INTEGRATION OF COVER CROP TECHNOLOGY AND IMIDAZOLINONE RESISTANT MAIZE ON WEEDS AND MAIZE YIELD IN TWO ASAL AREAS OF KENYA

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Integration of cover crop technology and imidazolinone resistant maize on weeds and maize yield in two ASAL areas of Kenya

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DECLARATION

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

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DEDICATION

I dedicate this PhD thesis to all the maize value chain players and actors. May it serve as a tool for disseminating generated knowledge for sustainable increased maize productivity, food security, and generating more income for maize farmers in Kenya.

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LIST OF ABBREVIATIONS AND ACRONYMS

AATFq	African Agricultural Technology Foundation
ACT	Africa Conservation Tillage
AEZ	Agro-ecological zone
ANOVA	Analysis of Variance
ASALs	Arid and Semi arid Lands
CA	Conservation Agriculture
CT	Conservation Tillage
CDF	Community Development Fund
CIMMYT	International Centre for Maize and Wheat
DAP	Days after planting
ECA	East and Central African Countries
ECAMAW	East and Central Africa Maize and Wheat Research Network
FAO	Food and Agricultural Organisation of the United Nations
FCRI	Food Crops Research Institute
GMO	Genetically modified organisms
Ha	Hectares
IFAD	International Fund for Agricultural Development
IR	Imidazolinone Resistant (Imazapyr resistant)
IIRR	International Institute of Rural Reconstruction
IITA	International Institute of Tropical Agriculture

KALRO	Kenya Agricultural and Livestock Research Organisation
KARI	Kenya Agricultural Research Institute
KASAL	Kenya Arid and Semi Arid Lands
LM	Lower midland
LR	Long Rains
M	Metres
M	Million
N	Number of observations or data points
NARL	National Agricultural Research Laboratories
NPK	Nitrogen, Phosphorus and Potassium
OECD	Organisation for Economic Cooperation and Development
PRA	Participatory Rural Appraisals
SE	Measurement Standard Error
R	Pearsons' correlation coefficient
$\mathbf{R^2}$	Coefficient of determination
S-N-K	Student Newman Keuls
SPSS	Statistical Package for Social - Scientists
SR	Short rains
SSA	Sub Saharan Africa
T	Tonnes
US	United States
USDA	United State Department of Agriculture

ABSTRACT

Weeds compete for nutrients and soil moisture resulting to low maize (*Zea mays* L) yields in drylands. Previous efforts to minimize weed related yield losses are hampered by limited knowledge on weeds and management technologies needed to boost maize productivity. This thesis reports four studies conducted to address four objectives. Study one was a survey conducted in 2009, to determine weed species diversity and density in maize growing fields in two counties: Machakos (Kalama where cover crop technology showed potential to suppress weeds and increase maize yields); and, Makueni (Kee a neighbouring region where cover crop technology was not introduced). A quadrat was placed randomly and weed species in the sample area counted and recorded. This was repeated in four other locations in a "W" designated pattern in each maize field. The procedure was replicated in 12 villages. Study two was done to examine sociological factors influencing cover crops adoption in Kalama and Kee using a multistage sampling technique. A semi-structured questionnaire was administered to 80 randomly selected participants to obtain sociological information including gender, age category, education levels, and cover crops adoption. Two binary logistic regression models were used to determine the factors affecting cover crops adoption by respondents. In order to enhance weed control under cover crop study three was done to evaluate effect of Imazapyr coated (IR-maize) on rape weed (*Brassica napus* L.) emergence and growth in green house for 35 days. Rape was chosen because it is highly sensitive to Imazapyr herbicide. Study four was done to evaluate the effect of dolichos (*Lablab purpureus* L.) and open pollinated imazapyr coated (IR-maize) on weed species composition, density and maize yield in three years at Kenya Agricultural and Livestock Research Organisation, Kiboko. Initial weeds were controlled using glyphosate at 1.6 kg ai ha^{-1}. Twenty four plots were marked, each measuring 4 x 5 m. Six treatments 1) IR-maize coated, 2) IR-maize coated + brown dolichos, 3) IR-maize coated + black dolichos 4) IR-maize uncoated, 5) IR-maize uncoated + brown dolichos, 6) IR-maize uncoated + black dolichos were laid out in a randomized complete block design replicated four

times. IR-maize was planted at a spacing of 90 x 45 cm with 2 seeds per hole. Weeds were sampled from a 1.0 m^{-2} quadrat 21 and 42 days after planting (DAP) and recorded for types of species and density .The data on weed species and densityand maize yield was subjected to analysis of variance using Genstat version 12.0. Study one established that 25 weed species infested maize fields; and, species were mainly annuals and few perennials. *Oxygonum sinuatum* (Meisner.) Dammer and *Bidens pilosa* (L.) were the most abundant among broadleaf species while *Dactyloctenium aegytium* (L.) Willd and *Eleusine indica* (L.) Gaertn. were abundant among grasses. An inventory of weed species was developed. Weed species were location specific; and, management technology (ies) were needed. Study two analysis indicated that 80% of the respondents had adopted cover crop technologies at Kalama compared to 57.5% at Kee. Men were less likely to adopt ($P < 0.05$). At Kalama age category affected cover crops adoption ($P < 0.05$); however, age had no significant effect at Kee. Education indicated mixed effects on cover crop adoption suggesting other factors not covered are influencing. Knowledge and skills, demonstration of gains and related cost had effect on cover crop adoption ($P < 0.05$). Majority of farmers, adopters or non-adopters used seeds from market. Non-adopters in Kee (37.5%) used relief seed suggesting other factors were required to give the threshold to influence adoption. Study three results showed that herbicide coated IR-maize reduced mean weed dry matter by 12 times compared to uncoated IR-maize ($P < 0.05$). Herbicide coated IR-maize with dolichos or beans or cowpeas reduced weed dry matter by 6 times compared to uncoated IR-maize with cover ($P < 0.05$). Weed dry matter in herbicide coated IR-maize watered once a week was lower than watered twice ($P < 0.05$). Watering twice a week decreased emerged weed count in herbicide coated IR-maize with dolichos, beans or cowpeas ($P < 0.05$) respectively. Study four established that eighteen (18) weed species infested Kiboko field. Interaction of dolichos and herbicide coated IR-maize had no effect on the number of weed species. Dolichos reduced the density of *Portulaca quadrifida* L. and *Paraknoxia parviflora* L., and increased *Eleusine indica* L ($P < 0.05$). Dolichos

decreased weed species composition by 14% (21 DAP) and 33% (42 DAP) compared to no cover. Maize yields were higher in plots with dolichos than without ($P < 0.05$). From the results, knowledge on weeds could be used to determine appropriate adaptive weed management, pin point problem weeds that need concerted research efforts, and form a base for measuring weed changes in future.

Key words: Conservation agriculture, Cover crop, Herbicide resistant-maize, Maize production, Sustainable yields; Weed management

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Introduction

Agriculture is the backbone of the Kenyan economy. Kenya's agriculture is envisioned to play a major role within the economic pillar, of Kenya's Vision 2030 (Government of the Republic of Kenya (GOK), 2007). More than 75% of arable land is in the Arid and Semi-Arid Lands (ASALs), which are prone to erratic weather, conditions (Jaetzold *et al*., 2005). ASALs form 88% of the landmass, with varying aridity; covering semi-arid, arid and very arid agro-ecological zone (Jaetzold *et al*., 2005). This include lower Eastern Kenya including Machakos and Makueni. In Machakos and Makueni Counties, resource poor smallholder farmers produce cereals (maize, sorghum, and millets), legumes (beans, cowpeas, pigeon peas and green grams), root and tubers (cassava/sweet potato) in mixed cropping systems. Maize (*Zea mays* L.) which is the staple food crop is highly sensitive to weed competition. High weed infestation is a challenge in maize cropping system. Maize planted in fields heavily infested with weeds resulted in substantial yield reductions even when rainfall was adequate (Abdin *et al*., 2000). Majority (90%) of the smallholder farmers manages weeds using hand hoes or animal drawn mould board ploughs which is laborious. Hand-weeding is labour intensive; labour is scarce and costly especially at the critical period of maize development. These results in delayed weeding and increased duration for weed crop competition. Studies in Machakos and Makueni Counties farming systems (Mwangi *et al*., 2011) indicated that appropriate weed management practices can contribute to increased maize productivity. The weed survey was anticipated to form a baseline to guide formulation of adaptive weed management strategy (ies) and to provide parameters to measure their progress at Kalama and Kee. In addition, a weed survey could show changes in weed occurrence in future comparisons/weed predictions. Kalama division in Machakos was selected because weeds posed a challenge in maize research activities earlier with introduction of conservation agriculture (CA). Kee division in Makueni was selected on the basis of its proximity to Kalama division and also provided a good comparison. The area is classified under arid and semiarid land. Average annual rainfall is about 500 mm with the exception of hilly areas where it ranges from 800 - 1200 mm. The annual rainfall has about 25 - 50% potential evaporation. Average annual temperature ranges from 21 – 24ºC (Jaetzold *et al.*, 2005). Maize is the preferred staple food crop giving high yields when rainfall is adequate and failing when rainfall is inadequate. Maize is highly sensitive to competition particularly under water stress and this contributes to low yields (Weed Soft, 2006; Rashid & Rasul, 2010).

Although there is still no known general method to manage all weeds species efficiently, literature describes several specialists' techniques that manage weeds; however, all these involve knowledge on weeds and the technology. Previous efforts to minimize weed related yield losses in Machakos and Makueni Counties, were hampered by limited farmer knowledge on weeds and management techniques that could boost yields under ASAL (Personal communication).

Options to increase maize yields included (1) use of improved crops such as drought tolerant, 2) high yielding cover crop varieties such as dolichos, beans, pigeon peas, cowpeas, green grams, sorghums, millets and pumpkins, which could provide cover on flagile soils, minimize their disturbance and improve health in maize cropping systems 3) new innovative maize technologies (CIMMYT, 2005), 4) integration of herbicide coated imidazolinone-resistant (IR)[1] seeds (Kabambe *et al*., 2008), (3) conservation agriculture (CA) technologies (IRRI & ACT, 2005; Gachene & Mwangi, 2006; Boahen *et al*., 2007) and (4) access to agricultural production technologies and innovations (Minten & Barrett, 2008) among others.

Research (Gachene & Mwangi, 2006; Karuma *et al*., 2011; Mwangi *et al*., 2015a) showed that legume cover crop technology managed weeds, and increased yields of maize. However, information on cover crop adoption in Africa is limited and sometimes conflicting (Giller *et al*., 2009). Moreover, information on the most significant variables that affected the probability of cover crop adoption which could help understand potential barriers to adoption, and contribute to designing successful development projects and setting research priorities for Kenya and similar regions was lacking.

In addition, research with herbicide coated IR-maize seeds did not affect root zone of legume intercrops 15 cm from coated seeds (Kanampiu *et al.*, 2002; Kanampiu *et al.*, 2003); however, the effects on weeds species diversity and density under conservation agriculture in a drought prone area needed to be addressed. This study evaluated potential in cover crop technology integration with herbicide coated IR-maize on weeds and maize yields under conservation agriculture at KALRO-Kiboko. The aim of this project were to determine weed diversity and density; and, cover crop adoption and factors likely to influence adoption, so that steps could be taken towards effective

[1] Imidazolinone - resistant (IR) maize contains genes conferring resistance to imidazole herbicides.

measures to increase adoption. Adoption was likely to increase maize yields among other benefits (Gachene & Mwangi, 2006; Kramberger *et al.*, 2009; Ngome *et al.*, 2011); and, therefore, cover crops could be integrated in innovative weed management strategies for competitive maize cropping systems in ASAL.

This thesis is divided into eight chapters. Chapter one introduces the project. Chapter two covers the literature reviewed. Chapter three is a weed survey carried out to establish the weed species diversity and density in maize growing fields in Machakos and Makueni Counties. Chapter four examines cover crops adoption and factors likely to influence adoption in Kalama and Kee divisions. Chapter five is a study to test the effect of coated IR-maize on rape weed in the green house. Chapter six reports evaluation on the effect of integration of cover crop technology and coated IR-maize on weeds and maize yields in ASAL field conditions. Chapter seven gives a general discussion, conclusions and the recommendations of the project. The hypothesis of the study was that IR-maize coated with imazapyr and cover crop integration will not control all weeds surrounding maize and increase the yield. This study introduced a new technique of cover crop integration with herbicide coated IR–maize that allowed direct measurement of weed management and maize yields in ASAL.

1.1.1. Study location

This study was conducted in Machakos and Makueni Counties (Fig. 1.1 and 1.2). Conservation agriculture (CA) showed potential to increase maize yields hence the motivation to carry out studies here.

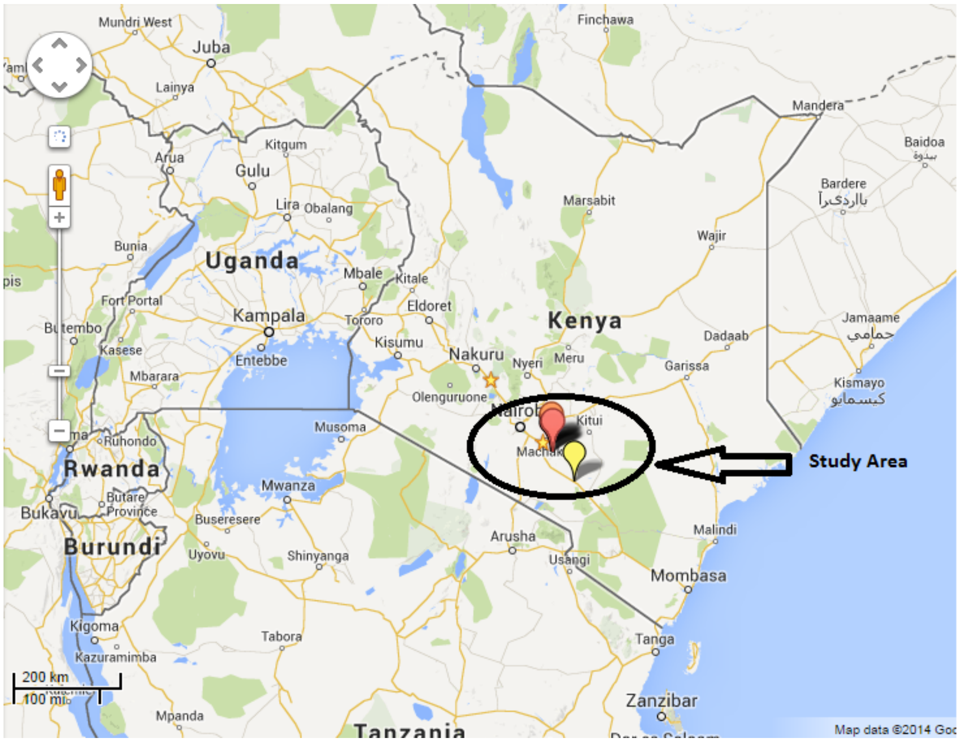

Figure 1.1: A map of Kenya showing Kalama and Kee and surrounding regions

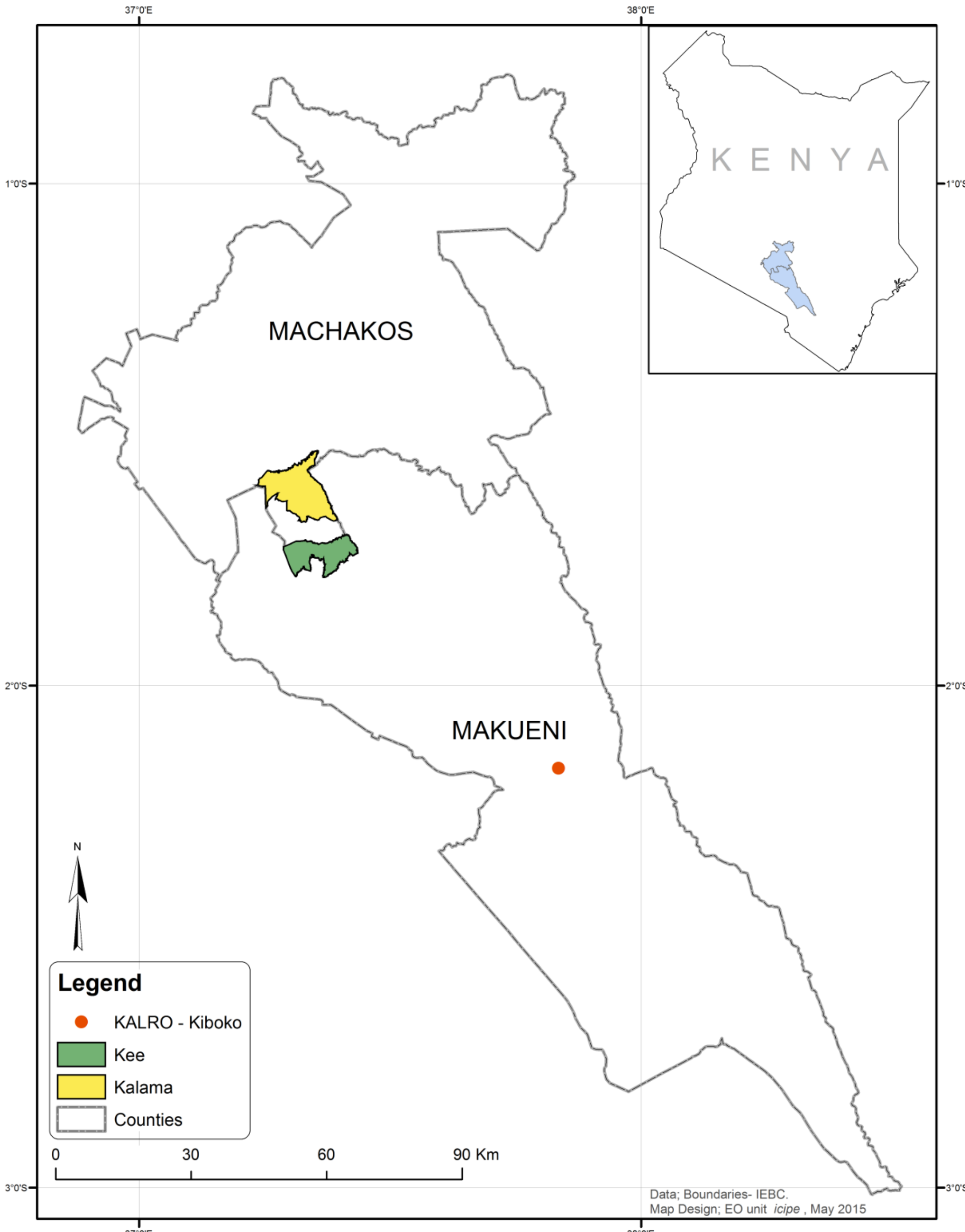

Figure 1.2: A map of Kenya showing the study area, Machakos and Makueni County

1.1.2. Conservation Agriculture (CA)

The term was introduced in 1970 and adopted by UN FAO in Rome in 1990 (FAO, 2005). Often it is used interchangeably with other terms like conservation tillage (CT), no-tillage, zero–tillage, direct seeding/planting, minimum tillage, conservation farming, and planting without ploughing (FAO, 2005).

CA is more than just a crop establishment technique or a particular method of cultivation. CA essential elements are maintaining minimal soil disturbance, having permanent or semi-permanent organic soil cover and use of crop rotation or plant association. They are all applied simultaneously or alternatively (IIRR & ACT, 2005). It is different from conventional agriculture in that it retains crop residues on soil surface as cover, and does not incorporate them into soil by tillage nor burn them.

In the past, tillage in conventional cultivation practices were required for incorporating residues and other soil amendments into the soil for preparing seedbed, controlling weeds that have germinated or carried over from previous season, releasing minerals through mineralization and oxidation of soil organic matter, and breaking any compacted layers. These functions are increasingly being questioned by farmers and researchers who have found that with minimum-tillage and some adaptation of other practices, conventional tillage is not necessary.

Weed management in CA context is different from the current farmer's traditional practice. Soil has to be covered and therefore cover crops are crucial. Cover crops can be defined as crops grown to cover soil with other benefits including supressing weeds. In Africa, it is prudent to select cover crops with a high rate of biomass production, drought tolerant, pest and disease resistant and easy to manage (Mwangi, 2003). When the elements of CA are applied correctly and continuously, dependence on external inputs and labour could be reduced while yields and earnings increased.

In ASAL, minimum soil disturbance can be achieved by using 1) sub-soiler to break the soil hard pan and Magoye ripper ridger (i.e. a ripper tine fitted to a normal moldboard plow beam) to widen the planting furrow for manure placement (IRRI & ACT, 2005); and, 2) cover crops such as commonly known hyacinth bean, dolichos or lablab and locally "*Njahi"* (*Lablab purpureus* or *Dolichos lablab*). Cover crops are planted at the same time as maize between the maize rows to achieve agronomic and environmental benefits. The agronomic benefits included increased organic material, infiltration and conservation of soil moisture, and improved soil for better root development. Covering effects suppressed most of the weeds emerging after the first weeding and reduced weeding labour by 42 to 50% and time spent by 75% (Gachene & Mwangi, 2006; Boahen *et al*., 2007).

1.2 Statement of the problem

There was high weed infestation in resource-poor smallholder maize based cropping systems (Mwangi, 2003). Plant species composition and abundance at any given time reflects outcomes from suite of dynamic forces including environmental characteristic, management practices and species interactions (Webster & Coble, 1997). The differences in population diversity are the reason weeds so frequently succeed in association with neighboring crop (Dekker, 1997). Weed species diversity is dynamic as wind, birds, water, implements, ploughing, contaminated seeds, and animals introduce more and new weeds. However, comprehensive information on the weed species in Machakos was lacking. Weeds grow aggressively (Demjanova *et al*., 2009) competing with maize during the early stage of maize development. Currently, labour is scarce therefore expensive, as youth have migrated to urban areas leaving the children, old, and the sick who can not cultivate land effectively. Consequently, weeds get a long duration to compete with maize resulting in depressed final yields. The consequences are more severe when soil moisture is inadequate (Abdin *et al*., 2000). Manual weeding practiced by majority of the resource poor farmers aims at 100% soil inversion and therefore exposes the limited soil moisture to evaporation. Moreover, promoting CT systems was constrained by weeds and unavailability of crop residue and appropriate cover crops which could suppress weeds and conserve soil moisture (FAO, 2005). Various reports (Chabi-Olaye *et al*., 2005: Gachene and Mwangi 2006; Mwangi *et al*., 2015b) have indicated some of the benefits of growing cover crop in maize cropping systems including weed supression. Adoption of cover crop technology has been reported for some farming systems (Singer *et al*., 2007). However, information on cover crop adoption in maize cropping systems in arid and semi-arid regions in Kenya and the factors likely to influence adoption were limited. Without knowledge on the factors with a significant effect on likelihood of cover crop adoption by farmers, steps to increase adoption may not be effective. Factors with significant correlation to cover crops adoption needed to be analysed and output used to develop models for predicting farmers' likelihood to adopt or not to adopt. But, information on the most significant variables affecting the probability of cover crop adoption that could help understand potential barriers to adoption, and contribute to designing successful development projects and setting research priorities for Kenya and similar regions was lacking. In addition, imazapyr coated (IR-maize) has potential to control weeds (Broome *et al*., 2000; Kanampiu *et al*., 2002; CIMMYT, 2005). Kabambe *et al*. (2008) have shown that apart from *Striga* weed species control; there is a weed free band of 2-5 cm around the base of each maize plant. This suggested that coated IR–maize and cover crops could allow innovative integrated weed management in CA systems. However, information on cover crop technology integration with IR-maize was limited creating a knowledge gap.

1.3 Justification of the study

Weeds infestation in maize (*Zea mays* L.) cropping systems in ASAL remains a challenge due to many factors including resource poor farmers' weeding practice which involves 100 % soil inversion to make fields clean of all crop residues; and, this requires much labour (8.8 man day's ha^{-1}). Labour which is scarce therefore increases production cost (about Ksh 7,920 ha^{-1}) to unsustainable level.

The weeding operation exposes the limited soil moisture to evaporation forces aggravating the matter for maize seedling under moisture stress because maize is sensitive to weed competition particularly under moisture stress. Efforts to increase maize yields with improved varieties are affected by weeds infesting maize cropping systems. Studies (Frieben & Kopke, 1995; Hald, 1999) have indicated that management practices contribute to weed species diversity. Most farmers in the area of study grow a local maize variety known as "Kinyanya". Kinyanya yields are low ranging from 0.3 - 0.5 t ha^{-1} during the long rains (April-May) which is unreliable, and 0.9 - 1.2 t ha^{-1} in the short rains (November-December) that are more reliable. There is a potential yield of over 3 times farmers practice using improved drought tolerant maize varieties with conservation tillage technologies (Mwangi, 2003; Gachene & Mwangi, 2006). This could contribute towards the target to end hunger, achieve food security and promote sustainable agriculture (Goal 2), (UN Sustainable Development Goals, 2015).

Research (Mwangi *et al*., 2015a) showed that cover crops intercropped with maize were effective in managing most of the weeds after canopy establishment; and, maize yield increased after rotation with legume cover crops such as dolichos. However, due to small land acreage, the opportunity cost of growing pure cover crop for rotation purposes in subsequent season is not practical.

In addition, application of conventional pre-emergence or post emergence herbicides is not feasible due to several factors such as lack of quality water, environmental hostility, farmer's sceptism, lack of sprayers, herbicide inaccessibility and high cost.

Research (CIMMYT, 2005) indicated that herbicides such as imazapyr have potential to control weeds with reduced carry over effects in maize fields. Diffused imazapyr that was not absorbed by maize seedling created a weed free band around the maize base. The principle behind the weed free band is to manage weeds or cover crops that could compete with maize. In addition, herbicide coated IR-maize would have other benefits including reduced labour to manage weeds and increased maize productivity; seeds are coated and packed by seed industry stewardship ready for use; and, stakeholders stand to gain; information on this technology under ASAL conditions was lacking.

Moreover, findings (Gachene & Mwangi, 2006; Karuma *et al*., 2011; Mwangi *et al*., 2015a) showed that legume cover crops managed weeds effectively. However, information on cover crop adoption and factors associated with likelihood to adopt were lacking. Hence, there was need to examine cover crops adoption and factors likely to influence adoption. Information to improve understanding of effects of cover crop integration with herbicide coated IR-maize on weeds management and maize productivity under ASAL environmental conditions was limited, hence the need for the study.

1.4 Overall objective

To assess the potential of integrating IR-maize with cover crop technology for weed management and increased maize yields in ASAL areas of Kenya.

1.4.1. Specific objectives

1. To determine the weed species diversity and abundance in Kalama and Kee.
2. To determine adoption levels and factors influencing adoption of cover

crop technologies for weed management in Kalama and Kee.

3. To evaluate the effect of IR-maize coated with imazapyr on emergence and growth of common weed species in the green house at KALRO-Kabete.

4. To evaluate the effect of cover crop technology integrated with imazapyr coated IR-maize on weed composition and density, and maize yield in the field at KALRO-Kiboko.

1.5 Null Hypotheses (H_0)

1.5.1. There is no difference between weed diversity/density infesting maize fields in Kalama and Kee.

1.5.2. Age, gender or education levels of respondents have no significant effect on cover crops adoption in Kalama and Kee.

Cover crop knowledge sources, seed sources, preferred seeds, and constraints have no effect on adoption at Kalama and Kee.

1.5.3. Imazapyr from IR-maize seed coat will have no effect on weeds surrounding the maize in green house at KALRO-Kabete.

1.5.4. Cover crop synergy working together with Imazapyr from coated IR-maize will have no effect on weeds sorrounding maize and maize yields in the field at KALRO-Kiboko.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany of maize (*Zea mays* L.)

Maize belongs to Division: Magnoliophyta, Class: Liliatae, Order: Cyperaales, Tribe: Andropogoneae, Sub family: Panicoideae, Family: Poaceae or gramineae, genus: *Zea*, and species: *mays* (OECD, 2003). Botanists believe it grew first in North America. First explorers found the six main types of maize (Floury, waxy, popcorn, dent, sweet and pod maize) grown by American Indians; which occurred in red, blue, pink, black and white colours (OECD, 2003; Australia government, 2008).

Maize is a C - 4 plant and hence more efficient in water and carbon dioxide use compared to C - 3 plants. All grasses and grain crops are C - 4 and therefore of primary economic importance (Australia Government, 2008). Maize a typical annual grass, forms seasonal root system, erect stem (made of nodes and internodes), and some cultivars produce elongated lateral branches (tillers). Maize is cultivated in most parts of Kenya including in ASAL areas. Majority of the farmers grow different varieties depending on region, seed availability in the market or seeds donated including relief agencies. In Machakos and Makueni, the most common variety grown is "Kinyanya" a local variety and some hybrids. Local weed management practices including plowing using drought power or hoeing using manual power exposes the limited soil moisture to evaporation (Croissant *et al*., 2008). Hence the need for novel management practices that control weeds and conserve moisture.

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).

2.2 Economic importance of maize

Maize is the third most important cereal world-wide in terms of area cultivated, after wheat and rice (Khan *et al*., 1999; Abbassian, 2013). In Africa it is the second most important food crop after cassava. It is grown in 25 m ha in Sub Saharan Africa (SSA); and, is the most important cereal crop in SSA (Khan *et al*., 1999). It is a crop that grows from sea level to 3800 m above sea level with a growing season of 42 - 364 days reflected in high diversity of morphology and physiological traits (Paliwal, 2000a; Australia Government, 2008). Adaptation of maize means good performance with respect to yield and other agronomic traits in a given environment (all conditions in which the plant is subjected during the growing season). Maize is economically useful at different developmental stages depending on the producer goal from forage, baby corn, green maize, seed grain and stover.

2.3 History and production trend of maize

There are five species in genus *Zea*. Species *Zea mays* L.; sub species *Zea mays* ssp. *mays* is the only cultivated species. Other species and subspecies are wild grasses referred to as teosintes. While the possibility of secondary Centre's of origin in South America cannot completely be ruled out, the oldest (7000 years) archaeological maize was found in Mexico's valley of Tuhuscan (Ames, IOWA, 1985; Gibson & Benson, 2012). Teosinte (*Zea Mexicana*) is the wild progenitor of maize (Ames, 1985; Australia Government, 2008). Pod corn (extinct) was domesticated explaining the remarkable variability found within species. Regardless of the origin, maize has proven to be one of the most adaptable and variable member of grass family (Ames, IOWA, 1985; Australia Government, 2008; Gibson & Benson, 2012). Evolution mainly under domestication has resulted to biotypes with adoption ranging from tropics to temperate zone and growing period extending from 6 to 52 weeks (Australia Government, 2008; Gibson & Benson, 2012). During domestication of maize, every region in which it has been produced have a selection of maize cultivars or landraces which farmers have maintained or improved; and, they have adapted to local requirements and characteristics (Paliwal, 2000a). In Machakos and Makueni Counties most farmers mainly grow a local variety known as “Kinyanya”.

2.4 Ecological and cultural requirements

Maize requires 765 mm of rainfall and must be distributed especially within 3 weeks period centered on tasseling; and 140 days frost free (Brown *et al*., 1984; Australia Government, 2008). Associated evapotranspiration varies with plant density, stage of growth, and available water atmospheric conditions for example 0.2 - 2.5 mm/day for young plants to 4.8 mm/day in the reproductive phase (Shaw, 1977). Correlations between rainfall and the grain yield during vegetative growth and reproductive stages are 59%, 61% and 60% (Rashid & Rasul, 2010). Rainfall ranging 200 - 300 mm at uniform intervals during vegetative phase (3^{rd} to 9^{th} leaf stage) increases yield while higher amounts reduce. The most water sensitive stage is reproductive stage, beginning of tassling/silking to grain formation (Laver, 2003; Australia Government, 2008; Abendroth & Elmore, 2011; Milander, 2015).

The geographical potential for growing is greater than any other cereal. It does best at 21 - 27°C and pH 6.0 - 7.2 (Paliwal, 2000a). Densities depend on cultivar with inter-row ranging from 0.5 - 1.0 m. It has been breed to grow 0.6 - 1.17 m tall. It matures when Kernel ceases to increase in weight. Typical maize grain yields, range between 2 - 8 t ha $^{-1}$ for rain fed depending on region, and 5 - 13 t ha $^{-1}$ for irrigated maize crop (Australia government, 2008; Hussain *et al*., 2015). Yield variability is more in SSA than elsewhere in the world, and depending on the region and management among other factors. Variability in production for various regions in the period 2005 – 2008 is shown: Brazil 3.8 t ha^{-1}, Thailand 3.9 t ha^{-1}, Mexico 2.5 t ha^{-1}, Philippines 2.5 t ha^{-1}, and, SSA 1.4 t ha^{-1} (Byerlee & Heisey, 1997).

In Kenya, most of the maize productivity gains were achieved in 1980s through smallholder adoption of appropriate improved seed and fertilizer and state policies that were encouraged through supporting markets and prices, practices and advisory services (Smale *et al.*, 2011). However, high dependence on pre-dominant rain-fed agriculture, whose productivity and profitability is largely determined by unpredictable rainfall; and, inappropriate management practices are critical reasons for inability to produce adequate maize in Kenya (Africa) today (Smale *et al.*, 2011).

2.5 Global maize uses

In high income countries, 70% is used as feed, 3% as food and 27% as biofuels, industrial and seed. In sub-Saharan Africa (SSA) 70% is used as food outside South Africa and only 12% is used as feed, the rest (18%) is used as industrial raw material for oil, commercial animal feed production (dog feed, fish feed, silage), paper and pharmaceuticals manufacture (Smale *et al*., 2011).

Maize is used as human food in different forms (corn meal, popcorn, roast maize, unleavened bread, soft drink, cornflakes, and horminy-nixtamalization among others). It is a major source of starch world-wide in home cooking and industries (maize glutein, maize syrup, grain alcohol) (Paliwal, 2000b; Australia Government, 2008; Gibson & Benson, 2014; Milander, 2015). In addition it is used in alternative medicine (silk), as chemicals (plastics, fabrics, adhesives), as cooking oil and bio-fuels (research for biogas diesel in Germany using Fischer Tropsch method) (Brown *et al.*, 1984). It is used in horticultural (as sweet corn, roast maize) and agronomically as field maize (dry grain) or seeds. Production of different maize types depends on use i.e. flour (*Zea mays var.amylacea*), waxy (*Zea mays var.ceratina*), dent (*Zea mays var.identata*), popcorn (*Zea mays var.everata*), sweet (*Zea mays var.saccharata* or *Zea mays var. rugosa*), Flint (*Zea mays var. indurata*) pod (*Zea mays var.tunicata*) and Stripped (*Zea mays var. japonica*). For instance in the US yellow starchy, and white for dry milling, South

America white, Argentina flint white or yellow, France yellow, Mexico yellow, South Africa white and yellow for animal feed. Greatest economic value is from dent (*identata*) maize. Yellow maize contains pigment zeaxanthin and 200 - 900 mg of beta carotene per 100 g, feeding it to chicken increases pigmentation of skin and eggs, and beta carotene is converted to vitamin A (Sajilata *et al*., 2008). Flint has a hard vitreous endosperm for gruel, highest yield potential and is the most widely grown (Paliwal 2000b; Milander, 2015).

The biggest non-food user of maize starch is the paper industry. Oil and protein by products of commercial starch production are used in food manufacturing (Paliwal, 2000b). In Kenya maize is used as a horticultural crop for green maize, baby corn, food crop (Ugali and githeri), forage, commercial crop (grain and seed), in industries for producing starches, animal feed and oil production. Agriculture employs 65% of Kenya's workforce (DNA, 2016). Among the workforce are the different actors along the maize value chain including: farmers, input suppliers, traders, millers, retailers and consumers (Kangethe, 2011).

2.6 Prediction of maize production

Trends in average maize grain yield and area harvested in different regions of Africa, from 1961 to 2007 showed East Africa average annual yields stagnated at 1-1.5 t ha^{-1} but in the same period the total area harvested increased from about 3.8 - 12.6 m ha (FAO, 2008). These yields were relatively low compared to world average of 4.3 t ha^{-1}. In Machakos County, farmers' average yield was 2.3 - 2.7 t ha^{-1} compared to Dekalb maize variety 4.5 - 7.0 t ha^{-1} depending on weed management and soil (Mwangi *et al*., 2011) indicating that, potential exists to increase maize yields through appropriate weed management. Appropriate technologies used prudently to manage weeds could promote contribute to Sustainable Development Goal 2: To end hunger, achieve food security and promote sustainable agriculture (UN, Sustainable Development Goals, 2015).

2.7 Weeds and weed management

Weeds aggressively compete for the limited soil moisture and nutrients, and are known to extract more water per unit of dry matter than field crops (Croissant *et al.*, 2008; Schiffner, 2012). Weeds evolve in response to cropping systems by adapting and occupying niches available in the agro-ecosystem at all levels of organization resulting to a high degree of heterogeneity in weed population (Dekker, 1997). The successful behavior in a weed population is the aggregate of diverse, individual plants' behaviors, an emergent property of the population (Dekker, 1997). Plant species composition and abundance at any given time reflects outcomes from suite of dynamic forces including environmental characteristic, management practices and species interactions (Webster and Coble, 1997; Pal *et al*., 2013). The differences in population diversity are the reason weeds so frequently succeed in association with neighboring crop (Dekker, 1997). To estimate the weed problem and interferance in the maize cropping system inorder to plan an effective management, the first step is to know the species and density (Dekker, 1997). Lack of documentation of estimates of the prevalent weed species, limited knowledge on weed species and density, a growing interest on weed challenges particularly with introduction of conservation agriculture, and economic importance of weeds in reducing yields provided the impetus for a weed survey.

A weed survey is a field search scheduled to provide a single point in time assessment or "snapshot" of the location and overall abundance of the weed population to supply the basic information upon which to develop weed management strategies (Dewey & Anderson, 2004). Weed survey methods could either be direct (where surveyors determine the location and relative abundance of weeds on a landscape scale and the variation in density within small areas) (Frick & Thomas, 1992) or alternatively be indirect (clientele can be surveyed to elicit perceptions of weed populations at their specific locations or in their general area) (Loux & Berry, 1991; Frick & Thomas, 1992).

Adequate nutrients and soil moisture are crucial at the critical stages for maximum yield and quality of maize (Abendroth *et al*., 2011; Maqsood *et al*., 2012; Hussain *et al*., 2015). To minimize competition for nutrients and moisture, weeds can only be allowed in maize field for a limited length of time; and, must be controlled for a certain period critical for maize before they interfere and cause yield loss (Liebman & Davis, 2000; Dogan *et al*., 2005; Knezevic & Avishek, 2015). This critical period varies from about 3 - 14 leaf stage (Hall *et al*., 1992; Weed Soft, 2006). This study focused on developing an integrated weed management approach including cover crops, herbicide coated seeds and herbicide to increase yields.

The country was last self-sufficient in maize in 1999, however there is now a shortage after every two to three years. In the study area, households produce maize adequate for 4 months annually (Personal communication). The scenario with increasing prices, chronic undernourishment due to low productivity, and poor health on work force, limited rural development, and climate change effects was likely to aggrevate weed problem in maize cropping system. This could affect the efforts towards food security. Integrated weed management technologies (Harker & O'Donovan, 2013) could be used to increase maize yields; however, technological knowledge and knowhow under the scenario in ASAL was limited.

2.8 Maize trade and price

Maize has increasingly become a cash crop in Africa (Badu-Apraku *et al*., 2012). Kenya produced adequate maize last in 1999. The deficit has been covered through local, regional and international trade. Prices could be affected due to expanding biofuel industry (Taheripour *et al*., 2011). The option was either to 1) increase efficiency in maize production, 2) reclaim and place more semi-arid land under production and 3) use advances in technology including cover crops, herbicides and herbicide resistant seeds to enhance productivity. To do so requires knowledge on the weeds; and, technologies appropriate for ASAL areas; and, this was limited.

2.9 Current status of Conservation Agriculture (CA)

Research has shown that Conservation Agriculture (CA) (minimum tillage, cover crops and rotations or associations used simultaneously) increases crop productivity and profits (FAO, 2011; Mhlanga *et al.*, 2015; Mwangi *et al*., 2015a). Friendrick *et al.* (2012) reported that CA had a role in protection and enhancement of soil health and quality to sustain productivity. In Kenya, majority of smallholder farmers (SHF) still rely on conventional approaches of farming; and, practice elements of CA principles and practices to ensure food security without regard of CA (K'Owino, 2010). Common practices include mixed cropping systems related to agroforestry, residue retention and cover. Large scale farmers (LSF) still use tractor drawn ploughs; but, have up to date sprayers (K'Owino, 2010). In Kenya, few cases of CA have been reported (K'Owino, 2010; DNA, 2014; CETRAD, 2016; Kyongo, 2016); however, documentation of results and lessons across different regions, soils, and climate is limited. Significant barrier to CA adoption could be associated to the mismatch between immediate costs such as time to learn the practices compared to long term benefits including soil health and conservation (Mine *et al*., 2014). Information on CA adoption in maize cropping systems in ASAL was limited.

2.9.1. Use of cover crops to increase productivity

Cover-crops help build soil organic matter which is perhaps the best indicator of soil health and productivity. Soil health is critical for healthy crops and long term productivity. High quality healthy soil supports crop production by promoting roots development, increasing nutrients pool, increasing beneficial biota, decreasing pests and weed pressure. These are valuable for long term sustainable crop productivity (Lal, 1995). However, in ASALs, where most soils are flagile and bare most part of the year, this knowledge is limited.

Achieving widespread adoption requires perception of yield benefits, understanding site specific advantages and disadvantages as well as site specific management practices that will make cover cropping a profitable practice in the production system (Bergtold *et al*., 2012; Bergtold *et al*., 2015). Seed maize could gain from increased cover crop adoption (Lal, 1995). However, most Kenyan smallholder farmers have not perceived a clear immediate economic benefit from adopting cover crops. Moreover, yield benefits depend on type of cover crop, weather, soil type and management among other factors; and, detailed information for this region is limited.

Soil cover can suppress weed emergence and growth, preventing weeds from releasing seeds back into the soil (Teasdale & Daughty, 1993). Mirsky (2008) predicted that, the degree of synchrony between weed emergence periodicity and cover crop biomass accumulation played an important role in defining extent of weed suppression. Teasdale and Mowler (2000) reported that 8000 t ha^{-1} cover crop biomass is required to inhibit 70% weed emergence consistently by physical impediment. Most cover crops operate on germination cues or allelopathy because they naturally produce inadequate levels of biomass (3000 - 5000 t ha^{-1}) to physically stop weed emergence.

Mulch produced by cover crops reduces the soil temperatures at the surface, reduces maximum soil temperatures and slightly increases minimum temperatures. This can affect weed seed behavior; it tricks the seed that it is too deep to germinate. In addition the phytocompounds from cover crop residues inhibit weed root and hycotyl growth following germination. Overtime this could reduce size of weed seedbank and contribute to long term weed management. A number of cover crops including cereal grain legumes and brassicaceae species have potential to suppress weeds through crop interference or allellopathy (Mirsky, 2008; Price *et al*., 2013). Small seeded weeds appear to be more sensitive to allelochemicals; therefore, species composition changes will result from cover crop management selecting against small seeded weeds, while leaving larger seeded broad leaved and perennial less affected. Liebman and Davis (2000) found a strong relationship between weed seed weight and radicle inhibition.

Live cover is more effective in inhibiting light mediated germination because it lowers red to far red ratio of light. Higher ratios can trigger phytochrome receptors in seeds to initiate germination (Teasdale & Daughty, 1993). Degradation of flesh leaves residue after first rains persists for two weeks and thereafter suppression is from germination cues and emerging seedlings. Effects of stimulation and phytotoxic compounds as well as germination cues and growth factors are highly dependent on environmental parameters and local conditions (Liebman & Davis, 2000).

Cover crops choice will depend on producer goals. To manage nitrogen leguminous crops are used. To reduce leaching non-leguminous are selected. To recover nutrients from deep soil layers deep rooted ones. In addition, cover crops could increase cropping systems resilience to climate change challenges. Dolichos produces more dry matter than cowpea especially during drought; and, this translates to nitrogen and improved soil physical conditions (Sheahan, 2012). This implies that knowledge on cover crops is required to use them appropriately to reap their benefits which could translate into important economic value. For example, prudent use of integrated weed management with cover crops could minimize production cost, give societal benefits and sustain maize productivity; however, knowledge and technological knowhow was limited.

2.9.2. Herbicide and herbicide resistant seeds to increase productivity

Herbicides operate by disrupting one or more of the vital processes in a plant. Imidazolinone herbicides block enzymatic reactions (Acetohydroxyacid Synthase (AHAS) or Acetolactate Synthase (ALS)) in chloroplast of higher plants. The mode of action (classified as WSSA, Group 2) inhibits synthesis of branched-chain amino acids namely: Valine, Leucine and Isoleucine (Ross, 2009; Martin, 2016). Blocked synthesis build up substrate which cause shoot meristem cease to grow, leaf veins become purple, roots develop poorly, and secondary roots are shortened. Symptoms develop slowly (2 - 3 weeks or more). Imidazolinone compounds are found as residues weeks/months depending on dosage. Drought, cool weather, ph < 6.5, high organic matter and no-till contribute to persistence in soil; and, this could be a recropping problem for sensitive crops. Warm moist soils, ph > 6.5 increases microbial breakdown. Imidazolinones can persist 60 - 436 days depending on environmental conditions and soil type (Tans *et al*., 2005; Martin, 2016). Imidazolinone herbicides are used because of low application rates, reduced environmental impact and good selectivity to control both monocots and dicots pre and post application to genetically engineered plants. Imidazolinones have similarities with glyphosate in that both herbicides inhibit amino acid synthesis. However, glyphosate targets enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSP synthase) which is responsible for aromatic amino acid synthesis (tryptophan, phenylalanine and tyrosine); and, the mode of action is classified as WSSA, Group 9 (Ross, 2009; Martin, 2016).

Crop resistance to herbicides is conferred through three mechanisms: resistance at the site, metabolic detoxification or prevention of herbicide from reaching the site of action. Imidazolinone resistant (IR) crops (such as IR-maize) have an altered binding site making them resistant to imidazolinone herbicides (Tans *et al*., 2005). The IR-maize crop and final grain yield is not affected by herbicides (James *et al*., 2001). Glyphosate resistant crops have an EPSP synthase transferred from bacterium; which are a little different in shape from EPSP synthase in plants. Plants then produce the different EPSP that renders them tolerant to glyphosate (Pfeiffer, 2016). Humans and most other mammals do not have pathways for production of nine amino acids including Valine, Leucine, Isoleucine, Methionine, Tryptophan, Phenylalanine and Tyrosine among others. Chemicals that block the synthesis of the nine amino acids are effective herbicides and contribute to increased productivity in targeted crops but pose little health risk to mammals.

Oil seed rape is a weed that can cause significant yield losses (Krato, 2012) which is highly susceptible to ALS inhibitors. Of late, uses of cover crops, herbicide and herbicide resistant seeds have received much attention. However, technological knowledge and skills on prudent use of these technologies and research targeting farmer's need in Kenya was limited.

CHAPTER THREE

3.0 WEED DIVERSITY AND DENSITY IN KALAMA AND KEE DIVISIONS

3.1 Abstract

Maize is one of the most widely planted crops in the world. In Kenya, maize is the staple food and an important cash crop. Weed management is a major challenge in smallholder cropping system under conservation agriculture. The objective of this study was to conduct a field investigation to determine weed diversity and density in maize cropping systems in Kalama and Kee divisions. This could be a tool towards development of an adaptive weed management strategy and guide future research. Sampling was done in a 1 m^2 quadrat placed randomly per site 14 - 21 days after beginning of the short rain season, 2009. Weed species density score was recorded. This was repeated in four other locations in a "W" designated pattern in each individual maize field. The number of weeds per square metre were scored using a scale of 0 to 4 where; 0 = No weed, 1 = 1 weed 2 = 2-5 weeds, 3 = 6-20 weeds, 4 > 20 weeds m^{-2} (KARI Crop Protection Officers, 1996); and, the average score per field recorded. Twenty eight weed species were prevalent; which, were significantly ($P < 0.05$) different. Most (18) species were broadleaf compared to grasses (8). *Oxygonum sinuatum* L. and *Bidens pilosa* L. were the most abundant (> 20 weeds m^{-2}) broadleaf weeds while *Dactyloctenium aegytium* L. and *Eleusine indica* L. were the most abundant grasses. Weed species density was variable in individual fields ($P < 0.05$). In Kalama there were 2-5 weeds m^{-2} compared to 6-20 weeds m^{-2} in Kee. Annual weeds recorded higher densities than perennial. Listed weed species, types, groups, location and density formed a weed inventory. These findings can be used to determine the most appropriate adaptive weed management strategy in maize fields under conservation agriculture, future changes in weed infestations and future research. This means therefore that weed management technology should be location specific that takes into account weed density and diversity.

3.2 Introduction

Weeds are a major problem in smallholder maize production systems in Africa, especially in arid and semi-arid (ASALs) regions in Machakos and Makueni Counties, Kenya. Weeds evolve in response to cropping systems by adapting and occupying niches available in the agro-ecosystem at all levels of organization resulting to a high degree of heterogeneity in weed population (Dekker, 1997). The successful behavior in a weed population is the aggregate of diverse, individual plants' behaviors, an emergent property of the population (Dekker, 1997). The differences in population diversity are the reason weeds so frequently succeed in association with neighboring crop (Dekker, 1997). Inadequate labour for weeding is a constraint in predominantly subsistence maize production systems of Kalama (Machakos) and Kee (Makueni) where soils are highly heterogeneous, low in organic matter and deficient in nitrogen (N). Manual weeding is carried out when soil is wet commonly using oxen drawn mould board plough and/or hand hoe regardless of the weed diversity. Farmers aim to achieve 100% soil inversion with the limited labor during the critical period of weeding and therefore the weeding activity is labor intensive. As a result of inappropriate use of mould board plough, soils are compacted except for about 4 cm of the top loose soil. In addition, weeding is delayed and often poorly done. Poor weed management practices often contribute to relatively low maize yields of local variety Kinyanya which range between 0.5 - 1.2 t ha^{-1}. Yield can be improved through timely operations and appropriate weed management under CA.

Maize planted in fields heavily infested with weeds showed substantial yield reduction (Abdin *et al*., 2000) which varies depending on plant density, soil N and stage of maize when weeds are removed (Tollenaar *et al*., 1994). Weeds are controlled between V3 - V4 and V7 - V14 leaf stage of maize development (i.e. from about 2 - 8 weeks after emergence), to avoid grain yield losses (Hall *et al*., 1992; Dogan *et al*., 2005). By about 14 days after emergence, all maize parts are formed (leaves, ears shoots, tassel in miniature, no of kernels determined). The growing point is still at or below soil protecting the young from yield reductions due to outside stress. The V5 - V8 stage (14 - 28 days after emergence), no yield loss. Yield loss sets in at V8 leaf stage especially due water stress (Weed Soft, 2006). Increased weed density 3 weeks after maize emergence reduced grain yield (Pal *et al*., 2013). The most sensitive of the yield components to weed competition is kernels per ear (V8 - V16) (about 28-55 days after maize emergence) (Laver, 2006; Abendroth & Elmore, 2011). Maize matures at around 21 leaf stage; and, the amount of yield loss that occurs depends on the maize growth stage, type of weeds, and density of weeds, time weeds emerged and environmental conditions (Liebman & Davis, 2000). Adequate surface mulch significantly improves weed control (Teasdale & Daughtry, 1993) relative to bare soil. The precaution to prevent loss of maize productivity due to avoidable circumstances is adaptive weed management. Adaptive weed management strategies requires knowledge on the density and diversity of weed species to inform development of appropriate technologies in Kalama and Kee. This was lacking; hence, a weed survey was conducted as the first step to identify weeds interfering with maize and estimate the problem. The objective was to determine the weed species diversity and density in Kalama and Kee divisions two to four weeks after the onset of rains. The null hypothesis (H_0) formulated for this study was: there is no difference between weed diversity and density infesting maize fields in Kalama and Kee divisions' maize cropping systems.

3.3 Materials and methods

3.3.1. Study area

The study was conducted in Kalama division in Machakos County and Kee division in Makueni County (Fig. 1.1 and 1.2).

3.3.2. Sampling

Two months before the field survey, farmers from Kalama and Kee were mobilized for meetings by frontline extension officers in the study area. In the meeting with farmer groups' (stakeholders) the researcher presented and shared a study brief. This was aimed at helping stakeholders understand the survey objectives, research targets, expected outputs, how farmers would get feedback from generated information and their role as stakeholders (providing sampling farms for data collection). Twelve members were randomly selected from the farmer groups. The 12 farmers were the owners of the maize fields where weed sampling was carried out as scheduled. A field was defined as an area of land (a *Fanya juu* bench terrace) that was seeded with maize. The 12 fields planted with maize were randomly selected to represent 12 farmer groups. These included Kikumbo, Kitonyini, Mikono, Katwaa, Utooni and Kalima Mungu from Kalama; and, Kasuguni, Kyamwalye, Mutulani, Ngutini, Kyuni and Kako from Kee. The number of samples was dictated by available resources and farmer group representation. The researcher served as the surveyor with two casual employees and a field extension worker assisting when required.

After identifying a maize field the sampling area was defined by a 1 m^2 quadrat randomly placed 20 meters from the edge of each field, within which each weed species was counted and the density score recorded. This was the first point of sampling. Then the surveyor followed a "W" designated pattern across each field to enumerate the weeds and the procedure repeated at each of the five locations. The weed count data was summarized and the average score per field recorded. For perennial grasses (such as *C. dactylon*) and perennial herbaceous weeds (such as *F. convolvulus*) the number of shoots rather than the number of plants was counted. For annual grasses (such as *E. indica*) an individual weed which had rooted was counted as a single plant regardless of the number of tillers. Density was defined as the mean number of individual plants of each species per square meter. Weed density (number of plants per metre) was scored using a scale of 0 to 4 where; 0 = 0 weed, 1 = 1 weed, 2 = 2 - 5 weeds, 3 = 6 - 20 weeds, 4 > 20 weeds per square meter (KARI Crop Protection Officers, 1996). The tools used for weed identification included: manuals (Terry and Michieka, 1987; Benhrendt and Hanf, 1979) and books (Ivens, 1967; Agnew, 1974; Lanin & Wartz, 2013). Any weed found in the field that the surveyor was unsure of was tagged, pressed and identified later. The field survey was carried out during short rains, November 5th to December 5th 2009. This time frame was chosen for several reasons. The weeds were vigorously growing in maize fields, most of the weeds were mature and flowering; and, easy to identify or recognize after drought.

3.3.3. Data Analysis

The data was keyed into computer using excel. Analysis of variance on recorded weed species from the 12 farms (Kalama and Kee divisions) was conducted to determine if weed species and density scores varied with division. Where results were significant means were compared using Student Newman Keus (SNK) (Abdi and Williams, 2010; Ritz *et al*., 2015).

3.4 Results

3.4.1. Weed diversity and density in Kalama and Kee division

Prevalent weed species differed amongest each other and across the division ($P < 0.05$). Prevalent weed species in Kalama were different from those in Kee division ($P < 0.05$). In Kalama, the two weed species, with the highest density (>20 weeds m^{-2}) were *Bidens pilosa* (L.) (Broadleaf) and *Eleusine indica* (L.) Gaertn. (Grass weed) while *Dactyloctenium aegyptium* (L.) Willd. *Acanthospermum hispidum* (D.C.) and *Oxygonum sinuatum* (Meisner.) Dammer had a density of 6 - 20 weeds m^{-2}. In Kee, *O. sinuatum* and *D. aegyptium* recorded the highest density (> 20 weeds m^{-2}) while *E. indica*, *A. hispidum* and *Nicadra physalodes* (L.) prevailed at 6 - 20 weeds m^{-2}. These results are shown in Table 3.1.

The prevalent weed species were significantly ($P < 0.05$) different amongst themselves in terms of type, density and characteristic. Some were in high densities in both divisions but some were in high densities in one division. Amongst the weed species prevalent in the 12 maize fields' majority (18) were broadleaf and 8 grasses. Most weed species were sprawling annuals and few perennials with no biennials. The top five most abundant weeds were *O. sinuatum*, *E. indica*, *D. aegyptium*, *B. pilosa*, and *A. hispidum* respectively (Table 3.2).

Table 3.1 Common weed species in Kalama and Kee divisions, 2009

Weed diversity			Kalama	Kee
Class	Common name	Botanical name	Weed score (weeds m^{-2})	
Broadleaf	Starbur	*Acanthospermum hispidum* D.C.	2.500	2.667
	Starbur	*Acanthospermum grablatum* D.C.	1.000	<0.001
	Pig weed	*Amaranthus hybridus* L.	0.167	1.333
	Black jack	*Bidens pilosa* L.	4.000	1.333
	Tar vine	*Boerhavia diffusa* L.	0.000	0.333
	Wondering Jew	*Commelina Bhenghalensis* L.	1.667	1.167
	Spindle pod	*Cleome monophylla* L.	1.000	1.833
	Asthma weed	*Euphobia hirta* L.	1.833	2.000
	Wild buckwheat	*Fallopia convolvulus* L.	<0.001	0.167
	Wild lettuce	*Launaea cornuta* (Oliv.&Hiern) C. Jeffry	<0.001	0.667
	Chinese lantene	*Nicadra physalodes* L.	2.167	2.667
	Double thorn	*Oxygonum sinuatum* L.	3.333	4.000
	Kitoto	*Paraknoxia parviflora*	<0.001	0.167
	Purslane	*Portulaca oleracea* L.	0.500	0.500
	Purslane	*Portulaca quadrifida* L.	0.500	0.667
	Sow- thistle	*Sonchus oleraceus* L.	1.333	0.667
	Mexican marigold	*Tagetes minuta* L.	1.667	1.667
	Late weed	*Trichodesma zeylanicum* L.	<0.001	0.167
	Puncture vine	*Tribulus terestris* L.	<0.001	0.167
Grasses	Crows-foot grass	*Dactyloctenium aegyptium* (L.) Willd.	3.167	3.667
	Love grass	*Setaria verticillata* (L.) Beauv.	1.167	1.667
	Wild finger millet	*Eleusine indica* (L.) Gaertn.	4.000	3.000
	Star grass	*Cynodon dactylon* (L.) Pers.	0.167	0.667
	Barnyard grass	*Echinochloa colona* L.	<0.001	0.500
	Couch grass	*Digitaria scalarum* (Schweinf.) Chiov.	0.167	0.500
	Horse tail	*Eragrostis tenuifolia* (A. Rich.) Steud.	0.000	0.167
	Buffalo grass	*Panicum maximum* (Jacq.)	0.333	0.667
Sedges	Nut grass	*Cyperus rotundus* L.ssp. rotundus	<0.001	0.667
Parasitic	Alectra	*Alectra vogelii* (Benth)	<0.001	0.334

Key: Score 0 = 0 weed, 1 = 1 weed, 2 = 2-5 weeds, 3 = 6 - 20 weeds, 4 > 20 (weeds m^{-2}), CV% = 50.1, SE= 0.305, $P < 0.05$

Table 3.2 Growth characterisation of prevalent weed species and density m^{-2} in Kalama and Kee, in 2009

Class	Common name	Weed species	Characteristic	Mean density score ± SE (0.22)
Annual	Starbur	*Acanthospermum hispidum* D.C.	Erect/branched	2.65
(Broadleaf)	Starbur	*Acanthospermum grablatum* D.C.	Sprawling	0.50
	Pigweed	*Amaranthus hybridus* L.	Branched erect	0.25
	Black jack	*Bidens pilosa* L.	Branched erect	2.74
	Tar vine	*Boerhavia diffusa* L.	Sprawling/erect	0.17
	Spindle pod	*Cleome monophylla* L.	Branched erect	1.42
	Asthma weed	*Euphobia hirta* L.	Sprawling	1.92
	Wild buckwheat	*Fallopia convolvulus* L.	Sprawling	0.08
	Chinese lantern	*Nicadra physalodes* (L.) Gaertn.	Erect/branched	2.4
	Double thorn	*Oxygonum sinuatum* (Meisner.) Dammer	Sprawling	3.71
	Purslane	*Portulaca oleracea* L.	Sprawling	0.58
	Purslane	*Portulaca quadrifida* L.	Sprawling	0.58
	Sow-thistle	*Sonchus oleraceus* L.	Erect/spreading	1.00
	Mexican marigold	*Tagetes minuta* L.	Erect/branched	1.67
	Puncture vine	*Tribulus terrestris* L.	Sprawling	0.08
	Late weed	*Trichodesma zeylanicum* L.	Erect/branched	0.17
Perennial		*Launaea cornuta* L.	Erect	0.08
(broadleaf)	*Wandering jew	*Commelina benghalensis* L.	Sprawling	0.92
Annual (Grasses)	Crows-foot	*Dactyloctenium aegyptium* (L.) Willd.	Spreading	3.42
	Love grass	*Setaria verticillata* (L.) Beauv.	Sprawling	1.41
	Barnyard grass	*Echinochloa colonum* (L.) Link	Prostrate	0.25
	Wild finger millet	*Eleusine indica* (L.) Gaertn.	Prostrate base	3.52
Perennial	Couch grass	*Cynodon dactylon* (L.) Pers.	Rhizome	0.42
(Grasses)	Blue Couch	*Digitaria scalarum* (Schweinf.) Chiov.	Rhizome	0.33
	*Horse tail	*Eragrostis tenuifolia* (A. Rich.) Steud	Branched tuft	0.08
	Guinea grass	*Panicum maximum* (Jacq.)	Tufted bunch	0.50
Sedges	Nut sedge	*Cyperus rotundus* (L.) ssp. Rotundus	Spreading	0.33
	Alectra	*Alectra vogelii* (Benth)	Parasite on cowpea	0.17

Key: Score 0 = No weed, 1 = 1 weed, 2 = 2-5 weeds, 3 = 6 - 20 weeds, 4 > 20 weeds m^{-2}, $P < 0.05$, SE = 0.22 ***** Short lived perennials

The mean density of weeds per prevalent weed group were significantly ($P < 0.05$) different amongst each other (Table 3.3).

Table 3.3 Mean number and density of weeds (plants m^{-2}) per group type

Type	Mean	Standard Error (SE)
Broad leaf	1.153	±0.093
Grasses	1.240	±0.139
Parasitic	0.167	±0.394
Sedges	0.333	±0.394
P-value	0.014	

Key: Score 0 = No weed, 1 = 1 weed, 2 = 2-5 weeds, 3 = 6 - 20 weeds, 4 > 20 weeds m^{-2}

On average, 2 - 5 weed species per quadrat ($1m^{-2}$) were recorded in the maize fields at Kalama compared to 6 - 20 species in Kee division (Table 3.4).

Table 3.4 Mean weed density score (plants m $^{-2}$) per group type for Kalama and Kee in 2009

Division	Weed Type	Mean Score (m^{-2})	Std. Error
Kalama	Broadleaf	1.15	±0.13
	Grasses	1.13	±0.20
	Parasitic	0.0	±0.56
	Sedges	0.0	±0.56
Kee	Broadleaf	1.16	±0.13
	Grasses	1.35	±0.20
	Parasitic	0.33	±0.56
	Sedges	0.67	±0.56

Key: Score 0 = No weed, 1 = 1 weed, 2 = 2 - 5 weeds, 3 = 6 - 20 weeds, 4 > 20 weeds m^{-2}

Results showed that weed density were significantly ($P < 0.05$) different. Weed species were significantly ($P < 0.05$) different across a field. *P. parviflora* density was significantly ($P < 0.05$) higher than all other species at Kiboko field in Makueni (fig 3.1). The density of other weed species was significantly ($P < 0.05$) lower than that of *P. parviflora* and *D. aegyptium* density (Fig 3.1).

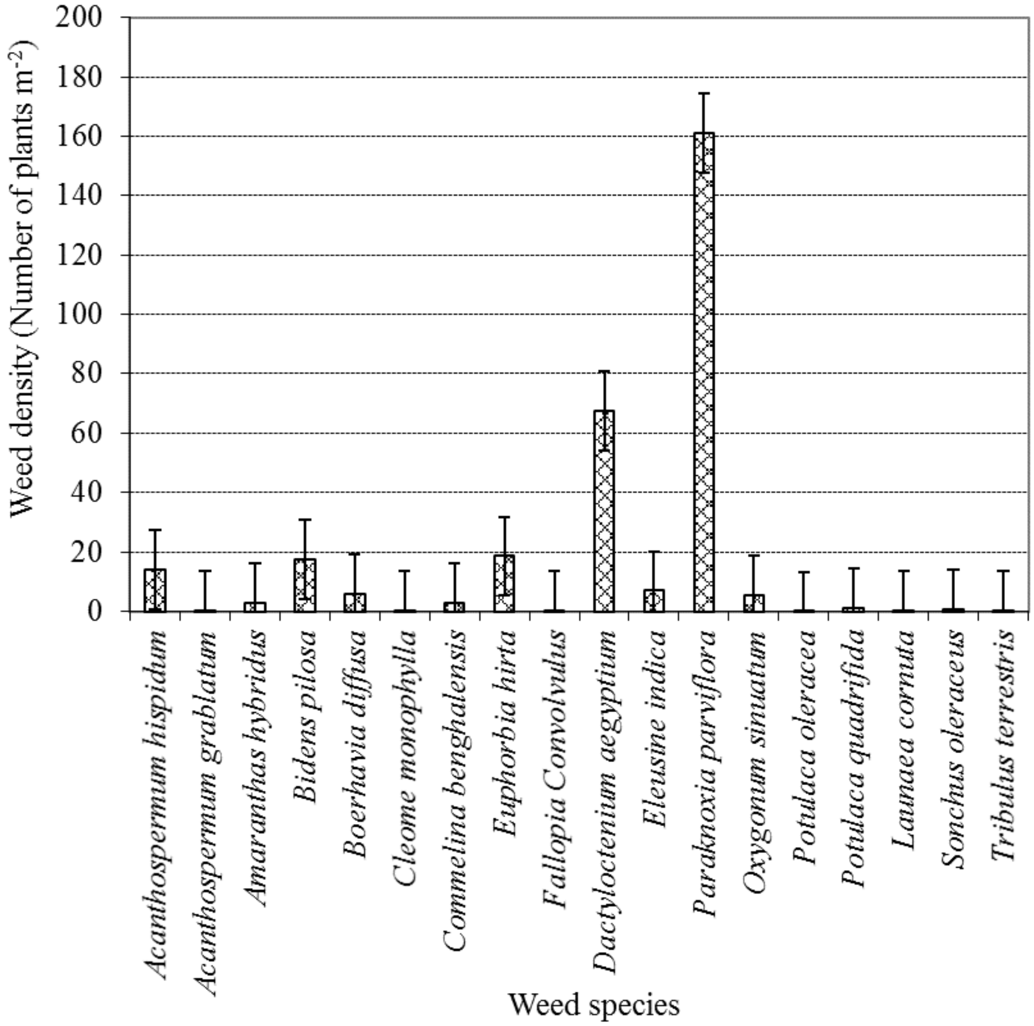

Figure 3.1: Diversity of weed species in a maize field at Kiboko in Makueni, 2009

The study noted that most weed species such as *F. convolvulus*, *O. sinuatum*, *A. grablatum, C. benghalensis,* and *E. hirta* had unique prostrate, sprawling and branching characteristics forming mats on the soil. The weed species occurred close together (associated) and formed mats on flagile soil.

3.5 Discussion

In this study, field searches were used to determine the location and density of weeds in the Kalama and Kee land scape scale. All sampled fields had been tilled manually using hand and/or oxen power before planting maize. A total of twenty eight (28) weed species infested maize fields. Most (18) weed species prevalent in Kalama were among those found in Kee division. There was a larger diversity of weed species ranging (6 – 20) in Kee compared to 2 – 5 species per metre in Kalama. This was attributed to different factors including altitude, mean annual rainfall and temperature (weather), and management practices; such as, cover crops technology effects introduced in Kalama maize fields compared to Kee where cover crop technology had not been introduced. This agreed with other findings (Liebman & Davis 2000; Pal *et al*., 2013) on weed species composition in maize fields. Management practices have been reported (Webster & Coble, 1997; Albrecht & Matthews, 1998; Hald, 1999) to affect weed diversity. Cover crops effectively managed different weed species through suppression, physical impediment and hindering germination (Teasdale & Daughtry, 1993; Teasdale *et al*., 2007).

Majorities of the prevalent weed species were in the group of broadleaf and a few were in the group of grasses. The most dominant weeds were annual broadleaf including *B. pilosa* and *T. minuta*, and grasses such as *D. aegytium*, and *E. indica*. This diversity difference could also be attributed to many factors including: genotypic variation where small genetic changes could provide differential functional variants with which to exploit available niches (Dekker, 1997), environmental heterogeneity (Gabriel *et al.,* 2006) and /or edaphic factors (Andreasen *et al*., 1991; Benton *et al.*, 2003), species diversity, seed longevity and species specific germination patterns (Higginbottham *et al*., 2000).

The only measure used in the analyses was the density (number of individual weed species per unit area), regardless of their relative impact on maize performance. The top two most abundant (> 20 weeds m^{-2}) weeds were *E. indica* and *B. pilosa* in Kalama while *O. sinuatum* and *D. aegyptium* were in Kee. Other abundant species (6 - 20 weeds m^{-2}) were *A. hispidum, D. aegyptium* and *O. sinuatum* recorded in Kalama compared to *N. physalodes*, *E. indica*, and *A. hispidum* in Kee. A mean of 2 to 5 weeds m^{-2} were recorded in Kalama compared to 6 - 20 weeds m^{-2} in Kee maize fields. In Kee, the species which were mainly small seeded annual broadleaf and grasses occurred in high densities probably due to their ability to increase prolifically and germinate easily in disturbed soils because all fields were manually plowed. This means the populations were composed of species with a wide spectrum and reproductive potential.

The mean density of *P. oleracea, P. quadrifida, T. terrestris, F. convolvulus, L. cornuta, B. diffusa*, and *A. hybridus* was generally lower in Kalama, compared to Kee. *Alectra vogelii* was found only in Kee in low density. Though localised *A. vogelii* an annual parasitic weed of legumes (such as runner bean (*Phaseolus coccineus*), mungbean (*Vigna unguiculata*), velvet bean (*Mucuna pruriens*), dolichos (*Lablab purpureus*), Bambara (*Vigna subterranean*), *Tephrosia* spp., and *Indigofera spp.*) and non-legumes (prevalent weeds including *A. hispidum, Euphobia spp.* and hibiscus) (Parker & Riches, 1993) is a weed of concern. Small holder farmers in semi-arid Eastern province of Kenya especially Kalama and Kee generally intercrop maize commonly with beans or cowpeas. Currently the listed host legumes are particularly promoted as cover crops or green manures in Arid and semi-arid East Africa maize cropping systems. Other susceptible cowpea cultivars could be introduced through various pathways. This implies that though very localised, *A.vogelii* is a weed of economic importance in individual affected farms, but could become a potential risk by expanding to other areas where traditional cowpeas landraces are being replaced with exotic susceptible cultivars introduced commercially or through trials. This implies that it is a weed to watch in future. Parker and Riches (1993) noted that *A.vogelii* was a problem in Embu in 1929 but is now widespread in Eastern parts of Kenya.

Most weed species such as *F. convolvulus, O. sinuatum, A. grablatum, C. benghalensis,* and *E. hirta* formed mats and occurred close together on flagile soil suggesting that they could physically block other emerging weeds and protect fragile soils when live or after desiccating them *in-situ*. This implies that knowledge could be used to manipulate the diversity and density of species to manage others through adaptive research strategies. This could minimize weed competition and propagation (through weed seeds and perennial propagates) to acceptable levels and add ecological benefit for the maize production systems. Araya *et al*. (2012) have demonstrated mulch residue for suppressing other emerging species, improving infiltration, reducing erosion and harvesting moisture to increase yield.

Weed species diversity and density were significantly ($P < 0.05$) different implying that adaptive weed management should be field specific. The differences in weed species in Kalama and Kee fields could be attributed to many factors including the survey date, edaphic, environmental and management as indicated in similar studies (Thomas, 1985; Frick & Thomas, 1992). This knowledge will provide a benchmark useful in planning strategic intervention; while characterizing weed diversity could be used in documenting changes in weed community over time and effectiveness of management practices.

3.6 Conclusion

This study shares knowledge on weed diversity and density in Kalama and Kee. The study demonstrated that maize fields were infested heavily by 28 significantly ($P < 0.05$) different weed species; belonging to four significantly ($P < 0.05$) different weed groups (18 broadleaf, 8 grasses, one sedges and one parasitic weed). The weed species density in Kalama was significantly ($P < 0.05$) different compared to Kee. In Kalama the weed density was lower (2 - 5 weeds m^{-2}) compared to 6 - 20 weeds m^{-2} in Kee. The most abundant (density ≥ 6 weeds m^{-2}) in descending order were *O. sinuatum* > *E. indica* > *D. aegyptium* > *B. pilosa* > *A. hispidum* > *N. physalodes.*

Listed weed species diversity in individual fields formed a weed inventory. Weed species diversity, density and unique mats formation characteristics could be manipulated through adaptive research to suppress other weeds, while their living cover or mulch could cover fragile soils and add ecological benefit for the maize production system. Developed knowledge on weed diversity and density could be used to determine the most appropriate adaptive weed management, pin point problem weeds that need concerted research efforts and form a base for determining weed changes in future particularly with climate change effects.

CHAPTER FOUR

4.0 ADOPTION LEVELS OF COVER CROPS FOR WEED MANAGEMENT IN MACHAKOS AND MAKUENI COUNTY

4.1 Abstract

Despite the many advantages of cover crops most farmers do not use them in their cropping systems. The objective of this study was to examine adoption and sociological factors associated with adoption of cover crops in Kalama (Machakos County) and Kee (Makueni County), Kenya. A semi-structured questionnaire was randomly administered to 80 participants to obtain sociological information including gender, age category, education levels, and adoption of cover crops. Two Binary Logistic Regression Models were used to observe the factors affecting cover crops adoption by respondents. Results showed that 80% of the respondents reported they had adopted cover crop technologies at Kalama compared to 57.5% at Kee. Results from Binary Logistic Regression Models with respondent's gender, age category and education level as predictors of cover crop adoption indicated that gender had a significant ($P < 0.05$) effect on adoption. Men were less likely to adopt. Age category had mixed effects on adoption of cover crops. At Kalama age category had a significant ($P < 0.05$) effect on adoption of cover crops but the effect was not significant on cover crop adoption at Kee. Education levels of respondents indicated mixed effects on cover crop adoption suggesting other factors not covered in the study were at play. In addition, results revealed that, cover crop knowledge and skills, demonstration of gains and related cost had a significant ($P < 0.05$) effect on cover crop adoption. Information sources, seed sources, preferred seeds, reasons for seed preferences and cover crop constraints showed no significant effect on cover crop adoption. The study concluded that capacity building was needed to develop cover crop knowledge and skills, demonstrate gains and costs to increase both men and women likelihood to adopt. In addition further research was needed to shed light on other factors which are likely to influence adoption.

4.2 Introduction

Smallholder farmers in Machakos and Makueni Counties grow maize, beans cowpeas, pigeon peas, cassava and sweet potatoes in mixed cropping systems (Mwangi, 2003). Maize is the staple food; and, average yields of the commonly grown local variety (*Kinyanya*) are low, ranging between 0.3 - 0.5 t ha^{-1} and 0.9 -1.2 t ha^{-1} during the long rains and short rain seasons respectively (Gachene & Mwangi, 2006). Yields are higher in short rains in these regions because of their reliability compared to the long rains.

Crop production is constrained by unreliable rainfall and weeds among other factors. Weeds aggressively compete for the limited soil moisture and nutrients; and, are known to extract more water per unit of dry matter than field crops (Croissant *et al.,* 2008; Schiffner, 2012). As a result of low farm productivity, majority of the smallholder farmers are food insecure and frequently rely on relief food from the government locally known as “Mwolyo”.

Conservation agriculture system which advocates for minimal soil disturbance and total soil cover for enhanced rainwater infiltration, storage efficiency and weed management was introduced in Kalama Division in 2001. Dolichos (*Lablab purpureus*) and mucuna (*Mucuna pruriens*) were introduced as cover crops for weed management. The technology resulted in increased average maize yields (Gachene & Mwangi, 2006). However, adoption levels of the cover crop technology, and factors that may have contributed to adoption, and the role of the cover crop technology in weed management have not been established.

This study was therefore carried out to evaluate adoption levels of the cover crop technology, determine the main factors that contributed to adoption levels and assess the potential of the cover crop technology for weed management among maize farmers in Machakos and Makueni Counties.

Problem statement and justification

Chabi-Olaye *et al*. (2005) and Mwangi *et al*. (2015a) have reported on some of the benefits of using cover crop. Singer *et al*. (2007) have reported on adoption of cover crop technology for some regions. However, information on cover crop adoption in maize cropping systems in Kenya and the factors influencing cover crop adoption are limited. It is crucial to identify the factors with a significant correlation effect on adoption of cover crops by farmers, so that steps to increase adoption may be effective. Factors with significant correlation to cover crops adoption can then be analysed using binary logistic regression and output used to develop models for predicting farmers' likelihood to adopt or not to adopt. Information on the most significant variables affecting the probability of cover crop adoption could help understand potential barriers to adoption, and contribute to designing successful development project and setting research priorities for Kenya and similar regions.

1.2 The specific objectives of this study were:

(1) To evaluate adoption level of cover crop technology and (2) determine social factors associated with adoption of cover crops at Kalama and Kee.

1.3 The research questions were:

What are the levels of cover crops adoption at Kalama (region where cover crop technology was introduced) compared to Kee (neighbouring region where the technology was not introduced)?

Does age, gender or education have any effect on cover crops adoption? Does cover crop knowledge sources, seed sources, preferred seeds, reasons for seed preferences or cover crop constraints have any effect on cover crop adoption? The Null hypotheses (H_o) that guided this study were 1) Age, gender or education levels of respondents have no significant effect on cover crops adoption in Kalama and Kee respectively. 2) Cover crop knowledge sources, seed sources, preferred seeds, reasons for seed preferences or cover crop constraints have no significant effect on adoption at Kalama and Kee respectively. To analyse the research questions, Binary Logistic Regression analyses were carried out and Models 1 and 2 constructed. In Model 1, Gender, age and education were included as predictor variables of cover crop adoption. In Model 2, Cover crop knowledge sources, seed sources, preferred seeds, and reasons for seed preferences were predictor variables of cover crop adoption. Where necessary, Chi square tested the relationship between the social factors and adoption of cover crops at $P < 0.05$ significant level.

4.3 Materials and methods

4.3.1. The study area

A multi-stage sampling technique was adopted. The first stage was purposively selecting Kalama Division in Machakos County and Kee Division in Makueni County study sites. Kalama division was selected because of earlier research activities, where CA with cover crops had been introduced in 2001 while Kee division was selected on the basis of its proximity to Kalama and with no previous introduction of the technology to serve as a control. The two counties are within arid and semi-arid region in Kenya, where unpredictable and unreliable rainfall, flush floods and recurrent droughts are a frequent major threat to food production. The area is dominated by smallholder farmers growing cereals (maize, sorghum and millet), legumes (beans, cowpeas and pigeon peas), root tubers (cassava and sweet potato) and fruit trees such as mangoes and papaya in a mixed cropping system. Livestock provide dairy products and manure, and oxen draught power for ploughing and weeding.

Most soils have a declining fertility, low organic matter and are compacted except for top 4 cm loose soil. The pH, organic carbon, moisture content, Cation Exchange Capacity and nutrients are highly variable which is partly attributed to farm management. The monthly soil temperatures range from the lowest (11.1 - 15.2°C) to the highest (22.2 - 27.3°C). The annual rainfall ranges from 400 - 800 mm.

The second stage was to purposively select 12 villages (six villages from Kalama and Kee respectively) and the third stage was purposively selecting 12 farmer groups to represent the 12 villages respectively. The study area had many registered farmer groups. On average, each group had 25-30 members (men and women). The members met monthly on a scheduled day to deliberate on matters arising. Groups were governed and guided by their own constitution with rules and regulations. A committee of elected leaders oversees individual roles and responsibilities in the group activities. There are penalties in breaking rules. Groups are known for their multiplier effect among members, and therefore many change agents work in collaboration to implement their agendas. A group was selected to participate if 1) it was officially registered and active with some on-going development activities or it had previously participated in conservation tillage activities and 2) resources allowed.

Group approach was deemed as a more cost effective strategy, for fair representation of villages and potential to form a base that could be used for comparing change over time. For reference purposes the region is administratively divided into Counties > Sub counties > Divisions > Locations > Sub-locations > Villages. A village was based on the number of households and topography of the area. Each village had about 400 households.

4.3.2. Data collection

The fourth stage was random selection of 80 farmers from the sample of 12 farmer groups to participate in the study. Individual farmers were randomly selected by allocating a number (1, 2 and 3) to every member of the accessible population. All number ones formed the sample of 40 from Kalama and Kee division respectively.

The participants were interviewed face to face by the researcher and 2 interviewers using a semi-structured questionnaire. Variables chosen were deemed necessary to bring out information required to determine adoption and factors influencing it.

The questionnaire which had been pretested and adjusted accordingly was administered to each participant. The questionnaire had 30 items and was designed with two parts. Part A of the questionnaire included gender, age, educational level and locality. Part B focused on issues related to cover crops including adoption. The factors explored were when farmers started growing cover crops (year), where they learnt the use of cover crops, their source of seeds, their preferred cover crops among 1-5 cover crop options, reasons for those preferences and views from participants with practical experiences in growing cover crops (referred to as experts). All adopters had planted legume cover crops for weed management in 2008/9 and non-adopters had not? Independent variables were scores on the dependant variable (adoption), dummy: (1 = Yes to adoption; and 0 = No to adoption) as tabulated (table 4 1).

Table 4.1 Factors considered in predicting adoption

Factors considered in predicting adoption	Type of measure	Type (s) of response (s) Categories
X1 = Gender	Dummy	(1 = male; 0 = female)
X2 = Respondents age	Category in years	(1 = 15-25, 2 = 26-35 , 3 = 36-45, 4 = 46-55, 5 > 55)
X3 = Respondents education	Categorical	(1 = primary, 2 = secondary, 3 = tertiary, 4 = illiterate).
X4 = Cover crop lessons sources was categorical	Categorical	(1 = attended training, 2 = on-farm demonstrations, 3 = farmer field schools, 4 = field day, 5 = exchange tours, 6 = mass media),
X5 = Seeds sources was categorical	Categorical	(1 = Group, 2 = Neighbour, 3 = project. 4 = market , 5 = relief agency),
X6 = Preferred seeds	Categorical	(1 = Pigeon peas, 2 = Beans, 3 = Lablab, 4 = Velvet bean),
X7 = Reasons for preferred seeds	Categorical	(1 = domestic use, 2 = protein source, 3 = dual purpose, 4 = drought tolerant, 5 = seed availability),
X8 = Cover crop constraints	Categorical	(1 = seeds, 2 = lack of information, 3 = diseases, 4 = pests, 5 = frost)

Prior to data collection assistants were trained to facilitate recording of data from participants as scheduled.

4.3.3. Analysis of data

The data was cleaned, coded, and keyed into computer. To analyse the research questions IBM SPSS computer software was used to run preliminary Pearson correlation tests. The factors that indicated significant correlation on adoption were subjected to Binary Logistic Regression. Descriptive and inferential statistical tool of frequency counts and percentage was used in the analysis of the research questions while Pearson Chi-square analysis tested the hypothesis using the formula below:

$$x^2 = \sum_{1}^{n} \frac{(O - E)^2}{E}$$

Where O = observed frequency, E = expected frequency, n = sample size, x = Chi–square value, *df* = degree of freedom (n-1). The null hypotheses stated: (H_O: Men are more likely to adopt cover crops than women), (H_O: Younger persons are more likely to adopt cover crops than older persons. (H_O: The more educated persons are less likely to adopt cover crops than illiterate persons). H_O = those who attended training on cover crop are more likely to adopt than those who learnt from mass media. H_O = Farmers who got seeds from their group were more likely to adopt than those got seeds from relief agency. H_O = those who preferred Pigeon peas are more likely to adopt than those who preferred Velvet bean. H_O = those whose reason for cover crop preference was domestic use are more likely to adopt than those whose reason was seed availability. H_O = Those whose cover crop constraints was seeds were less likely to adopt than those whose constraint was frost). The null hypotheses were tested at $P = 0.05$ level of significance. The null hypotheses were rejected at $P < 0.05$ and conclude that they are statistically significant. Otherwise, we accept at $P > 0.05$ and conclude that there is no overall statistical significance.

4.4 Results

Table 4.2 Sample distribution

County	*Sub-County*	*Division*	*Village*	*Agroecological Zone*	*Frequency count*
			Kalima Mungu	Upper Midland3	1
Machakos	Machakos	Kalama	Katwaa	Upper Midland 4	3
			Kyakatolwe	Upper Midland 4	1
			Usiwiu	Upper Midland 4	1
			Kikumbo	Lower Midland ¾	1
				Upper Midland 4	2
			Mikono	Upper Midland 3	1
				Upper Midland 4	4
			Utooni	Upper Midland 3	3
			Ivutini	Upper Midland 4	2
			Kathianioni	Upper Midland 4	1
			Kiatuni	Upper Midland 4	2
			Masungu	Lower Midland 4	1
				Upper Midland 4	1
			Usiwiu	Lower Midland 3	1
				Upper Midland 3	1
				Upper Midland 4	2
			Centre	Upper Midland 4	2
			Kitonyini	Upper Midland 4	2
			Kalanzoni	Lower Midland 3/4	1
			Kitonyini	Upper Midland 3	5

County	*Sub-County*	*Division*	*Village*	*Agroecological Zone*	*Frequency count*
			Ingethya	Upper Midland 4	1
Makueni	Kauti	Kee	Watuka	Lower Midland 3/4	1
			Uangani	Lower Midland 3/4	9
			Kee	Lower Midland 3/4	1
			Thoma	Lower Midland 3	1
			Kaiti	Lower Midland 3	1
			Kiamwalye	Lower Midland 3	1
			Kilia	Lower Midland 3/4	4
			Kinganga	Lower Midland 3	1
			Kyamwalye	Lower Midland 3/4	1
			Thoma	Lower Midland 3	5
			Kakuyuni	Lower Midland 3	1
			Kavyuni	Lower Midland ¾	3
			Mbakoni	Lower Midland ¾	5
			Mutulani	Lower Midland ¾	5
			Kyuluni	Lower Midland ¾	1
			Grand total		80

Table 4.3 The sociological profile of respondents (n = number of counts)

Factors		Region				
		Kalama		Kee		
Gender	Category	Adoption	Non-adoption	Adoption	Non-adoption	Statistics
	Male	14	5	14	12	Chi square = 4.314
	Female	18	3	5	9	P = 0.038
	Total	32	8	19	21	*df* = 1
Age (years)	25-35	4	0	3	3	Chi square = 1.169
	36-45	8	3	3	6	*P* = 0.760
	46-55	13	2	10	8	df = 3
	>55	7	3	3	1	
	Total	32	8	19	18	
Education	Illiterate	14	1	3	1	Chi square = 4.314
	Primary	12	2	13	7	*P* = 0.124
	Secondary	4	5	3	12	df = 3
	Tertiary	1	0	0	1	1
	Total	31	8	19	21	50

4.4.1. Responses on adoption of cover crops in Kalama and Kee.

Results to the research question: "Did you plant cover crops in 2008/2009?" indicated that majority (80%) of the respondents in Kalama had adopted cover crops while about 52.6% of the respondents in Kee had adopted in 2008/2009. Among all respondents, 66.7% had adopted while 33.3% had not. Actual frequency of adoption at Kalama was significantly different from expected (*Chi* = 6.568, *df* = 1, $P < 0.05$) indicating that adoption differed from non adoption. Actual frequency of adoption at Kee was not significantly different from expected (*Chi* = 0.105, *df* = 1, $P > 0.05$) indicating that adoption did not differ from non adoption at Kee (Fig. 4.1).

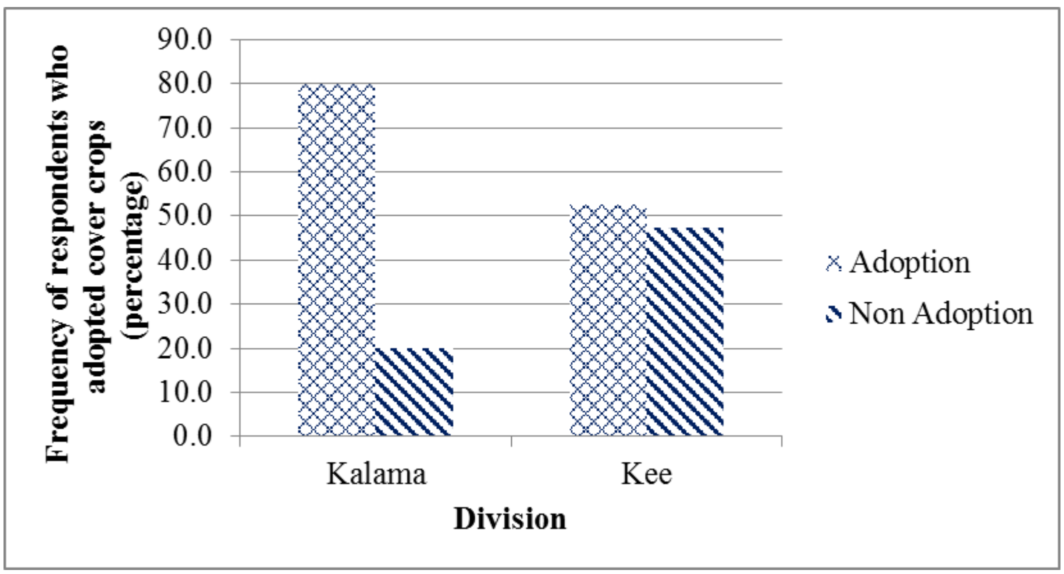

Figure 4.1: Fequency of respondents in cover crop adoption at Kalama compared to Kee division in 2009.

The cover crop adoption trend (Fig. 4.2) is indicated as a cumulative of the responses to the question "*When did you start growing cover crops (year)?*". There was a steady increase in frequency of adoption (trend) from 2002 to 2003 followed by a gradual increase from 2003 to 2007 then a halt in 2008 for Kalama. Adoption levels in Kee increased from 2003 to 2008 but at a much lower rate compared to Kalama (Fig.4.2).

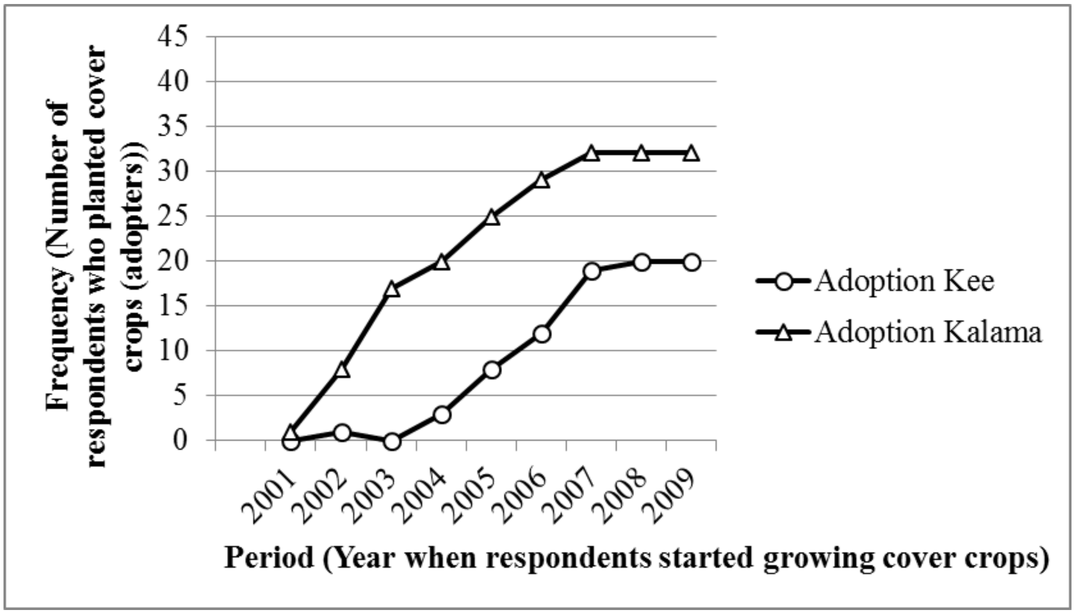

Figure 4.2: Cumulative frequency of respondents' showing cover crop adoption trend in Kalama and Kee from 2001 to 2009 (Source of data: Field Survey)

4.4.2. Factors influencing adoption of cover crop technology

Multivariate analysis was done on social factors (the respondents' age, education, and gender) considered as potential predictor variables in cover crop adoption Binary logistic regression Model 1. A preliminary Pearson correlation test (*2-tailed*) indicated that these potential predictor variables had significant ($P < 0.05$) correlation effect on cover crop adoption. These meant that the variables considered (Table 4.4) had potential predictive ability in the Model.

Table 4.4 Pearson correlations

	Kalama			Kee		
Variables	*P*-value	Sig.	Pearson correlation (r)	*P*-value	Sig.	Pearson correlation (r)
Age	*P<0.001*	**	-0.120	*P<0.014*	**	-0.0266
Education	*P<0.001*	**	-0.127	*P<0.001*	**	0.097
Gender	*P<0.001*	**	0.175	*P<0.001*	**	0.129
Knowledge source	*P*=0.781	NS	0.007	*P<0.001*	**	-0.610
Source of seed		*	-0.063	*P<0.001*	**	-0.175
Cover crops preferred	*P<0.001*	**	0.246	*P<0.001*	**	0.109
Reasons for preference	*P<0.001*	**	0.264	*P<0.001*	**	0.174

*, ** denotes Pearson correlation (r) is significant ($P < 0.05$) and ($P < 0.01$) respectively.

Binary logistic regression analysis for Kalama indicated that age of respondents, education, and gender had a significant effect ($P < 0.05$) on the likelihood to adopt cover crop (Table 4.5).

Table 4.5 Variables in the Binary Logistic Regression Model Equation (Kalama)

	Predictors	B	S.E.	Wald	df	Sig.	Exp (B)
Step 1[a]	Gender (1 = Male)	-1.240	0.135	83.900	1	0.000	0.289
	Education category			51.311	3	0.000	
	1 = Primary	0.549	0.233	5.554	1	0.018	1.731
	2 = Secondary	-0.372	0.220	2.880	1	0.090	0.689
	3 = Tertiary	21.160	2510.883	0.000	1	0.993	1.548E9
	Age category (Years)			103.555	3	0.000	
	1 = 25-35	19.859	2427.921	0.000	1	0.993	4.215E8
	2 = 36-45	-0.988	0.156	39.964	1	0.000	0.372
	3 = 46-55	0.581	0.144	16.385	1	0.000	1.788
	Constant	1.734	0.262	43.721	1	0.000	5.664

a. Variable(s) entered on step 1: Gender, Education, and Age.

Number of observations = 2400, LR Chi Square 527.25 (df 7), Log likelihood =2307.5, Nagelkerke = 0.315, Predicted = 79.4%

4.4.2.1. Binary Logistic Regression Model 1, Kalama

Binary logistic regression Model 1 for Kalama gave a Nagelkerke R of 0.315 which implies that the variables included in the model were able to explain 31.5% variance in the model estimation. This was considered decent. Chi Square 525.27, df 7 was significant ($P < 0.001$) indicating that all explanatory variables included in the model jointly influenced the likelihood of cover crops adoption. The predictor variables were able to explain 79.4% of the outcomes. Given the fore going goodness of fit measures, it is concluded that Binary logistic regression Model had integrity and hence appropriate for predicting cover crop adoption (Table 4.5).

4.4.2.1.1 Gender in Kalama:

There was a significant ($P < 0.001$) gender effect on the likelihood to adopt cover crop. Males were 71.1% less likely to adopt cover crops than females.

4.4.2.1.2 Education in Kalama:

There was a significant ($P = 0.018$) education effect on the likelihood to adopt cover crop. Respondents with primary education were 73.1% more likely to adopt cover crops than those illiterate. The effect of secondary education was not significant on cover crop adoption. Respondents with secondary education were 31.1% less likely to adopt cover crops than the illiterate. In addition, the effect of tertiary education was not significant on cover crop adoption although respondents were 54.8% more likely to adopt cover crops than the illiterate ones.

4.4.2.1.3 Age in Kalama:

There was a significant ($P < 0.001$) age effect on the likelihood to adopt cover crops. However the effect was not uniform across age categories. Age category (36-45 years) respondents were 62.8% less likely to adopt cover crops than those over 55 years. Age category (46-55 years) respondents were 78.8% more likely to adopt than those over 55 years. Age category (26-35 years) was 321.5% more likely to adopt cover crops than those over 55 years old but effect was not significant.

4.4.2.2. Binary logistic regression Model 1 Kee

Binary logistic regression analysis for Kee indicated that only gender had significant ($P < 0.05$) effect on the likelihood to adopt cover crop (Table 4.6).

The Binary logistic regression Model 1 for Kee gave a Nagelkerke R of 0.022 which implies that the predictors were able to explain 2.2% of the variance included in Binary logistic regression Model estimation. The chi square 37.997,1 df was significant ($P < 0.001$) which indicated that explanatory variable included in the model influenced the likelihood of cover crops adoption. The predictor variables were able to explain 55.3% of the outcome which was a slight improvement from 52.6% without predictors indicating the model was good with predictive ability. Given the foregoing goodness of fit measures, it was concluded that Binary logistic regression Model had integrity and hence was appropriate for predicting adoption of cover crops at Kee (Table 4.6).

Table 4.6 Variables in the Binary Logistic Regression Model Equation Kee

								95% C.I. for EXP(B)	
Predictor		B	S.E.	Wald	Df	Sig.	Exp (B)	Lower	Upper
Step 1[a]	Gender (1 = Male)	-0.550	0.090	37.409	1	0.000	0.577	0.484	0.688
	Constant	0.470	0.074	40.782	1	0.000	1.600		

a. Variable(s) entered on step 1: Gender. Number of observations = 2400, LR Chi Square = 37.997, (df = 1), Log likelihood = 3116.435, Nagelkerke = 0.022, Predicted = 55.3%

4.4.2.2.1 Gender at Kee:

There was a significant ($P < 0.001$) gender effect on the likelihood to adopt cover crops at Kee. Men were 42.3% less likely to adopt than women.

4.4.2.2.2 Age category and Education level in Kee:

There was no statistical significant age or education effect on the likelihood to adopt cover crops at Kee. Therefore these two variables were dropped from the final model (Table 4.6) for cover crop adoption for Kee.

4.4.3. Cover crops seed sources

Cover crops seeds sources for the two Divisions included; farmer groups, neighbours, projects, relief agencies and market. The actual frequency of seed sources did not differ significantly (*Chi* = 2.525, $df = 4$; $P > 0.05$) from expected indicating that seed sources did not influence adoption of cover crop technologies at Kalama. However the actual frequency of seed sources differed significantly (*Chi* = 10.902, $df = 4$; $P < 0.05$) from expected indicating that cover crop seed sources influenced adoption of cover crop technology at Kee. Majority of the farmers in both divisions whether adopters or non adopters bought seeds from markets (Table 4.7).

Table 4.7 Frequency of seed sources (No of responses) for Kalama and Kee Division

Division	Sources of seed	Adoption	Non adoption	Statistics
Kalama	Group	18	2	(*Chi*= 2.525,
	Neighbour	6	2	*df* = 4,
	Project	12	3	*P = 0.640*)
	Market	20	6	
	Relief	4	0	
Kee	Group	4	1	(*Chi* =10.902,
	Neighbour	3	5	*df*= 4,
	Project	3	1	*P* < 0.028)
	Market	22	13	
	Relief	3	12	

Actual frequency of cover crop seed sources among respondents differed significantly from expected (*Chi* = 21,589, *df* = 4, *P* < 0.05) indicating seed sources influenced cover crop adoption at Kalama. Also at Kee, actual frequency of seed sources among respondents differed significantly from expected (*Chi* = 51.559, *df* = 4, *P* < 0.05) indicating seed sources influenced cover crop adoption at Kee (Table 4.8).

Table 4.8 Relationship between observed and expected seed sources and adoption

Division	Source of seed	Observed N	Expected N	Residual	Statistics
Kalama	Group	20	14.6	5.4	(*Chi* = 21.58 *df* = 4, *P* < 0.05)
	Neighbour	8	14.6	-6.6	
	Project	15	14.6	0.4	
	Market	26	14.6	11.4	
	Relief	4	14.6	-10.6	
	Total	73			
Kee	Group	5	13.6	-8.6	(*Chi* = 52.56, *df* = 4 *P* < 0.05)
	Neighbour	8	13.6	-5.6	
	Project	4	13.6	-9.6	
	Market	36	13.6	22.4	
	Relief	15	13.6	1.4	
	Total	68			

4.4.4. Respondents preferred cover crop types

Results showed that 80% respondents in Kalama had preferred cover crops. The actual frequency of preferred cover crops did not differ significantly among adopters indicating preferred cover crop type did not influence adoption at Kalama (Table 4.9).

Table 4.9 Relationship between observed and expected preferred cover crops adoption in Kalama

Preferred	Adoption	Observed	Expected	Residual	Statistics
Beans	Adoption	14	12.27	1.32	(*Chi* =
	Non-adoption	1	2.73	-1.32	5.08,
Lablab	Adoption	19	18.00	0.68	
	Non-adoption	3	4.00	-0.68	*df* = 4,
Mucuna	Adoption	1	0.82	0.47	
	Non-adoption	0	0.18	-0.48	*P* > 0.05)
Cowpeas/Green	Adoption	2	1.64	1.68	
Grams	Non-adoption	0	0.36	0.68	
Pigeon peas	Adoption	18	27.27	-2.14	
	Non-adoption	8	4.73	2.14	

In Kee, 52.5% respondents had no preference. The actual frequency of respondent's preferred cover crops did not differ significantly from expected indicating that preferences did not influence adoption in Kee (Table 4.10).

Table 4.10 Relationship between observed and expected preferred cover crops adoption in Kee

Preferred	Adoption	Observed	Expected	Residual	Statistics
Beans	Adoption	19	20.86	-0.77	(Chi =
	Non adoption	19	17.14	0.77	1.45
Lablab	Adoption	11	10.98	0.01	
	Non-adoption	9	9.02	-0.01	*df* = 3,
Mucuna	Adoption	11	17.02	-0.01	
	Non-adoption	14	13.98	-0.01	*P* >
Pigeon peas	Adoption	9	7.14	1.11	0.05)
	Non-adoption	4	5.86	-1.11	

4.4.5. Cover crop information availability and access

The actual frequencies of information availability and access did not differ significantly from expected (*Chi* = 1.63, *df* = 5, *P* > 0.05) indicating that information availability and access did not influence adoption in Kalama (Table 11).

The actual frequencies of information availability and access did not differ significantly from expected (*Chi* = 0.25, *df* = 5, *P* > 0.05) indicating that information availability and access did not influence adoption in Kee (Table 4.12).

Table 4.11 Relationship between observed and expected information sources for adoption of cover crop in Kalama

Information source	Variate	Observed	Expected	Residue	Statistics
Attended training	Adoption	28.00	26.59	0.71	(*Chi* = 1.63,
	Non adoption	5.00	6.41	-0.71	
Farmer field school lessons	Adoption	9.00	9.00	-0.51	*df* = 5
	Non adoption	3.00	2.33	0.51	
On-farm demonstrations	Adoption	22.00	22.00	-0.72	*P* > 0.05)
	Non adoption	7.00	4.63	0.72	
Exchange tour	Adoption	17.00	17.00	17.00	
	Non-adoption	4.00	4.08	0.05	
Field day attendance	Adoption	27.00	27.00	-0.20	
	Non-adoption	7.00	6.60	0.20	
Others	Adoption	9.00	9.00	0.78	
	Non-adoption	1.00	1.94	0.78	

Table 4.12 Relationship between observed and expected information sources for cover crop adoption in Kee

Information source	Adoption	Observed	Expected	Residue	Statistics
Attended training	Adoption	6.00	6.45	-0.27	(Chi= 0.25,
	Non adoption	13.00	12.55	0.27	
Farmer field school lessons	Adoption	3.00	2.38	0.53	*df* = 4,
	Non adoption	4.00	4.62	-0.53	
Exchange tour	Adoption	4.00	3.40	0.45	$P > 0.05$)
	Non-adoption	6.00	6.60	-0.45	
Field day attendance	Adoption	3.00	3.06	-0.04	
	Non-adoption	6.00	5.94	0.04	
Others	Adoption	2.00	2.72	-0.58	
	Non-adoption	6.00	5.28	0.58	

4.4.6. Binary Logistic Regression Model 2

Model 2 constructed with the predicting variables including: cover crop information and knowledge source, seeds sources, preferred seeds and reasons for seed preferences indicated no statistical significant effect on the likelihood to adopt cover crop at Kalama and Kee; therefore, it was dropped from final model for cover crop adoption.

4.4.7. Experts' views on cover crops and adoption

The experts' views on cover crops were responses to the question, *any comment or observation to share based on practical experiences of growing cover crops in Kalama and Kee*?. The frequencies of observed views differed significantly from expected (*Chi* = 49.8, *df* = 9, $P < 0.05$). Views expressed indicated three factors had significant effects on the likelihood to influence cover crop adoption a) 38/165 of the responses in Kalama compared to 48/165 of the responses in Kee indicated technological knowledge and knowhow), b) (31/165 in Kalama compared to 13/165 in Kee, indicated economic gains from using the technology and c) 10/165 in Kalama compared to 25/165 in Kee indicated the cost). The probability associated with the chi square statistic 49.8 is less than 0.05 indicating there was an association between experts' views' and the likelihood to adopt cover crop. Farmer's revealed that droughts used to recur after every 10 years; but this had reduced to every five years; and, in 2008/9 drought after three years. Region specific considerations for intervention measures with likelihood to influence adoption of cover crop are implicated (Table 4.13); and, also in (Table 4.14).

Table 4.13 Frequencies of respondents' views based on knowledge and experiences with cover crops in Kalama and Kee

Variables	Experts Views Description	Division Kalama	Kee	Total
Cover crop knowledge and Knowhow required	Cover crops should be promoted through training Requires knowledge and technical skills to optimize benefits. Group field trips and visits gave vital lessons and knowledge Management skills are required for cover crops use	38	48	86
Cover crop related costs	Financial support such as credit is lacking. Appropriate cover crops seeds are lacking	10	25	35
Demonstrated gains from cover crop technology	Improved /retained soil moisture, generated income Increased maize yields over three times farmers practice yield Other suitable food crops should be provided for cover crops Insured crop failure during drought and provided food security	31	13	44
	Total	79	86	165
	Statistics	Chi square = 14.684, df = 2, $P < 0.001$		

4.4.8. Respondent's recommendations on adoption of cover crops

The actual frequencies of respondents' recommendations did not differ significantly (*Chi* = 0.257, *df* = 2, $P > 0.05$) from expected indicating that respondents recommendations had no influence on adoption in Kalama. Similarly, the actual frequencies of respondents recommendations did not differ significantly (*Chi* = 2.358, *df* = 2, $P > 0.05$) from expected indicating that respondents recommendations did not influence adoption in Kee (Table 4.14).

Table 4.14 Respondents' frequency counts on recommendation to improve cover crops adoption in Kalama and Kee

			Recommendation				
Division	Adoption		More varieties	Short season	Management skills	Total	Statistics
Kalama	Adoption	Count	15	17	27	59	(*Chi*=0.257,
		%	25.4	28.8	45.8	100.0	
	Non Adoption	Count	4	4	5	13	*df* = 2,
		%	30.8	30.8	38.5	100.0	*P* > 0.05)
	Total	Count	19	21	32	72	
		%	26.4	29.2	44.4	100.0	
Kee	Adoption	Count	11	10	1	22	(*Chi*=2.358,
		%	50.0	45.5	4.5	100.0	
	Non Adoption	Count	13	13	6	32	*df* = 2
		%	40.6	40.6	18.8	100.0	*P* > 0.05)
	Total	Count	24	23	7	54	
		%	44.4	42.6	13.0	100.0	

At Kalama, the actual frequencies did not differ significantly (*Chi* = 6.66, *df* = 2, *P* > 0.05) from expected indicating that Kalama respondents' recommendations had no significant influence on adoption. At Kee, however, the actual frequencies differed significantly (*Chi* = 9.579, *df* = 2, *P* < 0.05) from expected indicating that respondents recommendations had influence on adoption at Kee (Table 4.15).

Table 4.15 Relationship between observed and expected respondents recommendation towards increased cover crop adoption

Division	Recommendation	Observed	Expected	Residual	Statistics
Kalama	Management intervention	32.00	24.00	8.00	(*Chi* = 4.083,
	More varieties of cover crops	19.00	24.00	-5.00	*df* = 2
	Short season cover crops	21.00	24.00	-3.00	*P* > 0.05)
Kee	Management intervention	8.00	19.00	-11.00	(*Chi* = 9.579
	More varieties of cover crops	25.00	19.00	6.00	*df* = 2
	Short season cover crops	24.00	19.00	5.00	*P* < 0.05)

4.4.9. Constraints in cover crop adoption

Results indicated that 100% of the respondents in Kalama faced constraints such as pests, diseases, lack of seeds, frost and lack of information regarding cover crop ranked from most important to least. In Kee, 30% respondents indicated they had constraints including lack of information on cover crops, seeds, pests, diseases and frost ranked from most. The constraint of Kee's respondents contributed to their low rate of adoption while

Kalama's respondents' constraints could be attributed to experiences as adoptors (Table 4.16).

Table 4.16 Respondents' responses concerning cover crops constraints, Kalama and Kee

Adoption		Frequency	Kalama	Kee	Total
Constraints	Yes	Count	40	12	52
		% within Division	100.0	30.0	65.0
	No	Count	0	28	28
		% within Division	0	70.0	35.0
Total		Count	40	40	80
		% within Division	100.0	100.0	100.0

However, actual frequency of the constraints did not differ from observed indicating there was no significant relationship (*Chi* = 0.81, *df* =1, $P > 0.05$) between constraint and adoption in Kee (Table 4.17).

Table 4.17 Relationship between observed and expected cover crop constraint in adoption at Kee

Cover crop		Observed	Fitted	Residual	Statistics
Faced constraint	Adoption	7	5.7	0.9	(Chi = 0.81,
	No Adoption	5	6.3	-0.9	
No constraint	Adoption	12	13.3	-0.9	*df* = 1
	No Adoption	16	14.7	0.9	*P* > 0.05)

Using weighted means, respondents ranked the constraints in adoption of cover crops in a declining order of importance (Table 4.18).

Table 4.18 Priority constraints for cover crops adopters in Kalama and Kee division

	Constraints	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Weighted mean
Kalama	Pests	14	20	4	2	0	33.2
	Diseases	4	18	17	1	0	29.0
	Seeds	14	2	15	9	0	28.2
	Blight and chilling temperatures	6	3	0	8	18	15.2
	Lack of information	2	0	3	19	16	14.6
Kee	Lack of information	32	3	1	0	0	35.0
	Seeds	3	37	0	0	0	32.6
	Pests	18	5	8	4	0	28.4
	Diseases	10	14	6	4	1	26.6
	Blight and chilling temperatures	0	0	0	0	2	0.4

Weighted mean = ∑ (Rank 1*value of rank 1 + rank 2*value rank 2...+ Rank 5*value rank 5)/ 5. Where Rank 1=5, Rank 2=4, Rank 3=3, Rank 4=2, and Rank 5=1

4.4.10. Weed problems under conservation agriculture

In Kalama, 96.9% of the respondents indicated that weeds were a problem while all respondents in Kee recognised that weeds were equally a problem. Actual frequency of weed problem did not differ significantly (*Chi* = 0.61, *df* = 1, $P > 0.05$) from expected indicating that weeds were a common problem under conservation agriculture practice in Kalama and Kee (Table 4.19).

Table 4.19 Weed problems in conservation agriculture based on frequency of responses in Kalama and Kee

Variate		Kalama	Kee	Total	Statistics
Weed problems	Frequency	31	19	50	(*Chi* = 0.61
	%	96.9	100.0	98.0	*df* = 1
No weed problems	Frequency	1	0	1	
	%	3.1	.0	2.0	*P* > 0.05)
Total	Frequency	32	19	51	
	%	100	100	100	

The respondents observed frequency of the weed composition was significantly different (*Chi* = 26. 08, *df* = 3, $P < 0.05$) from expected indicating the composition of problematic weeds in conservation agriculture differed in Kalama and Kee. Responses indicated that there were seven grass and 12 broadleaved species in the composition of problematic weeds (Table 4.20).

Table 4.20 Weed composition in maize fields under conservation agriculture as indicated by the frequency of respondents in Kalama and Kee.

Composition		Kalama	Kee	Total	Statistics
Broad leaved	Frequency	40	32	72	(*Chi* = 26.08,
	%	76.9	39.0		
Grasses	Frequency	0	27	27	*df* = 3,
	%	0	32.9		$P < 0.05$)
Sedges	Frequency	7	15	22	
	%	13.5	18.3		
Parasitic	Frequency	5	8	13	
	%	9.6	9.8		
Total	Frequency	52	82	134	

4.4.11. Emerging weed composition change

At Kalama 75% of the respondents compared to 100% in Kee indicated that they had observed weed composition change since 2005. The actual frequency showed that the change in weeds composition differed from expected (*Chi* = 5.63, *df* = 1, $P < 0.05$); indicating that the weeds composition change between Kalama and Kee differed. Among the eight emerging weed problems, four rare species *A. hispidum, A. vogelii*, *L. cornuta* and *O. sinuatum* showed increased frequency and density in the composition; whereas four species including *Portulaca oleraceus*, *A. glabratum*, *E. heterophylla*, and *B. diffusa*, that were not previously found were infesting maize fields (Table 4.21).

Table 4.21 Emerging weed problems in the composition based on responses (frequency) in Kalama and Kee division, 2009

Change Observed	Frequency	Division		Total	Statistics
		Kalama	Kee		
Yes	Count	24	19	43	(*Chi* =5.63
	% within Division	75.0	100.0	84.3	*df* = 1
No	Count	8	0	8	
	% within Division	25.0	0	15.7	P < 0.05)
Total	Count	32	19	51	
	% within Division	100.0	100.0	100.0	

4.5 Discussion

4.5.1. Adoption of cover crops

The study showed that adoption was higher at Kalama than Kee. There was a steady increase in adoption of cover crops at Kalama from 2001 to 2007 which was attributed to cover crop knowledge and knowhow, expected gains and incentives, while a halt could be associated with the national drought (2008-2009). Knowledge and technical knowhow in cover crop was developed through various capacity building activities. These included: field days, experts sharing of lessons, field tours, on-farm adaptive trials, practical training to develop skills using group dynamics, dissemination of communication products. Incentives included provision of seeds, fertilizers, and implements for conservation tillage to use for on-farm experimentation trials. Probably non-adopters were respondents who responded positively; but, did not risk growing cover crops during 2007-2009 when a national drought set in, explaining adoption did not show increase.

This implies that use of knowledge and knowhow in the concept of CA ameliorated the effects of drought on adopters. Adopters of CA attested to these by indicating the many benefits including increased yields, food security and insured crop failure amongst others. Adoption was much lower at Kee, than Kalama which could be attributed mainly to regional considerations including: lack of incentives (cover crop seeds, CA implements and technological training), poor infrastructure necessary to facilitate provision of support services by stakeholders and reduce market cost for Kee farmers. Kee adoption rate showed no increase in 2007 through to 2009 which could be attributed to national drought. Probably available cover crop seeds were lost to drought and used as food, hence no seed to plant when rains set in. This result concurs with Chombas' (2004) report that lack of necessary support services and incentives, location physical constraint, lack of human capital and skills are key factors affecting small holder farmers' adoption of technologies.

4.5.2. Factors influencing adoption of cover crops

This study focused on socio profile of respondents to understand social factors associated with adoption of cover crops at Kalama compared to Kee. Adoption is a decision at the individual farmer level subject to various factors (Kabede *et al.*, 1990). Findings on the likelihood to adopt cover crops or not could guide the stakeholders in making appropriate intervention measures.

Gender indicated significant effect on likelihood to adopt cover crops, suggesting that gender considerations are necessary in designing intervention measures to influence likelihood to adopt cover crops. In Kalama men were 71.1% less likely to adopt cover crops than women; compared to men in Kee, who were 42.3% less likely to adopt cover crops than women. This was probably becausemost women belonged to women groups and these groups were empowered through training and on-farm demonstrations. Kalama groups had few men compared to Kee groups. This means intervention considerations need to be region specific. In addition, the result suggests that intervention measures should consider factors associated with men's perception on usefulness of cover crops and women ease of use of cover crops to increase their likelihood to adopt. The result was contrary to Doss and Morris (2001) findings that gender had an insignificant effect in improved maize technology adoption. Furthermore, the result suggests that intervention measures should consider factors associated with men's perception on use of cover crops to increase their likelihood to adopt. Morris and Vankatesh (2000) reported that women were more strongly influenced by perception on ease of use while men were strongly influenced by their perception on usefulness of a technology.

Age indicated mixed effects on likelihood to adopt cover crops in Kalama suggesting that there could have been some unknown factor influence in play which was not included in the model that could be explored. This agrees with Lapar and Pandey (1999) who have indicated that age of farmer on adoption decision can be a composite of effects of farming experience and planning horizon. While longer farming experience equated with older farmers is expected to have positive effect on adoption, younger farmers may have longer planning horizons and therefore maybe likely to adopt cover crops. In addition, results showed that the farming community was aging as majority of cover crop adopters were over 35 years with few young people. As the population increases, more food will be required on each unit of land and the capacity to produce will rest on the youth. This implies that, though age indicated no significant effect on the likelihood to adopt cover crops in Kee, it could have implications on food production. This result agrees with Mwangi (2006) who reported that there was lack of agricultural professional skills among the youth (under 34 years). Results suggest that creating support systems to involve and engage youth actively could bridge the age gap while developing knowledge and skills could contribute to the likelihood to adopt cover crops. Age is an important factor that influences the probability to adopt new technologies because it is primarily a latent characteristic in adoption decision. However, there is contention on the direction of age effect on adoption (Kabede *et al*., 1990; Akudugu *et al*., 2012). The direction probably could be determined by the technology and exposure suggesting that all the age categories should be exposed to cover crops to increase the likelihood to adopt. Neill and Lee (2001) found that the age of household was negatively and significantly associated with adoption of velvet bean-maize relay crop.

In Kalama, findings indicated a significant ($P < 0.05$) primary education effect on the likelihood to adopt cover crops than the illiterate. Primary education respondents' were 73.1% more likely to adopt cover crops than the illiterate. This result agrees with other reports (Feder *et al*., 1985; Kabede *et al*., 1990) that education had a positive effect on adoption. However secondary and tertiary education effect was not significant. In addition, this study revealed that all the respondents at Kee had formal education which probably explains why Kee indicated more likelihood to adopt cover crops than Kalama. Also respondents belonged to community based groups which engaged in different activities including: informal learning forums such as farmer field schools, on-farm demonstrations, farmer field days and field visits. This means that even those who did not go to school (3.2%) got enlightened as long as their group was active. Therefore these could explain why the education factor did not make a significant difference. Uematsu and Mishra (2010) have reported that technology complexity has a negative effect on adoption and this could only be dealt with through education. The study results suggested that adoption of cover crops was influenced by regional differences between Kalama and Kee.

Members from groups which had earlier participated in growing cover crops referred to as experts contributed views which had significant effect on adoption of cover crops. This suggests that experience was probably the most important social factor which could have assisted farmers to analyze the gains and costs of the cover crop on the basis of own experiments or through analysis of information from other adopters or key informants. This further suggests that investing in farmer's knowledge and knowhow in cover crop, enhancing farmers' ability to analyze practical gains and making cover crops related costs such as seeds, fertilizer, and credit affordable were key factors that influenced the likelihood to adopt cover crops. This agrees with Kabede *et al.* (1990) who indicated that experience was the most significant factor in adoption of agricultural technologies. In addition the result indicated need for region specific consideration for effective intervention measures with likelihood to influence adoption of cover crop. This is in line with Asfaw *et al.* (2011) report on adoption of other agricultural technologies. This was emphasized by respondents' comments "*Use of cover crop technology had tremendous benefits in the region because where maize failed due to harsh weather conditions; the cover crops sustained farmers with grains, vegetables and forage while covering soil managed weeds, and improved water storage efficiency. This translated to increased yields"*. The finding agrees with Olorunmaiye (2010), Ngome *et al*. (2011) and Mwangi *et al*. (2015b) that cover crops suppressed weeds and increased maize yields. Based on their views, experienced farmers recommended more drought tolerant, short duration cover crop varieties and management intervention. This suggests that lack of suitable cover crops to fit into farmers' specific farming system, lack of drought tolerant varieties to cope with weather related risks and lack of management interventions to apply in different cover crops types influenced the likelihood to adopt. Feder *et al*. (1985) indicated that observed patterns of technology adoption are typically influenced by farmer's ability to bear the risk of a new and uncertain technology. The research concluded that preferences considered expected benefits from adoption and the off farm income generation activities farm households engage in and the risks they were able to bear by adopting or not in Kalama and Kee. Perhaps this explains why though majority of adopters and non-adopters bought seeds from market; and, majority of non-adopters in Kee used relief seeds, having seeds was not adequate to give them a reaction threshold to adopt. Lack of appropriate seeds during planting could lead to non-adoption even with knowledge and expected benefits. This implies that partnerships may need to be strengthened to avail preferred seeds to uptake pathways along the value chain. In this study a certain value of stimulus below the threshold no adoption was observed whereas at critical threshold value adoption was stimulated. As Akudugu *et al.* (2012) reported that the threshold is dependent on a certain set of factors. Research could shed light on factors needed to give thresholds for cover crop adoption in specific farming systems. Giller *et al.* (2009) indicated that it is important to use nonlinear, flexible approach when disseminating CA (cover crops) with emphasize on capacity building; and, with room for adaptations to local conditions.

Weeds were acknowledged as a problem by respondents in Kalama and Kee. About 96.9% of the Kalama farmers indicated they experienced weed problems in conservation agriculture compared to 100% in Kee. Weeding labour was a major constraint followed by increased weed species diversity, density, re-growth and emerging weed composition change. Increase in density of specific weed species including *O. sinuatum, A. hispidum and A. glabratum, E. heterophylla, B. diffusa, L. cornuta, P. oleraceae* and *A. quadrifida* could be attributed partly to the weather variability (high temperatures during the day and chilly nights) coupled by management practices that influenced burial of weed seeds leading to increased germination and dissemination of weeds. This is in agreement with Meng *et al.* (2012) who documented that temperature range of 12.5 – 20^{o}C at night and 25 – 35^{o}C during day gave the highest weed seed germination. Shiro (2006) noted that the soil temperature fluctuations that differ with soil depth control seed dormancy and survival, and that seeds appear to have seasonal sensing and burial depth detecting mechanisms based upon temperature fluctuations a condition similar to what was prevailing in the study area. With adoption of cover crops at high level (80%), cover crops reduced the weed species diversity, and managed grasses effectively. *O. sinuatum, T. minuta* and *B. pilosa* were the most frequent broad leaved weeds. In Kee, (where the cover crop adoption was low), *D. abyssinia*, *D. veluntina* and *D. aegytium* were the most frequent grass weeds.

With adoption of cover crop for weed management, factors such as the temperature fluctuations with depth and seed dispersal could be modified without soil disturbance hence reducing the emergence of certain weeds (Teasdale *et al*., 2007).

Weed re-growth was aggravated by common weeding practices with mould board or hoe which contributed to breaking weeds such as *P. quadrifida* into vegetative propagules. Each piece could be dispersed either through plough, animals or erosion to reproduce asexually when conditions were favorable. The findings in Kalama and Kee agrees with Buhler *et al*. (1996) who reported tillage systems influence on weed dynamics in maize systems. In addition, established weeds multiplied sexually leading to increased weed problem. With increased cover crops adoption weed density could be reduced, weeds suppressed and reproduction prevented; and, maize crop competitiveness against the weeds increased.

New weed species emerged and rare weeds increased in density from year 2005 indicating a weed community shift suggesting that management practices and weather variability effects may have contributed to the changes. Farmer's responses to research question "*on any observations or comments to share?"* indicated that droughts used to recur after every 10 years; then had reduced to every five years; and recently after every three years (Personal communication). This had lead to crop failure for none adopters of cover crop while adopters reported that crop failure was insured by cover crops.

Prevailing weeds had characteristics that made them successful under harsh weather conditions (Chilling at night and high temperatures during the day, drought and flush floods). This included: thorns, underground stems or tubers, or fleshy leaves, vines creeping and twining, entangling to form mats that completely covered the ground and root stocks ensuring their survival. Dukes and Mooney (1999) documented new evidence that suggests that many invasive species share traits that will allow them to capitalize on the various elements of global change.

In Honduras, Neill and Lee (2001) found that farmers who adopted mucuna for control of grass weeds (*Rottboellia cochinchinensis*) were much more aware of cover crop reseeding and resultant benefits compared to farmers who abandoned mucuna cover crops due to their poor understanding of the maize system.

Davis and Liebman (2003) and Teasdale *et al*. (2007) indicated that weed seedlings could easily be managed by cutting off sunlight. The degree of control will depend on weed species and the growth stage, thickness of soil cover and soils. Small seeded species are more sensitive to covering especially at cotyledon stage, because once stored energy is depleted; no energy is available for growth. Teasdale *et al*. (2007) indicated that weed seedlings require increased energy to penetrate through the cover; therefore, resulting to higher seedling mortality when energy is depleted.

Khan *et al*. (1993) indicated that weed suppression could be through allelopathy where chemical compounds in growth environment interfere directly with neighboring weed seedlings with subsequent reduced growth. The results suggested that there is need to build stakeholders capacity in weed biology knowledge to understand and facilitate planning effective management strategies. This could enable them to take advantage of the weed characteristics to mitigate and increase farmer’s resilience to weather variability effects.

The result indicated that constraints did not influence respondents’ likelihood to adopt cover crops. This implies that farmers overcame the constraints through certain coping strategies. An exploration study could bring out regional coping strategies and incorporate improvement of adoption. Kalama priority constraint in decreasing order of importance were (pests, diseases, seeds, blight and information compared to Kee’s (lack of information, seeds, pests, diseases and blight) where ranking was in decreasing order of importance. The weighted means ranking indicated priority intervention areas. Hence, in Kalama knowledge and technical skills to manage cover crops pest and diseases were a priority area of intervention; while, in Kee capacity build (information, knowledge and technical skills) and seeds were a priority to increase likelihood of cover crop adoption.

4.6 Conclusion

This study examined cover crop technology adoption. The study highlights some of the social factors likely to influence cover crop adoption at Kalama and Kee. Although reports indicate tremendous benefits, associated with growing cover crops, information on factors likely to influence adoption in Kalama and Kee farming systems is limited. Identification of factors that influence adoption of cover crops in the cropping system would contribute to the elaboration of strategies to achieve increased likelihood to adopt. From experienced farmers' views, knowledge and technical knowhow on growing cover crops, demonstrated gains and meeting related costs influenced likelihood to adopt cover crops. Adopters and non-adopters had different seed sources suggesting that, a reaction threshold to adopt cover crops was dependant on other factors beyond this study. Research could shed light on factors needed to give thresholds likely to influence adoption in unique farming conditions. Several lessons, useful to the development of strategies to influence cover crops adoption in the farming system emerged from this study. Binary logistic regression Model for predicting adoption indicated that men were less likely to adopt cover crops than women; implying that, capacity building is needed for men to change perception in usefulness of cover crops and women ease in growing cover crops to increase the likelihood to adopt. There was no consistency in age and education effects on the likelihood to adopt cover crops; therefore, development agents and policy makers should not target cover crops on basis of age and education. This study recommends first, capacity building for men and women to increase likelihood to adopt cover crops. Secondly, further research to identify other factors likely to influence adoption, analyze the gains and related costs of adopting cover crops in target cropping systems to remove uncertainity for men and women more likely to adopt cover crops. Thirdly, a policy formulation to facilitate knowledge and skills, empower farmers meet related costs, and remove location or regional barriers to cover crop adoption.

CHAPTER FIVE

5.0 EFFECT OF IMAZAPYR COATED IMIDAZOLINONE RESISTANT MAIZE ON MANAGEMENT OF WEEDS IN GREEN HOUSE

Abstract

Maize (*Zea mays* L.) the staple food crop in Kenya is sensitive to weed competition particularly under moisture stress. A pot experiment was conducted to evaluate the effect of imazapyr coated Imidazolinone Resistant (IR) maize on rapeseed (*Brassica napus* L.) growth under two water regimes in the green house at KALRO-Kabete. Eight treatments: 1) IR- maize, 2) IR - maize + bean cover crop, 3) IR - maize + dolichos cover crop 4) IR - maize + cowpeas cover crop, 5) Coated IR-maize, 6) Coated IR-maize + bean cover crop, 7) Coated IR-maize + dolichos cover crop, and 8) Coated IR-maize + cowpeas cover crop were arranged in a completely randomised design replicated four times. About 58% rape seedlings emerged 3 days after planting; however, the numbers reduced over the 35 days period. Watering once significantly ($P < 0.05$) reduced rape dry matter by over 10 times in herbicide coated IR-maize pots compared to uncoated with or with no cover crops; indicating that, watering twice a week reduced the herbicide coated IR-maize effect. Watering twice a week significantly ($P < 0.05$) increased dolichos dry matter which reduced rapeweed dry matter with or without herbicide coating.

5.1 Introduction

Weeding practiced by majority of the resource poor farmers is physical, tedious, and requires a lot of labour. Consequently, weeds are not removed promptly and therefore compete with crops for long. Hence, weeds and management practices could be contributing to water deficit in ASALs; though, maize plant requires specific amount of water. Maize is sensitive to deficit and surplus during vegetatitive and reproductive stage (Rashid & Rasul, 2010). Adequate nutrition and moisture are needed at critical stages of maize growth to obtain maximum yield (Maqsood *et al*., 2012). Cover crops suppress weeds and increase maize yields (Buhler, 1996: Mwangi *et al*., 2015a). Kabambe *et al*.

(2008) found that apart from *Striga species*, weeds did not grow 2-5 cm around IR-maize plants whose seeds were coated with Imazapyr prior to planting. This indicated that, there could be an opportunity to manage all weeds in a limited area surrounding herbicide coated IR-maize seed, but information when cover crop is integrated was limited. The objective of this study was to evaluate the effect of integrating Imazapyr coated IR- maize and cover crop technology on rape (*Brassica napus* L.) emergence and growth in the green house. Hypothesis (H_0): Imazapyr from IR-maize seed coat will have no effect on all weeds surrounding the maize.

5.2 Materials and Methods

5.2.1. Experimental site and design

The experiment was laid out in a green house at National Agricultural Research Laboratories (NARL), in Kenya Agricultural and Livestock Research Organisation (KALRO). Pots measuring 8x14x14 cm were used (Fig 5.1). The test crop was commercial Imazapyr (herbicide) coated Imidazolinone resistant maize (IR-maize) (Var. WS 303) obtained from Western Seed Company. Cover crops were; dolichos bean (*Lablab purpureus* L.), Field beans (KATX69), and cowpeas (*Vigna unguiculata*) obtained from KALRO seed unit. Soils used (orthic ferralsols with a sandy clay loam texture and a pH of 7.3-8.3) were collected from KALRO-Kiboko, a site selected for follow up field evaluation trials. Results would inform integrated weed management technology development targeting the region.

The soil was mixed thoroughly, 10 kgs put into large pots measuring 8x14x14 cm gauge500. Rapeseed germination tests were carried out before the experimental treatments were laid out. A sample of 60 rape seeds were thoroughly mixed with a little soil to ensure even distribution. The sample soil with seeds was added to each pot to cover the top 4 - 6 cm before the treatments were planted. Eight treatments: 1) IR- maize, 2) IR - maize + bean cover crop, 3) IR - maize + dolichos cover crop 4) IR - maize + cowpeas cover crop, 5) Coated IR-maize, 6) Coated IR-maize + bean cover crop, 7)

Coated IR-maize + dolichos cover crop, and 8) Coated IR-maize + cowpeas cover crop were arranged in a completely randomised design replicated four times. Factor A (water) as the main plot and Factor B (treatments) as the subplot. Four (4) open pollinated IR-maize seeds "Var. WS303" were planted at the middle of each pot. Two cover crop seeds were planted 5 cm away from IR- maize. Watering was done at two levels. In level one, immediately after planting one litre of clean tap water was added in each pot, until soil was moist. Soil moisture was maintained by adding one litre of tap water every three days for 35 days. For watering level two, each pot received one litre of water once a week. The watering regime: twice a week represented when soil moisture is adequate and watering once a week represented inadequate soil moisture simulating season and rainfall pattern in Machakos and Makueni Counties in the ASALs. The green house materials quality leaked in some water after heavy rain down pour. To control the effects, the green house was renovated, the experiment repeated, and watering techniques innovatively modified (sugarcane residues were put in watering cans outlet to reduce water drop impacts on the treatments).

5.2.2. Experimental layout in green house at KALRO-Kabete

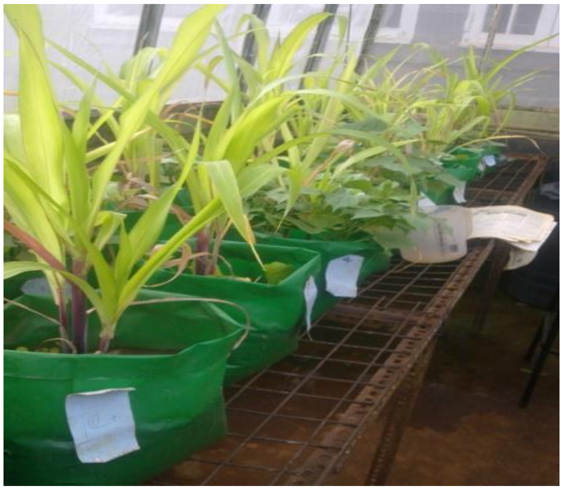

Figure 5.1: Environmentally friendly pots half filled with soil in green house at KALRO-Kabete

Figure 5.2: Treatments in the pots

5.2.3. Data collection

Weed data: The number of emerged rape seedlings per pot was counted at 3, 7, 10, 13, 16, 19, 22, 25 and 28 days after planting and recorded. The distance of emerged rape seedlings from IR-maize seedling was measured and recorded 3 days after germination. The emerged weeds were cut from the soil surface, placed in a labeled paper bag and weighed. The materials were air dried and then placed in the oven set at 60 degrees centigrade for 2 hrs to determine rape dry matter at 35 days after planting. Each sample was removed from the oven and reweighed. This was repeated until constant weight was obtained, and weight recorded.

Crop data: Maize dry matter and cover crop dry matter were evaluated 35 days after planting. Maize and cover crop biomass were cut from soil level and put in separate paper bags; and, labelled, air dried and then placed in the oven set at 60 degrees centigrade for 2 hrs. Each sample was removed from the oven and reweighed. This was repeated until constant weight was obtained, and weight recorded.

5.2.4. Data analysis

Using GenStat program Version 12 the data was subjected to analysis of variance (ANOVA). Significant means were separated using Student Newman Keuls (SNK) at ($P \leq 0.05$).

5.3 Results

5.3.1. Emerged Rape weed (plants per pot) and growth

There was a significant ($P < 0.05$) interaction effect between herbicide coated IR-maize and cover crops on mean rape weed (count per pot). This means that herbicide coated IR-maize effect in suppressing rape weed was affected by cover crop. Coated IR-maize plus dolichos, beans or cowpeas cover crops significantly ($P < 0.05$) reduced rape weed plants by 12%, 14%, and 16% respectively compared to coated IR-maize alone. Coated IR-maize plus dolichos significantly ($P < 0.05$) reduced rape seed count by 10% compared to uncoated IR-maize plus dolichos. Beans, cowpeas and no cover significantly ($P < 0.05$) reduced mean rape count per pot by 27.8%, 21.7% and 13.4% compared dolichos in the uncoated IR- maize. Means rape plants (count per pot) are compared among treatments (Table 5.1).

Table 5.1 Mean number of rape weed (plants per pot) 3 – 30 days after planting.

Treatment	Mean (plants per pot)
Coated IR- Maize	41.07[a]
Uncoated IR- Maize	34.92[bc]
Uncoated IR- Maize + Dolichos	40.32[a]
Coated IR- Maize + Dolichos	35.97[b]
Coated IR- Maize + Beans	34.97[bc]
Uncoated IR- Maize + Bean	29.10[d]
Coated IR- Maize + Cowpea	34.13[bc]
Uncoated IR- Maize + Cowpea	32.57[c]

Means in the same column followed by the same letter are not significantly different at ($P < 0.05$) according to Student Newman Keuls test. (CV% = 14.8)

There was no significant ($P > 0.05$) interaction effect among herbicide coated IR-maize x cover crops x watering x time (Days after planting) on weed count.

5.3.2. Number of rape weed (plants per pot) over 30 days after planting

Time (days after planting) had a significant ($P < 0.05$) effect on number of emerged rape weed (plants per pot). The number of emerged rape weeds were significantly ($P < 0.05$) reduced with time, and the rate is as depicted (Fig. 5.2).

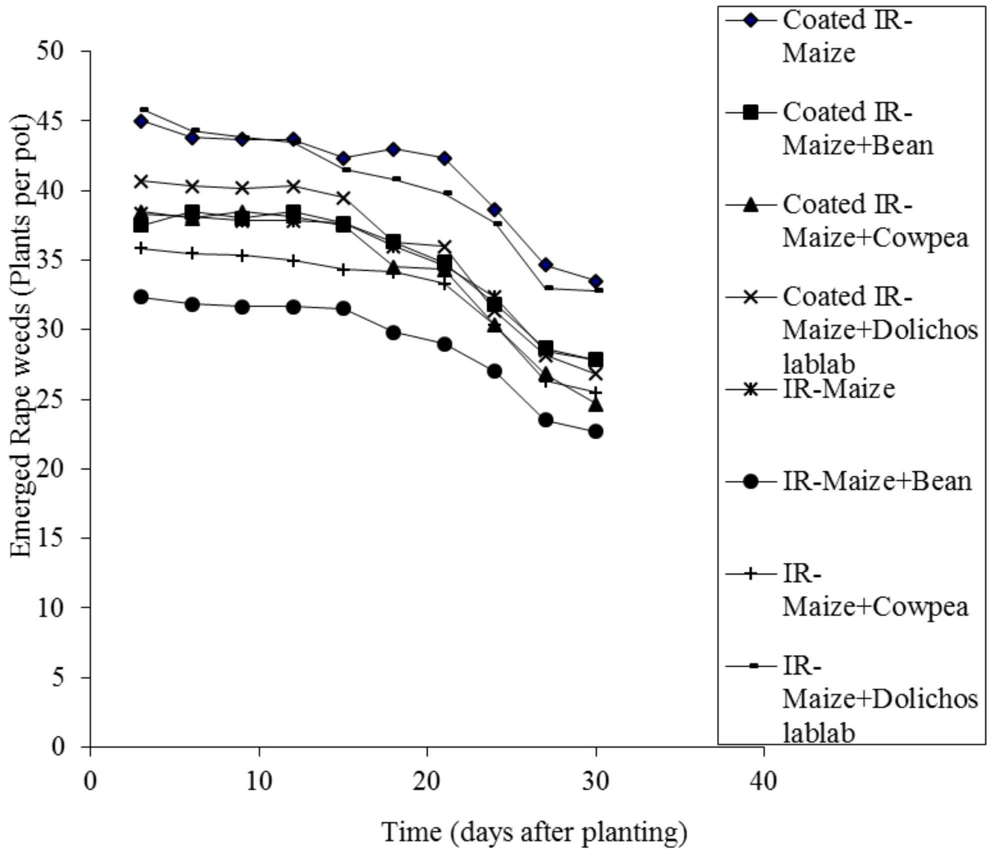

Figure 5.3: Rape weed (plants per pot) as affected by treatments every three days for 30 days after planting (at *P* < 0.05). (LSD = 2.9)

5.3.3. Interaction effect of herbicide coated IR-maize, cover crop, and watering regime on mean number of rape (plants per pot)

There was a significant ($P < 0.05$) interaction effect among herbicide coated IR-maize, cover crop, and watering regime on mean number of rape seedling (count per pot). Results indicated that watering twice a week effectively suppressed growth and reduced rapeweed (count per pot) in uncoated IR-maize plus dolichos compared to uncoated IR-maize plus dolichos watered once a week which had higher means. Watering twice did not significantly reduce means for coated IR-maize alone, with beans or cowpeas compared to watering once. Watering twice a week did not significantly reduce mean weed count for uncoated IR-maize with or without beans or cowpeas compared to watering once a week. Watering twice a week had no significant effect on number of rape weeds in uncoated IR-maize alone compared to watering once. Watering twice a week significantly ($P < 0.05$) reduced rape plants (count per pot) in herbicide coated IR-maize with dolichos compared to watering once. The mean number of rape (plants per pot) are compared among treatments (Table 5.2).

Table 5.2 Mean number of rape weed (plants per pot) 3 - 35 days after planting as affected by watering regime, cover crop and herbicide coating.

Treatment	Mean (plants per pot)
Uncoated IR-Maize + Dolichos + watering once	49.44^{a}
Uncoated IR-Maize + Dolichos + watering twice a week	35.17^{de}
Coated IR-Maize + watering once	45.33^{ab}
Coated IR-Maize + watering twice a week	40.94^{bcd}
Coated IR-Maize + Bean + watering once a week	37.78^{cde}
Coated IR-Maize + Bean + watering twice a week	36.83^{cde}
Coated IR-Maize + Cowpea + watering once a week	36.61^{cde}
Coated IR-Maize + Cowpea + watering twice a week	37.06^{cde}
Coated IR-Maize + Dolichos + watering once	42.06^{bc}
Coated IR-Maize + Dolichos + watering twice a week	35.50^{de}
Uncoated IR-Maize + watering once a week	38.00^{cde}
Uncoated IR-Maize + watering twice a week	36.06^{de}
Uncoated IR-Maize + Beans + watering once	33.72^{ef}
Uncoated IR-Maize + Beans + watering twice a week	28.11^{f}
Uncoated IR-Maize + Cowpea + watering once a week	35.72^{de}
Uncoated IR-Maize + Cowpea + watering twice a week	33.50^{ef}

Means in the same column followed by the same letter are not significantly different (P < 0.05) according to Student Newman Keuls test.

5.3.4. Emerged rape seedling distance from the IR-maize

There was no significant effect ($P > 0.05$) among the interactions: herbicide coated IR-maize, cover crops and watering on rapeweed seedling distance from coated IR-maize (data not shown).

There was no significant ($P > 0.05$) interaction effect between herbicide coated IR-maize and cover crops on mean distance of rape seedling from coated IR-maize (data not shown).

Watering twice or once a week had no significant ($P > 0.05$) effect on rapeseed distance from IR-maize. On average the distance of rape weed was 0.93 cm from IR-maize (data not shown).

5.3.5. Rape weed dry matter (g per pot) 35 days after planting as affected by treatments

5.3.5.1. Watering regime, herbicide coated IR-maize and cover crop effects on rape weed dry matter

There was a significant ($P < 0.05$) interaction effect of watering, herbicide coated IR-maize and cover crop on mean rape weed dry matter (g per pot) (Table 5.3). Herbicide coated IR–maize pots watered once a week reduced mean weed dry matter (g per pot) by 53.3% compared to pots watered twice a week. Herbicide coated IR–maize significantly ($P < 0.05$) reduced mean weed dry matter (g per pot) about 6.5 times compared to non coated IR-maize. Watering herbicide coated IR–maize twice a week significantly (P < 0.05) reduced mean weed dry matter (g per pot) about 18 times compared to watering non coated IR-maize watered twice a week. Dry matter was significantly ($P < 0.05$) less in pots with herbicide coated IR-maize watered once a week, with or without cover crops compared to watering twice a week. Pots with herbicide coated IR-maize alone had the lowest mean weed dry matter compared to pots with coated IR-maize plus cover crops. Uncoated IR-maize watered twice a week had the most rape weed dry matter (g per pot) compared to coated IR-maize. Cowpeas plus uncoated IR-maize watered twice had more weed dry matter compared to watering once a week. Beans plus uncoated IR-maize pots watered twice a week had more weed dry matter compared to treatments watered once a week. Dolichos plus uncoated IR-maize pots watered twice a week had significantly ($P < 0.05$) higher weed dry matter compared to pots watered once a week. Pots with uncoated IR-maize watered twice a week had significantly ($P < 0.05$) more weed dry matter compared to those watered once a week (Table 5.3).

Table 5.3 Herbicide coated IR-maize, cover crops and watering regime effect on mean rape weed dry matter per pot 35 days after planting.

Treatments	Rape dry matter (g per pot)
Water once a week + Coated Imidazolinone resistant	0[a]
Water once a week + Coated Imidazolinone resistant+beans	0[a]
Water once a week + Coated Imidazolinone resistant+cowpea	0[a]
Water once a week + Coated Imidazolinone resistant+lablab	0.067[a]
Water twice a week + Coated Imidazolinone resistant+lablab	0.200[a]
Water twice a week + Coated Imidazolinone resistant	0.533[a]
Water twice a week + Coated Imidazolinone resistant+beans	0.533[a]
Water once a week + Coated Imidazolinone resistant+cowpea	1.067[a]
Water once a week + Coated Imidazolinone resistant+lablab	1.133[a]
Water twice a week + Coated Imidazolinone resistant+cowpea	1.400[a]
Water once a week + Imidazolinone resistant+beans	1.400[a]
Water once a week + Imidazolinone resistant	6.467[ab]
Water twice a week + Imidazolinone resistant+cowpea	11.800[bc]
Water twice a week + Imidazolinone resistant+beans	12.267[bc]
Water twice a week + Imidazolinone resistant +lablab	12.400[bc]
Water twice a week + Imidazolinone resistant	18.467[c]

Means in the same column followed by the same letter are not significantly different ($P < 0.05$) according to Student Newman Keuls test. (CV=14.1%).

5.3.5.2. Effect of herbicide coated IR-maize and cover crop on rapeweed dry matter (g per pot) 35 days after planting

There was a significant ($P < 0.05$) interaction effect between herbicide coated IR-maize and cover crop on mean weed dry matter (g per pot). The pots with herbicide coated IR-maize had significantly ($P < 0.05$) lower weed dry matter (g per pot); which, was not significantly different with or without cover crop compared to uncoated IR-maize pots. Pots with uncoated IR–maize alone had significantly ($P < 0.05$) more weed dry matter ranging 75 -125% compared to pots with uncoated IR-maize plus bean, dolichos or cowpea cover crops (Table 5.4).

Table 5.4 Herbicide coated IR-maize and cover crop effect on rape dry matter (g per pot)

Treatments	Rape weed dry matter (g per pot)
Coated Imidazolinone resistant + Lablab	0.133[a]
Coated Imidazolinone resistant	0.267[ab]
Coated Imidazolinone resistant + bean	0.267[ab]
Coated Imidazolinone resistant + cowpea	0.700[ab]
Imidazolinone resistant + cowpea	6.433[c]
Imidazolinone resistant + lablab	6.767[c]
Imidazolinone resistant + beans	6.833[ac]
Imidazolinone resistant	12.467[d]

Means in the same column followed by the same letter are not significantly different ($P < 0.05$) according to Student Newman Keuls test.

5.3.5.3. Water effects on rape dry matter (g per pot) 35 days after planting

There was a significant ($P < 0.05$) watering effect on weed dry matter (g per pot). Pots watered twice a week had significantly ($P < 0.05$) more rapeweed dry matter (6 times more) than pots watered once a week (Fig. 5.3) 35 days after planting.

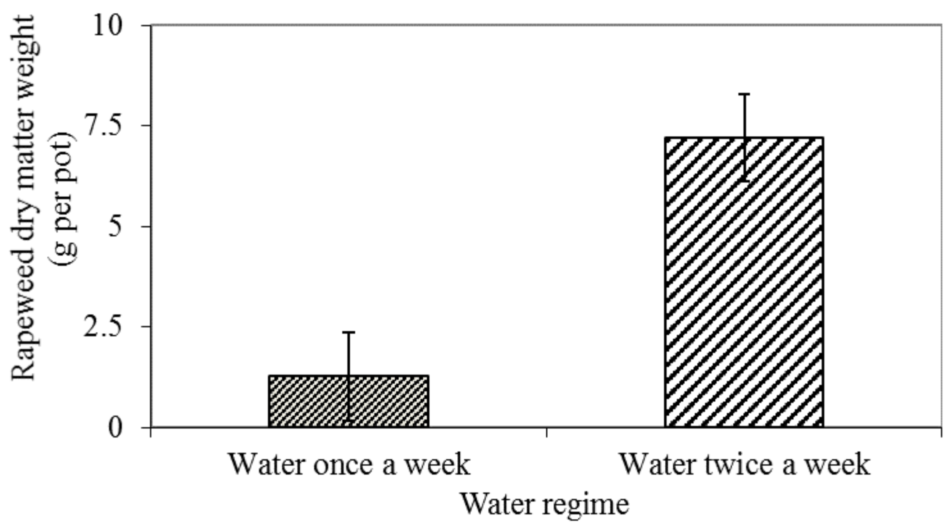

Figure 5.4: Rape weed dry matter (g per pot) as affected by watering regime 35 days after planting ($P < 0.05$). (Error bars represent LSD = 2.2)

5.3.5.4. Rape seed (height, cm) as affected by dolichos, beans and cowpeas cover crops and herbicide coated IR-maize.

There was a significant ($P < 0.05$) interaction effect between herbicide coated IR-maize and cover crops on mean rape weed height (cm). Herbicide coated IR-maize significantly ($P < 0.05$) reduced the rapeseed height compared to uncoated IR-maize with or without cover crops. Uncoated IR-maize with cowpeas had significantly ($P < 0.05$) lower rapeseed height compared to dolichos and beans. The means are compared among treatments (Table 5.5).

Table 5.5 Effect of herbicide coated IR-maize and cover crops on rape weed height (cm) 30 days after planting

Treatments	Rapeseed mean height (cm)
Coated Imidazolinone	6.86[a]
Coated Imidazolinone resistant + Cowpea	7.56[a]
Coated Imidazolinone resistant + lablab	8.94[a]
Coated Imidazolinone resistant + bean	8.97[a]
Imidazolinone resistant + cowpea	17.58[b]
Imidazolinone resistant + lablab	21.78[c]
Imidazolinone resistant + beans	22.06b[c]
Imidazolinone resistant	23.36[c]

Means in the same column followed by the same letter are not significantly different ($P < 0.05$) according to Student Newman Keuls test.

5.3.5.5. Number of leaves of rapeweed per plant per pot as affected by dolichos, beans, cowpeas and herbicide coated IR-maize 35 days after planting.

There was a significant ($P < 0.05$) interaction effect between cover crops and herbicide coated IR-maize on number of leaf count (3 rape plants per pot) 30 days after planting. Herbicide coated IR-maize plus dolichos reduced the number of leaves by 37.8% compared to uncoated IR-maize. Herbicide coated IR-maize had 33.3% less number of rapeweed leaves compared to uncoated IR-maize.The means are compared among treatments (Table 5.6).

Table 5.6 The average number of rape weed leaves per plant, 35 days after planting

Treatment	Means (No of leaves per plant)
Coated Imidazolinone resistant + Dolichos	2.8^{a}
Coated Imidazolinone resistant	3.0^{ab}
Coated Imidazolinone resistant + Bean	3.2^{ab}
Coated Imidazolinone resistant + Cowpea	3.0^{ab}
Imidazolinone resistant + Cowpea	3.5^{abc}
Imidazolinone resistant + Dolichos lablab	3.7^{abc}
Imidazolinone resistant + Beans	4.2^{bc}
Imidazolinone resistant	4.5^{c}

Means in the same column followed by the same letter are not significantly different ($P < 0.05$) according to Student Newman Keuls test. (CV% = 16.7)

5.3.6. Maize dry matter (g per pot) as affected by treatments

There was no interaction effect among herbicide coating, cover crops and water regime on IR-maize dry matter ($P > 0.05$) (Data not shown). This indicated that herbicide coated IR-maize, watering regime, dolichos, beans or cowpeas effect did not significantly influence IR- maize growth during the 35 days after planting.

5.3.7. Dolichos dry matter (g per pot) as affected by watering regime

Watering twice a week significantly ($P < 0.05$) increased the dolichos dry matter by 254% compared to watering once a week (Fig 5.4).

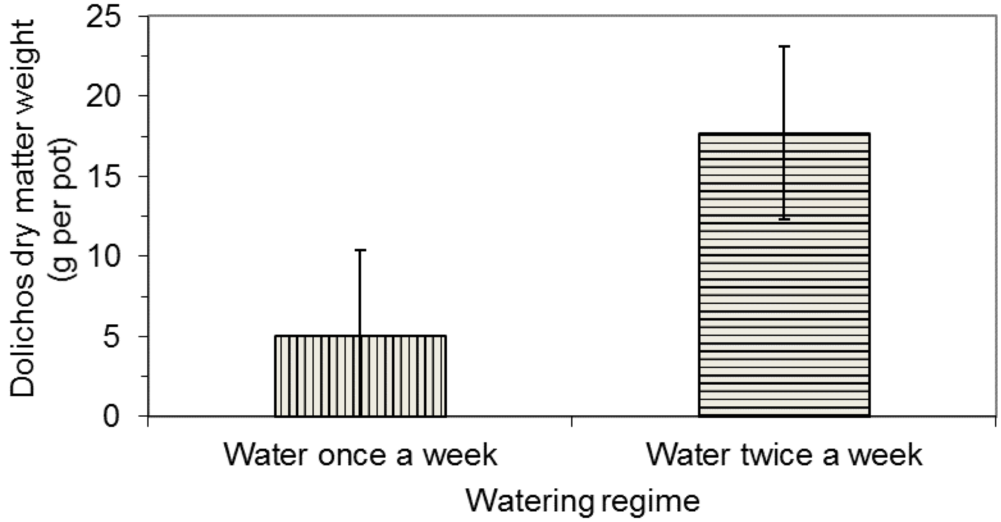

Figure 5.5: Effects of watering regime on dolichos dry matter (g per pot) (*P* < 0.05). (Error bars represent LSD = 10.8)

5.3.8. Coated IR-maize effects on dolichos dry matter (g per pot)

Herbicide coated IR-maize significantly ($P < 0.05$) reduced the dolichos dry matter by 125% compared to uncoated IR –maize (Fig 5.5); however, herbicide coated IR-maize showed no significant effect on cowpeas and beans dry matter (data not shown).

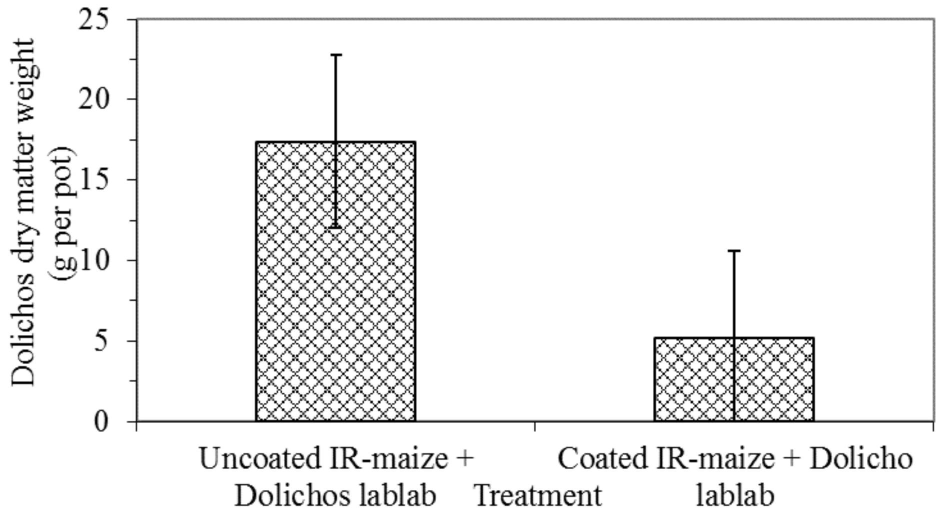

Figure 5.6: Dolichos dry matter (g per pot) as affected by coated IR-maize (*P* < 0.05). (Error bars represent LSD =10.8)

5.4 Discussion

Watering once a week, herbicide coated IR-maize, and cover crops (black dolichos, beans and cowpea) reduced number of rape weeds (plants per pot). Rape germinated and emerged three days after planting. Germination could have been influenced by genetics, suboptimal growth conditions, and treated seed storage. This is in agreement with Pekrun *et al*. (1998). In the pots with coated IR-maize, the number of emerged rapeweeds counted three days after planting decreased gradually within the 20 days period; and, the reduction rate was faster 20 to 30 days after emergence. This suggested that the herbicide from coated IR-maize diffused into the soil, and probably was taken up by emerged rape seedlings resulting to slow death; hence, contributing to the decreased numbers. Findings support the herbicide mode of action where blocked amino acid synthesis build up substrate causes shoot meristem cease to grow; and, symptoms develop slowly (2 - 3 weeks or more). This agreed with James *et al*. (2001), Martin (2016) and Ross (2016). However, similar decline in numbers of rape weeds in the pots with uncoated IR-maize indicated that some other factor could have played a role. This agreed with Peterson *et al*. (2001) who found that the older leaves and stem of rape produce more phytotoxins than younger leaves supporting the observed rape seedling faster decline with time. The result also agreed with Kelton *et al*. (2012) findings that rape seed produce glucosinalates secondary metabolites containing sulphur and nitrogen, which is hydrolysed by myrosinase (enzyme) in the presence of water to isothiocynates the active allellochemicals which may have played a role of suppressing rape growth resulting to the decline of the rape counts. Pekrun *et al*. (1998) has shown optimal germination of rape is 20^{o}C and high water availability; however, it could germinate under a variety of temperatures such as 50% germination three days after planting at 8^{o}C as recorded. Soil below 10^{o}C results to poor germination and emergence and may take longer (Pekrun *et al*., 1998). The conditions (temperature 18 - 22^{o}C, and soil moisture) were optimal for germination in this study.

Herbicide coated IR- maize in combination with dolichos significantly reduced emerged rape seedlings more when watered twice a week compared to watering once a week indicating more water increased dolichos. This effect was similar in pots with uncoated IR-maize and dolichos watered twice suggesting two things: 1) that increasing watering frequency from one to twice a week may have reduced the effect of herbicide coating; probably, through leaching away. 2) Significant increased ($P < 0.05$) in growth of dolichos (dry matter g per pot) may have suppressed rape count with or without herbicide coated IR- maize effect. Dolichos, beans and cowpeas integrated with herbicide coated IR-maize reduced emerged rape count compared to herbicide coated IR-maize alone ($P < 0.05$) indicating the rapeweed count reduction was partly attributed to cover crop effect. Oram *et al*. (2005) indicated that rape is a poor competitor. Dolichos, cowpeas and beans may have reduced rape growth and establishment by disrupting niche and rapeweed susceptibility to phytotoxic effects of crop residues and other soil amendments therefore reducing growth and density, agreeing with Liebman and Davis (2010). In this study dolichos effect resulting from its aggressive growth and biomass production, suppressed rape more than beans and cowpea showing the potential in dolichos as a better cover crop option in ASAL. Dolichos produced more dry matter than cowpea even with inadequate water and, this translated to improved soil physical conditions. This agreed with Sheahan (2012).

The average weed distance away from the coated IR-maize was about 0.93 cm. This was unlike Kabambe *et al*. (2008) the finding of 2-5 cm clear without weeds. The difference could be attributed to differences in experimental conditions such as temperature amplitude, watering regime and herbicide coated IR-maize seed storage conditions kept for one year. Watering once a week, herbicide coat, and cover crop significantly reduced weed dry matter (g per pot) compared to uncoated IR-maize (control). In addition, watering twice a week of already emerged uncoated IR-maize with cover crops significantly reduced rape dry matter suggesting two things: 1) that watering twice a week significantly increased growth of the cover crops which resulted in suppression effects that reduced weed dry matter and 2) reduced the herbicide effect. This suggests that cover crop and water synergy had suppressing effect on rape resulting to low dry matter or the allelopathic weed suppression effect agreeing with Kelton *et al*. (2012). The study results suggests that rape seed allellopathic effect could be examined under field conditions. Herbicide coated IR-maize and cover crop significantly ($P < 0.05$) reduced rape weed dry matter 12 times compared to uncoated IR-maize with cover; and, reduced rape dry matter 6 times compared to uncoated IR-maize with no cover. This indicated that herbicide from IR-maize was adequate to suppress rape growth which resulted to reduced dry matter; however, there were no significant differences among cover crops. Herbicide coated IR-maize suppressed rape weed growth as indicated by reduced dry matter, rape height, and number of leaves per plant. The rape variety was sensitive to imidazolinone; hence, the herbicide effect may have caused shoot meristem cease to grow, resulting to shorter weeds, fewer leaves, and lower dry matter 35 days after planting. This agreed with findings (Ross, 2009; Martin, 2016) that blocked synthesis by imidazolinones build up substrate which cause shoot meristem cease to grow. Rape variety used was sensitive to imidazolinone though there are many tolerant varieties (Australia Government, 2008).

Cowpeas, beans and dolichos significantly ($P < 0.05$) reduced rape weed dry matter per pot by almost a half compared to no cover crop. Pots with cowpeas, beans and dolichos respectively had no significant difference in weed dry matter quantities suggesting their suppressing effect on rape weed growth was similar within the period of study. However, dolichos produced significantly ($P < 0.05$) higher dry matter compared to beans and cowpeas in the green house. This suggested that dolichos integrated with herbicide coated IR- maize had more yield (unit area of production) compared to beans, or cowpeas or no cover crop in combination with maize per pot. In this study, dolichos suppressed weeds agreeing with Onyango *et al*. (2000) and Karuma *et al*. (2011). Davis and Liebman (2003), Gachene and Mwangi (2006) and Karuma *et al*. (2011) have indicated that dolichos added other benefits including modifying soil environment, increase soil moisture retention, improved workability and soil conditions increasing maize yield.

Watering dolichos twice a week resulted to more biomass which suppressed rape growth, indicating that though rape plants were more in numbers due to good moisture conditions for emergence; however, the plants were suppressed resulting to low dry matter. This confirms the combined synergy contributed to effective suppression of rape growth. The overall effect of herbicide coated IR-maize on rape weed dry matter was influenced by watering regime.

Coated IR-maize dry matter was not significantly affected by the bean, dolichos, or cowpea and no cover crop; compared to uncoated IR- maize 35 days after planting. This indicated that dolichos, cowpeas, and beans suppressed weed growth and significantly reduced density but had no significant effect on maize dry matter agreeing with others (Liebman & Davis, 2000; Masunda, 2010; Uchino *et al*., 2012). Maize crop yield loss sets in between 14 - 28 days after emergence (V5-V8 leaf stage), especially due to water stress. At about 14 days after emergence (V5 leaf stage of maize), all maize parts are formed (leaves, ear shoots, tassel in miniature, and no of kernels determined); and, the growing point is still at/or below the soil protecting the young maize from reductions due to outside stress agreeing with Weeds Soft (2006). In addition, dolichos are known to fix nitrogen more efficiently than beans or cowpeas; however, the effects of legume cover crops, could not have affected maize within the 35 days evaluation period because nitrogen fixation starts at about 10 weeks after emergence agreeing with Sheahan (2012). Dolichos were in its early establishment; yet to develop. Cameroon (1988) findings showed that it requires 130 days for maximum canopy. Humpreys (1995) indicated that for each 1000 kg dry matter of dolichos shoots about 40 - 45 kg N is fixed.

Pots with herbicide coated IR-maize and watering once or twice significantly increased dolichos dry matter which resulted to more rape weed suppression. Watering alone significantly ($P < 0.05$) increased dolichos dry matter; however, it did not affect dry matter of cowpeas and beans. The dolichos biomass intercepted the photo synthetically active radiation; leading to suppressed weed growth. This resulted to greater reduction in weed dry matter by dolichos a response probably associated to shading effect compared to bean or cowpea. The rape weeds grew significantly ($P < 0.05$) taller in strive to get the photosynthetically active sunlight through the dolichos biomass; than, those under beans and cow peas. In addition, there was no significant difference in rape height under dolichos, beans and no cover in uncoated IR- maize compared to cowpeas suggesting they had same effect on interception of photosynthetic radiation from the rape. This was consistent with Liebman and Davis (2000) and Ausra *et al*. (2010) findings on interception of photo synthetically active radiation by dense canopies. This result agreed with Linares *et al*. (2008) findings that dolichos dry matter was inversely proportional to weed dry matter.

5.5 Conclusion

- This study demonstrated that the effect of herbicide coated IR-maize significantly ($P < 0.05$) reduced weed growth, consequently the weed dry matter six times compared to uncoated IR-maize.
- The study found that the effect of herbicide coated IR-maize with cover crops significantly ($P < 0.05$) reduced weed growth, consequently the weed dry matter 12 times compared to uncoated with cover crop.
- The study confirmed that increasing water significantly ($P < 0.05$) increased dolichos above ground biomass. Dolichos biomass significantly ($P < 0.05$) suppressed weed growth more compared to beans, cowpeas, or no cover crop with or without herbicide coated IR-maize, however density counts were not affected.

CHAPTER SIX

6.0 EFFECT OF IMIDAZOLINONE RESISTANT (IR-MAIZE) COATED WITH IMAZAPYR HERBICIDE AND COVER CROPS ON WEED COMPOSITION AND DENSITY AND MAIZE YIELD.

6.1 Abstract

Weeds compete for nutrients and soil moisture resulting to low maize yields in dry lands. A three year field study was initiated in 2009 at Kenya Agricultural and Livestock Research Organisation, Kiboko to evaluate the effect of dolichos bean (*Lablab purpureus* L.) and open pollinated imazapyr herbicide coated imidazolinone-resistant (IR) maize on weed species composition, density, and maize yield. Initially, weed species were identified, and then controlled using glyphosate at 1.6 kg ai ha^{-1}. Twenty four plots were marked, each measuring 4 x 5 m. Six treatments 1) IR-maize coated, 2) IR-maize coated + brown dolichos, 3) IR-maize coated + black dolichos 4) IR-maize uncoated, 5) IR-maize uncoated + brown dolichos, 6) IR-maize uncoated + black dolichos were laid out in a randomized complete block design replicated four times. IR-maize was planted at a spacing of 90 x 45 cm and 2 seeds per hole. Weeds were sampled from a one meter squared quadrat 21 and 42 days after planting (DAP). Eighteen (18) weed species were prevalent before the experiment. Interaction of dolichos and herbicide coated IR-maize had no significant ($P > 0.05$) effect on weed species composition and density. However, dolichos significantly ($P < 0.05$) reduced the density of *Portulaca quadrifida* L. and *Paraknoxia parviflora* L., and increased *Eleusine indica* L. Weed species composition decreased by 14% (21 DAP) and 33% (42 DAP) in plots with dolichos compared to no cover. Maize yields were significantly ($P < 0.05$) higher in plots with dolichos than without. The study showed that dolichos integration with coated IR-maize managed weeds and increased maize yields in drylands.

6.2 Introduction

Worldwide, maize (*Zea mays* L.) produces the highest yields among cereals. The East and Central Africa (ECA) region produces an average yield of 1.8 t ha^{-1} (FAO, 2008). These yields are relatively low compared to the potential yield of 4.5-7.0 t ha^{-1} in ECA region (Mwangi *et al*., 2011). It is the most important staple crop in Kenya. It is an important cash crop vegetable (baby corn and green maize) and seed/grain. Maize is very sensitive to weeds in vegetative, reproductive and maturity growth stages. Maize planted in fields heavily infested with weeds resulted in substantial yield reductions even when rainfall is adequate (Abdin *et al*., 2000). Development in *Striga* weed management (Kanampiu *et al*., 2002; Kanampiu *et al*., 2003; Kabambe *et al*., 2008) has indicated that imazapyr herbicide coated imidazolinone-resistant (IR-maize) seeds absorbed part of the herbicide from the coat. Absorbed herbicide moved systemically through phloem and xylem and controlled any attaching *Striga species.* Imazapyr slowly tightly binds onto Acetohydroxyacid synthase (AHAS) enzyme and inhibits synthesis of branched amino acids (leucine, valine and isoleucine) resulting to plant death from lack of needed proteins for growth (Muhitch *et al*., 1987). IR-maize is naturally resistant to imazapyr herbicide (an imidazolinone). The herbicide not absorbed by the seed diffused into the soil and killed *Striga* seeds in the soil. Apart from controlling *S. hermonithica* species, it also left 2 - 5 cm surrounding maize clear of any weeds (Kabambe *et al*., 2008). The herbicide dissipated from coated maize seeds did not affect root zone of legume intercrops 15 cm from coated seeds (Kanampiu *et al*., 2002; Kanampiu *et al*., 2003). Research has indicated that many factors influence the weed community interaction (Shrestha *et al*., 2002). This has implications on weed density and diversity. The question is what is the effect of imazapyr coated IR-maize on weed species composition surrounding maize in a drought prone area under conservation agriculture? The objective of this study was therefore to evaluate the effect of dolichos and imazapyr herbicide coated IR-maize on weed composition, weed density and maize yield in Machakos County of Kenya.

6.3 Materials and methods

6.3.1. Study area

Field trials were conducted for tthree years (2009 - 2011) at Kenya Agricultural Livestock Research Organisation (KALRO) Kiboko. This is a research Station located in Makindu Division, Makindu District in Makueni County. It is located 155 km from Nairobi along Mombasa highway, at latitude 2.15°S, longitude 37.75°E and altitude 975 m above sea level. It lies in agro-ecological zone (AEZ) LM 5 (Roselt, 2011). Soils are classified as orthic ferralsols with a sandy clay loam texture in top 20 cm (according to FAO soil classification). The ecosystem has fragile soils. Soil tests prior to planting showed that the soil pH ranged from 7.3 - 8.3. The region has two wet seasons: a long rain season (March to May) and a short rain season (October to December); with an annual average rainfall of 600 mm. Rainfall is erratic and unreliable. Infiltration rates vary from moderate to rapid. It has a potential evaporation of 2000 mm. It is a hot dry region with a mean annual temperature of 22.6°C, mean annual maximum 28.6°C and mean annual minimum of 16.5°C (Roselt, 2011). A total of 18 weed species formed the composition in the field before trials were established. Majority (15 species) were broadleaf while three species were grasses. Annual broadleaf dominated (12 species), perennial broadleaf were few (three species) while the annual grasses were three species.

6.3.2. Plant materials

Imazapyr herbicide coated IR - maize (Imazapyr 30 g ha^{-1}) open pollinated variety (OPV) (WS 303) and uncoated IR - maize (*cv*. 303) was obtained from Western Seed Company. Black dolichos (*var*. HB 1002) and brown dolichos (*var*. Rongai) were obtained from KALRO seed unit.

6.3.3. Treatments and experimental design

To prepare the site in 2010, weeds were identified, slashed and glyphosate applied at 1.6 kg ai ha^{-1} (equivalent of 400 ml per 20 liters) using a knapsack sprayer with a low volume nozzle to control emerged weed seedlings.

Twenty four (24) plots were demarcated, each measuring 4 x 5 m and furrows made at a spacing of 90 cm. There were six (6) treatments 1) IR-maize coated, 2) IR-maize coated + brown dolichos, 3) IR-maize coated + black dolichos 4) IR-maize uncoated, 5) IR-maize uncoated + brown dolichos, 6) IR-maize uncoated + black dolichos. These treatments were laid out in a randomized complete block design (RCBD) and replicated four times. Maize was planted at a spacing of 90 × 45 cm and 2 seeds per hole. In the cover crop treatments, two rows of dolichos were planted between two rows of maize with intra-row spacing of 45 cm. During planting, compound fertilizer (NPK 23:23:0) was applied at 60 kg ha^{-1} P_2O_5 (equivalent to 13.8 kg N ha^{-1} and 6.02 kg P). After planting, all treatments were irrigated for 3 hours to field capacity (320 - 355 mm) and after every 3 days (at uniform intervals) between 6.00 pm - 6.00 am. This ensured adequate water expected to dissipate herbicide from coated IR-maize and meet water requirements for increased yield. All treatments were top-dressed with nitrogen (N) fertilizer applied at 31.2 kg N ha^{-1} as calcium ammonium nitrate (CAN 26% N) fertilizer at 120 kg ha^{-1} 21 days after planting (DAP). No weeding was carried out. Weeds were controlled using glyphosate at 1.6 kg ai ha^{-1} before the experiment was repeated in the same plots in 2011. Data on mean rainfall, relative humidity and mean temperature was collected from weather station in the centre. The effect of herbicide coated IR- maize and cover crops on weed species composition and weed density (count m^{-2}) was evaluated 21 and 42 DAP because this is the period within which uncontrolled weeds are expected to cause yield losses.

6.3.4. Data collection

Weed species composition and density assessments were done 21 and 42 DAP. A meter squared quadrat was placed randomly in each plot. Within the quadrat growing weed species were identified, counted and recorded. Blocking, replicating and randomizing treatments were expected to minimize variability in the field.

At physiological maturity, two middle rows out of the five maize rows were harvested. The whole maize plant was cut from ground level, tied with sisal twine, weighed using a spring balance and weight recorded, ears were counted, and cobs weight recorded. Thereafter, maize was shelled and grain dried to an average moisture content of 12.5% and weighed using top load balance. Three grain moisture readings per sample were taken using a multigrain moisture meter and their average moisture content recorded. Yield (at 12.5% grain moisture) = Grain yield x (100-actual grain moisture %) /87.5 (Badu- Apraku *et al.*, 2012). Weather data was collected from ICRISAT meteorology site-station in Kiboko.

6.3.5. Data analysis

Effect of herbicide coated IR-maize and cover crops on weed species composition was compared 21 and 42 DAP in 2010 and 2011. The data for weed and maize were subjected to Analysis of variance (ANOVA) using GenStat statistical package, Version 12.0. Where treatment effects were significant, means were compared using Student Newman Keuls (S-N-K) test at 5% significance level.

6.4 Results

The interaction effect among the herbicide coated IR- maize, cover crops and time on the weed species composition were not significant ($P > 0.05$). The number of species (plants m^{-2}) was not influenced by treatment. In addition, the ANOVA showed that there was no significant ($P > 0.05$) interaction effect among the herbicide coated IR- maize, cover crops and time on weed density (plants m^{-2}).

The interaction among herbicide coated IR- maize, cover crops and time on individual weed species showed a significant ($P < 0.05$) effect on *Boerhavia diffusa* L. and *Eleusine indica* L. The effects were weed species specific.

6.4.1. Effect of herbicide coated IR-maize, cover crops and time (Days after Planting) on *B. diffusa*.

The density of *B. diffusa* was significantly ($P < 0.05$) reduced in plots with coated IR-maize and cover crop than in uncoated IR-maize and no cover crops 21 DAP. The density of *B. diffusa* in herbicide coated IR-maize plots decreased with time (from 21 to 42 DAP) compared to uncoated IR-maize (Table 6.1) .

Table 6.1 Mean density of *Boerhavia diffusa* L. as affected by herbicide coated IR-maize, and cover crops in 21 and 42 Days after planting in 2010 and 2011

		2010		2011	
Days after planting	Cover crops	Uncoated IR-maize	Coated IR-maize	Uncoated IR-maize	Coated IR-maize
21	Black dolichos	1.00	0.38	1.25	2.88
	Brown dolichos	0.75	0.63	1.75	1.00
	No cover crop	0.25	0.63	22.50	0.38
42	Black dolichos	0.75	0.50	0.00	0.13
	Brown dolichos	0.25	0.25	0.00	0.75
	No cover crop	1.00	0.38	2.00	0.25
	Standard Error	3.54	2.51	3.54	2.51
	P-value	0.050			

6.4.2. Effect of interaction of herbicide coated IR-maize and cover crops on *E. indica*.

The interaction between herbicide coated IR-maize and dolichos cover crops significantly ($P < 0.05$) increased the annual grass weed *E. indica*. Plots having herbicide coated-IR-maize and cover crop had significantly ($P < 0.05$) higher density of *E. indica* compared to coated IR-maize alone with no cover. The density of *E. indica* was higher in uncoated IR-maize with no cover crop compared to coated IR-maize with no cover. The dolichos biomass shading effect probably reduced the effects of herbicide coat on *E. indica*. The density of *E. indica* was significantly ($P < 0.05$) different across the treatments (Fig. 6.1).

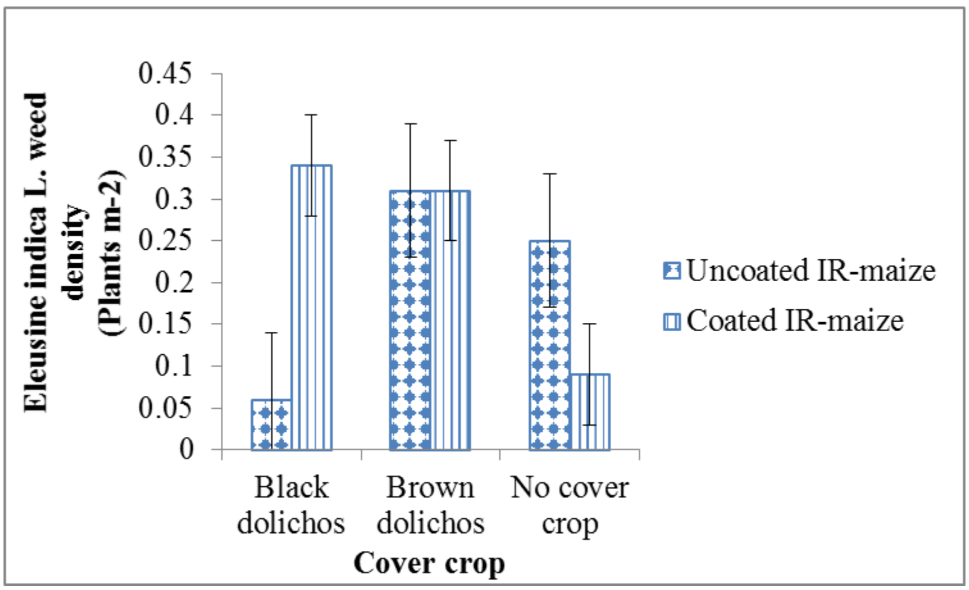

Figure 6.1: Effects of Imazapyr herbicide coated IR-maize and cover crop on mean density (plants m-2) of *Eleusine indica* L.

6.4.3. Effect of herbicide coated IR- maize on weed species composition *(Plants* m^{-2}*)*

There was no significant (*P* > 0.05) effect of the herbicide coated IR- maize on weed species (Plants m^{-2}). However, the weed species composition varied across treatments (Data not shown).

6.4.4. Effect of cover crops on the weed species composition (Plants m^{-2})

There was no significant (*P* > 0.05) effect of the dolichos on the weed species (Plants m^{-2}) 21 and 42 DAP. However the weed species composition varied across treatments. ANOVA on dolichos effects on individual weeds showed significant (*P* < 0.05) effects on three weed species, *Portulaca quadrifida* L., *Paraknoxia parviflora* (Stapf ex Verdc.) and *Eleusine indica L.* Dolichos significantly (*P* < 0.05) reduced the density (count m^{-2}) of two annual broadleaf weed species (*P. parviflora* and *P. quadrifida*) and significantly (*P* < 0.05) increased one annual grass (*E. indica*) (Table 6.2).

Table 6.2 Effect of cover crop on the mean density (plants m^{-2}) of *Portulaca quadrifida L.*, *Paraknoxia parviflora* (Stapf ex Verdc.) and *Eleusine indica* L. Gaertn

	Mean density of weed species (Plants m^{-2})		
Cover crops	*Portulaca quadrifida*	*Paranoxia parviflora*	*Eleusine indica*
Black dolichos	0.23^{b}	5.63^{b}	0.20^{b}
Brown dolichos	0.06^{b}	6.09^{b}	0.31^{a}
No cover crop	0.38^{a}	12.02^{a}	0.17^{b}
Standard Error	0.08	1.74	0.05
Significance level	*P* < 0.05	*P* < 0.05	*P* < 0.05

Means in the same column followed by the same letter do not significantly differ at (*P* < 0.05) according to Student Newman Keuls test.

6.4.5. Effect of time (Days after planting) on weed species composition

Time (DAP) had significant ($P < 0.05$) effect on the number of weed species (counts m^{-2}). There were more species (7.3 plants m^{-2}) 21 DAP compared to 5.5 plants m^{-2} 42 DAP (Fig. 6.2).

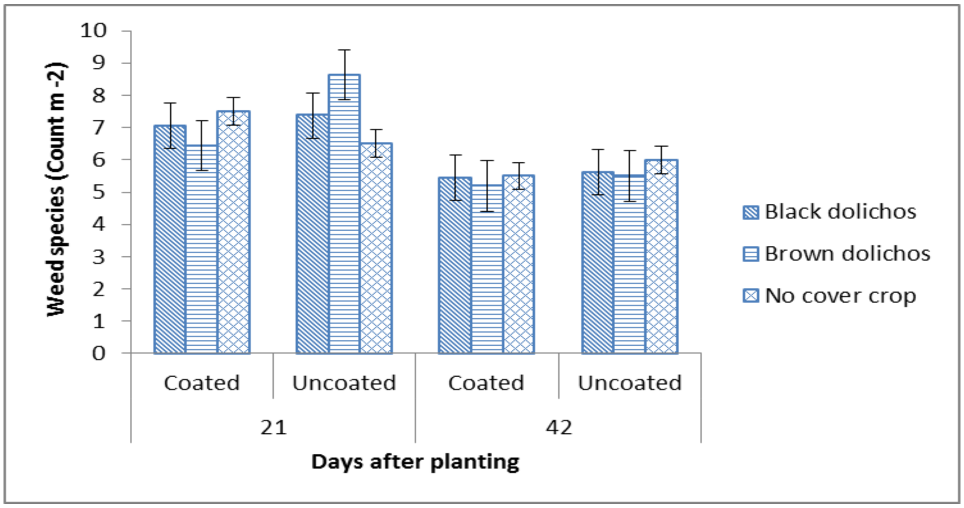

Figure 6.2: Diversity of weed species (counts m^{-2}) 21 days after planting (DAP) maize compared to 42 DAP ($P < 0.05$)

6.4.6. Effect of time (days after planting) on individual weed species in 2010 and 2011

Effect of time on individual weed species showed there was a significant ($P < 0.05$) effect on the density (count m^{-2}) of 10 annual weed species (*B. pilosa*, *B. diffusa*, *E. hirta*, *P. parviflora*, *O. sinuatum*, *S. oleraceae*, *T. procumbens*, *T. zeylanicum*, *D. aegyptium* and *E. indica*). Majority (8) of the species were broadleaf while a few (2) were grasses. The weed species density (count m^{-2}) 21 and 42 DAP in 2011 were significantly higher than in 2010 respectively except for *D. aegyptium*, *E. indica* and *O. sinuatum* (Table 6.3).

Table 6.3 The mean density of weed species (weeds m^{-2}) present 21 and 42 DAP in 2010 and 2011

Time		Mean density of weed species composition (weeds m^{-2}) rank									
Year	DAP	BP	BD	DA	EI	EH	OS	PP	SO	TP	TZ
2010	21	0.75^{c}	0.47^{a}	19.33^{a}	0.42^{a}	0.61^{b}	0.42^{a}	0.81^{c}	0.17^{b}	0.17^{b}	0.19^{b}
	42	0.69^{c}	0.47^{a}	3.75^{b}	0.53^{a}	0.47^{b}	0.36^{b}	0.81^{c}	0.14^{b}	0.14^{b}	0.11^{b}
2011	21	34.78^{a}	3.78^{a}	0.53^{b}	0.0^{b}	6.14^{a}	0.0^{c}	8.44^{b}	4.14^{a}	4.14^{a}	54.81^{a}
	42	3.19^{b}	0.58^{a}	0.53^{b}	0.0^{b}	1.06^{b}	0.0^{c}	19.86^{a}	1.36^{b}	1.36^{b}	9.03^{b}

Means in the same column followed by the same superscript letter do not significantly differ at ($P < 0.05$) according to Student Newman Keuls test. Key: DAP = Days after planting, BP = *Bidens pilosa*, BD = *Boerhavia diffusa*, DA = *Dactyloctenium aegyptium*, EI = *Eleusine indica*, EH = *Euphorbia hirta*, OS = *Oxygonum sinuatum*, PP = *Paraknoxia parviflora*, SO = *Sonchus oleraceae*, TP =*Tridax procumbens* and TZ = *Trichodesma zeylanicum*

6.4.7. Effects of herbicide and cover on IR- maize yields (t ha $^{-1}$).

There was no significant ($P > 0.05$) interaction effect between herbicide and cover crop on maize grain yield; however, yields differed between 2010 and 2011.

6.4.8. Effect of herbicide coat on IR-maize yields (t ha $^{-1}$).

ANOVA showed there was a significant ($P < 0.05$) effect of herbicide coated IR-maize on grain yield. Herbicide coated IR-maize had significantly ($P < 0.05$) less grain yield (t ha $^{-1}$) than uncoated IR-maize (Table 6.4).

6.4.9. Effect of cover crops on IR- maize yields

Dolichos had a significant ($P < 0.05$) effect on IR- maize grain yield and components (t ha $^{-1}$). Herbicide coated IR-maize grain yields were significantly ($P < 0.05$) increased by dolichos compared to no cover crops which had the lowest grain yield (t ha $^{-1}$) in 2010 and 2011 respectively (Table 6.4).

Table 6.4 Comparing maize yield (grain and components t ha^{-1}) in 2010 and 2011

	Maize dry matter (t ha^{-1})		Ears (count ha^{-1})		Ears weight (t ha^{-1})		Grain yield (t ha^{-1})	
	2011	2010	2011	2010	2011	2010	2011	2010
No cover	6.3^{a}	4.2^{a}	27625^{a}	28920^{a}	3.4^{a}	2.4^{b}	3.0^{a}	2.0^{b}
Uncoated								
Black dolichos	5.8^{ab}	6.5^{a}	25875^{a}	27094^{a}	3.4^{ab}	3.9^{a}	2.9^{ab}	3.3^{a}
Uncoated								
Brown dolichos	5.4^{ab}	4.7^{ab}	26625^{ab}	27880^{ab}	3.2^{ab}	2.6^{b}	2.6^{ab}	2.2^{ab}
Uncoated								
Black dolichos	4.9^{bc}	6.2^{a}	21125^{bc}	22120^{bc}	2.7^{bc}	3.9^{a}	2.3^{bc}	2.5^{ab}
coated								
Brown dolichos	4.0^{c}	5.5^{ab}	19875^{c}	20812^{c}	2.2^{c}	3.1^{ab}	1.9^{c}	2.5^{b}
coated								
No cover Coated	2.0^{d}	1.4^{c}	18706^{d}	19588^{d}	1.2^{d}	0.8^{c}	0.9^{d}	0.6^{c}
CV %	14.9	25.4	14. 8	14.8	17.4	27.9	19.5	25.8

Means in the same column followed by the same superscript letter are not significantly different (at $P < 0.05$) according to Student Newman Keuls.

6.4.10. Correlations effects of weeds and cover crops on maize yield

Final grain yield was negatively correlated (R^2 = -0.073; P = 0.201) with weeds (total dry matter 21 and 42 days after planting) in 2010; and, in 2011 (R^2 = -0.051; P = 0.290). Correlations were not significant. Models are shown (Fig. 6.3 and 6.4).

In a unit area of production, the total maize yield (maize stovers, cobs, residues and grain yield) had a positive correlation with total biomass yield of cover crops (R^2= 0.427; $P <$ 0.009). In addition, total maize yield per unit area had a positive correlation with grain yield (R^2 = 0.874, $P < 0.001$) in 2010 (Table 6.6).

Similarly in 2011, the total biomass yield of cover crops had a positive correlation with total maize yield (maize stovers, cobs, residues and grain yield) (R^2 = 0.418; $P < 0.042$). In addition, total maize yield (maize stovers, cobs, residues and grain yield) per unit area had a positive correlation with grain yield, R^2 = 0.877, $P < 0.001$ (Table 6.7).

In a unit area of production, total cover crop biomass yield was negatively correlated with weeds (R^2 = - 0. 280; P = 0.186) for 2010 (Table 6.6) compared to R^2 = - 0. 241; P = 0.256) for 2011 (Table 6.7).

Weed species diversity (count m^{-2}) had negative correlation (R^2 = - 0.051; Y= - 8.128x + 239.1 with maize grain yield in 2010 compared to R^2 = - 0.067, Y= -17.90x + 245) in 2011. This implies that the higher the weed species diversity (count m^{-2}), the lower the maize grain yield (t ha^{-1}). Descriptive statistics are shown (Table 6.5) for factors considered in correlations (Tables 6.6 and 6.7).

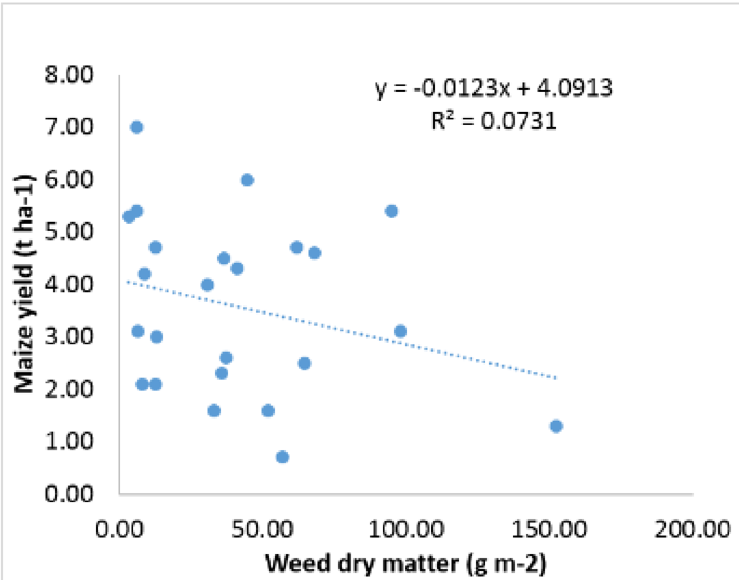

Figure 6.3: Maize yield as affected by weeds 21- 42 days after planting 2010

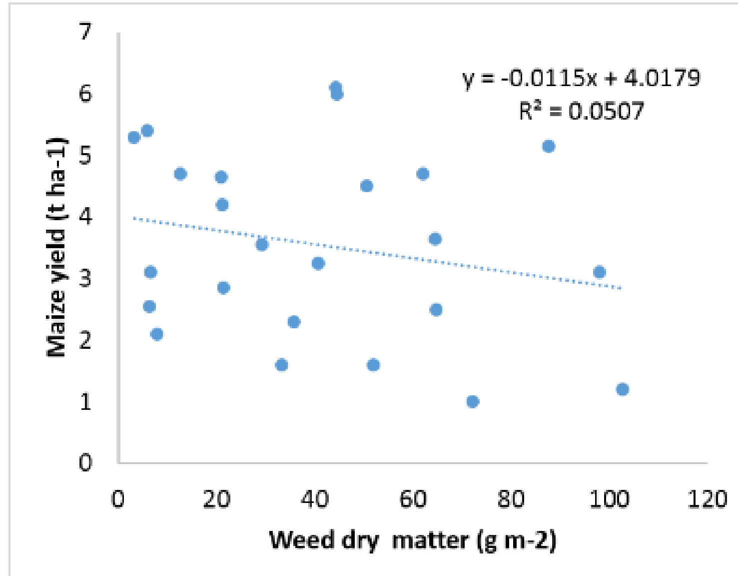

Figure 6.4: Maize yield as affected by weeds 21- 42 days after planting 2011

Table 6.5 Descriptive statistics for factors considered in yield correlations

Year	Factors	Mean	Std. Deviation	N
2010	Maize grain yield and components (t ha^{-1})	10.017	4.732	24
	Cover crop yield (t ha^{-1}	10.813	11.052	24
	Weed dry matter (g m^{-2})	41.092	36.450	24
	Grain yield (t ha^{-1}	3.588	1.654	24
	Herbicide coating	1.500	0.511	24
	Weed dry matter 21 d (g m^{-2})	31.463	33.522	24
	Weed 42 days after planting (g m^{-2})	9.629	7.623	24
2011	Cover crop yield (t ha^{-1})	10.502	10.504	24
	Grain yield (t ha^{-1})	3.544	1.520	24
	Total weed dry matter (g m^{-2})	41.179	29.721	24
	Total maize yield (grains and components) (t ha^{-1})	9.910	4.640	24
	Weed dry matter 21 days planting (g m^{-2})	31.238	26.917	24
	Weed dry matter 42 days after planting (g m^{-2})	9.942	7.428	24

Table 6.6 Bivariate correlations between cover crop dry matter, weed dry matter, maize yield (grain and components), and grain yield, 2010 (n=24)

Year 2010		Yield (grain & components)	Cover crop DM	WDM	Yield (Grain)	HC	WDM 21 DAP	WDM 42 DAP
Maize yield (grain and components)	Pearson Corr. (r)	1.000	0.377	-0.269	0.874**	0.045	-0.313	0.089
	P-value		0.070	0.204	0.000	0.835	0.137	0.678
Cover crop DM	Pearson Corr. (r)	0.377	1.000	-0.280	0.336	-0.001	-0.347	0.187
	P-value	0.070		0.186	0.109	0.996	0.097	0.382
Weed dry matter (WDM)	Pearson Corr. (r)	-0.269	-0.280	1.000	-0.270	0.096	0.980**	0.473*
	P-value	0.204	0.186		0.201	0.654	< 0.001	0.019
Grain yield	Pearson Corr. (r)	0.874**	0.336	-0.270	1.000	0.245	-0.306	0.053
	P-value	< 0.001	0.109	0.201		0.249	0.146	0.805
Herbicide coated IR-maize (HC)	Pearson Corr. (r)	0.045	-0.001	0.096	0.245	1.000	0.036	0.302
	P-value	0.835	0.996	0.654	0.249		0.867	0.151
Weed dry matter (WDM) 21 days after planting	Pearson Corr. (r)	-0.313	-0.347	0.980**	-0.306	0.036	1.000	0.287
	P-value	0.137	0.097	< 0.001	0.146	0.867		0.174
Weed dry matter (WDM) 42 days after planting	Pearson Corr. (r)	0.089	0.187	0.473*	0.053	0.302	0.287	1.000
	P-value	0.678	0.382	0.019	0.805	0.151	0.174	

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the $P < 0.05$ level. HC=Herbicide coated IR-maize. DAP = Days after planting.

Table 6.7 Bivariate correlations between cover crop dry matter, weed dry matter, maize yield (grain and components) 2011 (n=24)

Year 2011		CCDM	Yield (grain)	WD	Yield (grain and components)	WD 21 DAP	WD 42 DAP
Cover crop DM	Pearson Corr. (r)	1.000	0.358	-0.241	0.418*	-0.309	0.155
	P-value		0.086	0.256	0.042	0.141	0.469
Yield (grain)	Pearson Corr. (r)	0.358	1.000	-0.225	0.877**	-0.271	0.082
	P-value	0.086		0.290	< 0.001	0.200	0.704
WD	Pearson Corr. (r)	-0.241	-0.225	1.000	-0.255	0.970**	0.485*
	P-value	0.256	0.290		0.228	< 0.001	0.016
Yield (grain & components)	Pearson Corr. (r)	0.418*	0.877**	-0.255	1.000	-0.308	0.093
	P-value	0.042	< 0.001	0.228		0.144	0.665
WD 21 DAP	Pearson Corr. (r)	-0.309	-0.271	0.970**	-0.308	1.000	0.259
	P-value	0.141	0.200	< 0.001	0.144		0.221
WD 42 DAP	Pearson Corr. (r)	0.155	0.082	0.485*	0.093	0.259	1.000
	P-value	0.469	0.704	0.016	0.665	0.221	

(r) = Pearson Corr. * = Correlation is significant at $P < 0.05$. ** = Correlation is significant at $P < 0.01$. WD= Weed dry matter; CCDM= Cover crop dry matter WDM=Weed dry matter. DAP = Days after planting

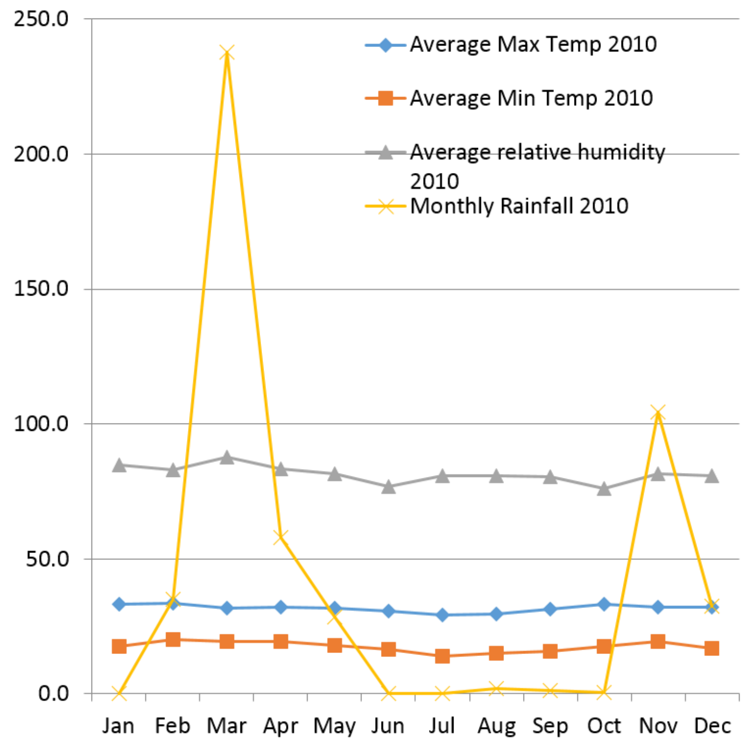

Figure 6.5: Weather variability at KALRO-Kiboko Research station, in 2010

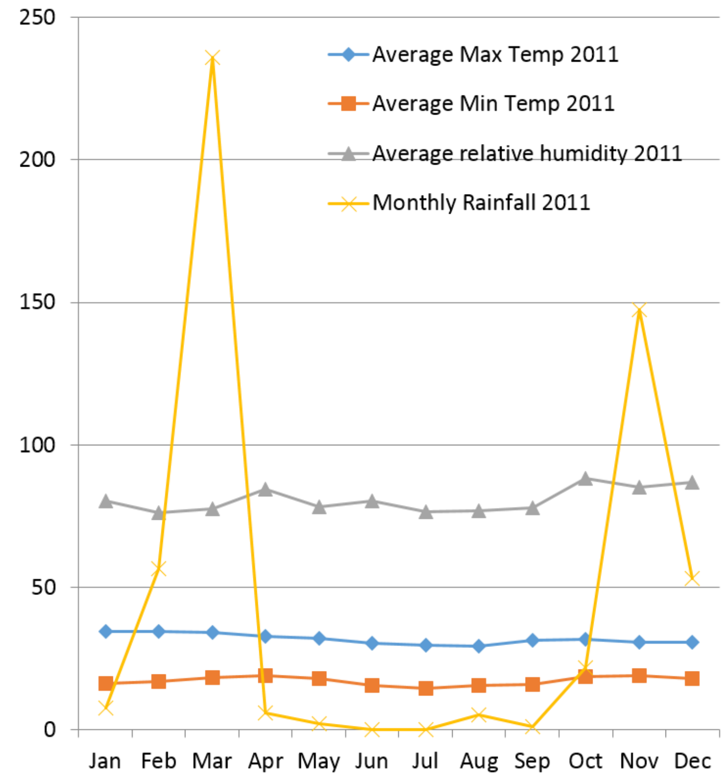

Figure 6.6: Weather variability at KALRO-Kiboko Research station, 2011

6.5 Discussion

6.5.1. Effects of herbicide coated IR-maize and cover crops on weeds

The interaction effect of cover crops, herbicide coated IR-maize and time (days after planting) on number of weed species was not significant. The effect was probably weed species specific, meaning that some species increased while others decreased which may have resulted to number of weed species (plants m^{-2}) remaining the same hence no significant effect. However, the interaction effect of herbicide coated IR-maize and dolichos significantly ($P < 0.05$) increased the density of *E. indica* (0.31weeds m^{-2}) compared to uncoated IR-maize alone (0.17) implying that probably dolichos biomass accumulation supported the growth of *E. indica*. In addition, *E. indica* a small seeded weed showed intensive resource uptake capacity overtaking slow growing dolichos resulting to higher density probably due to greater early dependence on external soil nutrient sources. *E. indica* has a large absorptive area per unit mass compared to *P. quadrifida* and *P. parviflora,* whose density was reduced by cover crops. Moreover, *E indica* a C - 4 tufted annual prostrate and spreading plant makes extremely rapid growth in full sunlight before the shading from crops. Seedlings have exceptional vigour. This could explain why *E. indica* density significantly ($P < 0.05$) increased in plots with dolichos**.** *P. quadrifida* a tiny sprawling annual herb does not do well where plants are established because it is a poor competitor (Cudney and Elmore, 2003; Foss and Antonelli, 2003). In bare soils *P. quadrifida* will form dense prostrate mats using available nutrient and moisture to keep away other weeds from reaching the soil surface (Mitich, 1997; Hanson, 2004).

The number of weed species (count m^{-2}) in the plots with dolichos cover crop, were reduced by 33% at 42 DAP and 14% at 21 DAP compared to plots with no cover. This implied that with time dolichos produced more biomass and the live cover crop vegetation which had accumulated was more effective in inhibiting light mediated germination of weeds. This is because it lowers red to far red ratio of light agreeing with

Teasdale and Mohler (1993). The number of weed species (count m^{-2}) observed 21 and 42 DAP could hence be attributed to seed longevity, species specific germination patterns and other complex processes that contribute species shifts over time (Higginbotttham *et al*., 2000; Shrestha *et al*., 2002).

This study showed that *B. pilosa*, *B. diffusa*, *E. indica*, *E. hirta*, *P. parviflora*, *S. oleraceus*, *T. procumbens* and *T. zeylanicum* density (number of weeds m^{-2}) was not significantly different 21 and 42 DAP; however, the weeds were more stunted 42 DAP compared to 21 DAP in 2010. This implies that probably dolichos canopy cover 42 DAP physically blocked sunlight resulting to stunted weeds, but same density. In addition, seasonal effects may have played a role. Under the dolichos shading effects 42 DAP, *O. sinuatum* density increased probably because it had more seed mass which supported its growth requirements meaning that 1) dolichos effect 42 DAP was weed species specific 2) stunting of weeds indicates a possible loss of species potential to reproduce over time 3) and reduced speed at which weed patches could expand across the field as Fabian (2008) indicated. This study indicated that shading effect contributed to suppression of *P. parviflora* and *P. quadrifida* (which were the most prominent) implying that given adequate time, dolichos cover crop could effectively manage weeds in the maize field. The weed *P. parviflora* and *P. quadrifida* have small seeds. After germination, the emerging weed seedlings used energy provided by the seedmass for respiration process to grow untill it was depleted. Due to dolichos shading and interception of needed photo synthetically active radiation for photosynthesis to sustain weed growth, this resulted to suppressed weeds. Suppressed weeds had inadequate energy to support seedling respiration; therefore, had periods of stress and induced carbon deficits that lead to disproportionate decrease in early season growth. Consequently, weeds had limited access to resources and competitive ability. This result agreed with those of Westoby *et al*. (2002) and Liebman and Sundberg (2006). Greater nutrient reserves in endosperm of larger *O. sinuatum* weed seeds facilitated penetration through thicker litter. Cover crops suppressed different weed species through physical impediment and hindering germination. This findings agreed with those of Teasdale and Daughtry (1993), Buhler (1996), Teasdale *et al*. (2007) and Mirsky *et al*. (2013).

This study has shown that use of cover crops, increased maize yields differentially (much more for uncoated IR-maize than coated maize) probably implying that weeds had more negative effect on coated-IR than uncoated before they were suppressed. Probably weeds could be characterized, their differential responses used innovatively such that weeds could benefit maize as Clements *et al*. (1994) suggested. This requires evaluation of target weed species within a smaller area (0.25 m^{-2}) where coated IR-maize had effect compared to one m^{-2} quadrat assessed in controlled experiment.

6.5.2. Effects of coated IR-maize and dolichos cover crop on maize yields

Uncoated IR-maize with black dolichos produced significantly ($P < 0.05$) higher yields than with brown dolichos probably due to the high black dolichos biomass (10 - 22 t ha^{-1}) and additional leaf litter (1.7 t ha^{-1}). The implication is more biomass produced by black dolichos had greater weed suppression effect compared to low brown dolichos biomass (4 - 10 t ha^{-1}) and foliage droppings dry matter (0.7 t ha^{-1}). The black dolichos had the highest yield in coated or non coated IR- maize probably because it produced the higher biomass and leaf litter per unit area than brown dolichos. This study confirmed that adapting legume cover crop technology sustained increased maize yields. The increase in yields was attributed to dolichos suppression of weeds; shading; and, probably improved soil health through added organic matter and fixed nitrogen. This results agrees with those of Humpreys (1995), Namakkha *et al*. (2012), and Reberg-Horton *et al.* (2012). Each unit of biomass produces an equivalent unit of nitrogen (Sheahen, 2012). In addition, foliage droppings could have contributed to mulching and improved soil water retention contributing to increased maize yield. Coated IR-maize with no cover crop plots were covered by weeds dry matter (0.3 t ha^{-1}) and had the lowest grain yield in both 2010 and 2011. This implies that weeds were more competitive than herbicide coated IR-maize in absence of legume cover crop hence depressed yields. In addition, the study found that freshly coated IR-maize produced higher dry grain yields in 2010 compared to same seed planted in 2011. This implies that other than weed management factor, other factors including seed quality (planting herbicide coated IR-maize seeds reserved from 2010 season) and weather conditions could have contributed to reduced yield potential; hence, the low yields in 2011 compared to 2010.

In 2011, yield increase in uncoated IR-maize could be associated to ecological benefits including reduced moisture loss and water runoff hence more infiltration. This result agreed with Gachene and Mwangi (2006), and Karuma *et al*. (2011). With no dolichos, the weed species consequently formed residue mulch (after they were desiccated with glyphosate) and increased yields. This implies that weeds formed a valuable ecosystem component that could be tapped to provide services complementing those of cover crops to increase maize yield. This was in line with Bivardar (2012). The high yields from uncoated IR-maize plots with no dolichos in 2011 implies that use of prevalent weed species could contributed to an appropriate management. Prevalent weeds could be dessicated with appropriate post emergence herbicide and the plant residue would form a cover on the soil. This could contribute to improved soil physical-chemical characteristics to benefit maize cropping system as suggested (Clements *et al*., 1994; Schonbeck, 2012).

In addition, the dolichos above the ground biomass covering effect; could have reduced the amplitude of heat wave reducing heat stress effect on the growing maize crop. Moreover, the extensive root system of dolichos probably could have contributed to improved soil physical conditions; which, could be attributed to stronger and dark green healthy maize crop compared to no cover plots. Also, the biomass reduced overhead irrigation water splash or runoff; hence, increased water infiltration compared to plots with no cover crop. This could have contributed to more water being available during the critical stages of maize growth translating to higher maize yield. In addition, improved soil health through organic matter, fixed nitrogen and leaf litter decomposition may have contributed to higher maize grain yield and components. This agrees result is in agreement with FAO (2011). In this study, black dolichos produced more biomass; and, every unit of biomass is equivalent to same unit of nitrogen (Sheahan, 2012), which also contributed to explain why black dolichos had higher yields (maize grains and components). This result is in agreement with those of Kramberger *et al*. (2009) and Ngome *et al*. (2011). However, brown dolichos yielded less biomass than black dolichos which was attributed to attack by powdery mildew and bacteria wilt. Diseases were attributed to seasonal-weather factors. Skerman *et al*. (1991) have indicated dolichos requirements for maximum vegetation production. Profitability of leguminous cover crops are reported (Lichtenberg *et al*., 1994; Mirsky, 2008; Sheahan, 2012).

6.6 Conclusion

This study shares knowledge on the effects of integrating dolichos with herbicide coated IR-maize on the number of weed species, density and maize yields. The study demonstrated that the weed density was significantly ($P < 0.05$) higher in 2011 than 2010, and significantly ($P < 0.05$) more 21 DAP than 42. In addition, weed species were more 21 DAP than 42 DAP. This means that management approach with cover crops needs to be used in combination with other technology (ies) that will be effective on controlling early emerging weeds. This will give the cover crop opportunity to establish and manage the weeds from 21 - 42 days after planting onwards. The interaction effects of coated IR-maize and dolichos were weeds' species specific (increasing or decreasing some weed count m^{-2}). Dolichos reduced the density of *P. parviflora* and *P. quadrifida* while it increased *E.indica 42* DAP. Dolichos significantly increased herbicide coated and uncoated IR-maize grain yield than no cover. Black dolichos significantly increased IR-maize yields (uncoated/coated) more than brown and no cover; and, contributed to sustained yield increase. With no dolichos coated IR-maize yield reduced by 25% year $^{-1}$.

CHAPTER SEVEN

7.0 GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 General discussion

This thesis discusses findings from four studies that were carried out to answer four research questions: What is the weed species diversity status in Kalama and Kee? What is the cover crop adoption level and what factors influence adoption? What is the effect of herbicide coated IR-maize on weeds under different water regimes? What was the effect of integrating cover crops and herbicide coated IR-maize on weeds and maize yield in the field conditions?

In Machakos and Makueni Counties, maize production challenges included: unreliable erratic rainfall, declining soil fertility and weed competition (Mwangi, 2003). Efforts to manage weeds effectively in the past may have failed due to limited knowledge on biology of weeds and novel weed management technologies. Therefore, this study focused on understanding weed species infesting maize fields; and, it is crucial in development of integrated weed management technologies (IWM) (Harker & O'Donovan, 2013): using conservation agriculture principles to minimise weed related yield losses. Weed management tactics are inadequate to manage weeds due to many factors including the high degree of heterogeneity, biology and management aspects (Coble, 1994; Dekker, 1997). Williams *et al*. (2009) indicated that characteristics of weed management systems are an important predictor of weed diversity. In the case of herbicides, one may be selective to grass weeds leaving broad leaved species dorminating.

In agroecosystems, knowledge of weed community structure is considered critical in planning sustainable weed management systems and directing future research (Dewey & Anderson, 2004). Rational IWM approaches require a thorough knowledge of the biology of weed species and the complex interrelationships that exists between them;

and, the socioeconomic conditions and farming systems in which IWM operate. Dekker (1997) observed that no weeds have disappeared from production fields and "that weeds always win".

This study carried out a weed survey to determine weed diversity and abundance in Kalama and Kee. The survey was done before first weeding to capture weeds that could compete if not managed within the critical period of weed management in the maize cropping season (Hall *et al*., 1992). Results indicated that weed species diversity and density infesting individual maize fields were highly variable and location specific. There were more broad leaved weeds than grass weeds. Annuals were more abundant than perennials; and, all fields had been manually tilled. The timing was crucial to provide a single point in time assessment of the location and overall abundance of the weed population to supply the basic information which could guide in developing weed management strategies. Dewey and Anderson (2004) defined a weed survey as a field search scheduled to collect basic weed information. This is important because competition on crop arises from the summed activities of individuals in a weed population and their interactions (Harper, 1977). The study revealed knowledge on weed diversity and population that will help understand basic dynamics; which, stakeholders could use to manipulate populations using various tactics based on economic need. This was in agreement with Thomas (1985) and Frick and Thomas (1992). The study revealed two implications: 1) weed management interventions should be location specific; 2) knowledge of the weed species infesting maize fields provided useful baseline information which could guide decisions concerning research priority, resource allocation, and monitoring changes with time. The study developed an inventory of weed species diversity and density. The weed inventory will be used to characterize weed diversity at Kalama and Kee agroecosystem, compare effectiveness of management practices, and document changes in weed composition over time in agreement with others (Harper 1977; Thomas, 1985; Frick & Thomas, 1992; Webster & Coble, 1997).

The reported weed infestations may have been influenced by weather pattern variability; where, the most adapted species dorminated agreeing with those of Dekker (1997).

Cover crop based conservation farming has attracted attention from farmers, researchers, and other stakeholders because of its ability to enhance soil health and conservation, manage weeds and save labour. This study examined factors with the likelihood to influence cover crop adoption; and, evaluated effects of cover crops integration with herbicide coated IR-maize on weeds and maize yield in Machakos and Makueni Counties. Results showed that, in Kalama and Kee, cover crops suppressed weeds and increased maize yields. The results are in agreement with those of Teasdale and Mohler (2000), Olorunmaiye (2010), Ngome *et al*. (2011), and Mwangi *et al*. (2015a). This study showed that weed interference effect on maize grain yields was higher in plots with no legume cover crops compared to plots with dolichos. This suggested that dolichos could have added nitrogen through fixation and the organic matter degradation. This result agrees with those of Tollenaar *et al*. (1994). The perception was that, if smallholder farmers adopted legume cover crops, they were likely to benefit from the potential demonstrated including increased yields in ASAL. However, information on adoption in Kenya (Africa) is limited and sometimes conflicting (Giller *et al*., 2009).

This study also revealed some of the sociological factors associated with likelihood to adopt cover crops in Kalama and Kee. The findings suggested that investing in farmer's knowledge and knowhow in cover crop, enhancing farmers' ability to analyze practical gains and making cover crops related costs affordable (including seeds, fertilizer and credit) were the key factors that influenced the likelihood to adopt cover crops. Experience in growing cover crops was probably the most important social factor because it assisted farmers to analyze the gains and costs. This result agreed with Kabede *et al*. (1990) that experience was the most significant factor in adoption of agricultural technologies. Increased cover crop adoption in other regions including Mexico and Brazil resulted from increased cost of fertilizers, realisation of the importance of using cover crops in reducing erosion and increased negative effects of fertilizer among other factors

(Nepal, 2010). Also, lack of knowledge on cover crop management, lack of experience in successfully incorporating cover crops in the cropping system, lack of research to inform specific regions or cropping systems and lack of incentives, could justify why farmers who may have wanted to use cover crops have been reluctant to do so (Nepal, 2010).

This study revealed that the experienced farmers recommended more drought tolerant, short season cover crop varieties and management intervention as a way forward to increase likelihood for cover crop adoption. This result implies that, according to expert farmers there are three areas of intervention with a likelihood to increase cover crop adoption. These are 1) availability of suitable varieties that fit into farmers' specific farming system; 2) appropriate varieties to cope with extreme weather patterns including very hot days, chilling nights or related risks; and, 3) development of knowledge and skills to manage different cover crops. The fact that majority of adopters and non-adopters bought seeds from market; and, majority of non-adopters in Kee used relief seeds, justifies the fact that having seeds was not adequate to give them a reaction threshold to adopt cover cropping. This implies that a certain value of stimulus "critical threshold value" for adoption was achieved where adoption was observed whereas below the threshold there was no adoption. Akudugu *et al*. (2012) reported that the threshold is dependent on a certain set of factors. Kabede *et al*. (1990) showed that adoption is a decision at the individual farmer level subject to various factors. In Kalama region respondents had experienced cover crop failure due to chilly nights in uphill areas. Therefore, this study indicated the need for region specific consideration for intervention measures with likelihood to influence cover crop adoption. This is in line with Asfaw *et al*. (2011) findings on adoption of other agricultural technologies.

This study found that where weed survey was carried out fields had been manually tilled; which, could be attributed to more weed infestation, increased labour demand and moisture loss due to evaporation. This may have affected efforts towards food security. In addition, farmers revealed that changing weather patterns and management aspects including manure imported from neighbouring Counties could have contributed to emergence of more and new weed species.

In order to enhance weed control under cover crop, a trial was done to evaluate effect of Imazapyr coated (IR-maize) on weed emergence and growth in green house with rapeweed (*Brassica napus* L.); which, was chosen because of its high sensitivity to Imazapyr herbicide. This study established that rapeweed seedlings emerged 3 days after planting; however, seedlings counts per pot declined over time (35 days period). Results also showed that, herbicide coated IR-maize watered once a week reduced the weed dry matter more than when watered twice a week. This suggested that watering twice a week reduced the herbicide effect probably through leaching or weeds had direct beneficial effects of water. The findings demonstrated that herbicide diffused from coated IR-maize; and, reduced weed dry matter six times than that of uncoated IR-maize. However, when dolichos was integrated, with herbicide coated IR-maize, it reduced weed dry matter 12 times than that of uncoated IR-maize. In addition, results showed that increasing water regime from once to twice a week contributed to higher dolichos above ground biomass and suppressed weed growth both with coated IR-maize and uncoated more than beans or cowpeas. This study indicated that dolichos had greater suppressive effect on weed than beans or cowpeas; and, suggested need for further field testing in ASAL maize cropping systems. Teasdale *et al*. (2007) indicated that weed seedlings require increased energy to penetrate through the cover therefore resulting to higher seedling mortality. Small seeded species are more sensitive to covering especially at cotyledon stage, because once stored energy is depleted; no energy is available for growth so the plant dies.

Field evaluations established that dolichos intergrated with herbicide coated IR-maize managed most of the weeds four weeks after planting; and, increased maize yield. Weed suppression with cover crops was species specific; and, early emerging annual weeds were the major problem. Annuals with small seeds were more sensitive to suppression by leaf litter than larger seeded species. The result agreed with Teasdale and Mohler (2000), Mirsky *et al*. (2013), and Mwangi *et al*. (2015a). Cover crops suppressed different weed species through physical impediment and hindering germination agreeing with Teasdale and Daughtry (1993), Buhler (1996), and Teasdale *et al*. (2007).

Results also revealed that dolichos suppressed weeds, which was reflected in higher maize yields in all plots with dolichos, compared to plots with no cover crop in second season. Other factors including quality of seed (planting herbicide coated IR-maize seeds reserved from 2010 season) and weather conditions could have influenced yields. This study confirmed that adapting legume cover crop technology benefited small holder farmer with sustained increased maize yields. The increase in yields was attributed to dolichos suppression of weeds; shading; and, probably improved soil health through added organic matter and fixed nitrogen. This result agreed with Kramberger *et al*. (2009), Ngome *et al*. (2011), and Namakkha *et al*. (2012) who reported that cover crops adoption in maize based cropping system contributes a range of benefits which depend on cover crop type. The benefits include: increased residue crop cover and infiltration (Ngwira *et al*., 2011), enhancing soil factors (Abdin *et al*., 2000; Nyalemegbe *et al*., 2011), increased maize yields (Chabi –Olaye *et al*., 2005; Mwangi *et al*, 2015b), managing weeds (Tim *et al*., 2000; Mhlanga *et al*., 2015; Mwangi *et al*, 2015a) and is more cost effective with increased gross margins particularly in drier years (Ngwira *et al*., 2011; Mhlanga *et al*., 2015) among other factors. This study showed that use of cover crops in weed management innovations increased maize yields in drylands including Kalama, and Kee. This implies that adoption and integration of legume cover crops has potential to reduce weed crop interference; and, benefit ASAL cropping system in many ways as mentioned. Tollenaar *et al*. (1994) found that weed interference effect on maize grain yield was higher at lower than higher nitrogen levels in the soil. However, Giller *et al*. (2009) suggested that it will be important to use nonlinear, flexible approach when disseminating cover crops (CA) with emphasize on capacity building and with room for adaptations to local conditions.

7.2 General conclusion

The study found that weed species diversity and density infesting individual maize fields were significantly ($P < 0.05$) different between kalama and Kee. The study developed an inventory of weed species diversity and density: a tool to guide weed management decisions; and, in measuring effectiveness of weed management, and assessing weed species change over time for appropriate action locally and at policy level. This study found that most species were annuals compared to perennials; and, sampled fields were manually tilled. Weed management with cover crops was species-specific with early annuals, high weed densities and perrennials posing the greatest challenges. Annuals with small seeds are more sensitive to suppression by cover crop than larger seeded species. This is because larger seeds have greater nutrient reserves in endosperm which is used for respiration and penetration through leaf litter. This study suggests that, weed suppression with cover crops requires substantial amounts of leaf biomass. This implies there is need to build capacity and avail cover crops species that produce lots of biomass. Weeds are successful; and, have adapted and occupied available niches in agroecosystems at all levels of organization, therefore multitactic weed management will be required. This information could be used for planning site specific interventions with cover crop based approaches.

The findings revealed that more respondents had adopted cover crop technologies at Kalama than Kee; and, that men were less likely to adopt. At Kalama age category had effect on cover crops adoption; however, age had no effect at Kee. Education had mixed effects on cover crop adoption; suggesting that, other factors not covered in the study were at play. This is because even in Kee where every farmer had formal education, adoption was lower compared to Kalama where few were illiterate yet adoption was higher. Views from farmers with experience in growing cover crops revealed that knowledge and skills; demonstration of gains; and, related cost had effect on cover crop adoption. Majority of farmers, adopters or non-adopters used seeds from market. More Non-adopters in Kee used relief seed suggesting other than seeds, other factors were required to reach the threshold needed to influence adoption. The study suggests further research to identify factors with likelihood to reach threshold for adoption under different farming systems.

This study highlights the key factors associated with cover crop adoption. They included capacity building to develop knowledge and skills; and, to demonstrate gains and related costs. This could improve men and women likelihood to adopt cover crops; and, remove uncertainty for those more likely to adopt. In addition, the findings suggested need to identify other factors (including institutional, economic and altitudinal) likely to influence adoption; and, give the threshold required for adoption in different farming systems. Also, results indicated need for a policy to guide and facilitate farmers meet related costs; and, remove regional barriers to cover crop adoption. Development of appropriate drought tolerant and short season cover crop varieties suitable for different regions and cropping systems; and, other incentives such as credit need to be in place for increased cover crop adoption.

In addition, this study shows finding on the effects of integrating dolichos with herbicide coated IR-maize on the number of weed species, weed density and maize yields. The findings demonstrated that there were more weed species 21 DAP than 42 DAP. The weed density was higher in 21 DAP compared to 42 DAP; and, was greater in 2011 than 2010. This study established that coated IR-maize and dolichos effects on weeds were species specific. Dolichos reduced the density of *P. parviflora* and *P. quadrifida* while it increased *E.indica 42* DAP.

Results showed that, dolichos increased herbicide coated and uncoated IR-maize grain yield than no cover crop. Black dolichos increased IR-maize yields (uncoated/coated) more than brown; and, contributed to sustained yield increase from 2010 to 2011. Coated IR-maize yields reduced by 25% year $^{-1}$. This suggests three things: 1) the yield potential of herbicide coated IR-maize planted in 2011 was reduced by using 2010 seed. 2) Dolichos improved soil fertility, physical conditions and shading which contributed to increased maize yield. 3) Coated IR- maize performs better in healthy soils, as confirmed by dolichos plots compared to no cover in 2010. Uncoated IR-maize yield increase in 2011 demonstrated that weed residue mulch is a resource that could supplement cover crops. This study has shown that integrating legume cover crops to suppress weeds will benefit ASAL maize cropping system in many ways. By adopting legume cover crops, Kalama and Kee farmers achieved immediate benefits from weed suppression, increased maize and dolichos grains yields. Farmers under similar conditions could benefit by adopting appropriate cover crops in their cropping system.

7.3 Recommendations

7.3.1. Recommendation for Agricultural Extension

1. The agricultural extension officers or agents should use survey findings as a baseline to guide in plannning location specific adaptive weed management strategy (ies); and, to measure the effects of intervention measures.
2. Extension workers and agents should use the findings to empower farmers i.e. to develop knowledge and skills, demonstrate gains and related costs inorder to improve men and women likelihood to adopt cover crops, and, to remove uncertainty for those more likely to adopt.
3. To increase adoption the extension workers or agents should assist farmers improve perception of yield benefits and understanding of site specific advantages and disadvantages; as well as, site specific management practices that will make cover cropping a profitable practice.
4. The Extension workers should work in partnerships and collaborations with stakeholders to facilitate integration of cover crop in weed management strategies to increase cover crop benefits in other cropping systems.

7.3.2. Recommendation to the farmers

1. Farmers should integrate dolichos with coated IR- maize or uncoated for weed management, increased yields, and sustainable maize CA cropping systems in drylands.
2. Farmers should evaluate the yield increase over time and translate it to economic gains to guide their decisions in cover crop adoption.
3. Farmers should use yield increase as one indicator of the cover crops benefits among others in the long run compared to no cover.
4. Farmers should learn from local experts and others; and, chose type of cover crops based on their production goals. In addition, they should aim for cover crop types that will give more benefits including weed suppression and enhancing soil health for sustainable food production.

7.3.3. Recommendation for Policy

To encourage use of sustainable CA practices in future food production such as cover crops, hence, reap benefits (including integrated weed management approaches, building and maintaining soil healthy, and increasing infiltration), Policy makers should:

1. Use survey findings to guide policy formulation on weed management in maize cropping systems; on monitoring weeds over time and inform appropriate actions especially for invasive species; and, for future weed comparisons or predictions.
2. Use findings to guide in formulating a policy that could facilitate cover crop knowledge and skills development, exchange and sharing in all cropping systems, and, remove regional barriers to adoption.
3. Empower farmers meet related costs such as time to get cover crop knowledge and management skills.

4. Should develop a policy to guide incentives that motivate farmers and cover immediate farming costs such as such as credit services, time to learn CA technologies and practices, for those likely to adopt cover crops.

7.3.4. Recommendation for future research

1. Explore and characterize weed diversity for use in appropriate adaptive weed management tactics to benefit different maize cropping systems or regions.
2. Identify other factors including: institutional, economic and atitudinal likely to influence and give the threshold required to increase adoption in other cropping systems or counties.
3. Develop appropriate drought tolerant, short season cover crop varieties which should cope with climate change effects including fluctuating extreme high temperatures in the day and chilly nights.
4. Explore adopter’s coping strategies because local constraints did not influence adoption.

REFERENCES

Abbassian, A. (2015). Study Maize International Market Profile. Competitive Commercial Agriculture in Sub Saharan Africa (CCAA). Food and Agriculture Organisation of the United Nations. *Research Gates* Pdf.

Abdi, H., & Williams, L.J. (2010). Newman –Keuls Test and Turkey Test. In: Neil Salkind (Ed.) *Encyclopedia of Research Design*. Thousand H Oaks, CA: Sage.

Abendroth, L.J., Elmore, R. W., Boyer, M.J., & Marlay, S.K. (2011). Corn Growth and Development. PMR 1009 (28pp.). Ames, Iowa: IOWA State University. Pdf.

Abdin, O.A., Zhou, X.M., Cloutier, D., Coulman, D.C., Favis, M.A., & Smith, D.L. (2000). Cover crops and interrow tillage for weed control in short season maize (*Zea mays* L.). *European Journal of Agronomy, 12*, 93-102.

Agnew, A.D.Q. (1974). Upland Kenya Wild Flowers. London: Oxford University Press.

Akudugu, M.A., Guo, E., & Dadzie, S.K. (2012). Adoption of Modern Agricultural Production Technologies by Farm Households in Ghana: What factors Influence their decisions? *Journal of Biology, Agriculture and Health care, 2*(3), 2224-3208.

Albrecht, H., & Matthews, A. (1998). The effects of organic and integrated farming on rare arable weeds on the Forschungsverbund Agrariokosysteme Munchen research station in southern Bravaria. *Biological Conservation,* 86, 347-356.

Ames, T.K., Rahman, A., & Gray, J.S. (2001). Control of Weeds in Imidazolinone Tolerant Maize with Imazethapyr plus Imazapyr. Arable Weeds, Pests and Diseases. *Newzealand Plant Protection, 54,* 162-167.

Anderson, R.L. (2008). Residue Management Tactics for Corn Following Spring Wheat 22(1): 177-181. Retrieved from www.ars.usda.gov/research/publications.htm?SEQ_NO_115

Anderson, R.L. (2013). Steps of yield advancement with no-till cropping systems in a semi-arid cropping system in a semi-arid climate. *Grain, 74*, 103-109.

Andreasen, C., Streibig, J.C., & Haas, H. (1991). Soil properties affecting distribution of 37 weed species in Danish fields. *Weed Research, 31*(4), 181-187.

Araya, T., Cornelis, W.M., Nyssen, J., Govaerts, B., Getnet, F., Bauer, H ,…& Deckers, J. (2012). (2012). Medium term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. *Field Crops Research, 132*, 53-62.

Asfaw, S., Shiferaw, B., Simtowe, F., & Hagos, M. (2011). Agricultural technology adoption, Seed access constraint and commercialization in Ethiopia. Agricultural technology. *Journal of development and agricultural Econonomics, 3*(9), 436-477.

Ausra, M., Rimantas, V., & Robertas, K. (2010). Crop density and Fertilization effects on weed suppression in spring oil seed rape. *Zemdirbyste- Agriculture, 97*(2), 83-88.

Australia Government, (2008). The biology of *Zea mays* L. ssp.mays (maize or corn). Office of the gene Technology Regulator. Retrieved from www.extension.iastate.edu/ilf/news/Fieldday1 SU.Farm.htm

Badu-Apraku, B., M.A.B. Fakorede, A. Menkir, & D. Saogo, (Eds). (2012). *Conduct and Management of Maize Field Trials*. Ibadan: IITA. Retrieved from www.iita.org/c/document_library/get_file?

Benhrendt, S., & Hanf, M. (1979). Grass Weeds in World Agriculture. Aktiengescellschaft. D-6700 Ludwigshafen: BASF.

Benton, T.G., Vickery, J.A., & Wilson, J.D. (2003). Farmland Biodiversity. Is habitat heterogeneity the key? *Trends in Ecology and Evolution. Review. 18*(4), 182-188.

Bergtold, J.S., Duffy, P.A., Hite, D., & Raper, R.L. (2012). Demographic and management factors affecting the adoption and perceived yield benefits of winter cover crops in the Southeast. *Journal of Agriculture and applied Economics, 44*(1), 99-116.

Bergtold, J.S., Anand, M., & Molnar, J.M. (2015). Joint Adoption of Agricultural Practices by Row Crop Producers in Arabama. Arabama: Auburn University. *Pdf.*

Bivardar, S.R. (2012). Green weeds as a source of manure used for production of maize vegetation. *International Journal Science, 1*(1), 46-48.

Boahen, P., Dartey, B.A., Dogbe, G. D., Boadi, E. A., Triomphe, B., Daamgard-L, S., et al. (2007). *Conservation agriculture as practised in Ghana*. Nairobi: African Conservation Tillage Network. Food and Agriculture Organisation of the United Nations.

Broome, M. L., Triplett, G. B., & Watson, C. E. (2000). Vegetation control for no-tillage corn planted into warm-season perennial species. *Agronomy Journal*, *92*(6), 1248-1255.

Brown, W.L., Darrah, L.L. Zuber, M.S., & Glover, D.V. (1984). Origin, Adaptation, and Types of Corn. *National Handbook. The Corn Crop*. NHC-10: Iowa State University Extension. *Pdf.*

Buhler, D. D. (1996). Development of alternative weed management strategies. *Journal of Production Agriculture*, *9*, 501-505.

Buhler, D. D., Robert, P. K., Scott, M. S., Jeffery, L. G., & Frank, F. (1996). Field Evaluation of a Bio-economic Model for weed Management in Corn (*Zea mays*). *Weed Science, 44*, 915-923.

Buhler, D.D., Liebman, M., & ObryCki, J.J. (2000). Theoretical and practical Challenges to IPM approach to weed management. *Weed Science, 48*(3), 274-280.

Byerlee, D., & Heisey, P.W. (1997). Evolution of maize Economy, In Byerlee and CK Eicher (Eds.), *Africa's emerging Maize revolution* (pp1-9). Boulder, Colorado: Lynne Rienner Publications.

Cameron, D. G. (1988). Tropical and subtropical pasture legumes. 17. Lablab bean (*Lablab purpureus*): The major leguminous forage crop. *Queensland Agricultural Journal, 2*, 110-113.

CETRAD, (2016). *The Laikipia Conservation Agriculture Project*. Nanyuki: CETRAD. Retrieved from http://www.stewardshipcommunity.com/stewardship-in-practice/conservation-agriculture/the-laikipia-conservation-agriculture-project.html

Chabi-Olaye, A., Nolte, C., Schultthess, F., & Borgemeister, C. (2005). Effects of grain Legumes and cover crops on maize yield and plant damage by *Busseola fusca* (Fuller) Lepidoptera: Noctuidae in the humid forest of south Cameroon. *Agricultural Ecosystems and Environment, 108* (1), 17 - 28.

Cherr, C.M., Scholberg, J.M.S., & McSorley, R.G.M. (2006). Green manures Approaches to Crop Production: A synthesis. *Agronomy Journal*, *98*, 302-319.

Chomba, G.N. (2004). *Factors affecting Small holder farmers adoption of Soil Water Conservation practices in Zambia*. Unpublished MSc Thesis dissertation. Michigan: Michigan State University.

CIMMYT, (2005). *Deployment of IR-maize through the StrigAway Technology. Consideration for Potential Seed Producers.* Nairobi: CIMMYT. Retrieved from www.cimmyt.org.

Clements, D.R., Weise, S.F., & Swanton, C.J. (1994). Integrated weed management and weed species diversity. *Phytoprotection, 75*(1), 1-18.

Coble, H.D. (1994). Future Directions and Needs for Weed Science Research. *Weed Technology, 8*, 410-412.

Croissant, R.L., Peterson, G.A., & Westfall, D.G. (2008). Tillage effects; expect soil water loss from tillage operations. *The Tropical Agriculturalist. Food Crops and Drought*. CTA: Macmillan.

Cudney, D., & Elmore, C. (2003). *Statewide Integration Pest Management Program*. University of California. Retrieved from agron-www.agron-iastate.edu/-weeds/

Davis, A.S., & Liebman, M. (2003). Cropping system effects on giant foxtail demography. Green Manure and tillage timing. *Weed Science, 51*, 919-929.

Dekker, J. (1997). Weed Diversity and Weed management. *Weed Science, 45*(3), 357-363.

Demjanova, E., Macak, M., Dalovic, I., Majernik, F., Try, S., & Smatana, J. (2009). Effects of tillage systems and Crop rotations on weed density, weed species composition and weed Biomass in maize. *Agronomy Research, 7*(2), 785-792.

Dewey, S.A., & Anderson, K.A. (2004). Distinct Roles of Surveys, Inventories, and Monitoring in Adaptive Weed Management. *Weed Technology*, *18*, 1449-1452.

DNA, (2014). *Some farmers in Makueni have used Conservation Agriculture to beat climate change effects*. Nairobi: DNA. Retrieved from *http://www.nation.co.ke/business/farmers-beat-climate-change-with-Conservation Farming-/996/2345594/view*

DNA, (2016). Agriculture employs 65% of Kenya's workforce. Nairobi: *The Sunday Nation*, p. 9. Retrieved from *http://.www.nation.co.ke*

Dogan, M. N., Boz, O., & Unay, A. (2005). Efficacies of Reduced Herbicide Rates for Weed Control in Maize (*Zea mays*. L.) during critical period. *Journal of Agronomy, 4* (1), 44-48.

Doss, C.R., & Morris, M.L. (2001). How does gender affect the adoption of agricultural innovation? The case of improved maize technologies in Ghana. *Journal of Agricultural Econonomics, 25*, 27-39.

Dukes, J.S., & Mooney, H.A. (1999). Does global change increase the Success of biological invaders? *Trends in Ecology & Evolution, 14*(4)*, 135-139*.

Fabian, D.M. (2008). *Weed Seed bank dynamics and integrated management of Agricultural weeds*. *A self learning Research guide*. Montana: Montana State University Extension. Pdf. Retrieved from www.msuextension.org.

Feder, G., Just, R.E., & Zilberman, D. (1985). Adoption of Agricultural Innovation in Developing Countries: A *Survey. Economic Development and Cultural Change, 33*, 255-298.

Food and Agriculture Organization (FAO), (2005). *International Workshop on Modernising Agriculture*. *Visions and Technology for Animal Traction and Conservation Agriculture Vol 11*. Sunset Hotel and Conference Centre, Jinja. Retrieved from www.fao.org/ag/ca/doc/jinja-vol 2.pdf

Food and Agriculture Organization (FAO), (2011). *Conservation Agriculture Worldwide*. Retrieved from *http://www.fao.org/ag/ca/6.c.html*

Foss, C., & Antonelli, A. (2003). *Weeds*. Washington: Washington State University Hortense. Retrieved from http://pop.wsu.edu/hortense/sript/query/displayweed-asp. 2006/2/17

Frick, B., & Thomas, A.G. (1992). Weed surveys in different tillage systems in southern western Ontario field crops. *Canadian Journal of Plant Sciences*, *72*, 1337-1347.

Frieben, B., & Kopke, U. (1995). Effects of farming systems on biodiversity. In J.Isart & J.J. Llerena. (Eds.), *Biodiversity and Land Use; The role of Organic Farming: Proceedings of the First ENOF Workshop* (pp.11–21). Barcelona. Retrieved from http://www.esajournals.org/doi/abs/10.1890/1051-0761.

Friendrick, T., DerpSch, R., & Kassam, A. (2012). *Overview of global spread of Conservation agriculture: Reconciling Poverty Eradication and Protection of Environment*. *Special issue 6.* Retrieved from *http:/facts reports.revues.org/194.*

Gabriel, D., Roschewitz, I., Tscharntke & Thies, C. (2006). Beta diversity at different spatial scales: plant communities in organic and conventional agriculture. *Ecological Applications, 16*, 2011-2021.

Gachene, C.K.K., & Mwangi, H.W. (2006). Green Manure/Cover Crops for Soil Erosion Control and Conservation Agriculture in Central and Eastern Highlands of

Kenya. In J. G. Mureithi, J.W. Wamugongo, C.K.Gachene, E.Marjatta (Eds.), *Enhancing Agricultural Productivity in East Africa. Development and Up-scaling of Green Manure Legume Technologies in Kenya* (pp.145-170). Nairobi: Kenya Agricultural Research Institute. Legume Research Network Project.

Gibson, L., & Benson, G. (2014). *Origin, History and Uses of maize zea mays*. Ames IOWA: Iowa-State University. Retrieved from www.agron.iastate.edu/courses/agron212/readings/corn-history.htm

Giller, K.E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and small holder farming in Africa: The heretics' view. *Field Crops Research, 114*, 23-34.

Government of the Republic of Kenya (GOK), (2010). Economic Review of Agriculture and Kenya Population and Housing Census.

Government of the Republic of Kenya (GOK), (2007). *Kenya Vision 2030*. *The popular version*. 4th Floor Kenyatta International Convention Centre (KICC). Retrieved from http:// www.planning.go.ke.

Hald, A.B. (1999). Weed vegetation (wild flora) of long established organic versus conventional cereal fields in Denmark. Farmland biodiversity: is habitat heterogeneity the key? *Annals of Applied Biology, 134*, 307–314.

Hall, M. R., Swanton, C.J., & Anderson, G.W. (1992). The Critical Period of Weed control in Grain Corn (*Zea mays* L.). *Weed Science, 40*(3), 441-447.

Hanson, G. (2004). Common Purslane (*Portulaca oleraceae*). Moscow: University of Indaho. Retrieved from http://www.cnr.uidaho.edu/range454/2004.weeds.common purslane html.

Harper, J.L. (1977). *Population Biology of Plants*. San diego, CA: Academic Press. 892 p.

Harker, K.N. & O'Donovan, J.T. (2013). Recent Weed Control, Weed Management and Integrated Weed Management. *Weed Technology, 27*, 1-11.

Higginbottham, S., Leake, A.R., Jordan, V.W., & Ogilvy, S.E. (2000). Environmental and Ecological aspects of integrated, organic and conventional farming systems. *Aspects of Applied Biology*, *62*, 15–20.

Humphreys, L.R. (1995). Diversity of productivity of tropical Legumes. In J.P.F., DMello & C. Devendra (Eds.). *Tropical Legumes in Animal nutrition* (pp.1-21). Wallington UK: CAB. International.

Hussain, S., Sher, A., Khan, A., Jiancai, Li., Ameen, A., & Shakoor, A. (2015). Effect of Phosphorus and different irrigation regimes on the yield components of maize (*Zea mays* L.). *Academic Journal of Agricultural Science and Research, 3*(9), 267-271.

IIRR & ACT, (2005). *Conservation agriculture: A manual for farmers and extension workers in Africa.* International Institute of Rural Reconstruction, Nairobi; African Conservation tillage Network, Harare. ISBN 9966-9705-9-2

Ivens, G.W. (1967). *East African Weeds and Their Control*. Nairobi. Oxford University Press.

Jaetzold, R., Schimidt, H., Hornetz, B., & Shisanya, C. (2005). *Farm Management Handbook of Kenya*. Vol 11/C1. *Natural Conditions and Farm Management Information*-Part C. Eastern Kenya. FAO.

James, T.K., Rahman, A., Gray, J.S., & Mellsop, J.M. (2000). Weed Competition in maize crop under different timings for post-emergence weed control. Arable weeds, Pests and Diseases. *Newzealand Plant Protection,* 53, 269-272.

Kabambe, V.H., Kanampiu, F., & Ngwira, A. (2008). Imazapyr (herbicide) seed dressing increases yield, suppresses *Striga asiatica* and has seed depletion role in maize (*Zea mays* L.) in Malawi. *African Journal of Agricultural Biotechnology, 7* (18), 3293-3298.

Kabede, Y., Gunjai, K., & Coffin, G. (1990). Adoption of New Technologies in Ethiopian Agriculture: The case of Tegulet-Bulga District, Shoa Province. *Agricultural Economics, 4*, 27-43.

Kanampiu, F.K., Ransom, J.K., Dennis, F., & Gressel, J. (2002). Imazapyr and pyrithiobac movement in soil and from seed coats to control *Striga* in legume intercropping. *Crop Protection, 21,* 611-619.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Dennis, F., Ransom J.K., et al. (2003). Herbicide seed coating technology is successful in multi-site on-station studies, farmers' fields in different conditions. *Crop Protection, 22*, 697-706.

Kangethe, E. (2011). Situation Analysis: Improving Food Safety in the Maize Value Chain in Kenya. Report prepared for FAO. 89pp.

KARI Crop Protection Officers, (1996). Weed sampling. In J.A. Sutherland, G.N. Kibata, & Farrell, G. (Eds). *Field Sampling Methods for Crop Pests and Diseases in Kenya* (pp.16). Nairobi: KARI/ODA Crop Protection Project.

Karuma, A., Gachene, C.K.K., Gicheru, P.T., Mwang'ombe, A., Mwangi, H.W., Clavel, D., et al. (2011). Effects of legume cover crop and subsoiling on soil properties and Maize (Z*ea mays* L.) growth in semi-arid area of Machakos District Kenya. *Tropical and Subtropical Agroecosystems*, *14*, 237-243.

Kelton, J., Price, A.J., & Mosjidis, J. (2012). *Weed control*. In A. Price, (Ed.),….(pp.-) Retrieved from www.Interchopen.com

Khan, R.U., Muendel, H.H., & Chaudhry, M.F. (1999). Relative effect of weeds on topping and ratooning rapeseed (*Brassica napus* L.). *Pakistan Journal of Botany*, *25* (2), 127-133.

K'Owino, I.O. (2010). *Conservation Agriculture in Kenya: Analysis of Past Performanace and Emerging trends*. Kakamega: Masinde Muliro University.

Knezevic, S.Z., & Avishek, D. (2015). The CriticaL Period for Weed Control: Revisiting Data Analysis. *Weed Science*, *Special Issue 63, 188-202.*

Kramberger, B., Kaligaric, M., & Bracko, B. (2009). Effects of cover crops on soil mineral nitrogen and on the yield and nitrogen content of maize. *European Journal of Agronomy, 31* (2), 103-109

Krato, C. (2012). *Consequences for weed management in crop rotations by introducing Imidazolinone Tolerant oil seed rape varieties*. Unpublished PhD Dissertation. Stuttgart: University of Hohenheim.

Kyongo, E. (2016). Conservation Agriculture Farming in Kenya. Participatory Approaches for Integrated Development (PAFID). Retrieved from Yu-*Tube- https://www.youtube.com/watch.*

Lal, R. (1995). The role of Residue Management in Sustainable Agricultural Systems. *Journal of Sustainable Agriculture, 5*, 51-78

Lanin, W.T., & Wertz, B.A. (2013). *Weed descriptions, Broadleaf Weeds*. Pennsylvania: Pennsylvania State University College of Agricultural Sciences *Plantscience.psu.edu/research/centers/turf/extension/factsheets/weed-management/ broadleaf*

Lapar, M.A., & Pandey, S. (1999). Adoption of soil conservation: the case of the Phillipine uplands. *Agricultural Economics, 21*, 241-256.

Laver, J. (2003). *What happens within corn plant when drought occurs?* Wisconsin: University of Wisconsin Extension. Retrieved from *http://www.uwex.edu/ces/ag/issues/drought/2000/corneffect* html

Lichtenberg, E., Hanson, J.C., Decker, A.M., & Clark, A.J. (1994). Profitability of legume cover crops in the Mid-Atlantic Region. *Journal of Soil and Water Conservation, 49*(6), 582-585.

Liebman, M., & Davis, A.S. (2000). Integrated soil, crop and weed Management in low-external Input Farming Systems. *Weed Research, 40*, 27-47.

Liebman, M., & Sundberg, D.N. (2006). Seed mass affects the susceptibility of weed and crop species to phytotoxins extracted from red clover shoots. *Weed Science, 54,* 340-345.

Linares, J., Scholberg, J., Boote, K., Chase, C.A., Ferguson, J.J., & McSorley, R. (2008). Use of the Cover Crop Weed Index to evaluate Weed Suppression by Cover crops in citrus orchards. *Horticultural Science, 43* (1), 27-34.

Loux, M.M., & Berry, M.A. (1991). Use of a Grower Survey for Estimating Weed Problems. *Weed Technology, 5*, 460 - 466.

Maqsood, M., Shehzad, M.A., Sarwar, M.A., Abbas, H.T., & Mushtaq, S. (2012). Impact of different moisture regimes and nitrogen rates on yield and yield attributes of maize (*Zea mays* L.). *African Journal of Biotechnology, 2*(34), 8449-8455.

Martin, H. (2016). *Evaluating constraints and opportunities in managing weed populations with cover crops.* Unpublished PhD Thesis. Pennsylvania: Pennsylvania State University. *Pdf.*

Masunda, B.Z. (2010). *Evaluation of cover crops species for biomass production, weed suppression and maize yields under irrigation in the Eastern Cape Province South Africa.* Unpublished Msc Thesis. Hare: University of Fort Hare. *Pdf.*

Meng, S., Analiza, H.M.R., Shir, D., Sharma, B., & Amit, J.J. (2012). Factors affecting the germination of tall Morning glory (*Ipomoea purpurea*). *Weed Science, 60*(1), 64-68.

Mhlanga, B., Cheesman, S., Maasdorp, B., Muoni, T., Mabasa, S., Mangosho, E., et al. (2015). Weed Community responses to rotations with cover crops in maize based conservation agriculture systems of Zimbabwe. *Crop Protection, 69*, 1-8.

Milander, J. J. (2015). *Maize yield and components as influenced by Environment and Agronomic Management*. Unpublished MSc Thesis. Nebraska: University of Nebraska. *Pdf.*

Mine, S., Zoubek, S., Cory-Watson, D., & Lowe, M. (2014). Adoption of Conservation Agriculture: Economics incentives in the IOWA Corn value chain. Retrieved from *www.daturesearch.com./wp-content-upload/Datu_Iowa-conservation* - *Agriculture-FINAL Pdf.*

Minten, B. & Barrett, C.B. (2008). Agricultural Technology Productivity and Poverty in Madagascar. *World Development*, *36*(5), 797-822.

Mirsky, S.B. (2008). *Evaluating Constraints and Opportunities in Managing Weed Populations with Cover crops.* Unpublished PhD Thesis. Pennsylvania: Pennsylvania State University. *Pdf*.

Mirsky, S.B., Ryan, M.R., Teasdale, J.R., Curran, W.S., Reberg-Horton, C.S., Spargo, J.T., et al. (2013). Overcoming Weed Management Challenges in Cover Crop-Based organic Rotational No-till Soyabean Production in the Eastern United States. *Weed Technology, 27*, 193-203.

Mitich, L.W. (1997). Common Purslane (*Portulca oleraceae* L.). *Weed Technology, 11*(2), 394-397.

Mohler, C.L. (1996). Ecological bases for the Cultural Control of Annual weeds. *Journal of Production Agriculture*, *9,* 468-474.

Morris, M.G., & Vankatesh, V. (2000). Age differences in technology adoption decisions: Implications for a changing workforce. *Personnel Psychology*, *53*(2), 375-403.

Muhitch, M.J., Shaner, D.L., & Stidham, M.A. (1987). Imidazolinones and Acetohydroxyacid synthase from higher plants. *Plant physiology*, *83,* 451-456.

Mwangi, H.W. (2003). *Dolichos lablab* as Cover Crops: Experiences with Farmers Groups in Eastern Kenya. A poster prepared for 2nd World Congress in Brazil, 5-8th August 2003.

Mwangi, J.W. (2006). Population growth and Structure. In: Waithaka Lydia (Ed.), *Research Agenda on Population and Development in Kenya. National*

Coordinating Agency. Retrieved from *Pdf.ncpd-ke.org/.System/.Research Agenda*

Mwangi, H.W., Kihurani, A.W., Wesonga, J.M., Ariga, E.S. & Kanampiu, F. (2015a). Effect of *Lablab purpureus* L. cover crop and imidazolinone resistant (IR) maize on weeds in drought prone areas, Kenya. *Crop Protection, 72,* 36-40.

Mwangi, H.W., Kihurani, A.W., Wesonga, J.M., Ariga, E.S., & Kanampiu, F. (2015b). Factors influencing adoption of cover crops for weed management in Machakos and Makueni counties of Kenya. *European Journal of Agronomy,* 69, 1-9.

Mwangi, H.W., Mgonja F., Admassu, H., Opio, F., Rwomshana, I., Karau J., et al. (2011). *Upscaling of soil water management Technologies and Drought Tolerant Varieties for increased maize productivity in ECA Countries*. Retrieved from www.asareca,org/resources/reports/ASARECAGA paper .2011.pdf

Namakkha, A., Abubakari, I.U., Dadari, S.A., Ado, S.G., Hamid, A.H., Sharifai, A.I., et al. (2012). Effects of tillage systems and nitrogen level on growth of maize (*Zea mays*. L.) in Northern Guinea Zone of Nigeria. *Greener Journal of Agricultural Sciences*, *2*(5), 172-179.

National Wild Life Federation Staff (NWFS), (2012). Roadmap to increased Cover crop production. *Pdf*.12pp.

Neill, S.P., & Lee, D.R. (2001). Explaining the Adoption and Disadoption of Sustainable Agriculture: The Case of Cover Crops in Northern Honduras. *Economic Development and Cultural Change*, *49*(4), 793-820.

Nepal, S. (2010). *An Economic analysis of cover crops in corn dominated production systems*. Unpublished MSc Thesis. Louisiana: Louisiana State University. Pdf.

Ngome, A.F.E., Becker, M., & Mtei, K.M. (2011). Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 112*(1), 1-10.

Ngwira, A.R., Aune, J.B., & Mkwinda, S. (2011). On-farm evaluation of yield and economic benefits of short term maize legume intercropping systems under CA in Malawi. Conservation agriculture in dry lands. *Field Crops Research, 132*, 149-157.

Nyalemegbe, K.K., Asiedu, E.K., Ampontuah, E.O., Nyamekye, A.L., & Danso, S.K.A. (2011). Improving the productivity of Vertisols in the Accra plains of Ghana using leguminous cover crop. *International Journal of Agricultural Sustainability*, *9*(3), 434-442.

OECD, (2003). Consensus doc on the biology of *Zea mays* subsp. Mays (maize) Report No. 27 Environment Directorate: Organisation for Economic Cooperation and Development.

Olorunmaiye, P.M. (2010). Weed control potential of five legume cover crops in maize cassava intercrops in a Southern Guinea Savannah Ecosystem of Nigeria. *Australian Journal of Crop Science*, *4*(5), 324-329.

Onyango, C., Onduwo, A., Okoko, N., Kidula, N., & Mureithi, J.G. (2000). Green manureing to improve soil fertility and reduce Striga weed infestation in SHF in South Nyanza. Kenya. Retrieved from *www.kari/fileadmin/publications/legumes-Project/...2000/ 22pdf*

Oram, R., Kirk, J.T.O., Veness, P.E., Hurlstone, C.J., Edlington, J.P. & Halsau, D.M. (2005). Breeding Indian mustard (*B. Juncea* L). (Unpublished in press).

Pal, R. W., Pinke, G., Botta-Duket, Z., Camptella, G., Bartha, S., Kalocsan, R., et al. (2013). Can management intensity be more important than Environmental factors? A case study along an extreme elevation gradient from Central Italian Cereal fields. *Plant Biosystems*, *147*, 343-353.

Paliwal, R.L. (2000a). Genetic Resources. In R.L Paliwal. G.Granados, HR Lafi lle, AD. Vlolle. (Eds.) *Tropical maize: Improvement and Production* (pp. 105-114). Rome: Food and Agriculture Organization of the UN.

Paliwal, R.L. (2000b). Uses of maize. In R.L. Paliwal, G.Granados, H.R, Lafi lle, & AD. Vlolle. (Eds.) *Tropical maize: Improvement and Production* (pp. 45-57). Rome: Food and Agriculture Organization of the UN.

Parker, C., & Riches, C.R. (1993). *Parasitic weeds of the world; biology and control*. 332pp. Wallingford, UK: CAB International.

Pekrun, C., Hewwit, J.D.J., & Lutman, P.J.W. (1998). Cultural Control of Volunteer oilseed rapeseeds in relation to temperature. *Weed Research, 37*: 419-431.

Peterson, J., Belz, R., Walker, F., & Hurle, K. (2001). Weed suppression by release of Isothiocyanates from Turnip rape mulch. *Agronomy Journal, 93*, 37-43.

Pfeiffer, M. (2016). *Glyphosate Mode of Action. Pesticide Training Resources*, 2009. EPSP Pdf. Retrieved from http: // wwww.ptrpest.com

Price, A.T., & Norsworthy, J.K. (2013). Cover crops for weed management in Southern Reduced Tillage Vegetables Cropping Systems. *Weed Technology, 27*(1), 212-217.

Rasul, G., & Rashid, K. (2010). Rainfall variability and maize production over the Potohar Plateau of Pakistan. *Pakistan Journal of Meteorology, 8*(15), 63-74.

Reberg-Horton, C., Grossman, J. M., Kornecki, T.S., Meijer, A.D., Price, A.J., & Place, G.T. (2012). Utilising cover crops mulches to decrease tillage in organic systems in the South Eastern, USA. *Renewable Agriculture and Food Systems, 27*, 41-48.

Ritz, C., Kniss, A.R., & Streibig, J.C. (2015). Research Methods in Weed Science: Statistics. *Weed Science, 63*(Special Issue1), 166-187.

Roselt, (2011). *Kibwezi-Kiboko Observatory Baseline Progress Report*. Kibwezi: L'Observatoire du Sahara ET du Sahel (OSS) (69pp). Retrieved from Roselt.www.oss-online.org/sites/…/05.pdf.

Ross, M.A., & Childs, D.J. (2016). *Imidazolinone mode of action summary*. Purdue: Purdue University, WS-23-W Pdf. Retrieved from http/www.extension.purdue.edu/extmedia/ws/-23-w.html

Sajilata, M.G., Singhai, R.S., & Kamat, M.Y. (2008). A Review: The carotenoid Pigment. *Comprehensive Review of Food Science and Food Safety, 7,* 29-49.

Schiffner, R. (2012). Drought management on Cropland Fields. Kansas: National Resource Conservation Service Hays. Retrieved from http:/www.ks.nrcs.usda.gov/news/coneds12/drought_cropland.html

Schonbeck, M. (2012). Twelve steps Towards Ecological Weed Management. Retrieved from www.extension.org/paper/18539-in-twelve-steps-toward-ecological-weed-management-in-organic-vegetables

Shaner, D. L. (2014). Lessons learned from the history of Herbicide Resistance. *Weed Science, 62*(2), 427-431.

Shaw, R.H. (1977). Climatic requirements. Corn and Corn Improvement. G.F. Sprague (Ed.). *American Society of Agronomy, 18*, 591-623.

Sheahan, C.M. (2012). Plant guide for lablab (*Lablab purpureus* L.). Cape May: USDA-Natural Resources Conservation Services, Cape May. Retrieved from *http://plants.usda.gov/plantsguidepdf/pg.Iapu6.pdf*

Shiro, T. (2006). Survival and changes in germination response of *Rumex obtusifoliaus*; *Polygonum longisetum* and *Oenothera biennis* during burial at three soil depths. *American Journal of Environmental Sciences, 2*(2), 74-78.

Shrestha, A., Knezevic, S.Z., Roy, R.C., Ball-Coelho, B.R., & Swanton, C.J. (2002). Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *European Weed Reseach, 42,* 76-87.

Singer, J.W., Nusser, S.M., & Alf, C.J. (2007). Are cover crops being used in the US Corn Belt? *Journal of Soil & Water Conservation, 62* (5), 353-358.

Skerman, P.J., Cameron, D.G. & Riveros, F. (1991). Leguminosas Forrajeras. A review of *Lablab purpureus* L. SUNET: Swedish University. Retrieved from http//:ftp.sunet.se/wmirror/www.cipar.org.co/1rrd/1/2/co/ull2r.htm

Smale, M., Byelee, D., & Jayne, T. (2011). The World Bank development Research. Agriculture and Rural Development Team Policy Working Papers.5659. Retrieved from http/www.goggle=bv571554.elibrary.worldbank.org/doi/pdf/10.1596/1813-9456.

Taheripour, F., Hertel, T. W., & Tyner, W.E. (2011). Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis. *Journal of International Agricultural Economics, 42*(3), 325-342.

Tans, S., Evans, R.R., Dahmer, M.L., Sigh, B.K., & Shaner, D.L. (2005). Imidazolinone-tolerant crops: history, current status and future. *Pest Management Science*, *3*, 246-257.

Teasdale, J.R. (1996). Contribution of cover crops to weed management in South American Systems. *Journal of Production Agriculture*, *9*, 475-479.

Teasdale, J.R., & Daughtry, C. S.T. (1993). Weed suppression by Live and Desiccated Hairy Vetch (*Vicia villosa*). *Weed Science, 41*(2), 207-212.

Teasdale, J.R., & Mowler, C.L. (1993). Light transmittance, soil temperature, and soil-moisture under residue hairy vetch and rye. *Agronomy Journal, 85*, 673-680.

Teasdale, J.R., & Mowler, C.L. (2000). The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Science, 48*, 385-392.

Teasdale, J.R., Brand Saeter, L.O., Calegari, A., & Neto, F. S. (2007). Cover crops and Weed management. In Upadhyaya, M.K., & Blackshaw, R.E. (Eds.). *Non chemical weed management*. *Weed technology, 14,* 545-548.

Terry, P.J., & Michieka, R.W. (1987). Common weeds of East Africa. FAO. Pp. 151.

Thomas, A.G. (1985). Weed Survey System Used in Saskatchewan for Cereal and Oilseed Crops. *Weed Science, 33,* 34-43.

Tim, G., Liebman, M., & Jemison, J. Jr. (2000). Cover crops for sweet corn production in a short season environment. *Agronomy Journal*, *92,* 144-151.

Tollenaar, M., Dibo, A.A., Aquilera, A., Weise, S.F., & Swanton, C.J. (1994). Effects of Crop Density on Weed Interference in Maize. *Agronomy Journal,* 86(4): 591-595.

Webster, T.M., & Coble, H.D. (1997). Changes in the Weed Species Composition of the Southern United States: 1974 to 1995. *Weed Technology*, *11*(2), 308-317.

Weed Soft, (2016). *Corn growth stage Development*. Retrieved from http://weedsoft.unl.edu/documents/growthstagesmodule/corn/corn Pdf.

Westoby, M., Falster, D.S., Moles, A.T., Vesk, P.A., & Wright, I.J. (2002). Plant Ecological Strategies: Some Leading Dimensions of Variations between Species. *Annals of Revolutionary Ecological Systems, 33*, 125-159.

Williams, M.M., Davis, A.S., Rabaey, T.L., & Boerboom, C.M. (2009). Minimum tillage with herbicides. *Field Crops Research, 113*, 161-169.

Uchino, I., Jitsuyama, I., Sugiura, Y., & Nakamura, G. (2012). Effect of interseeding cover crops and fertilization on weed suppression under an organic and rotational cropping system: Stability of weed suppression over years and main crops of potato, maize and soya bean. *Field Crops Research, 127*(27), 9-16.

Uematsu, H., & Mishra, A.K. (2010). Can Education Be a Barrier to Technology Adoption? *Agricultural & Applied Economics Association 2010 AAEA, CAES & WAEA Joint Meeting*. Colorado: Denver. Retrieved on 11th December 2012.

UN Sustainable Development Goals (SDGs), (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. A/RES/70/1. 35pp.

APPENDICES

Appendix 1: Survey Questionnaire

Adoption of legume cover crops for weed management in maize (zea mays L.) cropping systems in Machakos and Makueni Counties.

PART A. Biodata

1. Enumerator(s) Name____

2. Enumerator CODE ____

3. Date of interview (DD/MM/YY/ / / /

4. District Name ____ [___]

5. Division Name ____ [___]

6. Sub-location ____ [___]

7. Village Name ____ [___]

8. Questionnaire no ______________________________________ [___]

9. Agroecological Zone ____________________________________ [___]

10. Respondent's name____

11. Respondent's gender. 1. Male [ ] 2. Female [ ]

12. Respondent's age in years 1.15-25 [ ] 2.25-35 [ ] 3.35-45 [ ] 4. 45-55 [ ]

13. Respondents education 1. Primary [ ] 2. Secondary [ ] 3. Tertiary [ ] 4. Illiterate [ ]

14. Respondent's position in the household (Tick)

1. Husband [ ]	5. Daughter [ ]
2. Wife [ ]	6. House help/ farm laborer [ ]
3. Co-wife [ ]	7. Hired manager [ ]
4. Son [ ]	8. Other (specify) [ ]

PART B. Status of use of cover crops for weed management in maize production

15. a) Are weeds a problem in maize production? (Tick) 1. Yes [ ] 2. No [ ]

15. b) If yes, which ones? (Tick)

1. Broad leaved (specify) [ ] ________________
2. Grasses (specify) [ ]________________
3. Sedges (specify) [ ]________________
4. Parasitic (specify) _______________
5. Other (specify) _______________

16. a) Are there new emerging weeds that were not occurring or were not a problem 5 years ago? (Tick) 1. Yes [ ] 2. No [ ]

16. b) If yes, list or name them.

1.

2.

3.

4.

17. Do you practice conservation tillage? (Tick) 1. Yes [__] 2. No [ ]

18. If yes, what is the weed problem in conservation tillage? (Tick)

1. Population abundance [ ] ____________________

2. Diversity (Spectrum) [ ] ____________________

3. Re-growth (many times of weeding) [ ] ________

4. Labor scarcity [ ] ___________________

5. Other (specify) [ ] ___________________

19. Which method do you practice in weed management?

20. Did you plant legume cover crops for weed management in year 2008/2009? (Tick)

1. Yes [ ] 2. No [ ]

21. When did you start growing cover crops? Year.

22. Where did you learn the use of cover crops for weed management? (Tick)

1. Attended training [ ]

2. On-farm demonstration site [   ]

3. Lessons learnt in farmer field School [   ]

4. Participated in field days [   ]

5. Participated Farmer exchange tours [   ]

6. Other [   ] (specify) ____________________________.

23. Where did you source your cover crop seeds from? (Tick)

1. Group [   ]

2. Neighbor [   ]

3. Project provision in farmer group demonstrations [   ]

4. Market [   ]

5. Other [   ] (specify)

24. Do you have preferred cover crops? (Tick)

1. Yes [   ]   2. No [   ]

i). If yes, which legumes cover crops do you prefer? (Tick)

Legumes cover crop

1. Pigeon peas (*Cajanus cajan*)[   ]

2.. Beans (*Phaseolus vulgaris*) [ ]

3. Lablab (*Dolichos lablab*) [ ]

4. Mucuna (*Mucuna pruriens* [ ]

5.Other [ ](specify)___________

ii). Why that preference? 1. Domestic use [ ] 2. Protein source [ ] 3. Serve dual purpose [ ] 4. Drought resistant [ ] 5. Availability of seed and later use [ ]

25. Do you face constraints in adoption of legume cover crops? (Tick)

1. Yes [ ] 2.No [ ]. If yes what constraints? (Rank)

Constraints	Rank
1.Seeds	
2.Lack of information on cover crops	
3.Diseases	
4.Pests	
5. Other (specify)	

26. If you plant maize and legume cover crops indicate the following information:

a) How do you plant? (Tick)

1. Sole crop in lines [ ]

2. Intercrop in lines [ ]

3. Relay crop [ ]

4. Rotation [ ]

5. Other [ ] (Specify) ____________

b) Do you plant one or more than one seed per hole?

1. One seed [ ], 2. Two seeds [ ] 3. More than two seeds [ ]

c) Why plant more than one seed per hole?(tick)

1. Livestock feeding (when thinning, maize is fed to livestock) [ ]

2. In case one seed does not germinate [ ]

3. To suit the spacing of rows [ ]

4. To produce green maize [ ]

5. Other [ ](Specify)______________________

d) What is the spacing between maize hills? (Indicate spacing units) 1. 25 centimeters [ ]

2. 30 cm [ ] 3. 45 cm [ ] 4. 60 cm [ ]

27. How do you use your legume cover crop residue? (Tick)

1. Left on the farm [ ]

2. Used as feed for own cattle [ ]

3. Other [ ] (Specify) _______________________________

28. What is your present land size in hectares under 1. Maize crop [   ]   2. Cover crop [ ]

29. What is your recommendation with regards to legume cover crops in conservation agriculture?

Recommendations

1. More varieties [   ]

2. Short season legume cover crops [   ]

3. Management intervention [   ]

4. Other [   ] (Specify)______________

30. Any other comment or observations to share?

Thank you,

Comments:

Appendix 2: Analysis of variance structure

Appendix 2.1 Weed species diversity (count m^{-2}) for Kalama and Kee divisions

Source of variation	Sum of Squares (s.s)	Degrees of freedom (df)	Mean Square (m.s)	F (v.r)	*P-value*
A: Division	0.964	1	0.964	1.727	0.190
B:Weed Species	437.036	27	16.187	28.991	<0.001
A x B	39.369	27	1.458	2.612	<0.001
Error	156.333	280	0.558		
Total	1050.000	336			
Corrected Total	633.702	335			

Appendix 2.2 Rapeseed emergence and growth (plants per pot)

Source of variation	d.f.	s.s.	m.s.	v.r.	*P-value*
Rep stratum	2	8718.7	4359.35	65.64	
A:Days (7-30) after planting	9	7977.95	886.44	13.35	< 0.001
B:Treatment	7	6380.76	911.54	13.72	< 0.001
A x B	63	261.28	4.15	0.06	1
Residual	398	26434.3	66.42		
Total	479	49772.99			

Appendix 2.3 Rapeseed dry matter (g per pot) 35 days after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	P-value	
A: Watering regime	1	422.45	422.45	30.62	< 0.001	at $p<0.001$
B: Treatment	7	879.41	125.63	9.11	< 0.001	at $p<0.001$
A x B	7	337.71	48.24	3.5	0.007	at $p<0.01$
Residual	32	441.49	13.8			
Total	47	2081.07				

Appendix 2.4 Weed Diversity (count m^{-2})

Source of variation	*d.f.*	*s.s.*	*m.s.*	*v.r.*	*P-value*
Block stratum	3	1.823	0.608	0.30	
A: Time (Days After Planting)	1	35.021	35.021	17.56	< 0.001
B: Coated IR-maize	1	2.083	2.083	1.04	0.314
C: Cover crop	2	0.042	0.021	0.01	0.990
A x B	1	0.083	0.083	0.04	0.839
A x C	2	1.760	0.880	0.44	0.647
B x C	2	4.667	2.333	1.17	0.323
A x B x C	2	5.698	2.849	1.43	0.254
Residual	33	65.802	1.994		
Total	47	116.979			

Appendix 2.5 Standardised Grain Yield (t ha^{-1}) 2010

Source of variation	d.f.	s.s.	m.s.	F.	*P*-value
Block	3	24.5746	8.1915	9.34	
A: Herbicide Coated IR-maize	1	3.7604	3.7604	4.29	0.056
B: Cover crop	2	16.7575	8.3788	9.56	0.002
A x B	2	4.6408	2.3204	2.65	0.104
Residual	15	13.1529	0.8769		
Total	23	62.8863			

Appendix 2.6 Standardised Grain Yield (t ha^{-1}) 2011

Source of variation	d.f.	s.s.	m.s.	F.	*P*-value.
Rep stratum	3	2865957.	955319.	8.80	
A: Herbicide Coated IR-maize	1	3580310.	3580310.	32.97	< 0.001
B: Cover crop	2	249180.	124590.	1.15	0.344
A x B	2	368018.	184009.	1.69	0.217
Residual	15	1628996.	108600.		
Total	23	8692461.			

Appendix 2.7 Number of ears (Count ha^{-1}) 2010

`	d.f.	s.s.	m.s.	F.	*P*-value
Rep stratum	3	192375000.	64125000.	9.80	
A: Herbicide Coated IR-maize	1	40041667.	40041667.	6.12	0.026
B: Cover crop	2	374770833.	187385417.	28.64	< 0.001
A x B	2	47145833.	23572917.	3.60	0.053
Residual	15	98125000.	6541667.		
Total	23	752458333.			

Appendix 2.8 Number of ears (Count ha^{-1}) 2011

Source of variation	d.f.	s.s.	m.s.	F.	*P*-value
Rep stratum	3	83213203.	27737734.	2.07	
A: Herbicide Coated IR-maize	1	277950234.	277950234.	20.72	<0.001
B: Cover crop	2	483802.	241901.	0.02	0.982
A x B.	2	17387969.	8693984.	0.65	0.537
Residual	15	201222266.	13414818.		
Total	23	580257474.			

Appendix 3: Respondents in Makueni and Machakos Counties

Kee division in Makueni		Kalama division in Machakos	
Julius M.M.	Julius Kyalo	Sammy Mutie	Mary Wambua
Tabitha K.	Peter M.M	Ruth Malua	Jonathan Kyania
Regina Kitivi	Chalse M.K	Penina Makau	Antony Mulela K
Agnes Ndiso	James M.Mutungi	Rebeka Ndaka	Margaret Kasyoka
Stephen Kitela	Monica W.M	Danson Ndumbi	Magdalene Masika
Nicholus M.M	Rose Nseki	Justus Mweu	Priscila Maweu
Charlse M.D	F.M.Kioko	Philip Ngui	Philomena Kitetu
James K.M	Fidelis Ndunda	Daniel Ndonye	Andrew Mulalya
John M.M	Cathrine N.Lazaro	Sammy Kilundo	Daniel Muange N.
Enoch M.	Robert M.Muringe	Monika Kyania	John M.Mutua
Mary Mbai	Benson Nzomo	James Nzivo	Francis Ndambuki
Stephen N.	Samuel M.Nzombe	Sera Nzilia	Rachel Mwangangi
Benson Masila	Robert T.Mwau	Ruth Mathuli	Esther Mwangangi
James M.Ngovi	Rhoda M.Kaunda	Stella Muteti	Sammy Mutunga
Mary Maliku	Michael M.Mativo	Serah Guoko	Alice Maundu
Peter N. Kithi	Joseph M.Masika	Esther Mutua	Philip Kilaki
Susan Masai	Franscisca Kimuyu	Mwikali Muia	Joseph Nzuve
Julius Ndome	Sammy Muthembwa	Esther Mwololo	David M. Muindi
James K.Kaluva	Peter N.Mbuvi	Mary Ndunda	Mary Muthoka
Betty Kyule	Lena Kaluki M	James M.Kilungu	Rose Ndeto

Appendix 4: Plates

Plate 1: Weeds species density (plants m^{-2}). a. Species counted, cut at soil level and put into a labelled bag.

Plate 2: Weed species diversity (Number of species m^{-2}). b. Different species associating close to form mats on fragile soil.

Plate 3: Farmers practice: Young lady weeding with a hoe.

Plate 4: Farmers practice: Old lady weeding with a panga.

Plate 5: Field trial with overhead irrigation after planting in KALRO- Kiboko, 2011

Plate 6: Field trial at KALRO - Kiboko showing maize treatments, 2011.a. Residue from previous crops.