T1	None	None	None
T2	None	None	Hand weeding
T3	None	None	Post-emergence herbicide
T4	None	Hand weeding	None
T5	None	Hand weeding	Hand weeding
T6	None	Hand weeding	Post-emergence herbicide
T7	Pre-emergence herbicide	None	None
T8	Pre-emergence herbicide	None	Hand weeding
T9	Pre-emergence herbicide	None	Post-emergence herbicide

Key:T1 = No weeding (Weedy check), T2 = Hand weeding at 50 DAP, T3 =Post emergence herbicide application at 50 DAP, T4 =Hand weeding at 25 DAP, T5 =Two hand weedings at 25 and 50 DAP, T6 =Hand weeding and Post-emergence herbicide application at 25 and 50 DAP respectively, T7 =Pre-emergence herbicide application at one DAP, T8 = Pre-emergence herbicide application and Hand weeding at one DAP and 50 DAP respectively, T9 = Pre-emergence herbicide application and Post-emergence herbicide application at one DAP and 50 DAP respectively.

Table 4.2: Weed management treatments applied in experiment II

Treatments	Weed management treatments 1 day after planting	25 Days after planting	50 Days after planting
	(DAP)	(DAP)	(DAP)
T1	None	None	None
T2	None	None	Hand weeding
T3	None	None	Post-emergence herbicide
T4	None	Hand weeding	None
T5	None	Hand weeding	Hand weeding
T6	None	Hand weeding	Post-emergence herbicide
T7	Pre-emergence herbicide	None	None
T8	Pre-emergence herbicide	None	Hand weeding
T9	Pre-emergence herbicide	None	Post-emergence herbicide
T10	None	Post-emergence herbicide	None
T11	None	Post-emergence herbicide	Hand weeding
T12	None	Post-emergence herbicide	Post-emergence herbicide

Key: T1 = No weeding (Weedy check), T2 = Hand weeding at 50 DAP, T3 =Post emergence herbicide application at 50 DAP, T4 =Hand weeding at 25 DAP, T5 =Two hand weedings at 25 and 50 DAP, T6 =Hand weeding and Post-emergence herbicide application at 25 and 50 DAP respectively, T7 =Pre-emergence herbicide application at one DAP, T8 = Pre-emergence herbicide application and Hand weeding at one DAP and 50 DAP respectively, T9 = Pre-emergence herbicide application and Post-emergence herbicide application at one DAP and 50 DAP respectively, T10 = Post-emergence herbicide application at 25 DAP, T11 =Post-emergence herbicide application and hand weeding at 25 and 50 DAP respectively, and T12 =Two Post-emergence herbicide application at 25 and 50 DAP.

4.2.3 Field preparation and planting

The field was ploughed and harrowed into a medium tilth. Each plot was composed of 4 rows measuring 4.5m long and 2.25m wide. Plots were divided by 1 m wide paths. The maize seeds were sown at inter- and intra-row spacings of 75 cm and 50 cm with 2-3 seeds per planting hole. The maize variety used was Phb3253 from Pioneer Seed Company. Diammonium phosphate (DAP) fertilizer was applied at a rate of one and a half teaspoonful (7.15 g) per planting hole corresponding to 249 kg/ha. Irrigation was applied immediately after planting in order to encourage germination of weed seeds. Two weeks after emergence, thinning was done to leave two seedlings per planting hole.

4.2.4 Treatments application

Herbicide application

Pre-emergence and post-emergence herbicides were used to manage weeds at different stages of maize growth. Primagram was used as the pre-emergence herbicide and was applied one day after planting prior to crop and weed emergence at a rate of 3l/ha (3 ml/plot), according to treatment assigned for each plot. Primagram is a broad spectrum herbicide that kills both narrow and broad leaved weeds immediately after emergence. It breaks down after about four days and therefore did not affect the germinating maize seedlings. The post-emergence herbicide used was 2, 4-D Amine and it was sprayed at 25 and/or 50 days after planting (DAP) at a rate of 30l spray solution/ha) (30.4 ml/plot). 2, 4-D Amine is a contact selective herbicide that kills only the broad leaved weeds. Since the field was not infested by many grass weeds, it was an efficient option of managing the weeds.

Hand weeding

Hand weeding treatment was applied at 25 and 50 days after planting either in or no combination with hand weeding, pre-emergence or post-emergence herbicide application.

4.2.5 Data collection

The two middle rows of every plot were used for sampling excluding 50 cm from the two edges of each row. Data on weeds was recorded only in 2016 at maize harvest time on number of weed species and weed fresh weight. The weeds were sun-dried for seven days and the dry weights recorded. Data on maize performance was recorded in 2015 and 2016 on various agronomical traits on per plot basis as follows: - Number of days to anthesis, number of days to silking, anthesis- silking interval, plant height at maturity (cm), plant height below the ear (cm), number of cobs per plant, number of leaves below and above the ear, cob length (cm), kernels per row, grain yield (kg), 100 kernel weight (g) and stover dry weight.

4.2.6 Data analysis

Data on dry weight of weeds on treated and control plots was used to calculate weed control efficiency based on the formula reported by Patel *et al.*, (2006) as indicated below:

$$\mathrm{WCE} = \left(\frac{\mathrm{DWC} - \mathrm{DWT}}{\mathrm{DWC}}\right) \times 100$$

Where,

WCE = Weed Control Efficiency

DWC = Dry weight of weeds from control plot (weedy check)

DWT = Dry weight of weeds from treated plot

All the agronomic data recorded were analyzed using Analysis of Variance (ANOVA) method following statistical procedures reported by Gomez and Gomez, (1984) and using GenStat Fourteenth Edition statistical package. Where significant differences among treatments were detected, the means were separated using the least significance difference (LSD) test at 0.05 level of significance as demonstrated by Steel *et al.*, (1997).

4. 3 Results

4.3.1 Weather conditions of the study area

The monthly mean air temperature (0^c) and total monthly rainfall (mm) for 2015 and 2016 cropping seasons recorded for Juja area, Thika Sub-County is presented in figures 3.2a and 3.2b. The 2015 cropping season (from August to December) was during the short rainy season characterized by lower intensity and amount of rainfall over a shorter period of time accompanied with slightly higher temperature while 2016 cropping season (from April to August) was in the long rainy season characterized by higher intensity and amount of rainfall over a longer period of time accompanied with slightly lower temperature.

4.3.2 Effect of different weed management practices on weed growth

The results (Table 4.3) indicated significant effect of different weed management treatments on weed density (P = 0.024) at maize maturity. Weed density ranged between 20 and 328 weed plants per m^2 with a mean of 136 weed plants per m^2.The data also revealed high significant effect of different weed management treatments on dry weight of weed plants (P =<.001) at maize maturity. Weed dry weight ranged between 1.2g/m^2 and 476.8g/m^2 with a mean of 63.47g/m^2.T1 (weedy check) recorded maximum weed density and highest weed dry weight with 0.0% weed control efficiency (WCE) as expected. Further, the results indicated that T12 (two post-emergence herbicide application at 25 and 50 days after planting) recorded minimum dry weight (6.4 g/m^2) and achieved maximum weed control efficiency (98.1%).All weed management treatments, except T3 (Post emergence herbicide application at 50 DAP) (75%), T4 (Hand weeding at 25 DAP) (76.4%), and T7 (Pre-emergence herbicide application at one DAP) (61.1%), had over 90% weed control efficiency (WCE).Minimum weed control efficiency was observed in treatment T7 (Pre-emergence herbicide application at one DAP).

Table 4.3: Effect of different weed management treatments on weed density, weed dry weight and weed control efficiency in 2016 cropping season

Treatments	Weed density (Weed plants/m^2)	Weed dry weight (g/m^2)	Weed control efficiency (WCE) (%)
T1	193.3 ^{a}	322.4 ^{a}	0
T2	156 $^{a\,b\,c\,d\,e}$	22 ^{c}	93.1
T3	118.7 $^{a\,b\,c\,d\,e\,f}$	81.2 $^{b\,c}$	75
T4	54.7 $^{d\,e\,f}$	76.4 $^{b\,c}$	76.4
T5	145.3 $^{a\,b\,c\,d\,e\,f}$	19.2 ^{c}	94.1
T6	161.3 $^{a\,b\,c\,d}$	12.4 ^{c}	95.8
T7	42.7 ^{f}	126 ^{b}	61.1
T8	128 $^{a\,b\,c\,d\,e\,f}$	14.8 ^{c}	95.4
T9	162.7 $^{a\,b\,c}$	15.2 ^{c}	95.3
T10	78.7 $^{b\,c\,d\,e\,f}$	29.6 $^{b\,c}$	90.8
T11	172 $^{a\,b}$	21.6 ^{c}	93.3
T12	114.7 $^{a\,b\,c\,d\,e\,f}$	6.4 ^{c}	98.1
Mean	136	63.47	
Minimum	20	1.2	
Maximum	328	476.8	
P-value	0.024	<.001	
Least Significant Difference	107.9	96.84	
Coefficient of Variation (%)	18	33.3	

Means within a column followed by the same letter are not significantly different at the 5% probability level using Fisher's protected LSD test {n=36}

4.3.3 Effect of different weed management practices on maize agronomic performance

In 2015 cropping season, the results (Table 4.4) indicated no significant differences (P >.05) among treatments for all traits studied except for anthesis-silking interval (ASI) which was significant (P = .002). ASI ranged from 4 to 7 days with a mean of 4.78 days. Lowest ASI (4.25 days) was recorded in T1 (weedy check), T2 (hand weeding at 50 DAP), T3 (post emergence herbicide application at 50 DAP) and T7 (pre-emergence herbicide application at 1 DAP) treatments and highest (6 days) was in T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively). T6 significantly increased ASI compared to T4 (hand weeding at 25 DAP) and T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively).

Table 4.4: Effect of different weed management regimes on agronomic performance of maize in 2015 cropping season

Treatments	Days to anthesis	Days to silking	Anthesis-silking Interval (Days)	*PH(cm)	Number of ears	Cob Length (cm)	Kernels / row	100Kernels weight (g)	Grain weight (Kg/ Ha)
T1	65.75	71.5	4.25^{c}	249.4	1.2	17.2	29.9	23.95	1444
T2	64.5	69.25	4.25^{c}	242.9	1.1	15.4	23.9	22.22	1271
T3	63.75	69.75	4.25^{c}	275.3	1.2	17	28	24.07	1777
T4	63.5	67.75	4.75^{bc}	259	1.3	16	26.4	22.47	1431
T5	62.25	66.5	5.75^{ab}	249.5	1.4	17.1	28.7	22.4	1431
T6	61.5	65.75	6^{c}	258.8	1.2	17.2	30.2	22.1	1530
T7	62.75	67.25	4.25^{c}	249.7	1.1	15.8	27.1	21.4	1209
T8	62.75	67	4.5^{c}	268.4	1.2	18.6	31	24.17	2270
T9	63.25	68.25	5^{abc}	253.6	1.1	16.9	28.8	22.5	1246
Mean	63.33	68.11	4.78	256.2	1.178	16.8	28.22	22.809	1512
Minimum	59	63	4	219.6	1	12.54	20.6	19.3	197.4
Maximum	68	75	7	286.4	1.8	20.6	35.8	26.5	3258
P-value	0.411	0.157	0.002	0.264	0.368	0.14	0.116	0.096	0.065
LSD	3.532	4.051	1.013	25.76	0.282	2.147	4.693	2.078	654.3
CV (%)	3.1	3	4.4	4.8	13.3	6.6	8.6	7.6	38.4

Key: *PH= Plant height (cm) (from the ground level to the tip of the tassel); LSD=Least significant difference; CV-Coefficient of variation (%); means within a column followed by the same letter are not significantly different at the 5% level of probability using Fisher's protected LSD test. {n=36}

In 2016 cropping season, the results (Table 4.5) showed significant differences among treatments for ASI (*P*<.001); and cob length (*P* =.014) and kernel/row (*P* =.006) while all the other traits studied were non-significant (*P* >.05). ASI ranged between 3 and 6 days with a mean of 4.47 days. The longest ASI was in T5 (two hand weedings at 25 and 50 DAP) which was significantly different compared to T9 (pre-emergence herbicide application and post-emergence herbicide application at 1 and 50 DAP respectively), T2 (hand weeding at 50 DAP) and T7 (pre-emergence herbicide application at 1 DAP).The shortest ASI was in T7 (pre-emergence herbicide application at 1 DAP).Cob length ranged between 13.2cm and 22.5cm with a mean of 17.87cm. Longest cob was in T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively), which was significantly different from T2 (hand weeding at 50 DAP) and T1 (Weedy check). The smallest cob was in T1 (weedy check). Number of kernels per row ranged between 20.2 and 37.4 with a mean of 30.01 kernels. Highest number of kernels per row was in T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively), which was significantly different from T10 (Post-emergence herbicide application at 25 DAP) and T1 (weedy check) while lowest number of kernels per row was in T1 (weedy check).

Table 4.5: Effect of different weed management regimes on agronomic performance of maize in 2016 cropping season

Treatments	Days to anthesis	Days to silking	Anthesis-silking interval	*PH (cm)	Number of ears	Cob Length (cm)	Kernels / row	100Kernel weights (g)	Grain weight (Kg/Ha)	Stover dry weight (Kg/Ha)
T1	75	79.33	4.33 b c d	209.3	1	14.95 i	22.73 k	22	3620	757
T2	74.67	78.33	3.66 e	215.1	1	16.92 b c d e f g h i	29.2 b c d e f g h	23.33	4508	1020
T3	76.33	81	4.67 bc	202.3	1	16.08 d e f g h i	26 e f g h i j k	22.67	3620	1020
T4	75	79.67	4.67 b c	231.3	1	18.15a b c d e f g	30.53 a b c d e f	22.67	4640	1185
T5	75.33	81.33	6a	232.8	1	18.83a b c d	33.33 a b c	24	4969	1086
T6	76	80.33	4.33 b c d	240.2	1	19.13 a b	30.87 a b c d e	23.33	5364	1152
T7	75.33	78.33	3 e	235.6	1.07	19.09 abc	33.4 a b	23.33	4245	1089
T8	74	78.33	4.33 b c d	229.1	1	19.75 a	35 a	22	4508	1218
T9	76.67	81.67	5b	216.1	1	17.8 a b c d e f g h	28.73 b c d e f g h i j	22	3949	1053
T10	75.33	80	4.67 b c	219.8	1	18.45 a b c d e	29.67 b c d e f g	22.67	4804	790
T11	74	78.33	4.33 b c d	222.3	1	18.37 a b c d e f	31.47 a b c d	23	4705	1020
T12	76.67	81.33	4.66 b c d	227.6	1	16.88 b c d e f g h i	29.13 b c d e f g h i	22.67	4442	954
Mean	75.36	79.83	4.47	223.4	1.006	17.87	30.01	22.806	4448	1029
Minimum	72	75	3	197.6	1	13.2	20.2	20	3060	296
Maximum	78	84	6	268.8	1.2	22.5	37.4	26	6713	1283
P-value	0.769	0.333	<.001	0.071	0.48	0.014	0.006	0.739	0.259	0.123
LSD	3.334	3.475	0.88	23.14	0.056	2.384	5.219	2.224	1315.5	311.5
CV (%)	0.8	0.7	6.5	1.1	1	3.9	2.8	0.8	3.2	9.8

Key: *PH= Plant height (cm) (from the ground level to the flag leaf); CV = Coefficient of variation; LSD = Least Significant Difference; means within a column followed by the same letter are not significantly different at the 5% level of probability using Fisher's protected LSD test. {n=36}

The combined analysis for 2015 and 2016 cropping seasons (Table 4.6) results showed that treatment by season interaction for all the maize traits studied were not significant ($P > .05$) except for number of kernels/row which was significant ($P = 0.024$). The results further showed that the effect of seasons was significant ($P < .05$) for all the maize traits studied except for the number of kernels per row and 100 kernels weight. Agronomic performance of maize was generally better in 2016 season than 2015 season. The treatment effects were significant for ASI ($P < .001$) while all the other traits studied were non-significant ($P > .05$).The longest ASI was in T5 (two hand weedings at 25 and 50 DAP) which was significantly different compared to T4(Hand weeding at 25 DAP) and T2 (hand weeding at 50 DAP). The shortest ASI was in T7 (pre-emergence herbicide application at one DAP)

Table 4.6: Effect of different weed management regimes on combined analysis of maize agronomic traits for 2015 and 2016 cropping seasons

Treatments	DA (Days)	DS (Days)	ASI (Days)	Cob length (cm)	Number of ears	Kernels /row	100Kernels weight (g)	Grain weight (Kg/ Ha)
T1	68.83	73	4.167 [d e f]	16.26	1.033	26.6	22.88	2394
T2	68.5	72.5	4 [e f]	16.37	1	26.47	22.88	2772
T3	69.17	73.67	4.5 [b c d e]	16.74	1.067	27.9	23.82	2632
T4	69.83	74.67	4.83 [b c d]	16.8	1.033	27.83	22.42	2748
T5	70.33	76.17	5.83 [a]	17.84	1.133	30.63	23.38	3101
T6	69.67	74.83	5.17 [a b]	18.12	1.033	30.63	22.52	3373
T7	69	72.67	3.67 [f]	17.31	1.067	30.27	22.55	2616
T8	68.5	72.83	4.33 [d e f]	18.98	1.067	33.23	23.42	3225
T9	70.33	75.5	5.167 [a b c]	17.19	1.067	28.63	22.12	2427
Mean	69.35	73.98	4.63	17.29	1.111	29.13	22.89	2810
Season mean								
2015	63.33 [b]	68.15 [b]	4.82 [a]	16.73 [b]	1.215 [a]	28.29	22.96	1116 [b]
2016	75.37 [a]	79.81 [a]	4.44 [b]	17.86 [a]	1.007 [b]	29.98	22.81	3944 [a]
P-value								
Treatment	0.857	0.224	<.001	0.221	0.757	0.053	0.703	0.172
Season	<.001	<.001	0.05	0.029	<.001	0.101	0.748	<.001
Treatment * Season	0.892	0.919	0.109	0.138	0.57	0.024	0.142	0.186
Least Significant Difference								
Treatment	2.962	3.255	0.7841	2.141	0.2113	4.318	1.926	799.3
Season	1.396	1.535	0.3696	1.009	0.0996	2.035	0.908	376.8
Treatment * Season	4.188	4.604	1.1089	3.028	0.2988	6.106	2.723	1130.3
Coefficient of variation (%)	1.9	2	6	1.6	7.2	3.9	4.9	4

Key: DA =Days to anthesis; DS = Days to silking; ASI = Anthesis- silking interval**;** *PH= Plant height (cm) (from the ground level to the flag leaf).

4.4 Discussion

4.4.1 Weed control efficiency

Effect of different weed management treatments on weed density and weed dry weight was significant implying that they succeeded in reducing weed plants as compared to T1 (weedy check).Similar finding was reported by Tesfay *et al.,* (2014) who found that highest weed density and dry weight were in weedy check. The lowest weed control efficiency and maximum dry weight of weeds recorded in the weedy check (0.0%) was a result of no weeding. Therefore, weedy check plots allowed weeds to grow to maturity thus, were woody and produced the highest dry weight. The highest weed control efficiency and minimum dry weight of weeds recorded in T12 (two post-emergence herbicide application at 25 and 50 DAP) was an indication that herbicides are more effective than hand weeding in reducing weed infestation in maize. This outcome was in accordance with Mehmeti *et al.,* 2012who reported that herbicides are more effective in reducing density and dry weights of weeds as compared to weedy check.

4.4.2 Effect of different weed management methods on maize agronomic performance

In both 2015 and 2016 seasons weed free treated plots which included T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively), T5 (two hand weedings at 25 and 50 DAP) and T9 (pre-emergence herbicide application and post-emergence herbicide application at 1 and50 DAP respectively), took a significantly longer anthesis- silking interval (ASI) of 5-6 days compared to infested treated plots such as T7 (pre-emergence herbicide application at 1 DAP)which took 3 days probably, due to unfavourable weather conditions at silking stage thus delayed silk elongation. The finding was in agreement with Subhan *et al.,* (2007) and Anorvey, (2011) who reported that plots treated with weed control methods took more days to silking than weedy check.

In 2016 cropping season better weed management at T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively) decreased competition for resources thus, provided optimum supply of resources for growth and development of maize cob, and ultimately increased cob length. Lack of weeding inT1 (weedy check) contributed to increased competition for resources and consequently decreased the cob size. This is consistent with previous reports that allowing weeds to grow for the whole season of maize evidently decreased cob size (Mehmeti *et al.*, 2012; Simic *et al.*, 2012; Babiker *et al.*, 2013). Highest number of kernels per row at T8 (pre-emergence herbicide application and hand weeding 1 and 50 DAP respectively) was attributed to effective weed management and sufficient supply of nutrients and water and consequently, increased carbohydrates for kernel formation.

The lowest number of kernels was in T1 (weedy check) due to competition for nutrients and water. Similarly, Anees, (2008) reported that herbicide use increases the number of kernels per row. Better weed management in T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) contributed to decreased weed-crop competition and as a result increased nutrients and water thus, directly increased maize dry matter production and eventually produced maximum yield. However, weed competition in T1 (weedy check) depleted nutrients and water in the soil and therefore, stunted the maize plants and subsequently produced lower yield. Riaz *et al.*, (2007) and Anorvey, (2011) reported that the lowest maize yield in T1 (control) was due to lack of weeding therefore weeds competed for essential resources.

4.4.3 Effect of season on maize agronomic performance

The combined season analysis showed that seasons were characterized by significant differences in weather conditions. 2016 wet season (long rains season) experienced favourable weather since the total rainfall (mm) was higher and average air temperature (^{0}C) was slightly lower than 2015 dry (short rains season) season. In 2015 cropping season (short rains season), weather was not favorable since there was lower amount of rainfall (mm) which limited the normal development of maize and probably the effectiveness of herbicides especially at tasseling to grain filling stage of maize growth. In 2016 cropping season (long rains season), higher amount of rainfall (mm) favoured normal growth and development of maize up to maturity. Therefore, maize agronomic performance was better in 2016 than 2015 cropping season. Similarly, Sulewska *et al.,* 2012 observed significant differences in weather in the years and seasons of conducting experiments. Lower amount of rainfall in 2015 cropping season (short rain season) contributed to significantly fewer days to anthesis and silking and delayed silking resulting in an increased anthesis- silking interval (ASI).2016 cropping season recorded significantly more days to anthesis and silking and a shorter ASI possibly due to higher amount of rainfall which favoured normal development of maize. A reduced ASI ensures good seed set (Zaremohazabieh and Ghadiri, 2011).

Higher amount of rainfall in 2016 cropping season contributed to direct increase in water and nutrients for growth and development of maize cob and therefore, significantly increased cob length. Lower amount of rainfall in 2015 season contributed to unavailability of water and nutrients for growth and development of maize cob and therefore resulted to decreased cob length. Higher grain yield in 2016 season could be attributed to optimum supply of resources which resulted to healthy crop and ultimately higher grain weight. These findings were in line with Riaz *et al.,* (2007); Zaremohazabieh and Ghadiri, (2011) observations who indicated that tasseling to grain filling stage of maize growth is the most sensitive period to water shortage, and any water deficit during this stage will adversely affect grain yield.

4.5 Conclusion

Weed management in maize fields is very important for obtaining good crop production. Results from this study indicated that all weed management treatments except T3 (Post emergence herbicide application at 50 DAP), T4 (Hand weeding at 25 DAP), and T7 (Pre-emergence herbicide application at 1 DAP) achieved 90% weed control efficiency implying that they succeeded in reducing weed density. Moreover, these treatments also increased the agronomic performance and maize yield compared to weedy check. In 2015 season T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively) showed better weed management, increased agronomic performance and grain yield. In 2016 season and combined season analysis T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) managed weeds efficiently and produced highest grain yield. Higher rainfall contributed to direct increase of available water and nutrients for normal growth and development of maize. Therefore, differences in maize yield were due to better agronomic traits in 2016 than 2015 season.

Overall, the results showed that T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) efficiently managed weeds and produced the highest grain yield and therefore, may be adopted by small scale maize farmers.

CHAPTER FIVE

ASSESSMENT OF THE COST EFFECTIVENESS OF DIFFERENT WEED MANAGEMENT REGIMES IN MAIZE FIELDS

5.1 Introduction

Weeds are the most costly of all agricultural pests (Dedecker, 2012). Inadequate weed control, especially at early crop growth stage, results in drastic reduction of maize yield in the range of 50- 90% (Sulewska *et al.,* 2012; Ndwiga *et al.,* 2013; Saudy, 2013). Weeds reduce maize yields and quality by competing for light, nutrients, water and carbon dioxide and consequently interfere with the normal growth of crops. Weed interference increases insect pest damage, harvesting difficulties, crop contamination while simultaneously increases management expenses and consequently increase the cost of maize production (Dedecker, 2012; Larbi *et al.,* 2013). As reported earlier in section 1.1, economic damage to crop production from weeds outweighs the more incidental damage inflicted by other biotic factors such as insect pests, rodents and diseases. According to Tesfay *et al.* (2014), weeds impose a yield loss potential of 37%, which is higher than that due to insect pests (18%), fungal and bacterial pathogens (16%) and viruses (2%). Therefore, determination of the most efficient and cost effective weed management option from a combination of hand weeding and herbicides would be desirable to realize sustainable maize production among the smallholder farmers. The objectives of this study were to 1) assess the effect of different weed management regimes on grain and stover yield of maize. and 2) determine the economic benefits expected from different weed management regimes.

5.2 Materials and methods

5.2.1 Study site

The study site is as indicated in sections 3.2.1 and 4.2.1. The trial was planted in crop research field (block A) (Figure 3.1) with sandy clay loam soils.

5.2.3 Experimental design and treatments

The study comprised of two experiments: Experiment I (Table 4.1) and experiment II (Table 4.2) as indicated in section 4.2.2.

5.2.4 Field preparation and planting

The field was prepared and planted as indicated in section 4.2.3.

5.2.5 Treatments application

Hand weeding, pre-emergence and post-emergence herbicides treatments were applied as indicated in section 4.2.4.

5.2.6 Data collection

The two middle rows of every plot were sampled for data recording excluding 50 cm from the two edges of each row. Data on maize performance were recorded on grain yield (kg) and dry stover weight (kg) per plot after harvest. During growth, the cost of weed management was recorded and the amount of money expected to be derived from sale of grain and stover from each plot determined.

5.2.7 Data analysis

5.2.7.1 Statistical analysis (ANOVA)

Grain yield (kg/ha) and dry stover weight (kg/ha) data recorded were analyzed using Analysis of Variance (ANOVA) method following statistical procedures reported by Gomez and Gomez (1984) and using GenStat Fourteenth Edition statistical package. Where significant differences among treatments were detected, the means were separated using the least significance difference (LSD) test at 0.05 level of significance as demonstrated by Steel and Torrie, (1997).

5.2.7.2 Economic Analysis

The financial returns obtained from the use of different weed management regimes was conducted using the Gross Margin analytical method (Olorunmaiye, 2011) where the total variable costs (inputs) and gross income (outputs) were estimated as indicated below.

(a)Total Variable Cost (TVC)

The prices of seeds, herbicides and fertilizers were obtained from the local Agro-vet shops in Juja. Labour costs for land preparation, hand weeding, irrigation, herbicide application, harvesting and post-harvest operations were estimated in terms of the time a labourer was expected to perform a specific task and converted to man days. Each man day was valued at the recommended JKUAT payment rates for casual labour. The cost of inputs and labour were estimated for each plot and converted into total variable costs per hectare (TVC). The TVC for different weed management treatments are presented in Tables 5.3 and 5.4.

b**) Gross income (GI)**

The market prices of maize grains and stover were obtained from the farmers located near JKUAT. Gross income for each treatment was obtained by multiplying the grain yield (kg/ha) and stover yield (kg/ha) with the price of grain (KSh 50 per Kg) (0.5 US$) and stover (KSh 5 per Kg) (0.05 US$).

(c)Gross margin (GM)

Gross margin for each treatment was computed as:

Gross margin (GM) /ha = Gross income (GI) /ha – Total Variable cost (TVC) /ha

5.3 Results

5.3.1 Weather conditions of the study area

Monthly mean air temperature (^{o}c) and total monthly rainfall (mm) for 2015 cropping season and 2016 cropping season are presented in figures 3.2a and 3.2b.

5.3.2 Mean values for grain and stover yield obtained under different weed management regimes in 2015 (August -December) and 2016 (April – August) cropping seasons

Results in Table 5.1 indicated no significant differences for grain yield. In 2015, T8 (pre-emergence herbicide application and hand weeding at 1 and50 DAP respectively) produced the highest grain yield (2270 Kg/Ha) and the lowest grain yield (1209 Kg/Ha) was recorded in T7 (pre emergency herbicide application at 1 DAP). In 2016 cropping season; T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) produced the highest grain yield (5364 Kg/Ha). The lowest grain yield (3620 Kg/Ha) was in bothT1 (weedy check) and T3 (post emergence herbicide application at 50 DAP). The results further showed that in 2016 season, the effect of weed management methods was not significant for dry stover yield. The highest quantity of dry stover (1218 Kg/Ha) was recorded in T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively). The least quantity of dry stover (757 Kg/ Ha) was recorded in T1 (weedy check).

Table 5.1: Mean values for grain and stover yield obtained under different weed management regimes in 2015 (August -December) and 2016(April –August) cropping seasons

Treatments	2015 cropping season Grain yield (Kg/Ha)	2016 cropping season Grain yield (kg/Ha)	2016 cropping season Stover dry weight(kg/Ha)
T1	1444	3620	757
T2	1271	4508	1020
T3	1777	3620	1020
T4	1431	4640	1185
T5	1431	4969	1086
T6	1530	5364	1152
T7	1209	4245	1089
T8	2270	4508	1218
T9	1246	3949	1053
T10	No treatment	4804	790
T11	No treatment	4705	1020
T12	No treatment	4442	954
Mean	1512	4448	1029
Minimum	197.4	3060	296
Maximum	3258	6713	1283
P-value	0.065	0.259	0.123
LSD	654.3	1315.5	311.5
CV %	38.4	3.2	9.8

Key: CV = Coefficient of variation; LSD = Least significant difference {n=36}

5.3.3: Combined season mean values for grain yield obtained under different weed management methods in 2015 short rains cropping season(August-December) and 2016 long rains cropping season (April–August)

The combined season analysis for 2015 (9 treatments) and 2016 (12 treatments) cropping seasons (Tables 5.2) results showed that treatment and treatment*season interaction for the entire maize grain yield were not significant (*P* >0.05). Further, the results showed that the effect of seasons was significant for maize grain yield. Maize grain yield was better (3944 Kg/ Ha) in 2016 cropping season than 2015 cropping season (1116 Kg/ Ha). The highest quantity of grain (3373 Kg/ Ha) was in T6 and the least quantity of grain (2394 Kg/ Ha) in T1.

Table 5.2: Combined season mean values for grain yield obtained under different weed management methods in 2015 and 2016{n=36}

Treatments	Grain weight (kg/ha)
T1	2394
T2	2772
T3	2632
T4	2748
T5	3101
T6	3373
T7	2616
T8	3225
T9	2427
Mean	2810
Season mean	
2015	1116 b
2016	3944 a
P-value	
Treatment	0.172
Season	<.001
Treatment * Season	0.186
Least Significance Difference	
Treatment	799.3
Season	376.8
Treatment *Season	1130.3
Coefficient of variation (%)	4

5.3.4 Economic Analysis for individual season

2015 cropping season results on maize grain yield (Table 5.3) shows that total variable cost per hectare was lowest in T1(weedy check) and the highest in T5 (two hand weedings at 25 and 50 DAP). Total value of output per hectare was lowest inT7 (pre-emergence herbicide application at 1 DAP) and highest in T8 (pre-emergence herbicide application and hand weeding at 1 and50 DAP respectively). Gross margin per hectare of maize ranged between Ksh-117,492.0 (-1,174.9 US$) and Ksh-18,125.8 (-181.3 US$). T1 (weedy check) was expected to produce the lowest grain yieldper hectare however, it recorded slightly higher grain yield per hectare than T2 (hand weeding at 50 DAP), T4 (hand weeding at 25 DAP), T5 (two hand weedings at 25 and 50 DAP) and T9 (pre-emergence herbicide application and post-emergence herbicide application at 1 and 50 DAP respectively). As a resultT1 (weedy check) attained the lowest loss per hectare.T5 (two hand weedings at 25 and 50 DAP) followed by T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) recorded highest total variable cost and relatively low grain yield therefore incurred big losses as expected.

Table 5.3: Gross margin of maize grain yield as affected by different weed management regimes in 2015

Treatments	TVC Ksh/Plot	TVC Ksh/Ha	Grain yield (kg/Ha)	Maize returns (TVO) Ksh/Ha	Gross margin Ksh/Ha
T1	91.5 (0.92)	90,325.8(903.3)	1,444	72,200(722.0)	-18,125.7(-181.3)
T2	141.5 (1.4)	139,684.1(1396.8)	1,271	63,550 (635.5)	-76,134.1(-761.3)
T3	121.3 (1.2)	119,743.3(1197.4)	1,777	88,850(888.5)	-30,893.3 (-308.9)
T4	141.5 (1.4)	139,684.1(1396.8)	1,431	71,550 (715.5)	-68,134.1(-681.3)
T5	191.5 (1.92)	189,042.4(1890.4)	1,431	71,550 (715.5)	-117,492(-1174.9)
T6	171.3 (1.7)	169,101.7(1691.0)	1,530	76,500 (765.0)	-92,601.7(-926.0)
T7	105.5 (1.1)	104,146.1(1041.5)	1,209	60,450 (604.5)	-43,696.1(-437.0)
T8	155.5 (1.6)	153,504.4(1535.0)	2,270	113,500 (1,135.0)	-40,004.4(-400.0)
T9	135.3 (1.4)	133,563.7(1335.6)	1,246	62,300 (623.0)	-71,263.7(-712.6)

Note: 2015 cropping season: Ksh 100= 1 US$; Prices: 1 kg maize = ksh 50 (0.5 US$); TVC = Total variable cost; TVO/Ha=Total value of output/hectare; Ksh/Ha= Kenya shillings per hectare; value in parenthesis is the monetary value in US${n=36}

2016 cropping season results based on maize and stover grain yield (Table 5.4) showed that Gross margin of all weed management treatments were not significant (*P* > 0.05). Further, the results show that total variable cost per hectare was lowest in T1 (weedy check) and highest in T5 (two hand weedings at 25 and 50 DAP). Total value of output was lowest in T1 (weedy check) and highest in T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively). Gross margin of maize ranged between Ksh124, 407 (1,244 US$) and Ksh64, 837.6 (648.4

US$) per hectare. T10 (post-emergence herbicide application at 25 DAP) gave the highest Gross margin per hectare of Ksh124, 407 (1,244 US$) and T5 (two hand weedings at 25 and 50 DAP) recorded the lowest Gross margin per hectare of Ksh64, 837.6 (648.4 US$).

Table 5.4: Gross Margin of maize grain and stover yield as affected by different weed management regimes in 2016

Treatments	TVC/Plot	TVC/Ha	MY(kg/ha)	MYR/Ha	DSY(kg/ha)	DSR/Ha	TVO/Ha	GM/Ha
T1	91.5 (0.92)	90,326(903.3)	3,620	181,000 (1810)	757	3,785 (37.9)	184,785 (1847.9)	94,459 (944.6)
T2	141.5 (1.4)	139,684 (1396.8)	4,508	225,400 (2254)	1,020	5,100 (51)	230,500 (2305)	90,816 (908.2)
T3	121.3 (1.2)	119,743 (1197.4)	3,620	181,000 (1810)	1,020	5,100 (51)	186,100 (1861)	66,357 (663.6)
T4	141.5 (1.4)	139,684 (1396.8)	4,640	232,000 (2320)	1,185	5,925 (59.3)	237,925 (2379.3)	98,241(982.4)
T5	191.5 (1.92)	189,042 (1890.4)	4,969	248,450 (2484.5)	1,086	5,430 (54.3)	253,880 (2538.8)	64,838 (648.4)
T6	171.3 (1.7)	169,102 (1691.0)	5,364	268,200 (2682)	1,152	5,760 (57.6)	273,960 (2739.6)	104,858 (1048.6)
T7	105.5 (1.1)	104,146 (1041.5)	4,245	212,250 (2122.5)	1,089	5,445 (54.5)	217,695 (2177)	113,549 (1135.5)
T8	155.5 (1.6)	153,504(1535.0)	4,508	225,400 (2254)	1,218	6,090 (60.9)	231,490 (2314.9)	77,986 (779.9)
T9	135.3 (1.4)	133,564 (1335.6)	3,949	197,450 (1974.5)	1,053	5,265 (52.7)	202,715 (2027.2)	69,151 (691.5)
T10	121.3 (1.2)	119,743(1197.4)	4,804	240,200 (2402)	790	3,950 (39.5)	244,150 (2441.5)	124,407(1244.1)
T11	171.3(1.7)	169,102 (1691.0)	4,705	235,250 (2352.5)	1,020	5,100 (51)	240,350 (2403.5)	71,248 (712.5)
T12	151.1(1.5)	149,161(1491.6)	4,442	222,100 (2221)	954	4,770 (47.7)	226,870 (2268.7)	77,709 (777.1)
Mean								88241
Minimum								7700
Maximum								172458
P-value								0.661
LSD								65605.5
CV%								8.5

Note: 2016 cropping season: Ksh 100= 1 US$; Prices: 1 kg maize = ksh 50 (0.5 US$); 1 kg Stover = Ksh 5 (0.05 US$); Ksh/ha= Kenya shillings per hectare; value in parenthesis is the monetary value in US$; TVC= Total variable cost; MY= Maize yield(Kg/ Ha); MYR= Maize yield returns (Ksh/Ha); DSY=Dry stover yield (Kg/Ha); DSR= Dry stover returns (Ksh/Ha); TVO=Total value of output (Ksh/Ha); GM= Gross margin (Ksh/ Ha); CV = Coefficient of variation; LSD = Least Significant Difference {n=36}

5.4 Discussion

5.4.1 Effect of different weed management methods on maize grain and stover yield

Maize grain yield was generally higher in 2016 than in 2015. One major factor responsible for the lower grain yield in 2015 than in 2016 was the lower total rainfall in 2015 short rain cropping season as compared to the higher total rainfall in 2016 long rain cropping season. Therefore, higher total rainfall in 2016 led to optimum supply of water and consequently a healthy crop stand and higher grain weight (Riaz *et al.,* (2007). Also, there was a sharp drop in the volume of rainfall during the tasseling to grain filling stage of maize growth in 2015 which might have contributed significantly to the lesser grain yields in 2015 than during the 2016 growing season.

These findings were in line with the observations of Tweneboah (2000) and Anorvey (2011), who indicated that water shortage during the tasseling to grain filling stage of maize growth unfavorably affects grain yield. Effective weed management by T8 (pre-emergence herbicide application and hand weeding at 1 and 50 DAP respectively) and T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) in 2015and 2016 seasons respectively led to high grain yield. Similarly, Subhan *et al.,* (2007) reported that herbicides and hand weeding lead to an increase in grain yield as compared to weedy check. Maize stover yield increase is directly proportional to the increase in height of maize plants and dry matter production. Better weed management decreased competition and increased resources hence produced maximum stover dry yield in T8 (pre-emergence herbicide application and hand weeding at 1 DAP and 50 DAP respectively). Weed competition in weedy check depleted the essential resources and consequently stunted the maize plants therefore producing lower stover dry yield. Anorvey (2011) reported that the lowest stover yield in the un-weeded check was due to competition for essential resources with weeds.

5.4.2 Economic analysis of various weed management treatments in maize

Gross margin per hectare values differed among treatments due to varying costs of production. Lowest gross margin per hectare was recorded in T5 (two hand weedings at 25 and 50 DAP) and was possibly due to the high cost of hand weeding. Similarly, Gianessi (2009) observed that two properly timed hand weedings were enough to reduce loss caused by weeds in maize plots. However, this weeding method was nearly three times as expensive as the combined cost of herbicide and labour for spraying. Muthamia *et al.,* (2001) too reported that use of herbicides resulted in significantly higher maize grain yields and economic benefits than hand weeding maize crop. The highest gross margin in T10 (post-emergence herbicide application at 25 DAP) was attributed to fairly low total variable cost of production due to lower cost of post emergence herbicide application. Similar results have also been discussed by Micheni *et al.,* (2014) who reported that the net benefits increased as a result of reduction in production costs associated with herbicides. Therefore, the results indicated that herbicides can improve the economic returns because of the increased yields of maize attributed to more effective weed management during the critical period of maize growth when there is a shortage of labour for manual weeding.

These results are in line of those reported by Micheni *et al.,* (2014) who reported that herbicides allowed large reductions in labour required for weeding. T6 (hand weeding and post-emergence herbicide application at 25 and 50 DAP respectively) could be an alternative option because it gave fairly high gross margin per hectare, good weed control efficiency and improved agronomic performance with the highest grain yield, except for its high cost of hand weeding. Riaz *et al.*, (2007) also revealed that among various weed control methods, chemical weeding at 2 – 3 leaf stage of weeds and hand weeding at 50 days after planting treatment showed promising results. Therefore, herbicide could be a substitute for hand weeding especially where labour is limiting and land is large (Anorvey, 2011).

5.5 Conclusion

Results from this study indicated that effect of different weed management regimes on weed density, weed dry weight and weed control efficiency were significant. Moreover, those treatments also increased the agronomic performance and yield of maize compared to weedy check. Similar results have been discussed by Tesfay *et al..,* (2014) who reported that the effect of different pre emergency and post emergency herbicides on weed density, weed dry weight and weed control efficiency were significant and that the treatments also significantly increased the yield and yield component of maize.

The results further showed that T6 (hand weeding and post emergence herbicide application at 25 and 50 DAP) was the most effective weed management option for improved agronomic performance and yield of maize while T10 (post-emergence herbicide application at 25 DAP) was the most cost effective treatment. However, due to high cost of hand weeding, gross margin of T6 (hand weeding and post emergence herbicide application at 25 and 50 DAP) decreased. T10 (post-emergence herbicide application at 25 DAP) gave the highest gross margin and achieved fairly good grain and stover yield. Therefore, On the basis of this study it is suggested that T10 (post-emergence herbicide application at 25 DAP) may be used by the small scale farmers for controlling weeds in maize with fairly good yield and economic returns. According to the analysis of this field experiment, the test hypothesis as stated in the three specific objectives is rejected.

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APPENDICES

Appendix I: Guide to some herbicides for use in manual

Herbicide, tradename and formulation	Dose product/ha	Crop stage	Weed stage	Weeds controlled	Remarks
Atrazine Gesaprim (500g/lFW) Gesaprim (800g/kg WP)	 2.5-5 L 1.5-3 kg	Pre-emergence or post-emergence	Before weeds are 3 cm high	Many annual broad-leafed weeds and some grasses but not Rottboellia (itch grass)	Apply to well prepared, moist soil when rain can be expected within a few days.
Atrazine +Metolachlor Primagram 500 (250+250 g/l FW) Primagram 200(100 +100g/lFW)	 2.5-6 l CDS application 10-12 l undiluted	Pre-emergence and up to 3-leaf stage	Pre-emergence or early post-emergence before weeds are 3 cm high	Many annual grasses and broadleafed weeds. Rottboelliais resistant.	Use low doses on light soils. Apply to well prepared, moist soil. In dry conditions, incorporate into the upper 5 cm

					of soil.
Metolachlor Dual (720g/l EC)	1.5-3.01	Pre-emergence, up to 4 weeks before sowing	Pre-emergence	Many annual grasses but not Rottboellia.	Can withstand hot, dry conditions for 10-14 days.
Paraquat Gramoxone (200g/ 1 ml)	1.5-3.01	Just before emergence or as a post emergence when crop is at least 40 cm high.	Post emergence to seedlings and young weeds.	Most annual grasses and broadleafed weeds.	Apply as often as required avoiding spraying developing prop roots to avoid lodging.