POPULATION DYNAMICS AND MANAGEMENT OF VECTORS OF VIRUSES CAUSING MAIZE LETHAL NECROSIS DISEASE IN BOMET COUNTY KENYA

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Reg no. A99/27698/2014

A Thesis submitted in Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Crop Protection (Agricultural Entomology Option) in the School of Agriculture and Enterprise Development, Kenyatta University

April, 2018

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other university or any other award"

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors

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DEDICATION

This thesis is dedicated to God for his everlasting presence and guidance. My husband Philip, my children Allan, Chris, Mitch and Nicole as well my late Mum, Eunice, My brother Masinde and my Dad Ronald Samita for their prayers and emotional support.

ACKNOWLEDGEMENTS

My profound gratitude goes to the Almighty God for his everlasting presence throughout this work. Special and sincere thanks go to my supervisors, Dr Muo Kasina, The late Dr George Kariuki and Dr Mukiri Wa Githendu for their guidance, encouragement, total devotion and mentoring. Together and individually they molted me intellectually by dedicating their time, resources and commitment to this work. Great thanks go to the entire staff, Department of Agricultural Science and Technology in Kenyatta University for their patience, intellectual advice and total guidance towards this work. I am greatly indebted to Kenyatta University for financing the survey aspect through the Dean's office, KAPAP for supporting the cropping system objective, ASARECA for supporting the Monitoring objectives on vector dispersal, varietal tolerance and ELISA tests; NACOSTI for surpporting the sticky roll and bio control strategies. I appreciate laboratory facilities provided by KALRO towards this work. My gratitude goes to the MLND team led by Dr Muo Kasina, Dr Zachary Kinyua and Dr Ann Wangai; your teachings and guidance is highly appreciated. The technical support team led by Dr Mary Quantai, Joseph Mulwa, Bonface Mbevi, Bournice Langat and Abel Too, you were great. My students Alice Nduta, Elizabeth Ndunge, Mercy Jelagat, Anita Nunu, Evans Wanjala and Millicent Nakhumicha, as well as my field Assistants; Bernard Kirui, Hillary Koech, Wesley Ruto and the entire community of Chepnyelieth and Korara in Bomet County of Kenya, thanks for your significant contribution to this research work. I finally acknowledge the special part played by my family: my spouse, your moral and financial support. My children, Allan and Chris for the special part you played in this research. Mitchel and Nicole, for your patience and infectious love and laughter.

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ACRONYMS AND ABBREVIATIONS

ANOVA	-	Analysis of Variance
ASARECA	-	Association of Strengthening Agricultural Research in Eastern and Central Africa
CIMMYT	-	International Maize and Wheat Improvement Centre
CGIAR	-	Consultative group for International Agricultual Research
DAS ELISA	-	Double Antigen Sandwich Enzyme Linked Immunosorbent Assay
ELISA	-	Enzyme Linked Immunesorbent assay
FAO	-	Food and Agricultural Organisation
FAOSTAT	-	Food and Agricultural Organisation Statistics
GAIN	-	Global Agricultural Information Network
GIEWS	-	Global Information and Early Warning System on food
ICIPE	-	International Centre for Insect Physiology and Ecology
IPM	-	Integrated Pest Management
KALRO	-	Kenya Agricultural and Livestock Research Organization
KAPAP	-	Kenya Agricultural Productivity and Agribusiness Project
KEPHIS	-	Kenya Plant Health Inspectorate Service
LSD	-	Least Significant Differences
MCMV	-	Maize Chlorotic Mottle Virus
MLND	-	Maize Lethal Necrosis Disease
MDMV	-	Maize Dwarf Mosaic Virus
NACOSTI	-	The National Commission for Science Technology and Innovation
NARL	-	National Agricultural Research Laboratories
PMDG	-	Pest Management Decision Guide
RNA	-	Ribonucleic acid
RT-PCR	-	Real Time Reverse Transcription Polymerase Chain Reaction
SCMV	-	Sugarcane Mosaic Virus

LIST OF DEFINITION

Frankliniella williamsi	Commonly known as Corn thrips, it transmits maize chlorotic mottle virus
Rhopalosiphum maidis	Commonly known as Corn leaf aphids, it transmits sugarcane mosaic virus
MCMV	A virus that infects mainly maize and transmitted by Corn thrips in Kenya. First reported in Kenya in 2009
SCMV	A virus that mainly infects sugarcane but co infects maize with MCMV to cause MLND
MLND	a disease that infects maize and is caused by a co infection of maize by two viruses MCMV and SCMV
Semipersistent	Mainly found in thrips retains the virus depending on the length of feeding before, during or after virus acquisition. The adults may be able to retain the virus for some time but it does not pass the virus onto the eggs laid.
Non persistent	The corn leaf aphid takes up the virus and can directly transmit the virus to a healthy plant but can retains the virus just for a few minutes to a few hours (1-2 hours)
Latent period	The time between inoculation and infectiousness of the host/ (inability to inoculate immediately following acquisition)
Action Threshold level	It is the average number of vectors per plant that will cause economic yield loss if the infestation is not controlled.

Economic Injury level	This is the lowest insect or pest density that can cause an economic damage
Economic threshold level	The pest density at which management action should be taken to prevent an increased pest population from reaching the economic injury level.
Economic damage	It commences when the cost of reducing the injury caused is equivalent to the potential monetary loss from the vector infestation/ damage

ABSTRACT

Maize production in Kenya is under threat due to infection by maize lethal necrosis disease (MLND). The disease is known to cause intensive complete yield loss. It is caused by a synergistic infection of maize by maize chlorotic mottle virus and sugarcane mosaic virus which are mainly vectored by corn thrips (*Frankliniella williamsi*, Hood) and corn leaf aphids (*Rhopalosiphum maidis*, Fitch) respectively. This study was carried out with the aim of investigating the following aspects; farmer's knowledge and practices on vectors of MLND causing viruses, movement and dispersal of the two vectors in a maize farm and various management strategies through sticky roll trapping, varietal tolerance, action threshold levels, polycropping systems and biocontrol strategies towards the control of the disease and vectors. Field trials were carried out in Bomet County for two seasons from November 2014 to September 2016 using a randomized complete block design. Data was collected by counting vectors, scoring for MLND severity and disease incidence. Presence of MCMV, SCMV virus was also carried out using ELISA tests. Data was analyzed using Genstat version 17 to get mean and significant means were there after separated using LSD. Survey results indicated majority of respondents in Bomet as being youths aged between 21 to 30 years while 58% of the farmers had attained education up to upper primary level. Only 23% were high school graduates. Majority of the farmers were aware of MLND but only 3% knew about the vectors of MLND.The use of vertically positioned blue sticky traps were more attractive to corn thrips compared to the yellow ones ($P = 0.023$). Similarly, blue sticky rolls trapped more corn thrips and prevented maize from MCMV infection ($P<0.001$) while the yellow sticky rolls trapped more corn leaf aphids and prevented maize from SCMV infection ($P<0.001$). Sampling of maize along the rows gave the best prediction for the vector infestations ($P<0.001$) while the upper plant region proved most effective for vector sampling.The most appropriate time for vector sampling was from 8.30 am to 10. 30 am as well as from 3.30 pm to 5.30 pm. The monthly spray regime had the highest net returns as compared to all the other spray regimes. More over, maize from the entire thunder sprayed plots tested MLND negative compared to the control that received no spray ($P<.001$). Results showed variety Pannar as the most resistant to MLND ($P<.001$) as well as landraces MLR1 and MLR 15 ($P = 0.002$). The companion crops used in the polycropping system showed coriander harboring significantly more corn leaf aphids compared with other companions ($P = 0.04$). Furthermore, maize planted with coriander tested negative for SCMV and hence MLND negative. Findings from this study provide scouting and monitoring strategies for both vectors as well as various successful management and control methods for the disease and its vectors. Adoption of techniques such as sampling patterns, sampling time, scouting methods, use of sticky cards and sticky rolls will give an indication of the vector status in the field as well as offer control mitigation measures. Varietal resistance coupled with action thresholds of the vectors and the use of companion crops was able to result into minimal disease spread and reduced chances of MLND occurance. This information can be used to formulate a management strategy for the vectors of MLND causing viruses as well as develop a national vector and disease monitoring plan for both the vectors and the disease. This will culminate into improved maize production and food security.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background Information

Maize (*Zea mays* L.) belongs to the grass family Poaceae (Gramineae), It is the principle staple food crop in Kenya with 90% of the Kenyan population directly or indirectly depending on it (FAOSTAT, 2013). It is also a key determinant of food security mainly for small holder farming communities (Shiferaw *et al.*, 2011). According to De Groote *et al.*, 2016, maize lethal necrosis disease (MLND) is one of the main constraints of maize production since 2011. The disease has spread widely to other East African countries and beyond (CIMMYT, 2012). Maize deficit of 600,000 metric tonnes was experienced in 2013 and this decline was attributed to maize lethal necrosis disease as one of the major constraints (GIEWS, 2013).

Maize lethal necrosis disease is caused by a coinfection of maize chlorotic mottle virus and sugarcane mosaic virus or any other virus belonging to the Family Potyviridae (Bockelman *et al.*, 1982). Maize Chlorotic Mottle Virus (MCMV) was first reported in Peru, Kansas, Nebraska and later on in China ((Niblett and Claflin, 1978; Castillo-Loayza, 1977; Jiang *et al.*, 1992; Xie *et al.*, 2011). In Kenya, MCMV was first reported in Bomet County in September 2011 as well as Naivasha (Wangai *et al.*, 2012). It then spread to other maize growing areas in the Rift Valley and other neighboring countries such as Uganda, Tanzania, and Democratic Republic of Congo (Lukanda *et al.*, 2012; Adams *et al.*, 2014). In Kenya, MCMV has been found to combine with SCMV to cause MLND which is capable of causing extensive and complete yield loss (Wangai *et al.*, 2012).

Samson *et al.* (2014) and De Groote *et al.* (2016) have reported extensive yield losses especially at the household levels.

The control of MCMV poses serious difficulties especially when the virus co infects maize with SCMV to cause the more threatening maize lethal necrosis disease. Studies by Makumbi and Wangai (2013), shows that no known genotype is tolerant to MLND.The viruses causing MLND can only enter into the plant through the wounds created by the feeding mode of insect vectors (Ellis *et al.*, 2008) and mechanical injury. The feeding vectors deposits or injects MLND causing viruses rapidly when feeding on non infected plants through a non persistent transmission mechanism (Zhang *et al.*, 2008; Triagiano *et al.*, 2008). The corn leaf aphid (*Rhopalosiphum maidis* Fitch) retains the SCMV virus just for a few minutes to a few hours (Thomas and Kerry, 1997). Contrary to this, the Corn thrips, *Frankliniella williamsi* Hood transmits maize chlorotic mottle virus in a semi persistent manner where the thrips retains the virus depending on the length of feeding before, during or after virus acquisition. The adults may be able to retain the virus for some time but it does not pass the virus onto the eggs laid. Alternatively, the infected nymphs can only retain the virus as nymphs but by the time they hatch into adults, the inoculant is normally too weak to be transmitted (Cabanas *et al.*, 2013).

Studies by Miano and Kibaki, 2013 report a 50 % success when chemicals were used to control vectors that transmit the MCMV and SCMV. However the chemical control measures have not been fully effective since any vector resistant to chemical control can still transmit the disease at a very high rate. Maize chlorotic mottle virus is reportedly vectored by corn thrips *Frankliniella williamsi* in Hawaii (Jiang *et al.*, 1992) and the beetles *Diabrotica* while sugarcane mosaic virus is transmitted by the corn leaf aphids, *Rhopalosiphum maidis* (Nault *et al.,* 1978; Noone *et al.,* 1994). In Kenya, notification of MCMV coincided with the reporting of *F. williamsi* in the country (Nyasani *et al.,* 2012). Both corn thrips and MCMV are new in Kenya and information about the host relation is currently under investigation. This study therefore investigated some key aspects of the vector monitoring procedures and possible management strategies with focus on corn thrips and corn leaf aphids.

1.2. Statement of the Problem

The recent outbreak of maize lethal necrosis disease in Kenya since 2011 has had devastating effects on maize production (Wangai *et al.,* 2012; Fatma *et al.,* 2015). Since then the disease has widely been reported in the neighboring regions such as Uganda, Tanzania, Zambia and Rwanda (Adams *et al.,* 2014; Lukanda *et al.,* 2014; Mahuku *et al.,* 2015). The disease is caused by a co infection of MCMV and SCMV which are respectively transmitted by *F. williamsi* (Cabanas *et al.,* 2013) and *R. maidis* (Noone *et al.,* 1994). Fatma *et al.* (2016), has reported generally on management strategies such as quarantine techniques, eradication through sanitation, plant protection through vector control and use of tolerant varieties that should be adopted by farmers. However limited information exists on monitoring and control strategies of MLND causing viruses and their respective insect vectors (Fatma *et al.,* 2016).

Studies are under way for selected varieties that have been artificially inoculated; however performance of our local varieties under natural pressure has not been undertaken (Zambrano *et al.,* 2014). Possible sources of resistance or tolerance to the vectors of MLND causing viruses have not yet been established in hybrid and landrace maize under natural pressure. Such information will be important for the future prospective germplasm breeding. Information on intensive integrated vector and cultural practices that aims at minimizing the vector infestation and MLND spread is limited. This may be why Mahuku *et al.* (2015) recommended the development of a robust research based approach for the MLND control. There exists a gap on farmer practices and knowledge on vector monitoring and management strategies that have been designed to curb the MLND menace (Mahuku *et al.,* 2015; Nelson *et al.,* 2011). This study therefore aimed at generating scientific findings and technigues that could be used towards the control of vectors of MLND as an option of the disease management.

1.3 Justification of the study

About 90% of the Kenyan population depends on maize directly or indirectly for food, income and labour (Groote *et al.,* 2011; FAOSTAT, 2013). Maize is also a key determinant of food security in the Country with a per capita consumption of 98 kg per annum especially for small holder farming communities (Groote *et al.,* 2011; Shiferaw *et al.,* 2011). Maize production is however threatened by maize lethal necrosis disease which recently invaded the region since 2011. The disease was first detected in September 2011 at lower elevations (1900 masl) in the Longisa division of Bomet County, Southern Rift Valley of Kenya. Since then Bomet has become an epicentre with high MLND incidence and severity levels. This has resulted into natural infection of maize by MLND neccesitating this study to take place in Bomet. Although wide campaigns on MLND have been launched by the government and research institutes, massive losses are still being experienced by farmers mainly in the Rift valley (GIEWS, 2013). In this area, MLND is reported to have damaged over 260,000 ha of maize, worth 2 billion Kenyan shillings in 2013. This caused a drop from 21 million bags to 16 million bags (GAIN, 2013).

Maize lethal necrosis disease is associated with co-occurrence of MCMV and SCMV that are respectively vectored by corn thrips and corn leaf aphids. These vectors have been sampled in areas affected by MLND and have different transmission mechanism that complicates efforts to control and manage them. Due to limited management and monitoring investigations, farmers tend to be ignorant of the vectors until the disease manifests itself. By the time the disease symptoms are noticed, the chances of saving the crop or controlling the vectors is very minimal. Unless urgent measures are taken to curb the vectors and disease at national and regional levels, large-scale crop losses will continue to be experienced leading to serious economic implications and food insecurity. There fore, this study is geared towards improved monitoring and control strategies of the vectors of viruses causing MLND. It is also anticipated that findings from this study will improve control measures of the vectors and minimize disease spread in the field.

1.4. Research questions

i. What is the current knowledge on vectors of MLND causing viruses contribute to the spread of maize lethal necrosis disease?

ii. What differences exists in the field dispersal and movement of *Frankliniella williamsi* and *Rhopalosiphum maidis* in a maize field?

iii. What is the efficacy of sticky roll control on vectors of maize lethal necrosis disease causing viruses?

iv. What are effective action threshold levels for *Frankliniella williamsi* and *Rhopalosiphum maidis* infesting maize?
v. Which maize genotype has resistance against vectors of maize lethal necrosis disease causing viruses?
vi. What are the effective cultural control practices for managing vectors of maize lethal necrosis disease causing viruses?
vii. What biological control agent is most effective against vectors of maize lethal necrosis disease causing viruses?

1.5. Hypothesis

i. Lack of knowledge on vectors of MLND causing viruses and poor farming practices does not contribute to the spread of maize lethal necrosis disease.
ii. The field dispersal and movement of *Frankliniella williamsi and Rhopalosiphum maidis* in a maize field does not differ.
iii. Sticky rolls have no effect on the control of vectors of maize lethal necrosis disease causing viruses
iv. There is no difference in action threshold levels of *Frankliniella williamsi* and *Rhopalosiphum maidis* infestationon in maize crops.
v. There is no tolerant/resistant maize genotype against vectors of maize lethal necrosis disease causing viruses.
vi. There is no difference in the infestation of vectors of maize lethal necrosis disease causing viruses on various maize polyculture cropping systems.
vii. Biological control has no effect on maize infestation by vectors of maize lethal necrosis disease causing viruses.

1.6. Objectives

1.6.1. General objective

To determine population dynamics of vectors of maize lethal necrosis disease causing viruses on maize and identify the potential management measures that minimize disease spread.

1.6.2. Specific objectives

i. To investigate farmers' knowledge and practices on vectors of maize lethal necrosis disease causing viruses in Bomet East Sub County.
ii. To determine the field dispersal and movement of *Frankliniella williamsi* and *Rhopalosiphum maidis* in a maize field.
iii. To determine the efficiency of the sticky roll technology in the control of vectors of MLND causing viruses on maize.
iv. To determine resistance/ tolerance level of maize to vectors of MLND causing viruses.
v. To establish the action threshold levels of *Frankliniella williamsi* and *Rhopalosiphum maidis* infestation on maize crops.
vi. To determine effective polyculture cropping systems that can minimize MLND spread by *Frankliniella williamsi* and *Rhopalosiphum maidis* on maize.
vii. To determine effective biocontrol strategy for *Frankliniella williamsi* and *Rhopalosiphum maidis* on maize.

1.7. Conceptual Frame work

Maize lethal necrosis disease was first reported in Kenya in 2011 (Wangai *et al.,* 2011). It is not yet known how the disease suddenly appeared in Kenya and China concurrently. This disease is caused by a synergetic infection of MCMV and SCMV of maize; however it is believed that vectors have played a major role in the disease outbreak and wide spread in Kenya and its neighbors. This study reviews a number of knowledge gaps on management and monitoring of vectors of maize lethal necrosis causing viruses as shown in figure 1.1

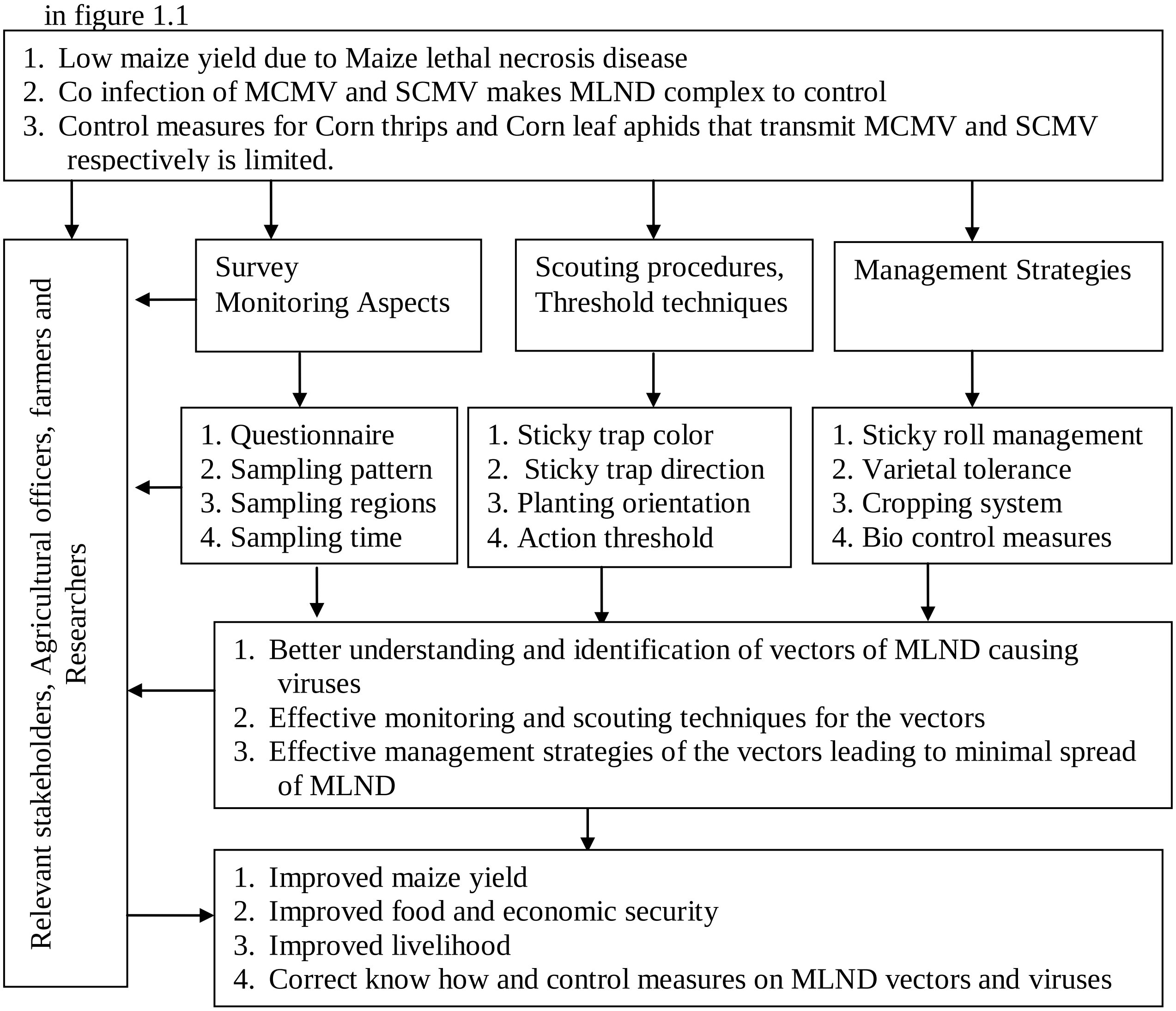


Figure 1.1: Conceptual framework

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Maize Production, consumption and constraints in Kenya

Maize (*Zea mays* L.) is an important staple crop in Eastern Africa and the entire Sub Saharan Africa (FAOSTAT, 2014). Maize has the ability to grow in diverse climates. The crop covers over 25 million hectares both in large and small scale farming system, out of this acreage, small holder farmer system is able to contribute 3.8 million metric tonnes of grains (Agbonifo and Olufolaji, 2012; FAOSTAT, 2013). Worldwide maize consumption in 2013/2014 was around 950 million metric tones while eight five percent of maize produced in the Sub Saharan Africa was used for food (FAOSTAT, 2014; Shiferaw *et al.*, 2011). Maize constitutes 56% of the crops in East Africa (Fischer *et al.,* 2014). In Kenya, maize production is one of the main focuses of the country's economic activities. It is concentrated mainly in the Rift valley region such as TransNzoia, Uasin Gishu, western region and Bomet among others (Kwach, 2009). Almost 75% of the maize in Kenya is grown in mid altitude and highland zones between 1100- 2900 metres above the seal level (Hassan *et al.,* 1998).

Maize is the main source of food and forms the backbone of food security as well as reducing poverty and providing rural employment in Kenya (Kwach, 2009; Kirimi *et al.*, 2011). According to Morris *et al.* (1999), maize Kernels provide 86% of the daily calorie requirements (10-19%), it is a good source vitamin B (Thiamin),vitamin B5 (Pantothenic acid) and fiber when moderate amounts are utilized (Morris *et al.,* 1999). According to Mghenyi (2006), starch from maize can be made into plastic fabrics and adhesives.

Green/ fresh maize can also be boiled or roasted on its cob as well as being served as popcorns (IITA, 2009). Maize is also a multipurpose crop used as livestock feeds, a bio fuel and as raw materials for industries (Morris and Lopez-Pereira, 1999).

Historical trends indicates wide yield fluctuations in maize in comparison to other cereal crops due to maize sensitivity to disease attack, pests and post harvest losses (Kodhek, 2005). According to Aulakh and Regmi, (2013) post harvest losses can be quantitative, qualitative and/ or economical across the supply chain from the time of harvesting to the time of consumption. Post harvest losses in maize accounts for 40% of cereal loss in Eastern and Southern African countries (Zorya *et al.,* 2011). This loss totals to 1.6 billion US dollars which is equivalent to adequate annual caloric requirement for 20 million people (FAO, 2013). Abass *et al.* (2014) postulates that post harvest losses in maize are equivalent to a leaky pipeline that mainly occurs at the field and storage level.

Maize lethal necrosis disease is one of the key causes of quantitative, qualitative and economical post harvest loss encountered in maize production. Grains reduce in physical weight and quantity, maize fields infected with MLND records significantly lower yield as reported by Samson *et al.* (2014). The qualitative and quantitative post harvest loss leads to low quality, edibility and consumer acceptability (Kader, 2004; Zorya *et al.*, 2011). Eventually economic post harvest losses are experienced when the monetary value of the grains reduces due to low quality and quantity (Tefera, 2012). Some other major factors that lead to low maize yield are soil constraints; the soil should be free of any stovers or plant debris to eradicate any changes of re infecting the new crop with MLND

(Gibbon *et al.,* 2007). This method reduces pathogens from infected areas before they become well established (Maloy, 2005). Seed production for some of the resistant traits in maize against draught, pests and diseases among others should be fast tracked and incorporated as resistant or tolerant to vectors of maize lethal necrosis causing viruses (Zambrano *et al.,* 2014). Currently maize lines are still under investigation for resistance against the vectors and viruses that transmit MLND causing viruses. No documented information shows whether seed production is underway or not (Mahuku *et al.*, 2015).

2.2. Maize lethal necrosis disease

Maize lethal necrosis disease is a viral disease that was recently reported in Kenya in the Rift Valley region and has since widely spread to other regions in the country (Adams *et al.,* 2013; Wangai *et al.,* 2012) and to the neighboring countries (Lukanda *et al.,* 2014, Adams *et al.,* 2014, Mahuku *et al.,* 2015). It was initially known as corn lethal necrosis disease in Kansas where it was first reported. It is caused by a co infection of maize chlorotic mottle virus with maize dwarf mosaic virus or wheat streak mosaic virus (Niblett and Claflin, 1978). In Hawaii, MCMV combined with maize mosaic virus (MMV) to cause maize lethal necrosis (Nelson *et al.*, 2011). The disease has also been reported in China (Xie *et al.,* 2011). Studies by Adams *et al.* (2013) and Wangai *et al.* (2012) showed that MCMV combined with sugarcane mosaic virus (SCMV) to cause maize lethal necrosis disease (MLND) in Kenya.

The symptom of MLND which is also called corn lethal necrosis disease shows bright yellow leaves starting with the upper leaves or mottling of young leaves is seen in the whorl and extends upwards towards the leaf tips. Other symptoms include leaf necrosis as seen in, severe stunting and premature death (Cabanas *et al.,* 2013). Infected plants are frequently barren, forming small ears that are deformed with little or no seed and recording a yield loss of up to 100% (Adams *et al.,* 2014; Wangai *et al.,* 2012). This is followed by necrosis of the leaf margin that progresses to midrib and eventually the whole leaf. In most cases, there is necrosis of young leaves in the whorl which leads to dead heart (Makumbi and Wangai, 2012).

2.2.1. Maize chlorotic mottle virus (MCMV)

Maize chlorotic mottle virus is from the genus Machlomovirus and family Tombusviridae (King *et al.,* 2011). Castillo and Herbert (1974) first reported it in Peru while Carrera-Martinez *et al.* (1989) reported the virus in the United States and Mexico. In 2011 the virus was found on maize both in China and Kenya (Xie *et al.,* 2011; Adams *et al.,* 2013). The MCMV strain found in Kenyan maize was 96% similar to the one found on maize in China (Adams *et al.,* 2013). Maize is among the main natural hosts for MCMV as well as sorghum as reported by Huang *et al.* (2016) and Achon *et al.* (2017). Maize chlorotic mottle virus is known to cause 10 to 15% losses under field conditions while mechanical innoculation causes about 59% yield loss (Castillo, 1977). The losses significantly increase to 90% when MCMV co- infects maize with any other potyvirus depending on the variety of maize and the season (Niblett and Claflin, 1978).

2.2.2. Transmission of MCMV by Corn thrips (*Frankliniella williamsi* Hood)

Maize chlorotic mottle virus is transmitted by the vector activity of adult corn thrips, *Frankliniella williamsi* (Cabanas *et al.,* 2013). This is also supported by Jiang *et al.,* 1992 who reported that *F. williamsi* was the only vector that could transmit MCMV onto healthy plant maize. Although studies by Zhao *et al.* (2014) show that *Frankliniella occidentalis* Pergande can transmit MCMV, the Kenyan MCMV isolate was not successfully transmitted by the flower thrips, *F. occidentalis* (Cabanas *et al.,* 2013). The thrips semi persistently transmits MCMV by acquiring it from infected plants for a maximum of 3 hours without the latent period (inability to inoculate immediately following acquisition). There after the infected corn thrips inoculates the virus to healthy plants (Cabanas *et al.,* 2013). Therefore the corn thrips requires longer periods (often at least 15 min) for efficient acquisition and inoculation of the plant by the vector.

The thrips transmit MCMV immediately after acquisition and can retain the virus for 6 days without latent periods (the time between inoculation and infectiousness of the host (Chen *et al.,* 2011; Uzest *et al.,* 2007). The chances of the larvae instars transmitting MCMV are scarce as compared to the adult thrips. Studies carried out by Cabanas *et al.* (2013) shows that, the larva that feeds on an infected leaf are not able to transmit the virus to a healthy maize plant. Larval stages that develop on MCMV infected leaves into adults cannot equally vector the virus from an MCMV infected crop to a healthy one. This could explain why Nelson *et al.* (2011) describes the transmission of MCMV by corn thrips as semi persistent. The virus binding is said to be mediated directly by the virus coat protein or indirectly by virus derived nonstructural proteins (Ng and Falk, 2006). Thrips have a rasping sucking mouth part that is highly destructive to plant tissues. During feeding, the thrips acquire the virus through the mouth parts from the infected plant tissues and inoculates the virus into tissues of a healthy plant (Sakimura, 1972). They suck sap leading to scarification of the plant and depletion of plant nutrients

(Ssemwogerere *et al.,* 2013). Studies by Mingfu *et al.* (2014) shows that MCMV can also be transmitted by western flower thrips *F. occidentalis*, however, in Kenya, only *F. williamsi* has been sampled on maize in areas with MCMV and maize lethal necrosis disease.

2.2.3. Symptom manifestation of Maize chlorotic mottle virus and plant host range

Maize is the only natural host of MCMV (Gordon *et al.,* 1984; Nelson *et al.,* 2011). Other species that can be experimentally infected or inoculated mechanically are grasses in the Poaceae family (Scheets, 2004) such as *Digitaria* species, *Setaria* species and Sorghum species (Bockelman *et al.,* 1982). According to Scheets (2004), MCMV symptoms vary depending upon the genotype, plant age of infection and environmental conditions. In the early stages of MCMV, leaf mosaics with fine chlorotic yellow streaks that are parallel to leaf veins are seen (Scheets, 2004; Cabanas *et al.,* 2011).

The streaks there after coalesce to form chlorotic mottling followed by leaf necrosis and plant death (Uyemoto *et al.,* 1981; Nelson *et al.,* 2011). The maize later forms short ears that are malformed and partially filled with premature aged husks (Nelson *et al.,* 2011). Natural infection of maize crops by MCMV can reduce crop yield by 10-15% (Castillo and Hebert, 1974; Loayza, 1976; Nault *et al.,* 1981). However, experimental yield losses have been reported up to 60% (Scheets, 2008). The male inflorescence (tassels) may be shortened after flowering (Uyemoto *et al.,* 1981; Nelson *et al.,* 2011).

2.3. Transmission of SCMV by Corn leaf Aphids (*Rhopalosiphum maidis* Fitch)

The corn leaf aphid (*Rhopalosiphum maidis*) is regarded as a specific pest for Poaceae family (Robinson, 1992; Kuo *et al.,* 2006; Razmjou and Golizadelo, 2010). It is mainly distributed in regions where sorghum and maize is cultivated (Fonseca *et al.,* 2004). In maize crops, infestation begins in isolated plants but spreads to the whole crop during the vegetative phase. The corn leaf aphid transmits SCMV to maize in a non persistent manner where acquisition and inoculation requires only very brief stylet penetration of less than one minute (Adams *et al.,* 2014). There is no latent period and the entire transmission cycle may therefore be completed within a few minutes. Viruses transmitted in this manner have also been referred to as 'stylet-borne' and aphids rapidly lose the ability to inoculate but the vector inflicts considerable damage to the crop (Almeida *et al.,* 2001; So *et al.,* 2010). Sugarcane mosaic virus is a member of the genus *Potyvirus,* family *Potiviridae.* The potyvirus is a phylogenetically diverse species for which the genome sequences of maize and sugarcane isolates cluster by host and geographical origin (Li *et al.,* 2013). The SCMV strain that was found in Kenyan maize is similar to the one found on maize from China (Adams *et al.,* 2013). This virus is transmitted by several species of aphids mainly of *Rhopalosiphum* species in a non persistent manner (Zhang *et al.,* 2008). *Rhopalosiphum maidis* has been sampled in Kenya where SCMV is prevalent (Adams *et al.,* 2014; Mahuku *et al.,* 2015).

This virus was reported to have caused serious losses on sugarcane and maize in Kenya during the 1980s (Louie, 1980) but has also been recently reported on maize infected with maize lethal necrosis disease (Wangai *et al.,* 2012). Various strains of this virus are able to infect a number of hosts such as wild sorghum; *Sorghum verticilliforum* (Srisink *et al.,* 1993), Pearl millet and *Pennisetum glaucum* (Karan *et al.,* 1992). Sugarcane mosaic virus causes systemic mosaic symptoms and infects the whole plant (Fatma *et al.*, 2016; Panagiotou and Panayotou, 1981). The mosaic and necrosis are observed on the leaves and sometimes the stems. In *Saccharum* species, *Sorghum bicolor*, *Zea mays* and various grasses, the following symptoms manifests; mosaic symptoms with contrasting shades of pale green to yellow chlorotic areas and necrosis occurs (Mahuku *et al.*, 2015; Noone *et al.*, 1994).

2.3.1. Distribution, Life cycle and Biology of *Frankliniella williamsi* (Thysanoptera: Thripidae)

Corn thrips (*Frankliniella williamsi*) is found in the order Thysanoptera, Sub order, Terebrantia and Family Thripidae. The adult female and most males are macroptera (have fully formed wings) (Laurence *et al.,* 2016). They have a uniformly yellow body with antennal segments I- V being yellow, however the second to fifth antennal segments are brown on their distal ends. Half of the basal segment of the antennae is yellow while the distal half part is brown (Mound and Hoddle, 2016). The corn thrips are believed to have originated from Central America and has since been widely distributed in tropical and subtropical countries (Mound, 2010). Corn thrips have been reported throughout most USA maize-producing regions such as Kansas and Hawaii (Reed *et al.*, 2006). *Frankliniella williamsi* has recently been reported in China and Kenya (Xie *et al.*, 2011; Wangai *et al.,* 2012b) , they have been observed in all fields where maize is grown including MLND and MCMV affected fields (Mahuku *et al.*, 2015). However, reports by Nyasani *et al.* (2012) and Moritz *et al.* (2013) indicate that corn thrips were reported in

East Africa in 2009 before MLND outbreak.Thrips are hemi metabolous insects with an intermediate metamorphic lifecycle, they undergo gradual or incomplete metamorphosis where the insect emerging from the egg resembles the adult insect (Healey, 2016).

The life cycle consists of an egg that takes 3 to 4 days to hatch (Mound, 1996), it has two active feeding larval instars that are wingless as shown in Figure 2.1. The larva hatches into propupae that later develops into a true pupae, the pupal instars are relatively quiescent but later hatches into adults (Figure 2.1) (Mound, 1996). Adults and larvae aggregate in concealed areas on plants, such as developing foliage in maize (Hansen *et al.,* 2003). The cycle can take 9-20 days depending on the temperature (Chin- Ling *et al.*, 2010). The development of the thrips occurs whenever the temperature exceeds 8-10°C (McDonald *et al.,* 1998). However, the most favorable temperature for development is 25-30°C (Reitz, 2008). Females drill a hole in a leaf where they insert their egg. They are capable of laying 30 eggs per individual per lifespan. The eggs are laid individually under the surface of young leaves or inside the buds (Capinera, 2008). The female lay eggs in the midrib of the leaf under the surface, the eggs hatch 3-4 days at optimum temperature, the larvae lives in the terminal buds of young leaves (Capinera, 2008). Thrips have two non-feeding pupae stages that hatch into adults after 1-3 days (Reitz *et al.,* 2012). The adults are golden yellow (Figure 2.1) and about 11mm long.

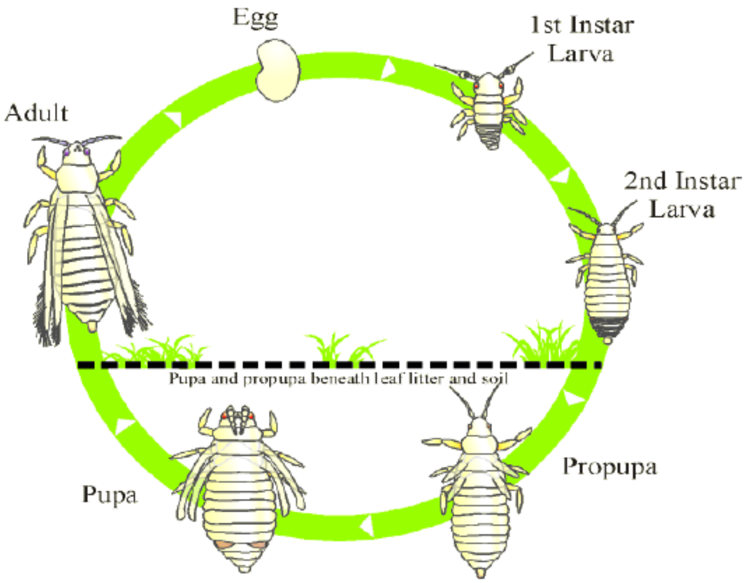


Figure 2.1: Life cycle profile for *Frakliniella* Thrips
Source: Hoodle, (2011)

They mainly feed on *Zea mays* (Chin- Ling *et al.*, 2010), *Ipomea reptana, Ageratum coryzoides, and Sorghum vulgare* and *panicum purpurascenes* (Wang *et al.*, 2002; Wang *et al.*, 2007). The thrips fly for a short distance, crawl or jump and can also be dispersed by wind (Mound and Gillespie, 1997). The rasping-sucking stylet mouth parts damage leaf cells during feeding and cause deformation and distortion of the tissues as they suck sap and can eventually cause wilting (Mound, 2010; Hunter and Ullman, 1989; Childers 1997).

The smallness and thigmotic behavior of the adult and larvae makes their detection difficult. The eggs are not readily detected since they are concealed within the plant tissue hence less susceptible to chemical control (MacDonald, 1998, Janmaat *et al.*, 2002; Simpson *et al.*, 2007). The thrips populations increases more during the dry season as they crowd on leaves of young plants and cause leaf curling, discoloration and even wilting (Chin- Ling *et al.,* 2010). Some of the thrips reproduce by parthenogenesis where no mating takes place (Gill *et al.*, 2015). Fertilization does not occur in all the eggs among thrips that have sexual reproduction, some eggs remain unfertilized and give rise to the males while the fertilized ones give rise to the females (Kumar *et al.*, 2013).

2.4. Life cycle and Biology of *Rhopalosiphum maidis* Fitch (Hemiptera: Aphididae)

The corn leaf aphids have a life cycle of 6-12 days in conducive environment (Capinera, 2008, Bayhan, 2009). They reproduce throughout the year with 35-40 generations produced annually (Ratcliff, 2004).The corn leaf aphids have short and overlapping generations and their populations can build up rapidly. Most of the aphids display parthenogenetic reproduction where they give birth to live young ones. In some cases, males are occasionally found and sexual reproduction may occur (Al-Eryan and El-tabbakh, 2004). The development rate and number of nymphs are mainly influenced by temperature and plant age (Foott, 1977). The youngest nymph is initially pea green in color with red eyes and colorless antennae and legs (Figure 2.2). This nymphal stage measures approximately 0.5 mm long. As the nymph progresses through the second to fourth instar stages, the length increases from 0.9 to 1.1 and 1.3mm (Capinera, 2008). The body color becomes darker as the appendages gains darker pigmentation (Figure 2.2). The third instar nymph is pale green but slightly darker on the sides (Figure 2.2). The legs are darker than the body while the head is darker green (Blackman and Eastop, 1984). Adults can be winged (Alates, figure 2.2a and b) or unwinged (apterous, Figure 2.2c). They are yellow green to dark olive green or bluish green; they often have a light powdery cover (Blackman and Eastop, 1984).

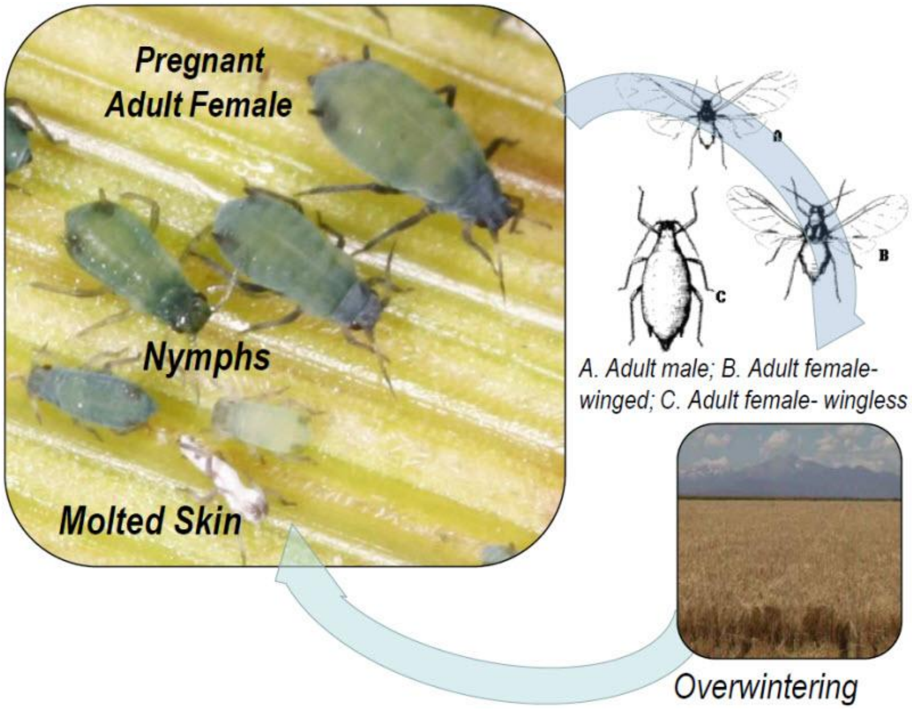


Figure 2.2: Life cycle of Corn leaf aphids (*Rhopalosiphum maidis*)
Source: Dupont pioneer Agronomy Sciences, (2010)

Alates produce an average of 49 nymphs in response to changes in weather, population density and host plant quality (Al-Eryan and El-tabbakh, 2004). The formation of alates is in response to overcrowding or poor host quality (OMAFRA, 2009). The migrating population is mainly winged alates; they settle and reproduce without mating by giving birth to live young ones. Both the alates and the wingless develop depending on the nutrient quality of the plant (Capinera, 2008). The winged aphids then fly to the nearby corn fields and enter the whorl.The damage caused by the aphids normally intensifies when soil moisture is in adequate OMAFRA, 2009; Rhazmjou and Golizadeh, 2010). The ability to vector sugarcane mosaic virus and maize dwarf mosaic virus exacerbates the damage potential of this aphid (Capinera, 2008; Al-Eryan and El-tabbakh, 2004).

2.5 Diagnosis of maize chlorotic mottle virus and Sugarcane Mosaic Virus in maize crops

Maize chlorotic mottle virus is difficult to diagnose based on symptoms alone because it has stunting and chlorosis that resembles nitrogen nutrient deficiencies or maize mosaic virus (Nelson *et al.,* 2011). According to Nelson *et al.* (2011) and Cabanas *et al.* (2013), enzyme-linked immunosorbent assay (ELISA) is the best for detecting MCMV. This was also reported by Townsend and Greif (1990), who found out that serology, was the most sensitive method to detect MCMV and SCMV. From the time it was introduced in plant virology, ELISA has been the most popular method for detecting viruses in plant material, insect vectors, seed and vegetative propagules (Clark and Adams (1977). The ELISA method is appropriate because it can be used to test a large number of samples in a short time. It is also simple, adaptable, sensitive and economical in the use of reagents. ELISA assays are based on the ability of the antibody to recognize and bind to a specific antigen Antibodies are either polyclonal or monoclonal, depending on how specific they are.

Several commercial companies produce high quality ELISA kits such as Agdia. Most commercially available ELISA kits for detecting SCMV and MCMV use the Indirect ELISA and the double antibody sandwich (DAS) ELISA technique (Hill, 1983; Adams *et al.,* 2014; Mahuku *et al.*, 2015). The sensitivity and reliability of an ELISA assay can be influenced by the quality of antibodies, the preparation and storage of reagents as well as incubation time and temperature. The selection of appropriate parts of plant samples and use of suitable extraction buffers can also affect Elisa efficiency (Cabanas *et al.,* 2013).

Ribonucleic nucleic acid (RNA) extraction from maize plants and thrips can also be done using the PCR amplified in Omega Bio Tech Kit (Mingfu *et al.*, 2014). Other methods of virus identification such as next generation sequencing can also be used to identify MCMV and SCMV virus on maize samples as explained by Adams *et al.* (2013). More over, the transmission electron microscopy (TEM) can also detect the presence of MCMV using a leaf- dip preparation method with uranyl acetate staining and carbon coated grids (Hill, 1983).

2.6. Control options of maize lethal necrosis disease

Maize lethal necrosis disease can be successfully controlled by planting of MCMV resistant or tolerant varieties (Mahuku *et al.*, 2015; Fatma *et al.*, 2016). Castillo and Nault (1982) identified some sources of resistance to MCMV which were incorporated into commercial varieties. Efforts have been undertaken to identify MLND resistant varieties of maize in East Africa (ASARECA, 2014). However, only N211 and KS23-26 lines of maize have shown mild MLND symptoms both in controlled environment and field environment (Zambrano *et al.*, 2014). Most Kenyan hybrid varieties have succumbed under the disease pressure when artificially inoculated, but so far there is no data on the tolerance/ resistance or susceptibility levels of the MLND causing viruses in these varieties. Reduction of initial innoculum through pathogen exclusion or quarantine strategies has also been suggested by Fatma *et al.* (2016). It is considered that controlling the spread of MCMV may prove more fruitful in controlling MLND compared with attempting to control the endemic SCMV (Adams *et al.*, 2014).

Maize lethal necrosis disease can also be controlled by reducing the rate of infection. This can be done by effectively eliminating infection of either SCMV or MCMV. This was demonstrated by Murry *et al.* (1993) when he used transgenic maize plants that were inoculated and infected with maize dwarf mosaic virus (MDMV) but was negative for maize leaf necrosis disease. Wangai *et al.* (2012) also suggested planting maize during the onset of rainfall instead of the short rainfall season; this creates a break in host availability hence reducing the vector population leading to low rate of infection and disease severance. Finally, integration of cultural practices coupled with insecticides for vector management and host resistance may prove the most effective method of controlling (Nelson *et al.,* 2011; Wangai *et al.,* 2012).

2.6.1. Phytosanitary control measures for vectors of maize lethal disease necrosis causing viruses

Vectors tend to survive on weeds and use them as reservoirs for the viruses that they vector. Good field sanitation such as weed control eliminates this alternative hosts for potential build up of vectors and the viral load (Wangai *et al.,* 2012b). According to Nelson *et al.* (2011), MCMV had been controlled for several years in the island of Kauai without spreading to other Hawaii islands. Most of the methods used were, planting of certified seeds during the on onset of the main rain season to reduce the population of vectors (Makumbi and Wangai, 2013). When closed seasons are strictly observed, the culture of relay planting of maize becomes limited reducing the chances of host, vectors and viruses interacting (Mahuku *et al.,* 2015). Application of fertilizer and manure application boosts the vigor of the crops to strengthen the plant resistance against MLND and the vectors (Wangai *et al.,* 2012).

2.6.2. Chemical control of vectors of maize lethal necrosis disease causing viruses

Seeds are dressed with imidacloprid to target soil borne and early season vectors (Makumbi and Wangai, 2013). The crops are then sprayed regularly after planting to control the vectors that transmit MCMV and SCMV (Nelson *et al.*, 2011). In Hawaii, insecticides were regularly sprayed on a weekly basis to control thrips from spreading MCMV (Nelson *et al.*, 2011). Other methods may include use of repellant plant extracts from black pepper and cinnamon against thrips (Andnet *et al.,* 2015). However, frequent chemical use in the control of thrips and aphids makes the vectors to develop pesticide resistance Nderitu *et al.* (2007a). The pesticides are also hazardous to humans and the environment (Nderitu *et al.*, 2008). This creates a need to develop ecologically friendly and sustainable control methods of the vectors (Niassy *et al.,* 2013; Adams *et al.,* 2014).

Maize lethal necrosis disease cannot be controlled by use of chemicals; however chemical products can be used to control vectors that transmit the viruses (Fatma *et al.*, 2016). Insecticides such as imidacloprid, deltamethrin and permethrin can be sprayed once every one or two weeks to control the vectors using rotation of multiple chemicals to avoid resistance development of the target vector (Mezzalama *et al.,* 2015).The corn leaf aphids can be controlled by use of systemic insecticides such as imidacloprid and abamectin which are less toxic and selective insecticides to the aphid predators and natural enemies (Tang *et al.,* 2013). These insecticides have the capability to sustain populations of beneficial insects and reduce aphid problems later on in the season (Tang *et al.,* 2013).

2.6.3. Cultural control of *Frankliniella williamsi* and *Rhopalosiphum maidis*

Intercrops have been known to affect the population of thrips such as *F. occidentalis, F. schlutezei* and *Thrips tabaci* among others. Studies by Ssemwogerere *et al.* (2013) showed fewer thrips population in intercrops as compared to monocrops of tomato and pepper. Karungi *et al.* (2000) had similar results when fewer flower thrips were observed on pepper and cowpea intercrop as compared to the maize monocrops. Similarly,intercrops of corn with french beans had fewer infestation of flower thrips compared to french beans monocrop (Nyasani *et al.*, 2012) while french beans intercropped with irish potatoes and sunflower was able to support the highest number of the predator *Orius* bugs as compared to the monocrops (Nyasani *et al.*, 2012; Ramert *et al.*, 2002). Polycropping has been known to create a microclimate that favours natural enemies (Munyuli *et al.*, 2007). For example, intercropping results in higher levels of natural enemies as compared with the monocropping (Capinera, 1985). The chemical environment and crop structure coupled with microclimate factors in a polycropping system can suppress the *F. williamsi* and *R. maidis* (Ramert *et al.*, 2002; Capinera *et al.*, 1985). It encourages resistance of the vector and also increases predation (Capinera *et al.*, 1985). However Tian *et al.* (2012) and Souza *et al.* (2004) reported lack of beneficial effect of intercropping maize with other crops in relation to the control of corn leaf aphids.

Crop rotation effectively controls MCMV when maize is alternated with non-cereal crops such as potatoes, sweet potatoes, cassava, beans and vegetables (Uyemoto, 1983). Resistant and tolerant maize cultivars to both the vectors and the virus transmitted can also be used (Gildow, 1983; Gibbon *et al.*, 2007). Border crops from Poaceae Family such as millet, sorghum, wheat and rice can be used to control corn thrips and corn leaf aphids since they can trap the vectors. Other crops such as coriander can also be used as a trap crop for the maize lethal necrosis virus because of their classification as weak repellants (Andnet *et al.*, 2015; Namikoye *et al.*, 2015). Cultural methods involving the adjustment of planting time have been used to control *R. maidis*. Late sowing in sorghum resulted into the low aphids'infestation in Egypt (Sabra, 2012). This can be used to reduce the corn leaf infestation population by avoiding planting maize during the peak season for the aphids (Sabra, 2012). According to Maia *et al.* (2006) water deficit in maize crops can also be used to control *R. maidis*.

2.6.4. Biological control of Vectors of MLND causing viruses (*Frankliniella williamsi* and *Rhopalosiphum maidis)*

Natural enemies such *as Orius* species (minute pirate bugs) predate on mainly thrips as the primary prey and they are quite mobile and readily move from a native area into agricultural crops. They are aggressive predators that seek out thrips even in close protected crops (Isenhour and Yeargan, 1981). The minute pirate bug (MPB), *Orius tristicolor* and *Orius insidious* are voracious predators both as adults and larvae, they search out and stalk their prey and aggregate in areas of high density of thrips (Vandervoet *et al.*, 2014). The MPB insert their eggs into plant tissues and the emerging nymph resembles adults but lack wings. The nymph is shiny colorless and turns green-yellow to amber then orange as it grows older (Vandervoet *et al.*, 2014). Fonseca *et al.* (2015) was able to demonstrate the use of *Chrysoperla externalis* as a predator for the *R. maidis*.

The combination of host plant resistance with other methods, including natural enemies, especially coccinellids and cultural control, such as early sowing, reduced the populations of *Aphis craccivora* Koch on the cowpea (Ofuya, 1997) and *A. fabae* on faba bean plants (Shannag and Obeidat, 2008). Both larvae and adult lady beetles are significant predators of corn leaf aphids, including *Propylea japonica*, *Propylea quatuordecimpunctata*, and many members of genus *Coccinellidae* (Bunker and Ameta, 2009).

The green lacewings, such as *Chrysoperla nipponensis* and larvae of *Chrysoperla carnea* and several spiders are also predators of *R. maidis* (Yan, *et al.*, 2012). The predatory mite *Hypoaspsis miles* Canestrin (Acari: Mesostigmata) has been previously used to control western flower thrips *Frankliniella occidentalis*. It targets the soil stages (pupae stages of the thrips (Kivett, 2015). The predatory mites complete their life cycle within 18 days at 20 °C conditions. Their eggs hatch 2-3 days into young nymphs that also fiercely predate on thrips eggs and young larvae. The predator can not offer total control but can only reduce emergence of adult thrips by 30%, hence it only enhances biological control when used in conjunction with other foliage feeding predators (Kivett, 2015). Some of the potential biocontrol organisms used are parasitoids such as *Aphis colemani* and *Lysiphlebus tetaceipes* in Brazil (Bueno *et al.*, 2006). Predators such as the Coccinelidae *Eriops conexa conexa* have been used to control *R. maidis* in Colombia (Duarte and Zenner, 2007; Duarte *et al.*, 2013) while predators of thrips such as *Neoseiulus cucumeris* have been used to control Flower thrips in Netherlands (Messelink *et al.*, 2013).

Red imported fire ants tend colonies of corn leaf aphids and protect them from predators and parasitoids, in return for feeding on the honeydew they produce (Greenstone and

Shufran, 2003; Khuhro, *et al.,* 2012; Omkar, *et al.,* 2011; Papanikolaou, *et al.,* 2013Yan, *et al.,* 2012; Van Emden and Harrington, 2007). The parasitoid wasp *Aphidius colemani* parasitizes the corn leaf aphids (Barta and Cagan, 2007). Other parasitoid that control corn leaf aphids includes *Lysiphlebus testaceip*es, *Lysiphlebia japonica*, *Aphidius colemani,* and *Lipolexis oregmae* (Vinson and Scarborough, 1991; Sampaio *et al.,* 2008) . Other biological control measures used are the parasitic fungi of order Entomophthorales which use corn leaf aphids as hosts (Dey and Akhtar, 2007; van Emden and Harrington, 2007). Entomopathogenic fungi, *Beauveria bassiana* (Balsano) has also been developed for use as a biological control, (Lord, 2005). The fungi infect the host cuticle through enzymatic degradation and mechanical pressure (Gillespie and Claydon, 1989). Once inside the host the entomopathogenic fungi may be distributed through the haemocoel as yeast like blastospores, hyphal bodies or protoplasts. This leads to dispersion and colonization in the insect haemocoel which leads to reduced feeding behavior and death within 3-14 days (Gillespie and Claydon, 1989). If the humidity is greater than 70%, the fungus reverts back to the mycelia growth and exits the host cadaver to sporulate and infect another host (Gillespie and Claydon, 1989). There is limited information on the use of various biological agents towards the control of corn thrips and corn leaf aphids.

2.6.5. Host plant resistance

Maize contains a secondary metabolite known as hydroxamic which is thought to play a role in resistance of maize cultivars to *R. maidi*s. It plays a role in plant defence mechanism (Beck *et al.,* 1983) against the corn leaf aphids. Maize germplasms identified with resistance to *R. maidis* include Jalal (Khan *et al.,* 2006) in Pakistan, VL-Popcorn and KH-517 in West Bengal (Pal and Bandyopadhyay, 2006), CR 955 in India (Bayhan and

Bayhan, 2011), Mp708 (Luther *et al.,* 2013) and Mo17 (Betsiashvili *et al.,* 2015) in USA. This resistance is also found in barley germplasms, BCU 2806, EB921, EB2507, Manjula, DL529 and K144 in India showed resistance to *R. maidis* (Verma *et al.*, 2011).

Development of vector resistant crops is an economically viable approach for disease and vector management (Kumar *et al.,* 2004). Various reports indicate that most Kenyan hybrids are susceptible to the MLND causing viruses which have been achieved through artificial innoculation (Kinyua *et al.,* 2015; Mahuku *et al.,* 2015; Wangai *et al.*, 2012). According to CGIAR (Consultative group for International Agricultual Research) (2012), maize is susceptible to MLND at all stages of development from seedling to near maturity, however limited knowledge exists on varietal tolerance to the MLND causing viruses and their respective vectors in the field. Mahuku *et al.* (2015) suggested that further research is required to determine the competence of the vectors in virus transmission. Any level of varietal resistance to the vectors, the viruses or both in maize could offer possible germplasm that could be used in breeding programmes. There is need therefore to fast track the development of varieties that are tolerant to MLND and its vectors or resistant to MLND and its vectors in all agro ecological zones (De Groote *et al.*, 2016; Fatma *et al.*, 2016). There is need to determine the efficiency of the vectors in virus spread and to monitor the extent to which different varieties and landraces contribute to the spread of the viruses. Identification of maize varieties with tolerance to MLND causing viruses and its vectors is significant in the management of the MLND. Although most genotypes are susceptible to the disease, any tolerance in any variety may provide germplasm for breeding resistant varieties.

2.6.6. Action Threshold of *Frankliniella williamsi* and *Rhopalosiphum maidis* and their scouting Procedures

When corn thrips transmit or vectors maize chlorotic mottle virus they cause significant infection and eventually impact negatively on the crop and the yield. Insecticides are the main strategy used to control thrips on corn in the USA (Rueda *et al.*, 2007). The concept of action threshold is timing the insecticide application to coincide with the need for instead of calendar sprays (Nderitu *et al.,* 2008; Pedico and Rice 2009). Action threshold for thrips has been established for different crops over the years, for example, the onions action threshold in Canada is 0.9 to 2.2 thrips per plant. However, it varies with geographical regions, the crop cultivar, effectiveness of the insecticide, plant stage and plant architecture (Gill *et al.,* 2015).

Action threshold for corn thrips on maize is yet to be developed. However different thresholds has been set depending on weather conditions and localized insecticide resistance (Reiners and Petzoldt, 2009). For example 4-10 and 10-15 thrips per plant action threshold was found for onion stages of 2-6 months and 6 months to mature leaves in America (Bird *et al.*, 2004). In Canada, the recommendations are 0.9 and 2.2 thrips per leaf for wet and 2.2 thrips per leaf for dry seasons respectively (Fournier *et al.*, 1995). The frequency of application was also depended on product residual and immigration of adults from the surrounding vegetation. Trials by Palumbo (2006) on lettuce indicate that the most efficient insecticide tested were only able to maintain thrips population to a constant number but did not reduce the number significantly. Alternatively, Nault and Shelton (2010) suggested adjustment of action threshold levels depending on weather and plant variety in onions. They reported an action threshold level of three larvae of *Thrips tabaci* per leaf when applying spinotoram while an action threshold of one larva per leaf was attained when methomyl and formetanate hydrochloride was sprayed.

Initially, threshold for the Corn leaf aphids have been set using the number of days before the cereal tasses and whether corn is drought stress (Helmi, 2011) or not. According to the Northern Plain Intergrated Pest Management (IPM) guide (2013), threshold for non drought stressed maize and 3 weeks before tasseling is 15 aphids per plant while that for drought stressed corn is 10 aphids per plant. The threshold increases to 30 aphids per plant on non stressed corn and 15 aphids per plant on maize under draught stress two weeks before tasseling. According to Palumbo (2006), Proper timing of insecticide application is critical for successful control of aphids with foliar sprays. Therefore, foliar sprays should be initiated when the apterous (wingless) aphids begins to colonize crops at 5 aphids per leaf in lettuce as well the increase in the number of alates. Scouting of *R. maidis* is normally done during the late whorl stage and the tassel emergence. Whorls of plants are normally inspected for aphid presence using the sequential sampling plan.This helps to decide when the action threshold of the vector is attained. Hoffmann *et al.* 1996 suggested that an action should be taken against corn leaf aphids when 15% of the crop has been affected. This can be carried out by checking a minimum of five locations on 25 plants as a sample. Fields should also be scouted twice per week when aphids are present; this is because they increase in numbers and the action threshold can be reached in a short time (Blackman and Eastop, 1984).

Scouting helps farmers to make decisions on the need and timing of intervention methods. Close inspection and management of these vectors requires efficient systems of monitoring their infestation. Thus field scouting is an essential component of their management. Apart from scouting, employing other decision making tools in managing the vectors is important, for example knowledge of action threshold for the vectors would help in understanding when to initiate a pesticide intervention procedure (Nault and Shelton, 2010). Use of insecticides is known to offer effective management against thrips in Kenya (Nderitu *et al.,* 2008). However correct use and time of spray of these products has not been determined for vectors of maize lethal necrosis disease causing viruses. Action threshold of these vectors would require knowledge on economic injury level which is the lowest number of vectors that would cause economic damage. According to Larsson 2005, Economic damage commences when the cost of reducing the injury caused is equivalent to the potential monetary loss from the vector population or damage. Therefore this study determines the spray regime that would provide farmers with the highest economic returns when controlling vectors of MLND causing viruses. This would enhance dependence on monitored spray applications that are economically viable. Furthermore; the study also determines the scouting regime and action threshold for the vectors transmitting MLND causing viruses.

2.6.7. Physical surveillance and Monitoring of vectors of maize lethal disease necrosis causing viruses

Corn thrips and Corn leaf aphids have also been controlled by different colors of sticky traps for early detection. White sticky traps that had ethyl isonicotinate, methyl isonicotinate, ethyl nicotinate caught 8, 12 and 4 times more thrips than the plain sticky roll with glue alone (Davidson *et al.,* 2009). Blue and yellow sticky traps have also been used in other areas to monitor thrips population and map their spread within a given area (Pearsall, 2002; Broughton and Harrison, 2012). The flower thrips *F. occidentalis* have been successfully monitored and controlled by use of blue sticky traps (Broughton *et al.,* 2015).

One of the essential components of integrated pest management is monitoring the pest or vector population to provide an early warning system that help farmers to take control measures or alter them in case they prove unsuccessful (Zayed *et al.,* 2015). According to Palumbo, (1998) yellow sticky traps were successfully used to monitor aphids' movement into the field especially if they are used properly by placing them within the field near the upwind edges. The sticky traps were able to provide an early indication of when the economic colonization on the crop was starting. Use of sticky traps in combination with proper sampling methods can increase the attractiveness and sensitivity towards the capture of the vectors as well as provide farmers with an early warning system (Zayed *et al.,* 2015). Accuracy in mapping of the population densities of these vectors will lead to implementation of intervention and mitigation measures and eventually provide appropriate control. Sticky traps of different colors (blue , yellow and white) have be used by various researchers to control both thrips and aphids eg Muvea *et al.,* 2014; Covaci *et al.,* 2012; Harbi *et al.,* 2013. However, there is no recorded evidence on their use to monitor and control vectors of MLND, *F. williamsi* and *R. maidis*.

The sticky roll is a new technology that expands the surface area to increase the trapping capacity and hence control the pest (Sampson *et al.,* 2013). These rolls therefore can be utilized to manage heavy infestation in maize crops if found effective in the reduction of vectors of MLND causing viruses. Sampson *et al.* (2013) found out that the blue and yellow sticky roll was highly effective in lowering infestation level of western flower thrips and aphids in a semi protected environment. There is no documented evidence on the use of blue and yellow sticky roll against *Frankliniella williamsi* Hood and *Rhopalosiphum maidis* Fitch.

CHAPTER THREE
3.0. MATERIALS AND METHODS

3.1 Study site

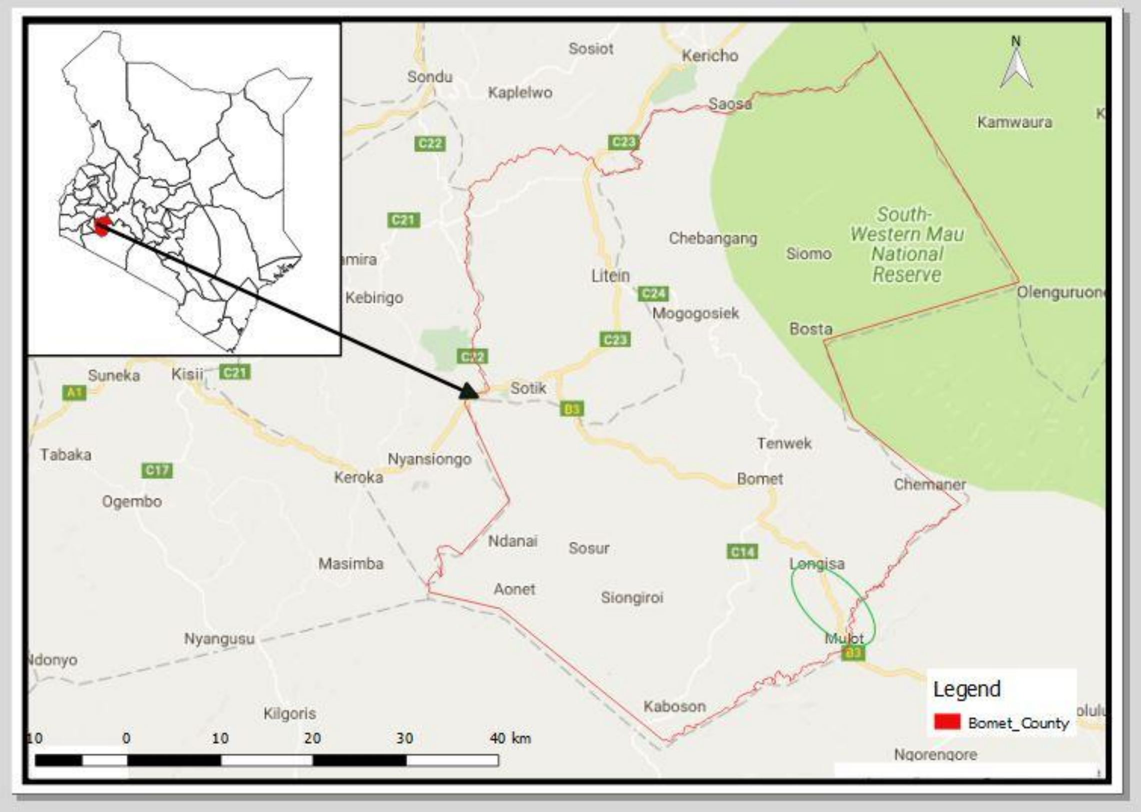


Figure 3.1. Map showing study site in Bomet County in South Rift region of Kenya

(© QGIS 2016 software version 2.10.1.

The study was conducted in the upper midland zone on the southern part of Bomet County of Kenya for two seasons from November 2014 to October 2016. The area is located between coordinates 0° 90’ 54’’ S 35° 40’ 97’’ E / 0° 90’ 69’’ S 35° 41’ 62’’ E and lies at an altitude of 1900- 2100 m above sea level (Kilonzo, 2014). The area has loamy soils and receives bimodal rainfall pattern amounting to 1200 mm-1400 mmper year. The long rainfall season is experienced from March to June while the short rain season occurs from November to December (Mutie *et al.,* 2006). The maximum temperature is usually 28-32°C and a minimum of 13°C (Jaetzold and Schmidt, 1982; Mutie *et al.,* 2006; Jaetzold *et al.,* 2012). Farmers mainly grow maize as food crop and cash crop. Maize is mainly grown as a monocrop but also as an intercrop with beans. A few farmers grow potatoes and a wide range of vegetables, at a small scale level (Jaetzold *et al.,* 2012).

3.2. Farm Survey

The study was carried out in Bomet East Sub County, Bomet County, Kenya from 17th to 20th August 2015. The Sub County has a population of 127,430 people in an area of 316.10km^2 (Jaetzold *et al.,* 2012). The Sub County has a mean monthly temperature of 18 °C with an annual rainfall of 1100 mm to 1500 mm (Jaetzold *et al.,* 2012). There are five wards in the Sub County namely, Longisa, Merigi, Kembu, Kipreres and Chemanar (Jaetzold *et al.,* 2012). Longisa and Kipreres Wards were chosen for this study due to their dominance as maize growing areas.

Sixty six respondents from accessible households were selected using a combination of simple random sampling and snow balling sampling technique based on Fisher *et al.* (1991) formular, $n = z^2\ p\ q/\ d^2$ (Where n = required sample size, z= standard normal deviation set at 1.96 which corresponds with 95% confidence level (Found in statistical tables, d = desired level of precision/accuracy (0.05), P = estimated proportion of the farmers present in the population, q = 1- P).

A community survey was carried out in August 2015 where questionnaires (Appendix 1) were administered to the respondents through face to face interviews. Information on vectors of MLND causing viruses, the disease and practices carried out by farmers were obtained from respondents. Furthermore, scores of MLND severity and incidence in the farms was also recorded by randomly sampling 50 maize plants per farm. Data collected on social and capital characteristics included, age, household position and level of education of the respondents as well as percentage income contributed by maize farming to the household. Maize status data including, area under maize coverage, age of the crop and the agronomical practices such as weeding, fertilization, disease and pest control was also obtained. Pest and disease data was recorded by getting the MLND incidence and severity levels as well as identifying the pests and vectors infesting the crop at different stages.

3.3. Field Experimentation Design and Layout

Field based trials were carried out in plots situated either in Korara and Chepnyeliliet village found between Mulot centre and Longisa Market in Bomet County. There were a total of eight experimental units set at different places according to the stated objectives. This was in consideration to factors such as; availability and size of land, time and the associated costs of land. Maize (*Zea mays* L.) variety Olerai-500-22A was used as the main variety of interest because it is recommended for the ecological area (KALRO, 2012). The treatments in each of the eight experimental units were arranged in a randomized complete block design and replicated four times for two seasons over a period of time.

3.3.1 Field dispersal and movement of *Frankliniella williamsi* and *Rhopalosiphum maidis)* in a maize field

Trials were carried out from 1st April 2015 to 18th August 2015 and repeated from 27th October 2015 to 8th April 2016. Plots measuring 3.75 x 5m were planted with Olerai-500-22A maize variety at 75x25cm spacing. Seven aspects comprising of; 1: color of sticky traps (Blue and yellow sticky cards), 2: Geographical orientation with blue sticky traps placed on plots edges towards the north, south, west and east directions, 3: Sticky traps orientatation at 90°, 120°, 150° and 180° angles. (The sticky traps were placed at the edge of the four sides of each plot) 4: Maize row orientation where maize was planted along the east to west contours and north to south contours, 5: Maize sampling orientation with samples obtained along the rows and across the rows. 6: Scouting regime composed of sampling on the lower, middle and upper regions of the plant. 7: Scouting time intervals that comprised of sampling treatments between 8.30 to 10.30 am, 12.30 - 2.30pm and 3.30- 5.30 pm.

The treatments in each aspect were independent from each other. Monitoring was done on a fortnight basis from one week after germination up to 7 weeks after germination. The sticky traps were collected after 24 hours and packed in transparent polythene bags for laboratory analysis. This was done by counting of the corn thrips and corn leaf aphids trapped under a dissecting light microscope. For the planting orientations and sampling patterns, destructive sampling was carried out at each replicate with nine plants being sampled from each plot across the seasons. The samples were placed in well labeled transparent sampling bags and transported to the laboratory for vector counting. For the scouting trial, leaves at each region were randomly selected and gently opened to detect the presence of corn thrips and corn leaf aphids.

3.3.2. Effect of sticky rolls in management of vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

The trials were carried out from 27th October 2015 to 8th April 2016 and repeated from 15th April 2016 to 1st September 2016. Plots measuring 3.75 x 5m were planted with Olerai-500-22A maize variety at 75 x 25cm spacing. There were seven treatments: blue and yellow sticky roll installed during germination, one week, and two weeks after germination and a control where no sticky rolls were installed. The sticky roll was 30 cm wide and was tied around the plots which were separated from each other by 2 m. The sticky rolls were installed to align with the canopy of the crop. Their placement above the ground was adjusted upwards to fit the crop canopy height. Blue and yellow sticky rolls were commercially obtained from Dudutech Limited at Naivasha.

The data was collected on a fortnight basis from both maize and traps samples from germination up to seventh week after germination. Destructive sampling and vector data was carried out. Furthermore, hand lens magnifying glasses were used to monitor the number of vectors trapped on sticky rolls at four randomly selected regions on the sticky traps measuring 10 cm x 10 cm. Maize samples were collected from each plot at three and seven weeks after germination to determine the viral load using the DAS ELISA and indirect ELISA for MCMV and SCMV.

3.3. 3. Action threshold level of vectors transmitting Maize Lethal Necrosis Disease causing viruses

To determine the action threshold level for vectors transmitting MLND causing viruses, two seasons of planting was carried out from 1st April 2015 to 18th August 2015 and repeated from 27th October 2015 to 8th April 2016 in plots measuring 3.75 x 4.75m. They were planted with maize variety Olerai 500-22A with five treatments of thunder spray (Imidacloprid and Beta cyhalothrin at the rate of 25ml per 20 litres of water) composed of weekly, fortnightly, 3 weeks and monthly spray intervals. In addition, a control with no spray application was included in the trial. The plots were separated from each other by a two (2) metre alley and covered with a wide polythene paper during spraying to minimize the spray drift between treatments.

The number of insects' vectors was counted. The corn thrips damage score per plot was also recorded. Data collection for the threshold trial was done just before spraying by destructive sampling and analysis in the labarotaory. Vector data, thrips damage and MLND severity of the crop was determined by scoring for the disease infection levels. Elisa tests were thereafter carried out to confirm the virus presence and their infection levels. Yield data was taken and recorded.

3.3.4. Varietal tolerance to vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

Field based trials were carried out from 1st April 2015 to 18th August 2015 and repeated from 27th October 2015 to 8 April 2016. Plots measuring 2.25 x 5 m were planted with maize at 75x25cm spacing in 6 rows. Five treatments composed maize varieties; H614, DK 8031, H515, H513, DK 80-33 and Olerai 500-22A were used. The plots were separated from each other by one meter. Monitoring was carried out using destructive sampling from germination up to 10 weeks on a fortnight basis. After the field collection, samples were taken to the laboratory to asses' corn thrips and corn leaf aphids' infestation levels and damage.

The second aspect of the experiment was carried out from 27 October 2015 to 8th April 2016 and repeated from 15th April 2016 to 16th September 2016. This consisted of two plantings with eighteen landraces (as shown in plate 3.1) as treatments planted during the onset of rainfall and repeated two weeks after the rain onset. In addition to vector infestation levels, samples were collected for Elisa tests to identify the virus presence and the MCMV and SCMV levels.

Plate 3.1: Maize cobs of various landraces used for the experiment in Bomet County
Source: Leley, (2015)

3.3.5. Management of vectors of maize lethal necrosis disease causing viruses using cropping system approach in Kenya

The trial was carried out from 25th December, 2014 to 12th April 2015 and repeated from 1st April 2015 to 18th August 2015). The dimension of the main experimental plot was 22.5 m by 8.75 m surrounded by 2 m guard row. Nine treatments composed maize intercropped or bordered by elephant grass (*Pennisetum purpureum*), Gadam sorghum (*Sorghum bicolor*), coriander (*corriandium sativum*), pearl millet (*Pennisetum glaucum*) and olerai maize variety as the control was planted in plots measuring 7.5 m x 5.25 m. The treatment plots and blocks were separated from each other by 1 m and 2 m respectively. Border crops and the outer rows of the intercrops were planted 2 weeks earlier while the inner rows of intercrops were planted at the same time with maize. Maize rows alternated with the intercrop with each plot having a total of three maize rows and four intercrops. Intra row spacing was 25 cm for maize, 20 cm for sorghum, 15 cm for pearl millet, 75 cm for elephant grass and 10 cm for coriander while inter row spacing was 75 cm

Two maize plants were randomly selected from the 2nd and 6th rows while the companion crops were randomly selected from the 3rd and 5th rows from all intercrop plots. For border plots, two maize plants were randomly selected from the first 1st and 3rd maize rows while companion crops were randomly selected from the inner border. Data collection on vectors, yield, MLND severity and incidence levels was carried out. Furthermore, Elisa tests were carried out to determine the MCMV and SCMV viral load.

3.3.6. Management of vectors of MLND causing viruses using biological control in Bomet County of Kenya

Field based trials were carried out from 27 October 2015 to 8th April 2016 and repeated from 15th April 2016 to 16th September 2016 in Bomet County, Kenya. Plots measuring 3.75 m by 5 m were planted with maize at 75 cm x 25 cm spacing fitting 6 rows. Four treatments were tested; 1: Beauvitech; Entomopathogenic fungi, *Beauveria bassiana*, 2: Hypotech; predatory mites, *Hypoaspis miles*, 3: Ecotech; botanical pesticide of garlic extracts and control treatment composed of no spray. The plots were separated from each other by two meters.

Predatory mites, *Hypoaspis miles* (Hypotech®), Entomopathogenic fungi, *Beauveria bassiana*, (Beauvitech®) and the botanical pesticide, garlic concentrate (Ecotech) were obtained from Dudutech limited Naivasha. All the treatment application was done after every fortnight commencing from two weeks after germination up ten weeks after germination. The hypotech recommended rate of application of 50 mites /m^2 equivalent to 500,000 mites per ha was used in this study. It was there after applied on top of the soil near the maize plants where the adults and nymphs of the predatory mites mainly feed on thrips pupae. Before use, the ecotech was shaken properly and mixed with water at the rate 2 litres of ecotech in 1000 litres of water. The active ingredient, garlic concentrate encourages healing of damaged tissues. The uptake through the leaves promotes the development of thicker leaf cell walls.

Beauvitech is a product that contains naturally occurring insect killing fungi. They kill insects by mechanical damage through tissue invasion, depleting nutrients and releasing of toxins. It is used to control thrips by causing a white muscadine disease in pests. The product contains spores of *Beauveria bassiana* strain J_{25} at a concentration of 1.0 X 10^{10}CFU/ gram in an inert carrier. Infection occurs within 24 to 48 hours of contact spores. The infected insects may live for 3-5 days after hyphal penetration. The beauvitech powder was mixed with water by using the recommended dose of 250g of beauvitech per ha in 1500 liters of water. However in this study 25g were mixed in 2 litres of water and thereafter mixing the suspension with water. Spraying was done immediately after mixing (by shaking of the Knapsack spray). The spray was done uniformly in order to cover the leaves thoroughly with adequate fungal spores. Destructive sampling and data collection was carried out in the laboratory. Vector, disease and yield data was collected as well MCMV and SCMV viral load.

3.4. Detailed Description of Experimental Data Collection

This involved procedures carried out either in the field or the laboratory during data collection. Vector count, thrips damage, MLND severity, DAS Elisa and Indirect Elisa procedures were carried out.

3.4.1. Assessment of corn leaf aphids and corn thrips population and damage

Two maize crops were destructively sampled from every replicate in a repeated measure study. The plants were destructively sampled per plot, packed in plastic transparent bags and taken to the laboratory for vector count. This was done after every fortnight from week 1 to the 10th week after germination. Thrips damage level on maize was scored using the scales described by Rahman *et al.* (1994). They were represented by 1 = no leaf damage; 2= leaf damage restricted to basal half of plant (1-25 % damage); 3 = leaf damage restricted to middle and basal half of plant (26-50 % damage); 4= entire plant damaged except terminal leaves (51-75 % damage); 4 = most of the plant damaged (76 - 100 % damage). Thereafter, maize lethal necrosis disease incidence and severity data was collected for a period of one month.

3.4.2. Assesment of Maize lethal necrosisis disease incidence and severity

Disease incidence was taken by counting the number of diseased maize along two inner rows and converting it into percentages. Severity of the MLND on leaves and ears was taken based on the following scales as described by Kinyua *et al.* (2015). 1-No symptoms seen on leaves, 2 -Very mild chlorotic mottling on 1-2 leaves or flecking on less than 50% of leaves without generalized chlorosis, 3-Mild chlorotic mottling on 3 or more leaves or flecking on more than 50% of leaves without generalized chlorosis, 4-Chlorotic mottling on less than 50% of leaves accompanied by necrosis on 1-2 leaves or severe chlorotic mottling on more than 50% of leaves but without necrosis and 5-Severe chlorotic mottling on more than 50% of leaves accompanied by necrosis on 3 or more leaves (Kinyua *et al.* 2015). MLND Severity scoring on the ears was to be as follows; 1-No symptoms seen on bracts. 2-Very mild ‘bleached appearance’ on bracts, covering less than 50% of the surface but without necrosis. 3-Mild ‘bleached appearance’ on bracts, covering more than 50% of the surface but without necrosis. 4-Severe ‘bleached appearance’ or browning on bracts, accompanied by necrosis on less than 50 % of the surface. 5-Severe ‘bleached appearance’ on bracts, accompanied by necrosis on more than 50% of the surface.

3.4.3. Laboratory Serological Sample analysis for Maize lethal necrosis viruses

Samples were obtained from plot treatments at the study site where treatments had been arranged in a randomized complete block design and replicated four times. This was done by randomly selecting five plants per plot. The leaf tips of the maize plants was cut using scissors and deposited in a transparent paper bag that was tightly enclosed. The scissors used for cutting was sanitized using 70% alcohol. The usable gloves were discarded and hands washed after every plot sampling. The samples were thereafter stored in a cooler box stacked with ice packs and transported to the Laboratory for storage at – 20 ◦C. Three extra controls were used in the Elisa tests; a positive control whose sample was isolated from virus infected control, a negative control whose sample was isolated from a healthy plant and the no sample control where the well in the plates was left blank. The three controls were important in each experimental analysis to check on the laboratory contamination. The positive and negative controls were laboratory generated with the positive control being taken from plants known and already tested positive for MLND causing viruses

3.4. 4. Detection of Maize Chlorotic Mottle Virus using (DAS-ELISA)

Preparation of the antigens (samples) was done by crushing 0.5g maize leaf samples in 5ml of distilled water inside crushing bags. The 500µl sample was then added onto the same volume of sample buffer that composed of Na_2CO_3 and $NaHCO_3$ with a pH of 7.4 in eppondorf tubes. The DAS ELISA was performed to test for MCMV using the standard method adapted from Clark and Adams, (1977) and modified by Adams *et al.*, 2012. Plates were coated using the capture antibody MCMV IgG in 1× DAS ELISA carbonate coating buffer at the ratio 1:1000 dilution. The mixture was incubated at 37ºC in a thermo shaker for 20 – 30 minutes. The micro titre plates were then washed and dried. The wells were loaded with sample antigen of 100µl followed by 200µl coating buffer in each individual well and incubated for 1 hour at 37ºC. There after washing and drying of the plate took place. The wells were then filled with the antibody (IgG) mixed in conjugate buffer (PBS-Phosphate buffer saline) – 2% polyvinyl pyrrolidone (PVP) – BSA ((bovin serum 0.2% albumin) at the ratio 1:5000 dilutions. Ther after, the mixture was incubated for 1 hour at 37ºC followed by washing and drying of the plate. Finally, a substrate was prepared by diluting 1mg of substrate Para neutral phenyl phosphate tablet (PNPP) with 1ml of substrate buffer (diethanolamine). A solution of 100 µl of the PNPP was eventually added to every individual well and colour changes observed after 45 minutes. The results were read using an ELISA reader spectrophotometer measurement at an absorbance of 405nm. Every time washing was carried out by flooding and rinsing the wells thrice with phosphate buffer saline-Tween 20 PBS-T that consisted of NaCl, KH_2PO_4 Na_2HPO_4 and KCl plus Tween 20. The plates were then dried by tapping them upside down on special absorbent tissues after every subsequent rinse.

3.4.5. Detection of Sugarcane Mosaic Virus SCMV (Indirect ELISA)

An indirect Elisa was carried out to test for SCMV using the Agdia antiserum. Samples measuring 100µl were loaded into the wells in 200µl carbonate coating buffer and incubated for 1 hour at 37ºC. The wells were there after rinsed and dried. Distilled water was used instead of the tween for rinsing the plates to minimize interference with the blocker. The blocker, composed of 200µl of 5% NDM (non fat dry milk) in Tris-HCl (Tris hydrochloric acid buffer 7.4) was distributed per well and left for 15-20 minutes at room temperature. The contents in the wells were then discarded and replaced with

SCMV IgG in 5% (non fat dry milk) NDM of PBST-PVP-BSA (1:1000) and eventually incubated at 37ºC for 1 hour. Rinsing and drying of the wells took place before the conjugate (5% NDM of PBST-PVP-BSA -Anti rabbit immune globulins) was mixed with the antibody (IgG) at 1:10000 dilutions in the wells and incubated for a period of 1 hour. Thereafter, the plates were washed and the wells filled with the substrate PNPP. The colour change was observed after 45 minutes and read using an ELISA reader spectrophotometer measurement at an absorbance of 405nm. Washing of the wells was done by rinsing three times with PBST at 2-3 minute interval in between the washings and drying.

3.4.6. Assessment of Yield data properties

At harvest, 10 maize plants were randomly selected for yield data collection. The cobs were harvested; percentage cob fill by grains was determined using the scales; 0% -No grains on the cob, 12.5% - single grain to few grains that filled up to an eighth of the cob, 25% - More than an eighth of the cob up to a quarter filled with grains, 37.5% - More than a quarter up to three eighths of the cob filled with grains, 50% - More than three eighths up to a half the cob filled with grains, 62.5% - More than a half up to five eighths of the cob filled with grains, 75% - More than five eighths up to three quarters of the cob filled with grains, 87.5% - more than three quarters up to seven eighths filled with grains and 100% - The whole cob was filled with grains. The cobs were then weighed and shelled. Fresh and dry weight of shelled grains, good grains and bad grains was recorded per plot (Good grains were considered edible while bad ones were considered to be inedible). Fresh weight was taken immediately after shelling while dry weight was taken when the moisture content was approximately 13.5%.

3.5. Data Analyses

Corn thrips and corn leaf aphids count, the MLND severity, MLND incidence data, the yield data and the viral load/ viral titter were collected and subjected to ANOVA in the Gen Stat 17th edition. Skewed vector data was transformed by square root before carring out ANOVA and geometrical means recorded. Post hoc analyses were carried out using the Fishers Protected Least Significance Difference Test (LSD) where the means differed significantly. According to Mezzalama *et al.* (2015), Elisa results can be interpreted visually based on the color developing in the wells; however a more accurate way by use a spectrophometer at a recommended wavelength of 450nm was adopted.

The threshold for determining whether a sample was negative or positive has often been two times the value of the healthy control (Nelson *et al.,* 2011; Adams *et al.,* 2014). In this study, this was put into consideration, but ANOVA was also used to determine whether there was a significant difference between the means of the treatments versus the controls. In this respect, a sample was considered positive for MCMVor SCMV when it significantly varied at $P < 0.05$ with the mean absorbance values of the uninfected plant controls (negative). There were three controls used in Elisa tests; the positive control whose sample was isolated from virus infected control, a negative control whose sample was isolated from a healthy plant and the no sample control where the well in the plates was left blank. The three controls were important in each experimental analysis to check on the laboratory contamination. The positive and negative controls were lab generated with the positive control being taken from plants known and already tested positive for MLND causing viruses.

The value of maize was used to determine the economic damage of the vectors. Linear regression analysis was used to determine the economic injury level and action threshold level of the vectors. Initially the profitability of each spray regime (gross marginal rate) was measured; the net returns were there after calculated by getting the difference in the cost incurred by each spray regime and the corresponding gross returns from the selling price of maize at that particular period. The most stable price for maize by the Cereal Board of Kenya was Kshs 3,000 per 90Kg bag which was equivalent to Kshs 33.30 per 1Kg of maize during harvesting time. The Total amount of insecticides per treatment was multiplied by the cost of the insecticide and extrapolated per hectare. The cost of Thunder was Kshs 700 per 100ml which was equivalent to Kshs 7 per millitre. The marginal rate of returns was calculated as the change in returns per the insecticide cost per the spray regime.

The economic injury level (EIL) was determined by the equation $Y = a + bx$ or $x = a - y/b$ (Nderitu *et al.,* 2008) where a = expected yield at zero infestation level while y = the yield below which the crop loss would be greater than the cost of the chemical control that would be deployed (Stewart and Khatat, 1980). Hence, $a - y$ = Economic damage, Therefore Economic injury level (x) = economic damage/b (negative terms) or x = Economc damage/slope of regression line (positive term) as explained by Nderitu et *al.* 2008. The action threshold level was there after laid down according to guidelines by Reichelderfer *et al.* 1984. This was determined by picking the point where the curve of EIL against the cost of the pesticide control (Positive slopping) meets the curve of EIL against the net returns (negative sloping).

CHAPTER FOUR

4.0. RESULTS

4.1. Farmers knowledge and practices against vectors of MLND causing viruses in Bomet East Sub County.

The spouse had the highest percentage number among the respondents interviewed followed closely by the head of the family (Figure 4.1).

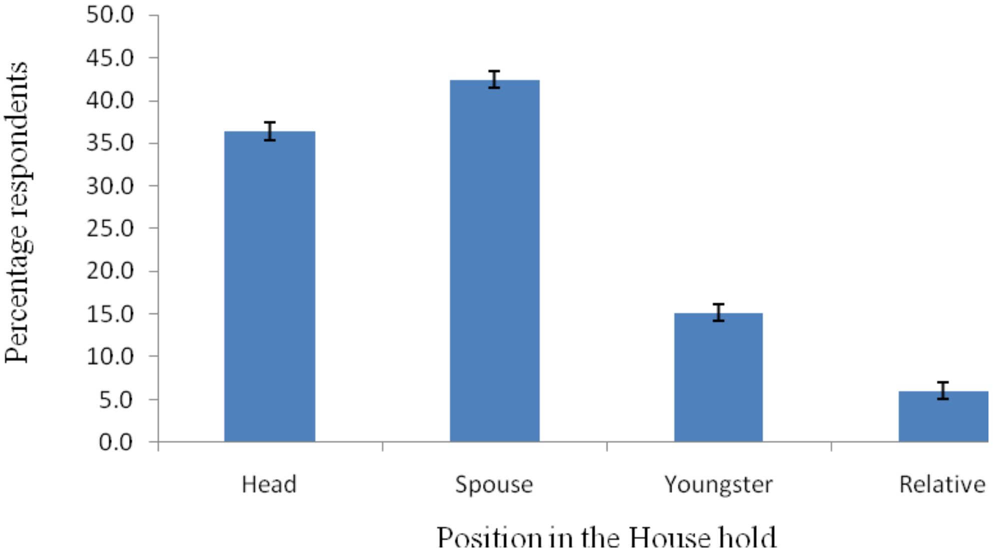


Figure 4.1: Distributions of maize farmers in Bomet County according to house hold position during August 2015

The findings of this study show that majority of the respondents population was within the age group of 21-30years. However 72 % of the farming population ranges between 21 to 50 years. Of this population, 27% take the position of yougsters at the household level. This means 42 % of the farmers in Bomet East Sub County were the youth with the age range of 31 to 40 years (Figure 4.2). The older generation of 61 to 90 years were very few and composed of only12% (Figure 4.2).

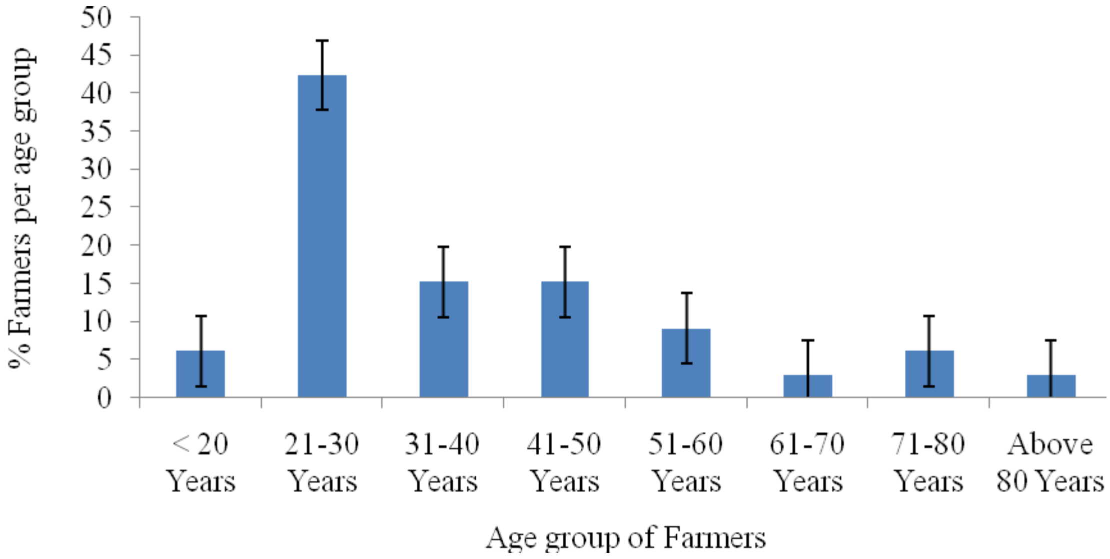


Figure 4.2: Distributions of Maize farmers in Bomet County according to their Age during August 2015

Majority (57.9%) of farmers in Bomet East Sub County had attained education up to upper primary level while 23.9 % had education up to secondary level (Table 2). Only 3 % of the respondents had post secondary education while 6.1 % had not received any formal education (Table 4.1).

Table 4.1: Distribution of Maize farmers in Bomet County according their education level during August 2015

Education level	Percentage
No Schooling	6.1
Lower Primary	9.1
Upper Primary	57.9
Secondary	23.9
Post-Secondary	3
Total	100

About a quarter of the respondents' do not rely on maize for an income (Table 4.2). However, 54% of the farmers reported that maize contributed to the economic well being of income in their house holds (Table 4.2).

Table 4.2: Percentage Contribution of maize to the farmers' income in Bomet County during August 2015

% income contributed by maize	**Percent**
0	24.2
1-25	27.3
26-50	27.3
51-75	9.1
76-100	12.1
Total	100.0

Majority of farmers in Bomet East Sub County have a half an acre of land while 18% have 0.25 acres and one acre of land under maize (Table 4.3). Three percent of the respondents had three quarters of an acre and one and a half acres respectively.

Table 4. 3: Pecentage Acreage under maize owned by Farmers in Bomet County during August 2015

Acreage under maize	Percentage farmers
0.125	12.1
0.25	18.2
0.5	39.4
0.75	3.0
1	18.2
1.5	3.0
2	6.1
Total	100.0

Majority of farmers in Bomet East Sub County practice first and second weeding of maize while 30 % use fertilizer during planting. A minimal 6% of the respondent's practice first and second weeding as well as spraying the crop with cyclone insecticide. Three percent apply fertilizer, weed and use pesticides that they could not remember as well as fungicides (Table 4.4).

Table 4.4: Types and quantity of Agronomical practices among Bomet County Farmers in August 2015

Agronomical practices	Percent
1^{st} and 2^{nd} Weeding	54.5
Fertilizer, 1^{st} and 2^{nd} Weeding	30.3
Fertilizer, 1^{st} and 2^{nd} Weeding and Pesticide	3.0
1^{st} and 2^{nd} Weeding, Spraying using Cyclone	6.1
Fertilizer, 1^{st} and 2^{nd} Weeding,Cyclone and Dithene	3.0
Fertilizer, 1^{st} and 2^{nd} Weeding, Pesticide and Fungicide	3.0
Total	100.0

Majority (91%) of the respondents were aware of the maize lethal necrosis disease while 3% did not know about the disease, thought it was rust, or a combination of rust and MLND (Figure 4.3).

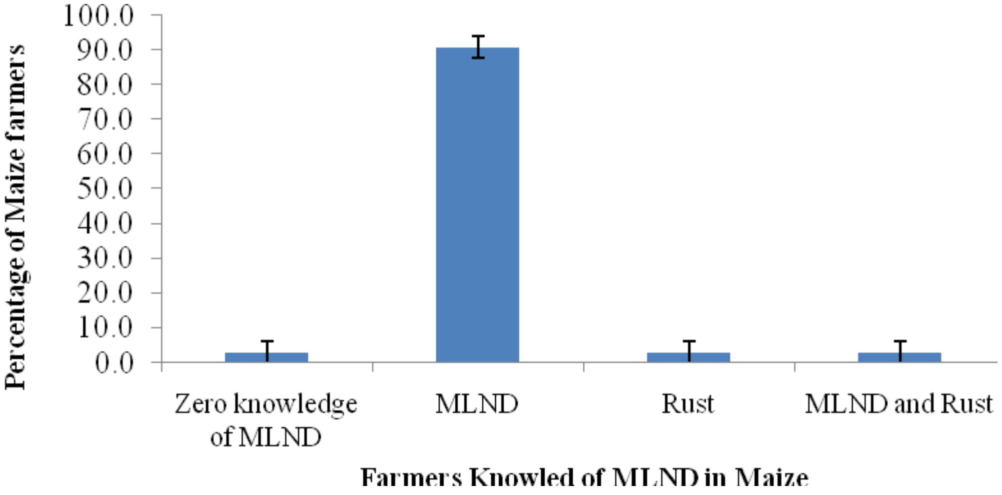


Figure 4.3: Percentage of maize farmers in Bomet County on knowledge of MLND during August 2015

Sixty (60%) of respondents reported the stem borer as the vector of viruses that cause MLND while 3 % reported either corn thrips alone, aphids alone or thrips and stem borer (Figure 4.4). Atleast 9 % of the respondents correctly identified the corn thrips and corn leaf aphids as vectors of MLND causing viruses. Nine percent of the respondents had no idea about vectors of viruses MLND causing (Figure 4.4).

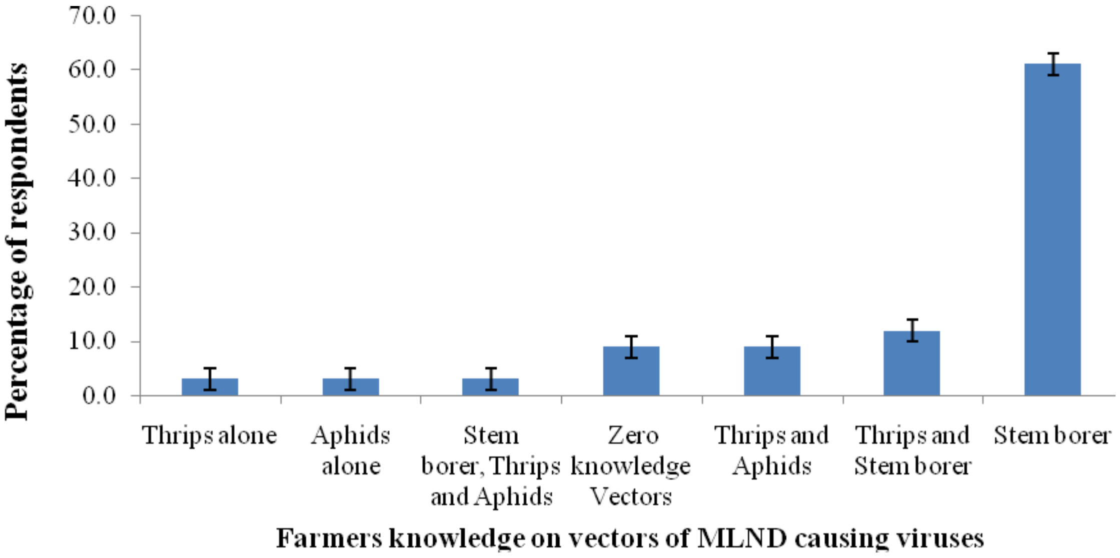


Figure 4.4: Percentage of Maize farmers in Bomet County on Knowledge of vectors of viruses causing MLND during August 2015

Maize grown in farmer fields at Bomet East Sub County was in different growth stages during the interview period (Figure 4.5). Forty eight percent of respondents had maize that was in the late whorl stage (2 months old) while 21% had maize that was in a flowering and fertilization stage (3 months old) (Figure 4.5). A total of 6% of respondents had maize that ranged between seedling and early whorls stage (less than a month) and grain fillingand maturity stage (4 months old) while 18% had maize under vegetative growth stage (1 month only) (Figure 4.5). The expected maize age at the time of survey was three months.

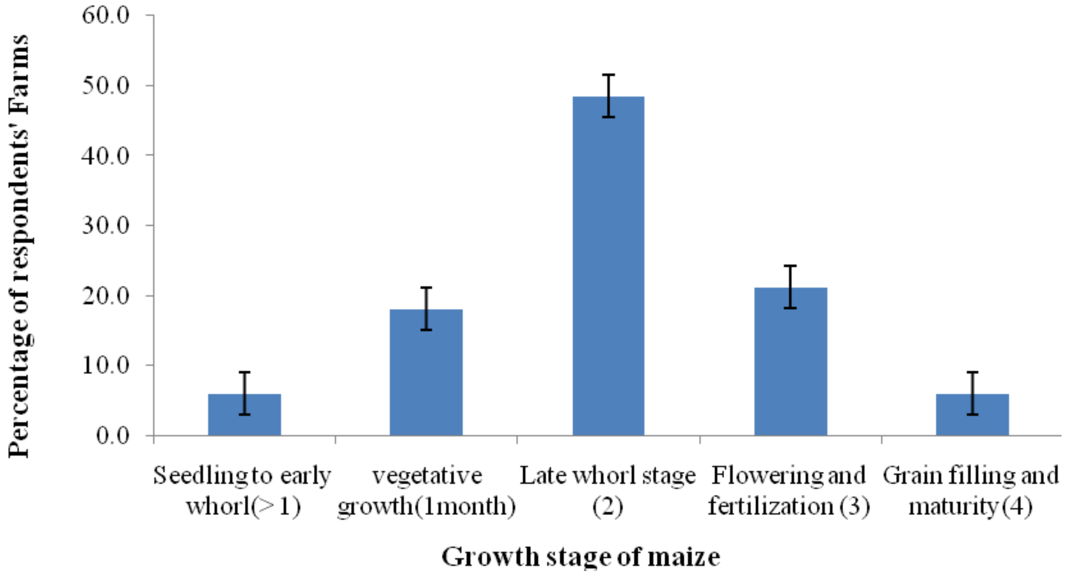


Figure 4.5: Percentage of Maize farmers in Bomet County on the growth stage of maize during August 2015

The MLND incidence levels was very high with 3% of maize having 60 to 80% MLND incidence level while 97% of maize had 90 to 100% MLND incidence levels. This is evident in Plate 4.1 (Table 4.5).

Table 4.5: Percentage of MLND incidence in farmers Maize fields in Bomet County during August 2015

Disease incidence %	Percent
60-80	3.0
90-100	97.0
Total	100.0

Plate 4.1: MLND infected maize in a farmer's Field in Bomet County during August 2015

Majority (36.1%) of maize found among respondent farms had been affected by MLND with a severity scale of 3 (Figure 4.6 and plate 4.1). Twenty three percent of the maize had an MLND severity of 4 while those with the most severe case (5) of MLND were 19.4 % as shown in plate 4.2. Only two % of the maize was healthy with a scale of 1 (not affected by MLND) (Figure 4.6).

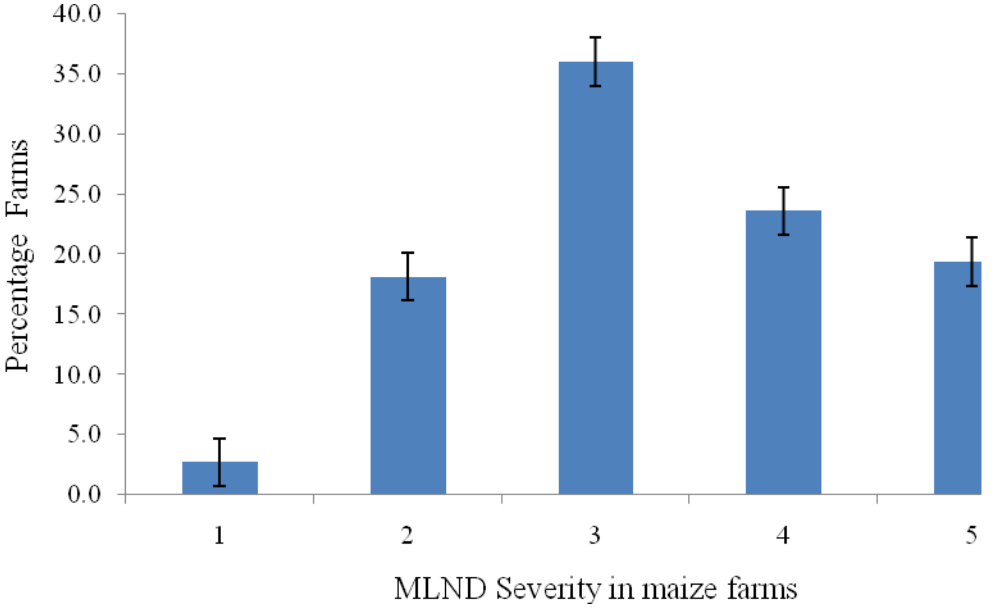


Figure 4.6: Percentage of respondents with maize affected by various MLND severity levels

Plate 4.2: The MLND severity score on maize leaves at different scales

Majority of maize aged three months and above had small ears. Almost 40% of this maize had undeveloped ears or no ears while 27% of the maize had medium and large ears (Figure 4.7).

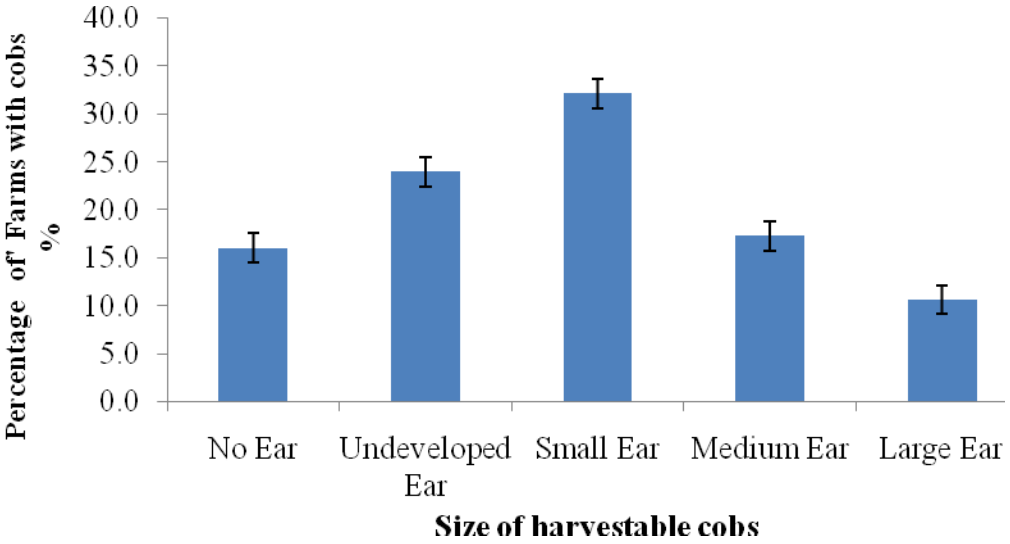


Figure 4.7: Percentage size of cob ears in maize farms at Bomet County during August 2015

There was a positive correlation between the education level and the agronomical practices applied by farmers ($r = 0.186, P \leq 0.001$) as well as the knowledge by farmers on vectors of MLND causing viruses ($r = 0.275, P \leq 0.001$) (Table 6). Income from maize had a positive correlation with the number of acres under maize ($r = 0.24, P \leq 0.0001$). There is a positive correlation between agronomical practices and maize acreage ($r = 0.68, P \leq 0.0001$) as well as a positive correlation between agronomical practices and the farmers knowledge on vectors of MLND causing viruses ($r = 0.24, P \leq 0.001$). A negative correlation was also found between agronomical practices and the disease incidence ($r = -0.116, P \leq 0.03$) as well as between the farmers knowledge on vectors and the agronomical practices ($r = -0.24, P \leq 0.001$).

Farmers knowledge on the vectors had a negative correlation with MLND severity ($r = -0.37$, $P \leq 0.0001$). Farmers knowledge on the vectors of MLND causing viruses had a negative correlation with MLND severity ($r = -0.37$, $P \leq 0.0001$). Knowledge on MLND by farmers was equally positively correlated to the percentage of income that farmers got from maize ($r = 0.216$, $P \leq 0.001$). The growth stage of the crop had a negative correlation with MLND severity ($r = -0.117$, $P \leq 0.03$) as well as with farmers agronomical practices ($r = -0.12$, $P = 0.029$). MLND severity had a negative correlation with the agronomic practices ($r = -0.206$, $P \leq$ as well as farmers knowledge of the vectors of MLD causing viruses ($r = -0.371$, $P \leq 0.001$). The disease incidence levels had a negative correlation with percentage income realized from maize $r = -0.335$, ($P\leq 0.0001$) (Table 4.6).

Table 4.6: Correlation between social capital characteristics, maize status, pest and disease data and yield data

	1	2	3	4	5	6	7	8	9	10	11	12
1	1	-.520**	.100	-.144**	-.046	.151**	-.297**	-.107	-.068	.172**	.186**	.035
2	-.520**	1	-.560**	.145**	.185**	-.103	.203**	.115*	.385**	.068	-.073	-.091
3	.100	-.560**	1	.067	.176**	.011	.186**	.123*	-.275**	-.288**	.019	-.042
4	-.144**	.145**	.067	1	.240**	-.308**	-.029	-.205**	.216**	-.513**	-.335**	.095
5	-.046	.185**	.176**	.240**	1	.107	.681**	.195**	.062	-.149**	-.187**	-.244**
6	.151**	-.103	.011	-.308**	.107	1	.182**	.011	.015	.345**	.594**	.051
7	-.297**	.203**	.180**	-.029	.681**	.182**	1	.241**	-.095	-.120*	.116*	-.206**
8	-.107	.115*	.123*	-.205**	.195**	.011	.241**	1	-.015	-.176**	.092	-.371**
9	-.068	.385**	-.275**	.216**	.062	.015	-.095	-.015	1	.071	.025	.055
10	.172**	.068	-.288**	-.513**	-.149**	.345**	-.120*	-.176**	.071	1	.174**	-.117*
11	.186**	-.073	.019	-.335**	-.187**	.594**	.116*	.092	.025	.174**	1	.146**
12	.035	-.091	-.042	.095	-.244**	.051	-.206**	-.371**	.055	-.117*	.146**	1

1. Position in the household 2. Age 3. Education level 4. Maize income contribution 5. Maize acreage 6. Months after germination 7. Agronomical practices 8. Farmers' knowledge on vectors 9. Farmers' knowledge on disease 10. Stage of crop 11. Disease incidence 12. MLND Severity *=Significant at $P<0.05$ **=Significant at $P<0.01$ ***=Significant at $P<0.001$

4.2. Field dispersal and movement of *Frankliniella williamsi* and *Rhopalosiphum maidis* in a maize field

The blue sticky card captured a highly significant number of corn thrips compared to the yellow ones. However there was no significant difference among the corn leaf aphids trapped by the blue and yellow color (Table 4.7).

Table 4.7: Mean number of corn thrips and corn leaf aphids trapped by blue and yellow sticky traps

Type of trap	Corn thrips	Corn leaf aphids
Yellow	8.5b	2.8
Blue	20.7ba	1.4
P value	0.023	0.16
t-value	2.64	1.43

***** Means within column followed by the same letter are not significantly different at $P = 0.05$).

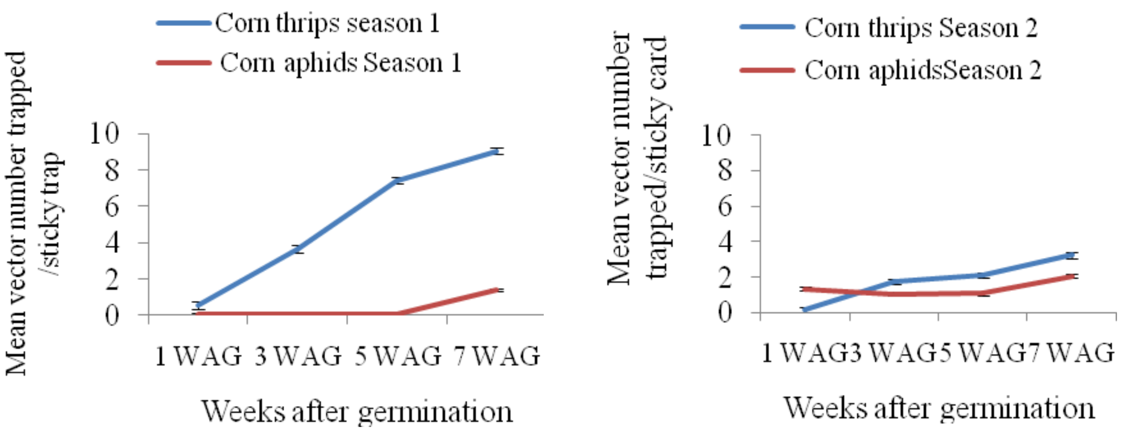
During the first season, the sticky trap inclined at 90° captured a significantly high number of corn thrips compared to those inclined at 120°and 180°. Corn thrips trapped by sticky cards inclined at 150° had no significant differences from those capture at 90° (Table 4.8). The sticky traps at angles of 90°, 120°, 150° and 180° did not significantly differ in the capture of corn leaf aphids. Pooled data from both seasons shows similar results as the first season although the second season showed no difference in the vectors captured by sticky cards inclined at all the angles (Table 4.8).

Table 4.8: Mean number of corn thrips and corn leaf aphids trapped by selected angle inclination of sticky traps in Bomet county of Kenya between May 2015 to January 2016

Season	Trap Orientation	Corn Thrips	Corn leaf Aphids
Season 1	90◦	6.9a	1.4
	150◦	5.2a	1.3
	120◦	3.6ab	1.2
	180◦	3.3b	1.2
	P value	0.01	0.4
	Se	1.8	0.2
Season 2	180◦	2.6	1.5
	150◦	2.4	1.6
	120◦	1.3	1.1
	90◦	1.4	1.1
	Pvalue	0.2	0.6
	Se	0.75	0.5
Season 1and 2	90◦	4.5a	0.9
	150◦	3.8a	1
	180◦	2.8ab	0.9
	120◦	2.3b	0.8
	P value	0.002	0.2
	Se	1.7	0.2

***** Means within column followed by the same letter are not significantly different at P = 0.05.

During the first and second season, corn thrips were significantly lower (P< 0.001) when the crop had one to two leaves {one week after germination (1 WAG)}. The corn thrips captured were significantly (P< 0.001) higher at 5 (mid whorl) and 7(late whorl) WAG compared to any other growth stage (Fig 4.8). Moreover, the corn leaf aphids significantly increased during the late whorl stage (just before tasseling) at 7 WAG compared to the other stages (Fig 4.8). Generally, the number of corn thrips was significantly higher (P< 0.001) compared to the number of corn leaf aphids trapped across all the crop stages for all the seasons. However, the number of corn leaf aphids was significantly higher (P< 0.001) than the corn thrips during the second season at 1 WAG (Figure 4.8). Both vectors were significantly higher (P< 0.001) during the late whorl stage (7 WAG) and this coincided with the disease manifestation in the crops (Figure 4.8).



WAG- Week after Germination, 1WAG (1-2 leaves) 3WAG; (early whorl) collar of fourth leaf visible, 5WAG; (mid whorl); collar of eighth leaf visible, 7WAG (late whorl); collar of 12th leaf visible

Figure 4.8: Trends of vector counts trapped by sticky cards at different directions after 24 hours across the various growth stages of maize

The corn thrips moving into the maize field were significantly higher compared to the ones moving out of the field in both seasons (Table 4.9). This was likewise for the corn leaf aphids (Table 4.9).

Table 4.9: Mean number of vectors moving in and out of a maize field caught by the sticky trap at Bomet County, Kenya

Season	Vector Movement	Corn thrips	Corn leaf aphids
Season 1	Out of the field	3.1b	0.17b
	In the field	7.3a	0.62a
	P value	0.001	0.008
	t-value	3.29	1.76
Season 2	Out of the field	1.0b	1.05
	In the field	2.9a	1.52
	P value	<.001	0.2
	t-value	3.79	1.25
Season 1 and 2	Out of the field	1.9b	0.66b
	In the field	4.82a	1.12a
	P value	<.001	0.03
	t-value	4.08	2.21

* Means within column followed by the same letter are not significantly different at P = 0.05).

Placement of sticky traps in different geographical orientations (directions) had no effect on either the corn thrips catch or the corn leaf aphids. This trend was similar for both seasons (Figure 4.9).

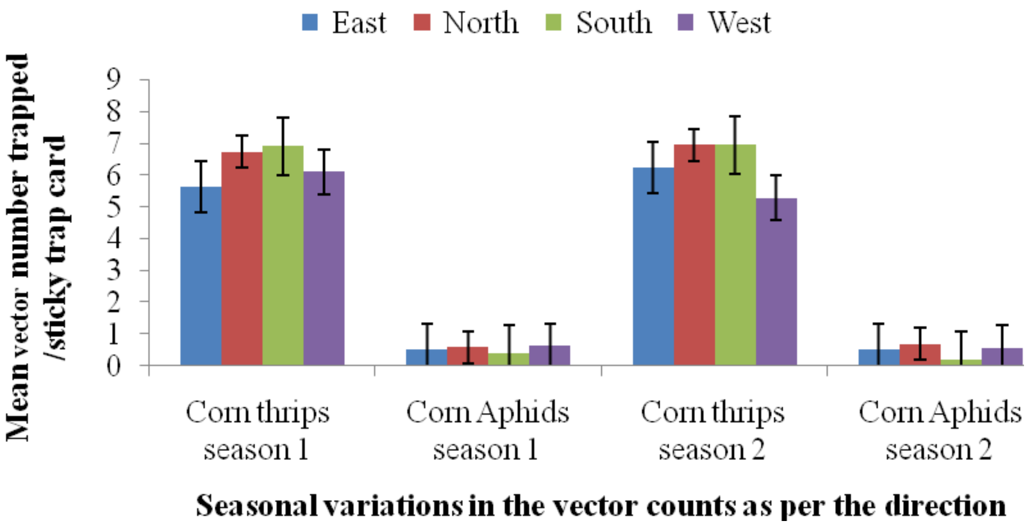
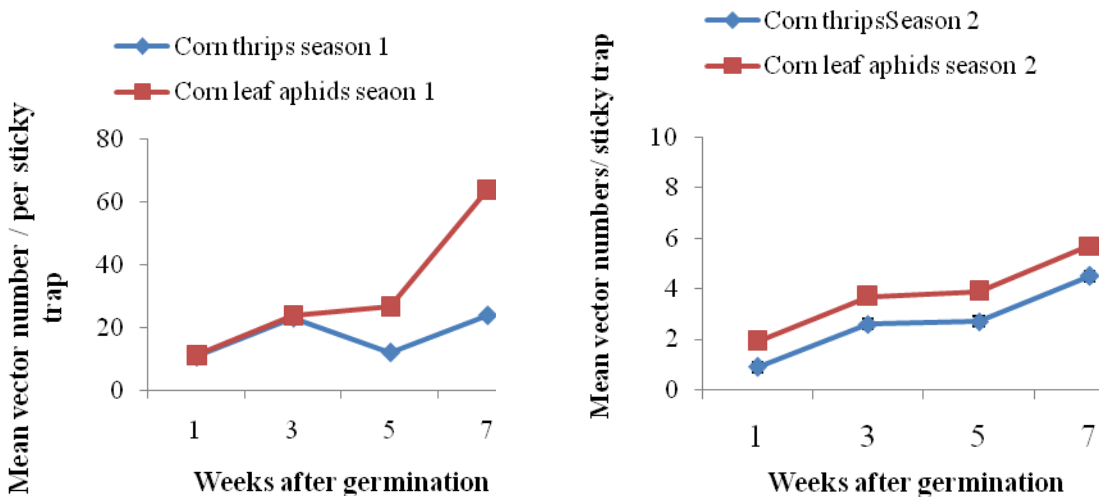


Figure 4.9: Mean number of corn thrips and corn leaf aphids trapped by different orientation of sticky traps across seasons on maize after 24hours

When maize was at the late whorl stage (7 WAG), pooled data from all directions showed captured corn leaf aphids to be significantly higher in both seasons than the corn thrips. A significant gradual increase in the number of corn leaf aphids as the maize grew older was observed (Figure 4.10). In contrast, infestation of corn thrips was lower than the corn leaf aphids in both seasons. However, a significant lower infestation was recorded during the early whorl stage for both seasons (3 WAG) (Figure 4.10).The corn thrips and corn leaf aphids moving into the maize field were significantly higher compared to those moving out in a 24 hour period in seasons (Table 4.10). A similar trend was also observed in corn leaf aphids (Table 4.10)



WAG- Week after Germination, 1WAG (1-2 leaves) 3WAG; (early whorl) collar of fourth leaf visible, 5 WAG; (mid whorl); collar of eighth leaf visible, 7WAG (late whorl); collar of 12th leaf visible

Figure 4.10: Trends in Mean numbers (Pooled) of Corn thrips and Corn leaf aphids trapped by sticky cards at different directions for a period of 24hours

Table 4.10: Mean number of vectors moving in and out of a maize field in Bomet County, Kenya as per the sticky card directions

	Vector movement	Corn thrips	Corn leaf aphids
Season 1	Out of the field	3.7a	0.4
	In the field	9.0b	0.6
	P value	<.001	0.381
	t-value	3.77	0.88
Season 2	Out of the field	4.9a	0.4
	In the field	7.5.b	0.7
	P value	0.218	0.18
	t- value	1.24	1.4
Season 1 &2	Out of the field	4.7a	0.5
	In the field	8.0b	0.6
	P value	<.001	0.5
	t-value	3.62	0.67

***** Means within column followed by the same letter are not significantly different at P =0.05.

When the crop is grown along the North South orientation, it attracts significantly more corn thrips compared with the one grown along the East West orientation; however this relationship is only significant for corn thrips (Table 4.11).

Table 4.11: Mean number of vectors of MLND causing Viruses sampled at different Maize row orientation of maize in Bomet County, Kenya

	Maizerow orientation	Corn thrips	Corn leaf aphids
Season1	Nort to South	13.9a	15.64
	East to West	11.4b	15.07
	P value	0.04	0.8
	t- value	2	0.2
Season 2	East to West	4.8	0.8
	Nort to South	3.9	0.5
	P value	0.8	0.7
	t-value	0.18	0.5
Season 1&2	East to West	7.5b	7.1
	Nort to South	8.5a	7.3
	P value	<.001	0.8
	t- value	1.6	0.16

***** Means within column followed by the same letter are not significantly different at P =0.05).
* Vectors trapped for a period of 24 hrs

Sampling along the rows recorded significantly higher corn thrips compared with across the rows (Table 4.12). A similar trend was recorded for corn leaf aphids although it was not significant (Table 4.12).When the crop is grown in an East to West orientation, infestation is best explained by sampling along the rows both for corn thrips and corn leaf aphids (Table 4.12). Additionally, when the crop is grown in a North to South orientation, infestation of both vectors is likewise best estimated by sampling along the rows (Table 4.12).

Table 4.12: Mean numbers of vectors of MLND causing Viruses sampled along and across rows at Bomet County, Kenya

	sampling pattern	Corn thrips	Corn leaf aphids
Season1	Along the rows	16.0a	17
	Across the rows	9.3b	13
	P value	<.001	0.16
	t- value	5.32	1.4
Season 2	Along the rows	4.82	0.76
	Across the rows	3.92	0.51
	P value	0.08	0.5
	t-value	1.72	0.7
Season 1and 2	Along the rows	9.8a	8.1
	Across the rows	6.3b	6.3
	P value	<.001	0.16
	t value	5.14	1.4

***** Means within column followed by the same letter are not significantly different at P =0.05).

More Corn thrips were significantly (P< 0.001) recorded infesting the upper part of the plant compared with the middle and lower regions in season one. The lower region had significantly lower infestation compared with the rest (Table 4.13). During season two, there was no significant difference recorded in terms of corn thrips infestation among the three plant regions (Table 4.13). Corn leaf aphids were significantly higher (P= 0.035) in the upper region of the plant during the first season. However, the second season showed significantly more (P= 0.003) corn leaf aphids on the lower region of the plant compared with the middle and upper regions that did not differ significantly (Table 4.13). The lower region of the plant had significantly more corn thrips damage compared with the upper region during both seasons significantly (Table 4.13).

Table 4.13: Infestation levels of vectors of MLND causing viruses on maize at various plant regions, Bomet County

	Season1			Season 2		
Plant region	Corn thrips	Corn leaf aphids	Thrips damage level	Corn thrips	Corn leaf aphids	Thrips damage
Lower	1.736c	0.7b	3.2a	5.7	2.783a	3.1a
Middle	4.639b	0.9b	2.7b	6.4	1.217b	2.9a
Upper	6.167a	5.8a	2.3c	5.7	0.942b	2.2b
P value	<.001	0.035	<.001	0.4	0.003	<.001
Se	0.54	2.2	0.14	0.7	0.5	0.3

* Means within column followed by the same letter are not significantly different at P= 0.05

When scouting for thrips, both seasons showed the time spans from 8.30 to10.30am and 3.30 to 5.30 pm significantly recording more corn thrips (P= 0.026), P< 0.001) compared to 12.30 to 2.30 pm (Figure 4.11). During the first season, corn leaf aphids were significantly (P = 0.04) more between 8.30 to 10.30 am although this did not vary significantly with the infestation at 3.30 to 5.30pm period. The corn leaf aphids were significantly lower between 12.30 to 2.30pm. Scouting time had no effect on corn leaf aphid infestation during the second season (Figure 4.11).

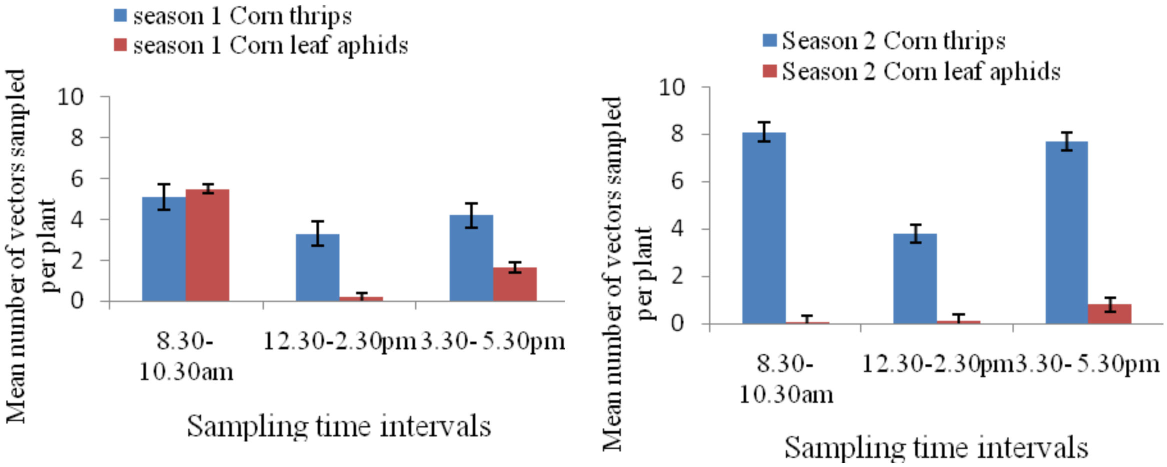


Figure 4.11: Infestation levels of vectors of MLND causing viruses on maize at different sampling time

4.3. Effect of sticky rolls in management of vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

The time of sticky roll installation had no effect on the corn thrips and corn leaf aphid infestation levels on maize in season 1 (Table 4.14). In addition there was no significant difference in the thrips damage levels across all the treatments (Table 4.14). However, MLND severity was significantly (P= 0.001) higher in maize from plots that had no protection compared with plots that were protected by sticky traps (Table 4. 14).

Table 4.14: Mean number of Vector infestation levels during season 1 on maize protected by sticky rolls installed at different times

Sticky roll color	Installation time	Corn thrips	Corn leaf aphids	Thrips damage	MLND severity
No protection	Control	7.29	2.24	2.375	2.675a
Blue	At germination	4.71	2.61	2.2	2.175b
Blue	1 WAG	4.97	2.23	2.225	2.337b
Blue	2WAG	7.18	1.45	2.375	2.362b
Yellow	At germination	6.35	1.72	2.3	2.237b
Yellow	1 WAG	6.05	1.42	2.375	2.188b
Yellow	2WAG	6.35	1.71	2.4	2.288b
p value		0.6	0.3	0.7	0.001
Se		3.0	1.28	0.15	0.2

***** Means within column followed by the same letter are not significantly different at P= 0.05.
WAG: Weeks after germination

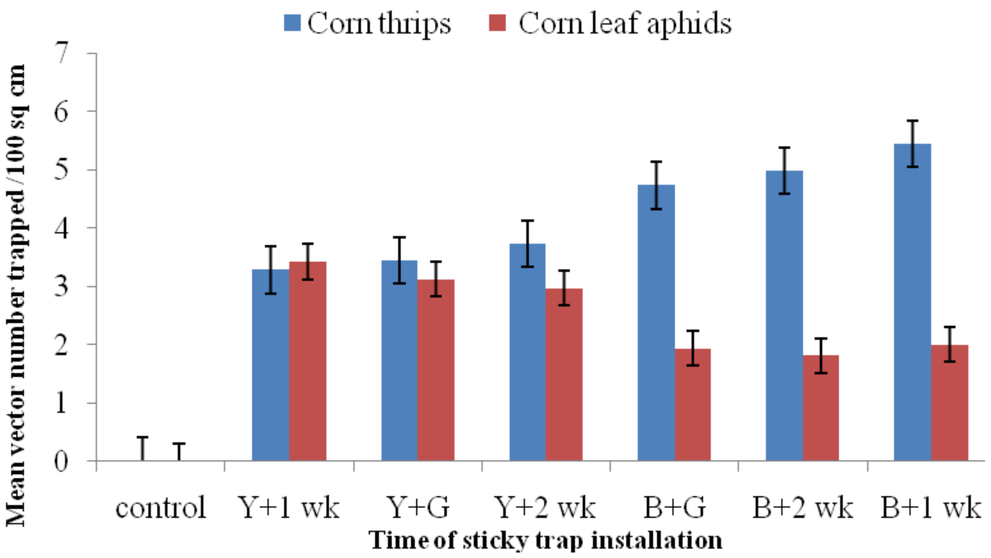
Sticky roll installation time had no effect on thrips damage levels, the corn thrips and corn leaf aphid infestation levels on maize during season 2 (Table 4.15). However, MLND severity was significantly (P= 0.02) higher in plots that were not protected by sticky roll. However, this did not differ significantly with severity in plots installed with blue sticky rolls at germination as well as yellow and blue at two weeks after germination (Table 4.15).

Table 4.15: Mean number of Vector infestation levels during season 2 on maize protected by sticky rolls installed at different times

Sticky roll color	Time of installation	Corn thrips	Corn leaf aphids	Thrips damage	MLND severity
No protection	Control	34.3	39.88	3.3125	3.763a
Blue	At germination	25.5	31.63	3.2188	2.737c
Blue	1 WAG	28.8	57	3.2188	2.938bc
Blue	2WAG	33.1	44.38	3.1875	3.013ab
Yellow	At germination	25.4	30.63	3.1562	3.2ab
Yellow	1 WAG	28.9	42.69	3.2188	2.875bc
Yellow	2WAG	27.3	35.4	3.1333	3.312ab
P value		0.06	0.8	0.9	0.02
Se		3.4	18.4	0.28	0.29

***** Means within column followed by the same letter are not significantly different at P= 0.05).
WAG: Weeks after germination

Time of installation (as shown in plate 4.3) had a significant effect (P <0. 001) on the number of corn thrips and corn leaf aphids trapped by the blue and yellow sticky rolls. Blue sticky rolls installed immediately after germination, one and two weeks after germination trapped significantly more corn thrips compared with the yellow sticky rolls at all regime whereas the yellow sticky rolls trapped significantly more corn leaf aphids compared with the blue ones (Figure 4.12).

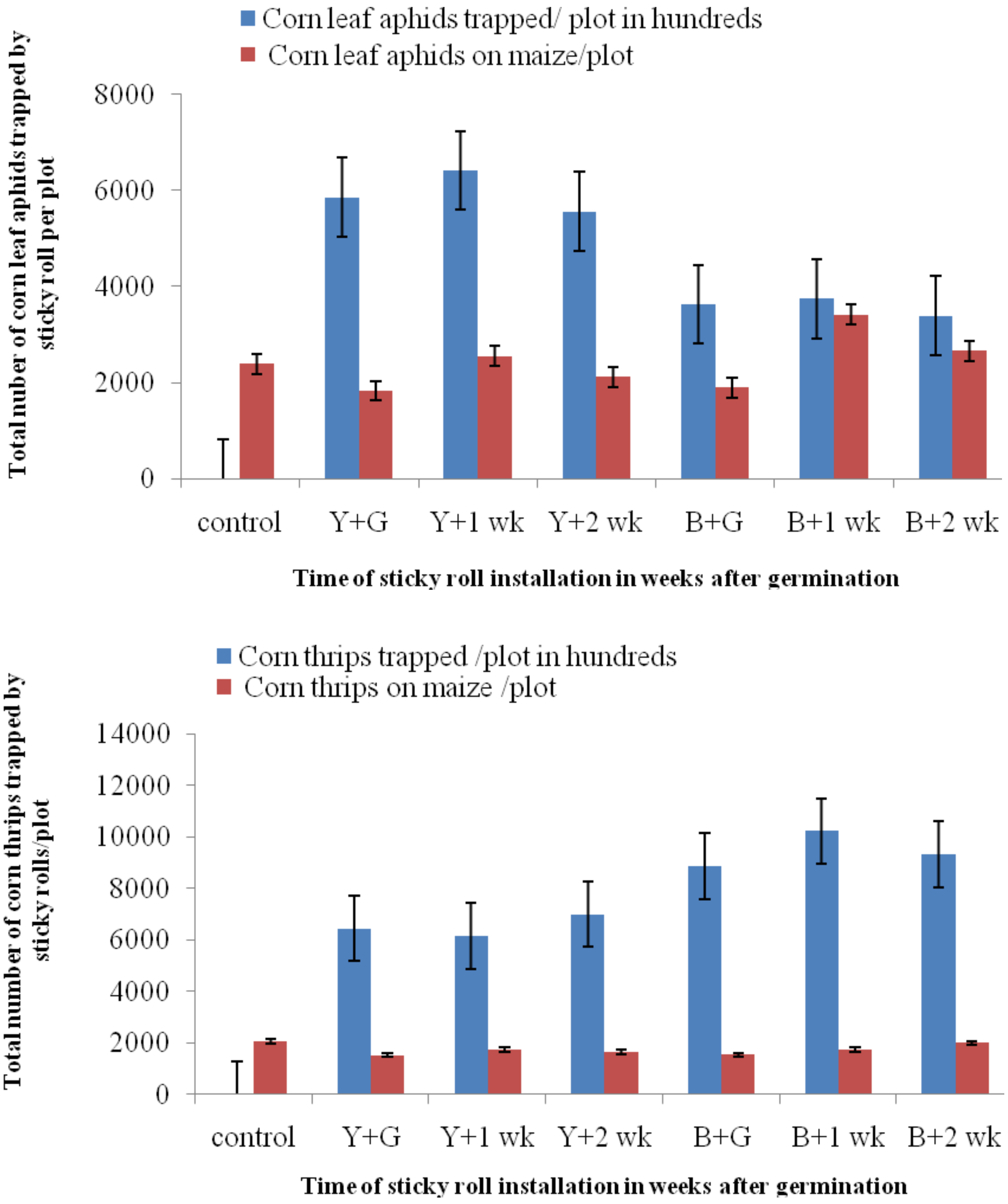


Control; no sticky roll,Y+G; Yellow sticky roll installed immediately after germination, B+G; blue sticky trap installed immediately after germination; B+1wk, Blue sticky roll installed one week after germination, Y+1wk; Yellow sticky roll installed one week after germination, B+2wk; Blue sticky roll installed 2 weeks after germination, Y+2wk; yellow sticky roll inatalled after germination

Figure 4.12: Mean number of vectors trapped on various sticky roll regimes per plot for two months

Plate 4.3: Sticky roll installation around plots in Bomet County of Kenya

More vectors were trapped by the sticky rolls compared to the ones found on maize (Figure 4.13). This means that the sticky traps were able to protect maize from the massive infestation by the corn thrips and corn leaf aphids (Figure 4.13). Correllation analysis shows a significant strong and negative relationship between MLND severity and trapped corn thrips (P = 0.02, r = -0.84) as well as with trapped corn leaf aphids (P = 0.001, r = -0.86). Additionally, corn thrips infestation on maize had a significant strong and negative correlation with corn thrips trapped by sticky rolls (P = 0.04, r = -0.69). However, the corn thrips infestation on maize had a significant strong and positive correlation with MLND severity (P= 0.02, r = 0.82) (Table 4.18).



Control; no sticky roll,Y+G; Yellow sticky roll installed immediately after germination, B+G; blue sticky trap installed immediately after germination; B+1wk, Blue sticky roll installed one week after germination, Y+1wk; Yellow sticky roll installed one week after germination, B+2wk; Blue sticky roll installed 2 weeks after germination, Y+2wk; yellow sticky roll inatalled after germination

Figure 4.13: Total number of vectors on maize and sticky roll for two months period

Samples taken three weeks after germination were MCMV negative in plots installed with yellow sticky rolls at one and two WAG. The MCMV viral load on maize from the control plots did not differ significantly with the one protected with blue sticky roll from 1 WAG and germination. However the positive (antigen from a positive sample obtained from the green house) control had a viral load that was significantly ($P < 001$) higher than any other positive samples (Table 4.16). Seven weeks after germination, maize from control plots and those from plots installed with yellow sticky rolls were MCMV positive while maize from plots protected by blue sticky rolls were MCMV negative (Table 4.15).Maize from control plots registered significantly ($P = 0.005$) higher MCMV viral load although this was not significantly different from the viral load from maize in plots installed with yellow sticky roll at one and two WAG (Table 4.16). Samples taken 3WAG from all plots tested SCMV negative; however, those picked at 7 WAG showed maize from plots installed with blue sticky rolls at 1 and 2 WAG as SCMV positive while maize protected with yellow sticky rolls and blue at germination was SCMV negative (Table 4.16). All maize protected by sticky rolls was MLD negative. Maize from plots not protected by sticky rolls showed different MLND stage levels as shown in plate 4.4.

Table 4.16: Status of MLN virus status on maize in various sticky roll installation regimes on maize in Bomet County of Kenya

Sticky roll color	Treatment	3WAG MCMV	MCMV status	SCMV 3WAG	SCMV status	MLND status	7WAG MCMV	MCMV status	SCMV 7WAG	SCMV status	MLND status
Positive	Positive	0.670a	+	0.246	+	+	0.402ab	+	0.555a	+	+
Yellow	1 WAG	0.284b	-	0.175	-	-	0.293abcd	+	0.145cd	-	-
Yellow	2 WAG	0.2745b	-	0.129	-	-	0.341abc	+	0.146cd	-	-
Blue	1 WAG	0.211bc	-	0.129	-	-	0.193cde	-	0.416ab	+	-
Control	Control	0.210bc	-	0.124	-	-	0.444a	+	0.402ab	+	+
Yellow	Germination	0.193bcd	-	0.173	-	-	0.363abc	+	0.130d	-	-
Blue	Germination	0.190bcd	-	0.139	-	-	0.259bcde	-	0.26bcd	-	-
Blue	2 WAG	0.166cd	-	0.180	-	-	0.262abcd	-	0.39ab	+	-
Negative	Negative	0.125cd	-	0.104	-	-	0.113de	-	0.113d	-	-
Blank	Blank	0.087d	-	0.097	-	-	0.085e	-	0.084d	-	-
	P value	<.001		0.3			0.005		<.001		
	Se	0.05		0.05			0.089		0.09		

***** Means within column followed by the same letter are not significantly different at P= 0.05.

+ Positive - Negative

Plate 4.4: Images of different stages of MLND on maize from plots not protected by sticky rolls

The time of sticky roll installation had no effect on percentage cob fill in maize. However weight of maize cobs per plot was significantly (P = 0.02) higher in plots protected by yellow sticky roll installed at germination (Table 4.17). This did not significantly differ with the weight of cobs in plots protected by blue sticky roll that was installed at germination. Similarly maize weight per cob and per grain displayed the same trend with plots protected by blue and yellow sticky rolls installed at germination significantly (P <001) posting more weight compared to the unprotected maize and maize protected by blue and yellow sticky rollsfrom 1 and 2 WAG (Table 4.17).

Table 4.17: Yield properties of maize in various sticky roll installation regimes for season 1

Sticky roll color	Time of installation	Maize weight(kg)/ plot	%cob fill	Weight of maize cobs (kg)/18.75m^2	Fresh weight in (kg)/18.75m^2	Weight (g)/ seed
Yellow	At germination	182.5a	89.6	21.90a	2.63a	0.4117a
Blue	At germination	169.5ab	82.6	20.34ab	2.44ab	0.4218a
Blue	1 WAG	165.5abc	82.8	19.86ab	2.38ab	0.3105b
Yellow	1 WAG	144.0bc	79.0	17.28bc	2.07bc	0.3256b
Yellow	2 WAG	140.8bc	73.8	16.89bc	2.03bc	0.2887b
Blue	2 WAG	134.0c	76.0	16.08c	1.93c	0.2656b
Control	Control	131.4c	83.8	15.77c	1.89c	0.2787b
	P value	0.02	0.2	0.02	0.02	<.001
	se	17.1	6.2	2.1	0.25	0.033

***** Means within column followed by the same letter are not significantly different at P=0.05.
To convert to tonnes multiply all figures in kg by 0.5333 ((10,000/area of plot (kg))/ 1000).

There is a strong and negative significant correlation between the MCMV viral load and the corn thrips trapped by the sticky roll (r = - 0.82, P = 0.003) (Table 4.18). In addition, the MCMV viral load shows a strong and high positive correlation with thrips infestation on maize (r = 0.91, P = 0.001). Similarly, a strong and negative significant correlation is found between MLND severity and the trapped corn leaf aphids (r =0.86, p =0.01) (Table 4.18). Corn leaf aphids and the SCMV viral load shows a strong and negative significant correlation (r = -0.74, P = 0.02). A similar trend is observed between the corn leaf aphids and the thrips damage (r = - 0.82, P = 0.03). Corn thrips infestation on maize has a strong and negative significant correlation with fresh weight per plot, weight of cobs per plot, and the weight per seed (r = -0.77, P = 0.02) (Table 4.18).

Table 4.18: Correlation in between vectors of MLND causing viruses and yield characteristics various sticky roll installation regimes on maize in Bomet County of Kenya

	1	2	3	4	5	6	7	8	9	10	11
1	-										
2	0.6231	-									
3	-0.1543	0.6055	-								
4	0.6848	0.3556	-0.4208	-							
5	-0.3223	0.029	0.6305	-0.8247*	-						
6	-0.3919	-0.8657**	-0.7404**	0.0332	-0.434	-					
7	0.9067***	0.8243**	-0.1373	0.8497**	0.532	-0.346	-				
8	-0.8241*	-0.844*	-0.2196	-0.505	0.086	0.481	-0.6942*	-			
9	-0.4646	-0.5674	-0.0291	-0.7755*	0.467	0.398	-0.6647	0.4123	-		
10	-0.465	-0.5678	-0.0294	-0.7753*	0.467	0.399	-0.6647	0.4129	1	-	
11	-0.4649	-0.5674	-0.0289	-0.7755*	0.467	0.399	-0.6648	0.4126	1	1	-

1. **MCMV viral load, 2. MLND severity 3. SCMV severity, 4. Corn thrips damage, 5. Corn leaf aphids on maize, 6. Corn**
2. **leaf aphids trapped, 7. Corn thrips on maize, 8. Corn thrips trapped, 9. Fresh weight per plot, 10. Weight per cob in g 11. Weight per cop per plot**

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

4.4. Action threshold level of vectors transmitting Maize Lethal Necrosis Disease causing viruses

The spray regimes had significant effects on the corn thrips infestation during the first and second season (Table 4.19). Plots sprayed on a weekly basis significantly recorded lower corn thrips infestations (P= 0.01) compared to those sprayed after three weeks, monthly spray intervals as well as the one sprayed with water and those not spayed (Table 4.19). The same trend was observed during the second season although the general corn thrips infestation levels were lower compared with the first season (Table 4.19). The spray regimes administered had no effect on corn leaf aphids infestation in both seasons and thrips damage level in season 1 (Table 4.19). However, thrips damage level was significantly lower in plots sprayed on a weekly basis during the second season (Table 4.19).

Table 4.19: Vectors of MLND causing viruses infestation on maize under different spray (Thunder) regimes in Bomet County, Kenya

		Season 1			Season 2		
spray regime	No. of sprays	Corn thrips	Corn leaf aphids	Corn thrips damage	Corn thrips	Corn leaf aphids	Corn thrips damage
Weekly	10	7.15c	1.9	2.15	3.7c	0.6	2.03b
Fortnight	5	11.05bc	2.1	2.43	4.9bc	0.2	2.31ab
After 3wks	4	14.4ab	3.8	2.53	7.6ab	0.4	2.44a
Monthly	3	16.3ab	4.7	2.45	8.3ab	1.0	2.47a
No spray	0	18.8a	7.5	2.75	8.6a	0.5	2.44a
P value		0.01	0.3	0.4	0.02	0.4	0.02
Se		3.7	6.9	0.6	1.97	0.6	0.17

***** Means within column followed by the same letter are not significantly different at P= 0.05.

During season 1, maize across the treatments was MCMV positive. The MCMV viral load of maize in plots that were not sprayed and those sprayed with thunder on a monthly basis had significantly ($P < 0.001$) higher MCMV viral load compared with the viral load on maize in plots sprayed after one, two and three weeks interval (Table 4.20). Maize sampled from plots that were not sprayed were the only ones that were SCMV positive hence were infected with MLND (Table 4.20).

During season 2, maize in plots sprayed on a weekly and fortnight basis tested MCMV negative while maize in plots sprayed after every 3 weeks, monthly and those not sprayed were MCMV positive (Table 4.21). In addition to that, maize sampled from plots that were not sprayed and those sprayed on a monthly basis tested SCMV positive hence were infected with MLND (Table 4.21).

Table 4.20: Disease status in plots under various spray regimes during season 1 in Bomet County of Kenya

Spray regime	MCMV	Status	SCMV	Status	MLND status
Blank	0.089d	Negative	0.0850d	Negative	Negative
Negative	0.124d	Negative	0.121cd	Negative	Negative
Weekly spray	0.2592c	Positive	0.1373c	Negative	Negative
Positive	0.2810c	Positive	0.2060b	Positive	Positive
Fortnight spray	0.2995c	Positive	0.1450c	Negative	Negative
After 3 weeks spray	0.3335b	Positive	0.1418c	Negative	Negative
Monthly spray	0.4545a	Positive	0.1350c	Negative	Negative
No spray	0.4802a	positive	0.2595a	Positive	Positive
P value	<.001		<.001		
Se	0.04		0.02		

***** Means within column followed by the same letter are not significantly different at P= 0.05.

Table 4.21: Disease status in plots under various spray regimes during season 2 in Bomet County of Kenya

Spray regime	MCMV	Status	SCMV	Status	MLND status
Blank	0.0890e	Negative	0.0850d	Negative	Negative
Negative	0.1240d	Negative	0.1210d	Negative	Negative
Weekly spray	0.1333d	Negative	0.1507d	Negative	Negative
Positive	0.2810ab	Positive	0.206bc	Positive	Positive
Fortnight spray	0.2102c	Negative	0.1095d	Negative	Negative
After 3 weeks spray	0.2590b	Positive	0.1758cd	Negative	Negative
Monthly spray	0.2873ab	Positive	0.2893ab	Positive	Positive
No spray	0.3220a	Positive	0.3230a	Positive	Positive
P value	<.001		<.001		
Se	0.04		0.08		

***** Means within column followed by the same letter are not significantly different at P =0.05.

Maize sampled at 3 weeks after germination from all plots were not sprayed were MCMV positive while those from plots sprayed by all other regimes were all negative (Figure 4.14) Maize sampled sampled at 7 weeks after germination from plots sprayed after every three weeks, monthly and those that did not receive any spray were MCMV positive. Those plots sprayed on a fortnight and weekly basis were all MCMV negative (Figure 4.14). Similarly the same trend was seen in SCMV infection in maize sampled at 7weeks after germination (Figure 4.15). At 3 and 7 weeks after germination, only maize from plots that received no spray was SCMV positive (Figure 4.15). The viral load of both MCMV and SCMV was significantly higher in maize sampled at seven weeks after germination compared with the viral load at three weeks after germination (Figure 4.14 & 4.15).

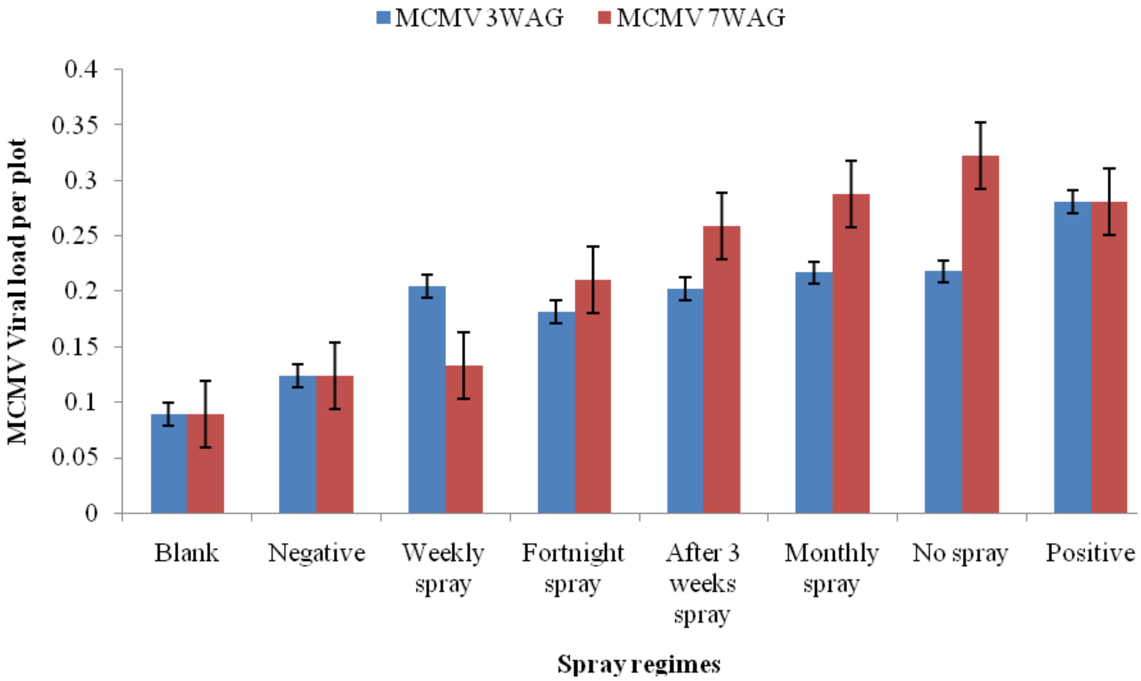


Figure 4.14: MCMV viral load at 3 and 7weeks after germination

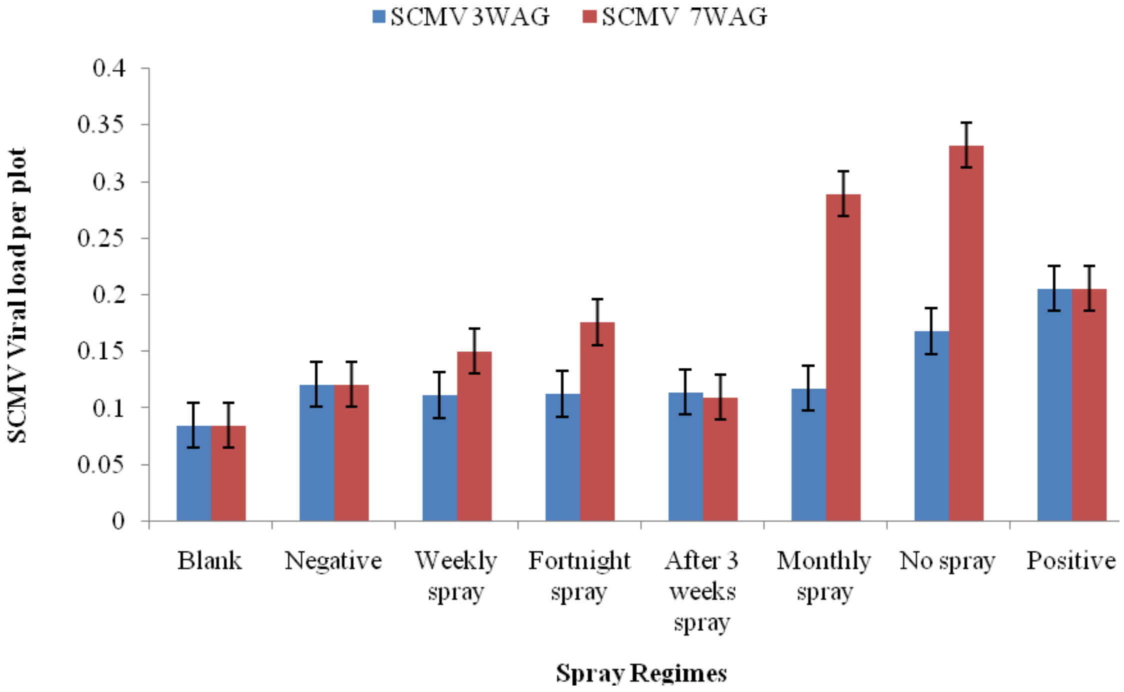


Figure 4.15: SCMV viral load at 3 and 7weeks after germination

During season 1, plots sprayed on a weekly basis recorded significantly high ($P<0.001$) and better yield properties compared with plots sprayed with the other regimes (Table 4.22). However, weight of good seeds and fresh weight of maize from plots that were sprayed after every two weeks did not differ significantly with those from plots sprayed on a weekly basis (Table 4.22). Significantly lower yield properties ($P<0.001$) were registered in maize from plots that were not sprayed compared with yield properties from plots sprayed with thunder (Table 4.22). During season 2, plots sprayed by thunder on a weekly basis recorded significantly more weight of cobs ($P= 0.01$) and good seeds ($P= 0.02$) compared plots that were not sprayed (Table 4.23).

Table 4.22: Yield properties of maize grown under different spray regimes during season 1 in Bomet County, Kenya

Spray regime	% cob fill	Weight of cobs (kg) / 18.75m^2	Weight of bad grains (kg) / 18.75m^2	Weight per grains (g)	Weight of good grains (kg) /18.75m^2	Fresh weight (kg) /18.75m^2	Dry weight (kg)/ 18.75m^2
Weekly spray	92.20	16.86a	0.33	0.2695a	11.6222a	11.946a	10.959a
Fortnight spray	94.21	13.94b	0.26	0.2024b	10.02ab	10.346b	7.677b
After 3 weeks spray	95.62	11.88bc	0.6	0.2083b	8.361bc	8.952c	7.569b
Monthly spray	93.00	12.36bc	0.49	0.1784b	8.349bc	8.904c	6.732bc
No spray	95.12	10.56c	0.54	0.2103b	7.659c	8.25c	6.342c
P value	0.78	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	2.95	1.38	0.4	0.02	1.04	1	0.95

***** Means within column followed by the same letter are not significantly different at P= 0.05

To convert to tonnes multiply all figures in kg by 0.5333((10,000/area of plot (kg))/ 1000)

Table 4.23: Yield properties of maize grown under different spray regimes during season 2 in Bomet County, Kenya

Spray regime	% cob fill	Weight of cobs (kg) / 18.75m^2	Weight of bad seeds (kg) / 18.75m^2	Weight per seed (g)	Weight of good seeds (kg) /18.75m^2	Fresh weight (kg) /18.75m^2	Dry weight (kg)/ 18.75m^2
Weekly spray	79.4	8.758a	0.2506a	0.00016	6.593ba	6.61	6.36a
Fortnight spray	78.8	8.327a	0.2326ab	0.00471	6.123a	6.24	5.917a
After 3 weeks spray	74.8	7.039a	0.2041bc	0.00099	5.257ab	5.38	5.06ab
Monthly spray	77	7.643a	0.1945bc	0.00025	5.699a	5.73	5.419ab
No spray	65	4.759b	0.168c	0.00096	3.605b	4.97	3.075b
P value	0.5	0.01	0.002	0.5	0.02	0.13	0.001
Se	13.5	1.15	0.024	0.00002	0.9	0.94	0.88

***** Means within column followed by the same letter are not significantly different at P= 0.05

To convert to tonnes multiply all figures in kg by 0.5333((10,000/area of plot (kg))/ 1000)

The spray regimes influenced the corn thrips infestation differently and this eventually resulted into significant yield differences that brought about different marginal rates of return per each regime (Table 4.24). Although higher yield was realized in maize from plots that received weekly sprays, the net returns from the same plots was lower due to the increased cost of insecticides (Table 4.24). Higher net returns were realized from the monthly spray regimes followed by the sprays made after every three weeks and fortnightly (Table 4.24). It is therefore evident that the thunder spray done on a monthly basis is the most economical since it resulted in the highest marginal net return (Table 4.24).

Table 4.24: Mean Yield of maize, cost of insecticide and marginal rate of return for different spray regimes at Bomet County Kenya

Spray regime	No. of sprays	Yield (Kg) per 75m^2	Yield (Kg) per ha	Value in (Kes) per ha	Total Thunder cost (Kes) /ha	Marginal return rate (Kes)
Monthly spray	3	24.302	3240.27	107998.09	28,800	79,198
After 3 weeks spray	4	25.258	3367.73	112246.55	46,300	65,947
Fortnight spray	5	27.188	3625.07	120823.47	55,400	65,423
Weekly spray	10	34.638	4618.4	153931.27	110,800	43,131

The linear function of yield against corn thrips infestation shows declining maize yield as the number of corn thrips density increases (Figure 4.16). The cost of thunder insecticide was linearly and positively related to economic threshold level of corn thrips (EIL) (Figure 4.17). The higher the economic injury levels the higher the cost of insecticide. Contrary to this observation, net returns of maize yield had a linear and negative relationship with the EIL of the corn thrips (Figure 4.18). Therefore using the equation in Figure 4.17 and 4.18 action threshold was 12 corn thrips per two plants hence 6 corn thrips per maize plant. At the point where they meet the action taken to control vectors is equal to the net returns realized from maize sales (y = 11.06x – 21.87, y = -4.571x+ 166.8).

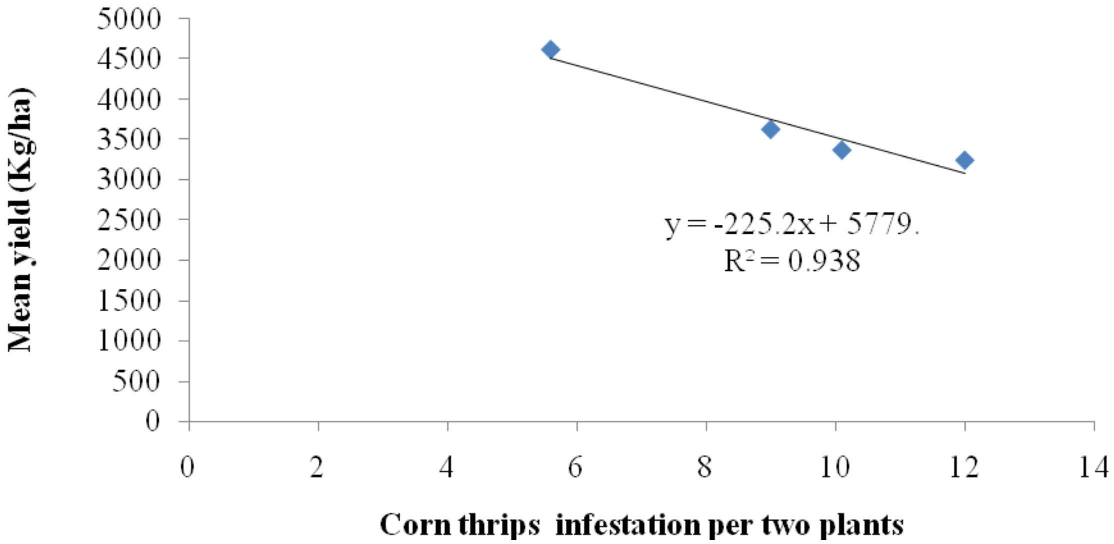


Figure 4.16: Regression of maize yield against mean number of Corn thrips on maize at Bomet County, Kenya

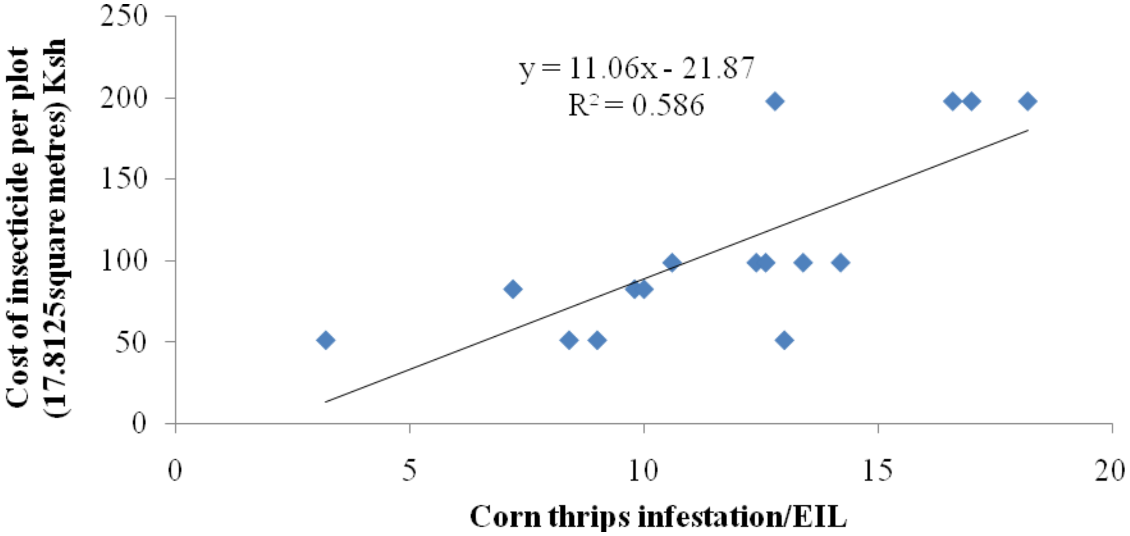


Figure 4.17: Regression ofcost of insecticide against Economic injury level of Corn thrips on maize at Bomet County, Kenya

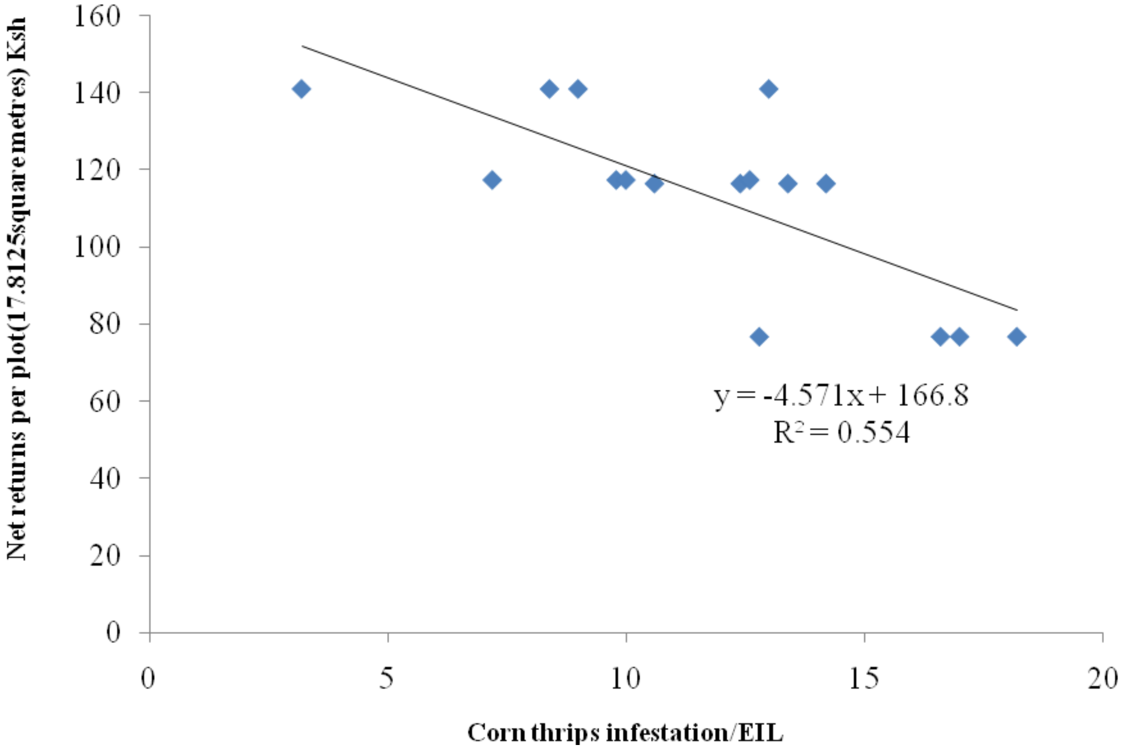


Figure 4.18: Regression of Net returns against Economic injury level of Corn thrips per two maize plants at Bomet County, Kenya

Maize yield declined as the number of corn leaf aphids density increased according to linear regression (Figure 4.19). Moreover, the cost of thunder insecticide was linearly and positively related to the economic threshold level of corn leaf aphids (EIL) (Figure 4.20). The results showed a direct proportion between the economic injury level and the cost of insecticide. However, net returns from maize yield had a linear and negative relationship with the EIL of the corn leaf aphids (Figure 4.21). Using the equation in Figure 4.20 and 4.21 action threshold was 6 corn leaf aphids per two plants hence 3 corn leaf aphids per maize plant. At the point of interception for the two graphs, action taken to control vectors is equal to the net returns realized from maize sales ($y = 10.40x + 44.29$, $y = -3.811x + 136.4$).

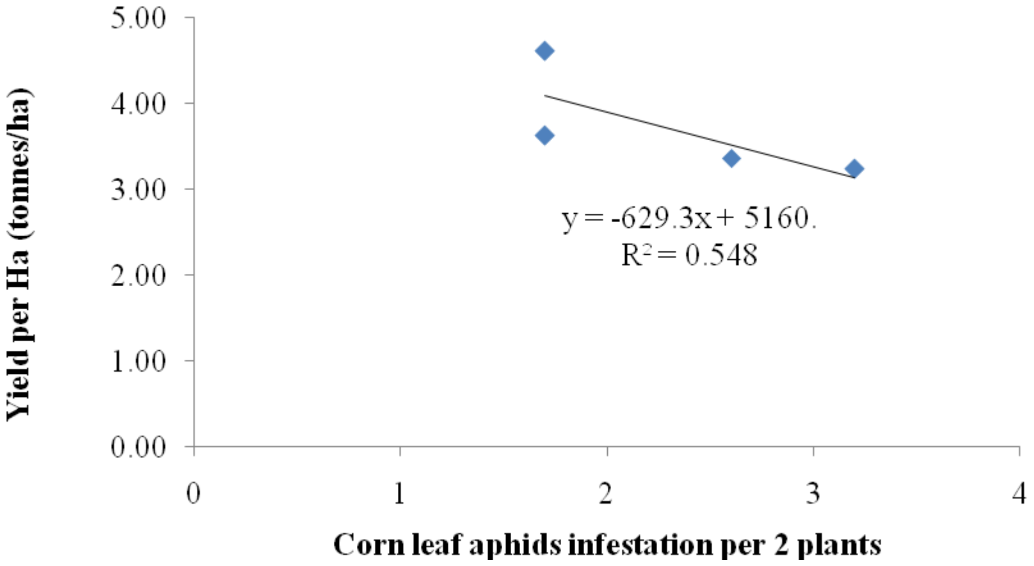


Figure 4.19: Regression of maize yield against mean number of Corn leaf aphids on maize at Bomet County, Kenya

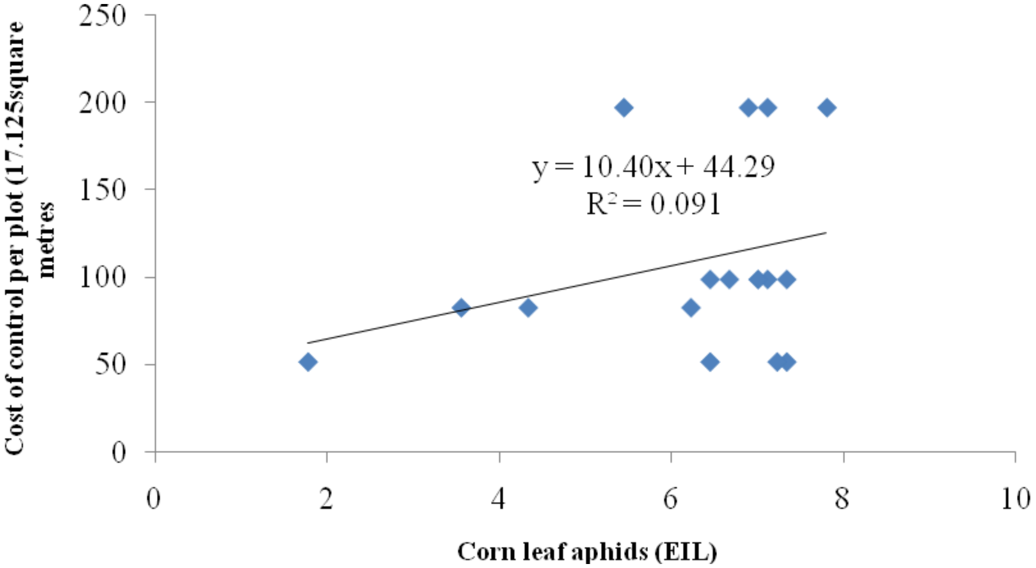


Figure 4.20: Regression of Economic injury levels (EIL) of Corn thrips and Corn leaf aphids against cost of insecticide control at Bomet County, Kenya

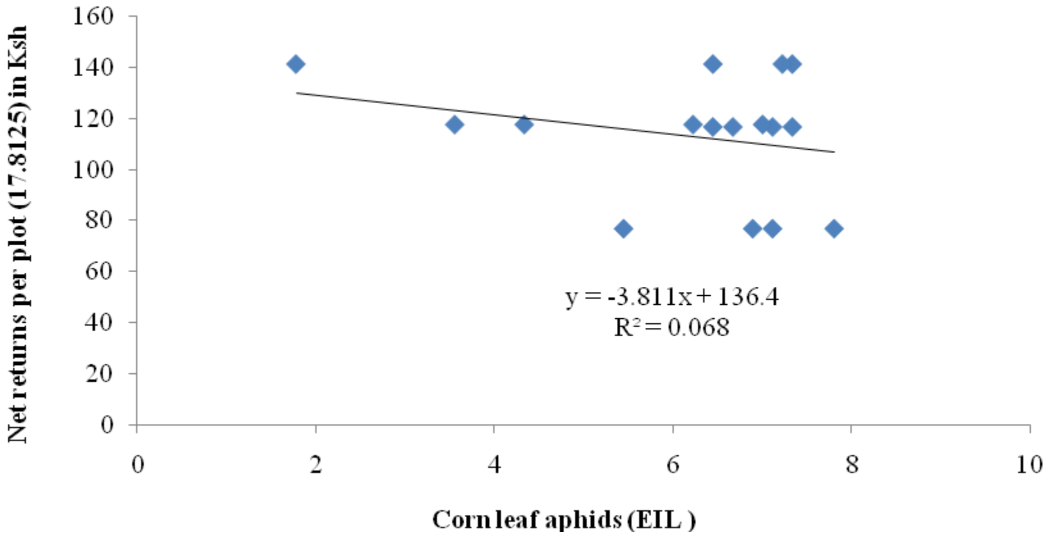


Figure 4.21: Regression of Economic injury levels of vectors against the Net returns per plot at Bomet County, Kenya

Increased, corn leaf aphids infestation resulted into lower yield as observed in weight per seed (r = -0.82, P= 0.04), weight of good seeds per plot r=-0.87, P = 0.02), weight of cobs per plot (r = -0.88, P =0.02) and fresh weight per plot (r = -0.86, P = 0.02) in season 1. (Table 4.25). Similarly, increased corn thrips infestation resulted into reduced weight per seed (r = -0.94, P = 0.006, weight of good seeds (r = -0.95, P = 0.003), weight of cobs per plot (r = -0.96, P = 0.002), fresh weight and dry weight of seeds per plot (r = -0.94, P ≤ 0.001) (Table 4.25). Moreover, increase in corn leaf infestation led to an increase in SCMV viral load (r = 0.87, P = 0.02) and MCMV viral load (r = 0.91, P = 0.01) (Table 4.25).

During season 2, severe corn thrips damage led to reduced weight per seed (r = -0.95, P = 0.020, weight of good seeds(r = -0.86, P= 0.02), weight of cobs (r = -0.91. P =0.01), fresh weight and dry weight per plot (r = 0.86, P value = 0.02) (Table 4.26). However, increased spray frequency resulted into an increase in dry weight of maize per plot (r = 0.9, P = 0.01) as well reduced MCMV viral load (r = -0.81, P = 0.04). Correlation analysis showed a decrease in MCMV viral load led to heavier weight per seed (r = -0.82, P = 0.04) while increase in the spray frequency led to increased weight per seed (r = 0.87, P = 0.02), weight of good seeds (r = 0.95, P = 0.002) and fresh weight per plot (r = 0.96, P = 0.001). (Table 4.26).

Table 4.25: Correlation among the vector infestation MLND viral load and yield characteristics, season 1 in Bomet County

		1	2	3	4	5	6	7	8	9	10	11
Corn leaf aphids	1	-										
Corn thrips	2	0.94**	-									
Thrips damage	3	0.88**	0.92**	-								
Dry weight	4	-0.79	-0.94**	-0.89*	-							
Fresh weight	5	-0.86*	-0.94**	-0.85*	0.93	-						
MCMV	6	0.91**	0.92**	0.79	-0.82*	-0.76	-					
SCMV	7	0.87*	0.73	0.76	-0.63	-0.75	0.63	-				
Spray frequency	8	0.94**	-0.97**	-70.85*	0.90*	0.97**	-0.87*	-0.82*	-			
Cob weight	9	-0.88*	-0.96***	-0.92**	0.95	0.99	-0.78	-0.76	0.96**	-		
Weight good seeds	10	-0.87*	-0.95**	-0.86*	0.93	0.99	-0.78	-0.74	0.97***	0.99	-	
Weight per seed	11	-0.82*	-0.94**	-0.96**	0.98	0.89	-0.82*	-0.67	0.87*	0.923	0.89	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

Table 4.26: Correlation among the vector infestation MLND viral load and yield characteristics in season 2, Bomet County

		1	2	3	4	5	6	7	8
Corn thrips	1	-							
Corn thrips damage	2	0.9089**	-						
Dry weight	3	-0.8131*	-0.7197	-					
Fresh weight	4	-0.8441*	-0.6937	0.9713	-				
MCMV	5	0.9686***	0.9463**	-0.8724	-0.8653	-			
SCMV	6	0.8409*	0.638	-0.7031	-0.7062	0.797*	-		
Weight of good seeds	7	-0.7836	-0.6169	0.956	0.9928	-0.812*	-0.6653	-	
Weight per seed	8	-0.96**	-0.8979**	0.9289	0.9149	-0.9877***	-0.8272	0.8679	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

The spray frequency showed a negative linear relationship with corn thrips and corn leaf infestation on maize (Figure 4.22).

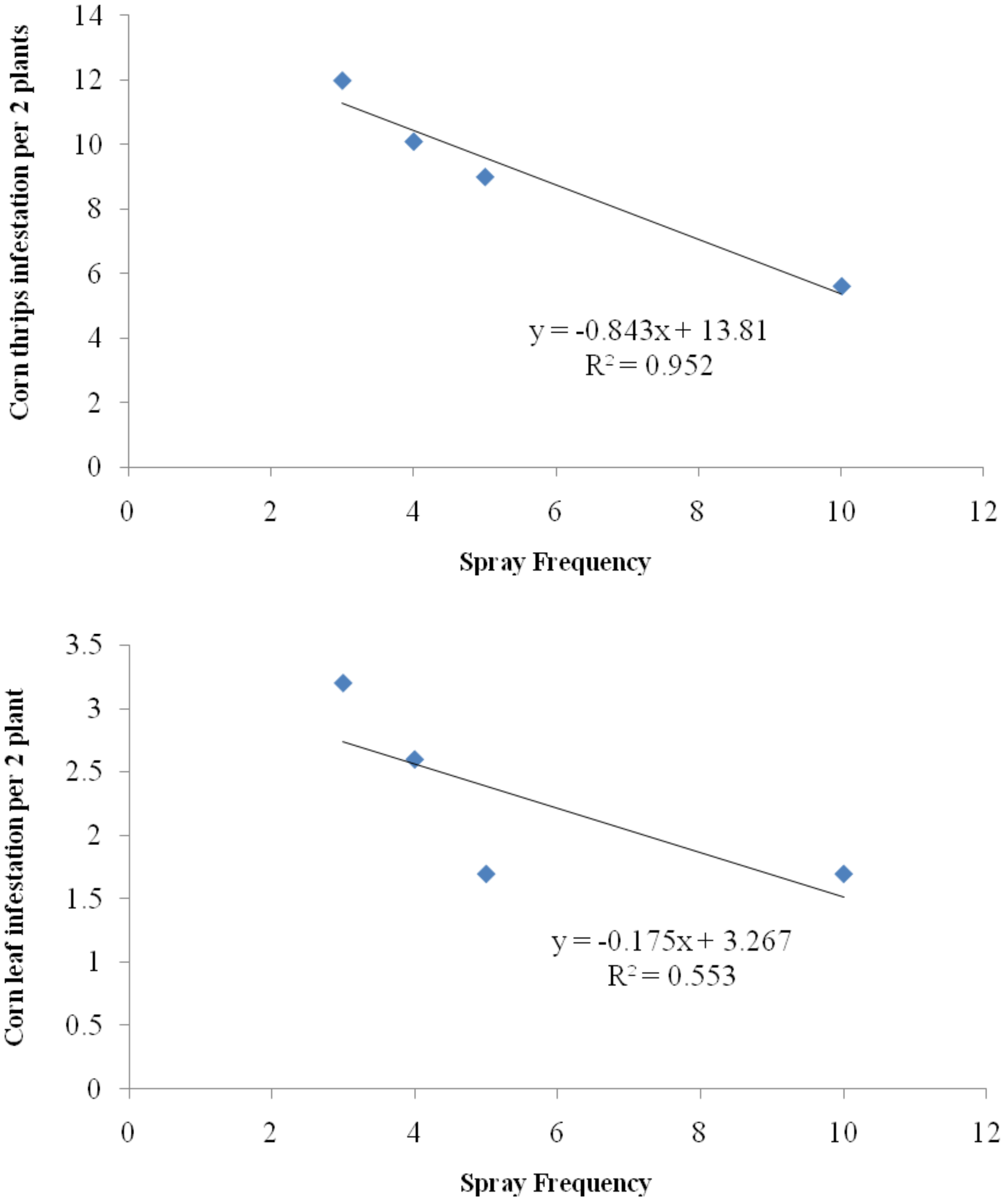


Figure 4.22: Regression of mean number of vectors against the spray frequencyon Maize at Bomet County, Kenya

Increase in the number of corn thrips and corn leaf aphids subsequently led to the increase in the viral load of MCMV and SCMV virus respectively (Figure 4.23).

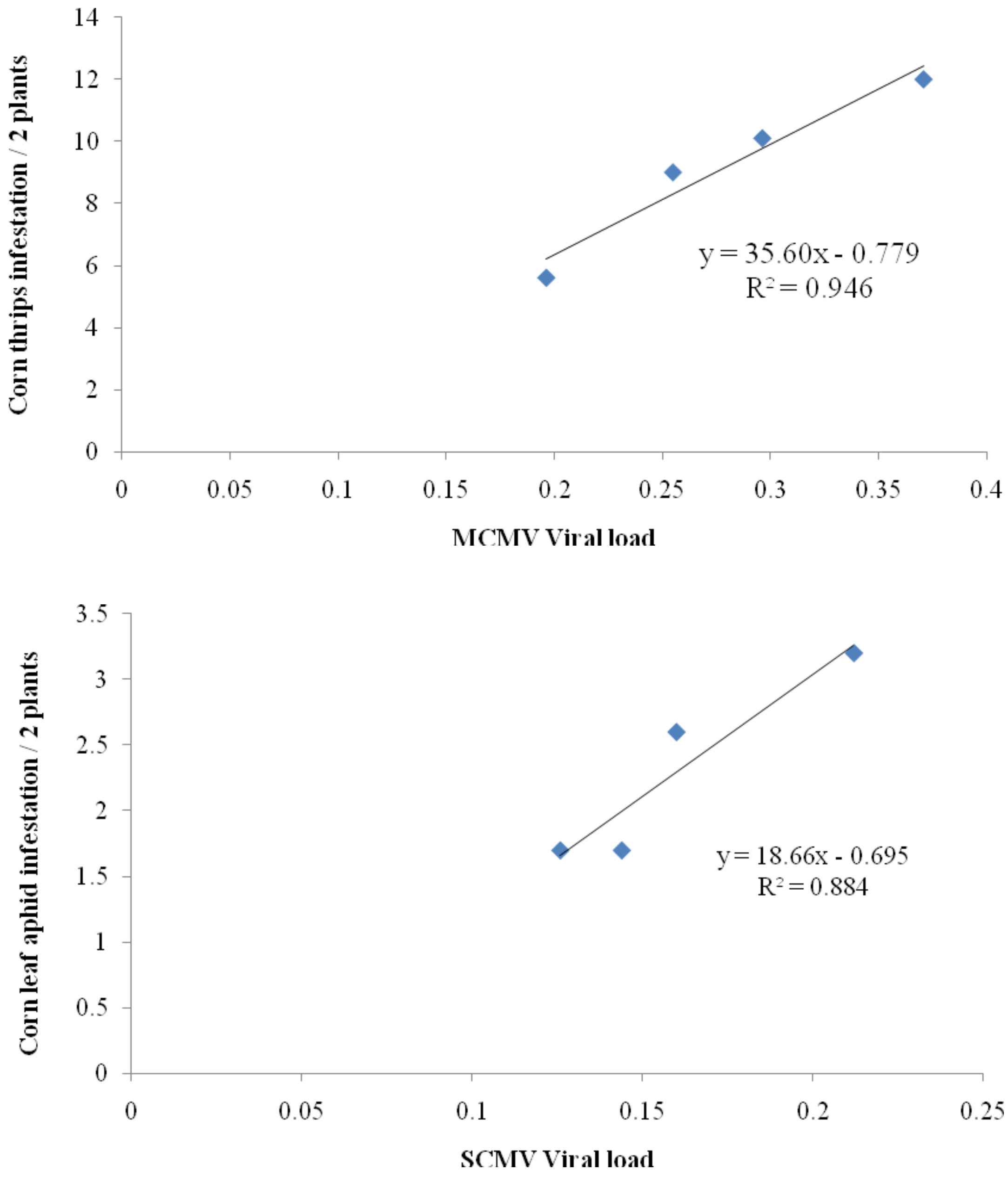


Figure 4.23: Regression of mean number of vectors against the MCMV and SCMV viral load on Maize at Bomet County, Kenya

Increase in MCMV and SCMV viral load in maize crops resulted into a decrease in maize yield (Figure 4.24). Every increase in MCMV viral load by one unit decreased 0.9532 tonnes per ha while increase in SCMV by 1 unit decreased maize yield by 0.1tonnes of maize per ha (Figure 4.24).

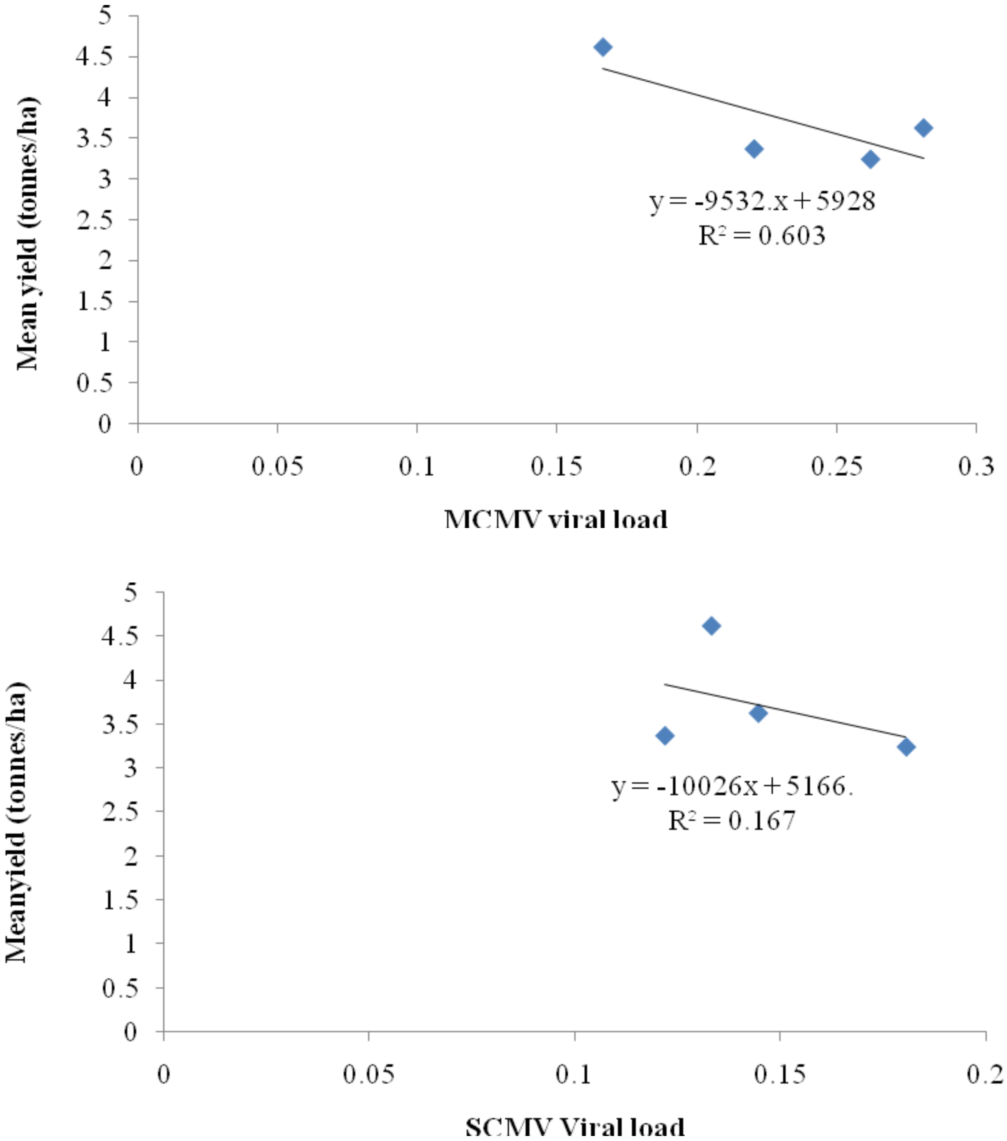


Figure 4.24: Regression of mean yield of maize against the MCMV and SCMV viral load on Maize at Bomet County, Kenya

There was a linear negative relationship between the corn thrips damage level on maize and the maize yield produced (Figure 4.25). Every increase in thrips damage per unit led to a decease of 8kg per plot (17.8125 m^2) (Figure 4.25).

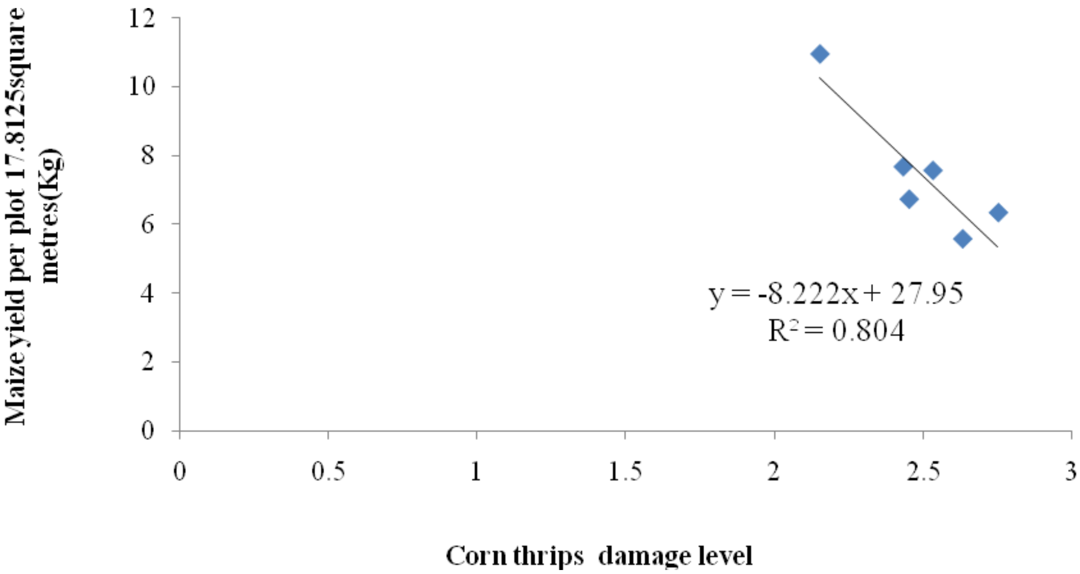


Figure 4.25: Regression of mean yield of maize against the corn thrips damage on Maize at Bomet County, Kenya

4.5. Varietal tolerance to vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

Corn thrips and corn leaf aphids’ infestation had no significance difference among all the varieties for pooled seasons as well both season one and season 2 (P = 0.8) (Figure 4.26).

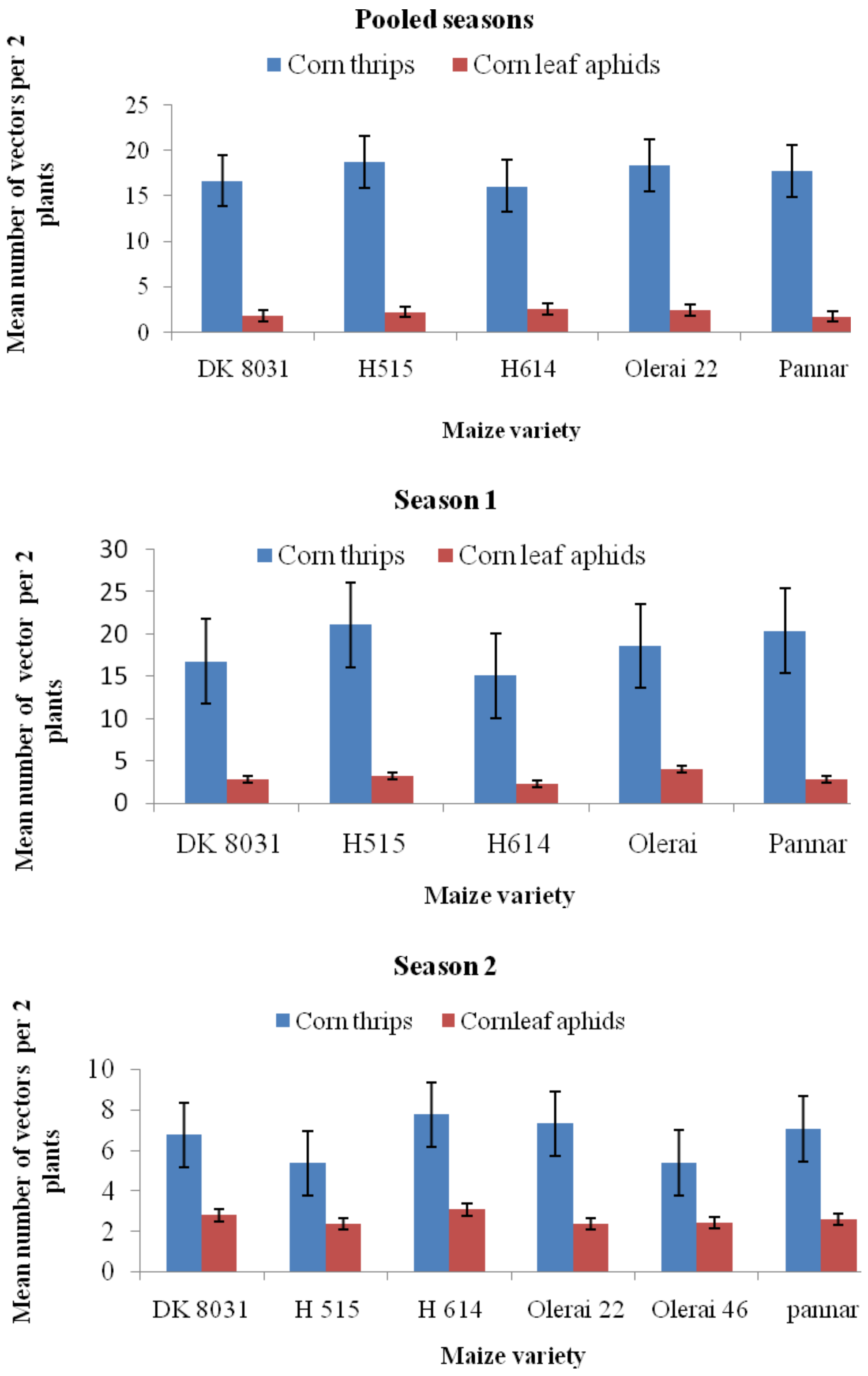


Figure 4.26: Mean numbers of vector infestation on different maize varieties in Pooled seasons, season 1 and 2

Corn thrips and corn leaf aphids' infestation levels had no significant difference among landraces planted during the rain onset and those planted two weeks after the onset of rainfall (Table 4.27). However, during the rain onset, MLR 13 had significantly (0.04) lower corn thrips damage levels compared with the others. This damage did not significantly differ from the one in MLR 1 MLR 3, MLR 8 and MLR 18 (Table 4.27).

Table 4.27: Mean vector infestation and corn thrips damage levels on landraces planted during the onset of rain and 2 weeks after the rain onset in season 1

	Planted during the rain onset			**Planted 2 weeks after rain onset**		
Variety	Thrips damage	Corn Thrips	Corn leaf aphids	Thrips damage	Corn thrips	Corn leaf aphids
MLR 4	3.344a	9.8	1.4	3.208	24.9	6.6
MLR 17	3.25ab	13.1	3.1	3.354	29.5	7.4
MLR 9	3.25ab	17.3	2.3	3.104	32.5	11.9
MLR 5	3.156ab	17.1	1.5	3.375	33.2	6.1
MLR 12	3.094ab	14.2	3.8	3.208	30.6	7.5
MLR 16	3.094ab	13.5	1.6	3.188	29.5	8
MLR 6	3ab	15.5	3.3	3.146	33.9	7.5
MLR 10	2.969ab	13.9	3.5	3.354	28.3	4.5
MLR 15	2.938ab	18.3	3	3.229	30.1	6.9
MLR 7	2.938ab	13.5	2.8	3.125	31.3	12.4
MLR 11	2.906ab	15.3	1.9	3.25	34.3	10.3
MLR 14	2.906ab	14.7	2.2	3.354	31.9	6.9
MLR 2	2.906ab	13.8	3.9	3.042	29	7.8
MLR 1	2.812bc	16.7	1.8	3.062	30.1	8.5
MLR 18	2.812bc	16.9	2.2	3.292	28.4	8.7
MLR 3	2.812bc	17.2	2.6	3.146	31.7	6.1
MLR 8	2.812bc	14.6	2	2.979	32.9	6.1
MLR 13	2.406c	12.4	2.7	3.25	33	11.6
Pvalue	0.04	0.4	0.4	0.37	0.6	0.57
Se	0.23	3	2	0.158	3.78	4.8

* Means within column followed by the same letter are not significantly different at P=0.05.

Corn thrips damage levels, corn thrips and corn leaf aphids' infestation levels had no significant difference among landraces that were planted during the onset of rain in season 2 (Table 4.28). However, in those planted two weeks after the rain onset, MLR 4 had significantly higher corn thrips damage levels compared with MLR13 which had the least damage (Table 4.28)

Table 4.28: Mean vector infestation and corn thrips damage levels on landraces planted during the rain onset and 2 weeks after rain onset during season 2

	Planted during the rain onset			**Planted 2 weeks after rain onset**		
Landrace	Corn thrips damage	Corn thrips	Corn leaf aphids	Corn thrips damage	Corn thrips	Corn leaf aphids
MLR 16	3.03	13.06	0.63	3ab	34.3	25.9
MLR 4	3.05	10	0.44	3.344a	24.5	21.8
MLR 17	3.25	12.75	3	3.25bc	38.6	32.8
MLR 9	3.11	17.12	1.5	3.25ab	31.9	29.4
MLR 5	2.12	18.06	0.69	3.156ab	21.4	15.1
MLR 12	3.25	14.12	4.19	3.094ab	31.4	21.1
MLR 6	3.2	16.12	4.5	3.094ab	31.7	23.6
MLR 10	2.47	13.75	4	2.969ab	18.4	9.1
MLR 15	3.13	17.94	2.75	2.938ab	28.1	22.5
MLR 7	3.2	13.31	2.31	2.938ab	25.1	20.2
MLR 14	2.97	14.75	1.75	2.906ab	32.2	21.1
MLR 11	2.97	15.88	1.13	2.906ab	37.8	30.2
MLR 2	2.62	13.75	4.88	2.906ab	20.8	16.1
MLR 18	3.09	17	2.31	2.812bc	33.4	27.2
MLR 8	2.69	14.38	1.19	2.812bc	28.4	29.6
MLR 3	2.72	17.12	3.56	2.812bc	29.2	24.9
MLR 1	3.25	16.25	1.19	2.812bc	32.3	24.5
MLR 13	3.23	13.81	2.81	2.406c	31.4	25.7
P value	0.9	0.3	0.4	0.03	0.2	0.5
Se	0.6	3.8	1.9	0.2	7	8.8

***** Means within column followed by the same letter are not significantly differentat P= 0.05

During season 1, corn thrips and corn leaf aphids infestation in maize planted during the onset of rain was significantly (P< 0.001) lower compared with maize planted two weeks after the rain onset (Figure 4.27). Similarly, infestation of corn leaf aphids in season 2 was significantly higher on maize planted 2 weeks after the rain onset compared with the infestation in maize planted during the rain onset (Figure 4.27). However the time of planting in relation to rain onset had no effect on corn thrips infestation during season two (Figure 4.27).

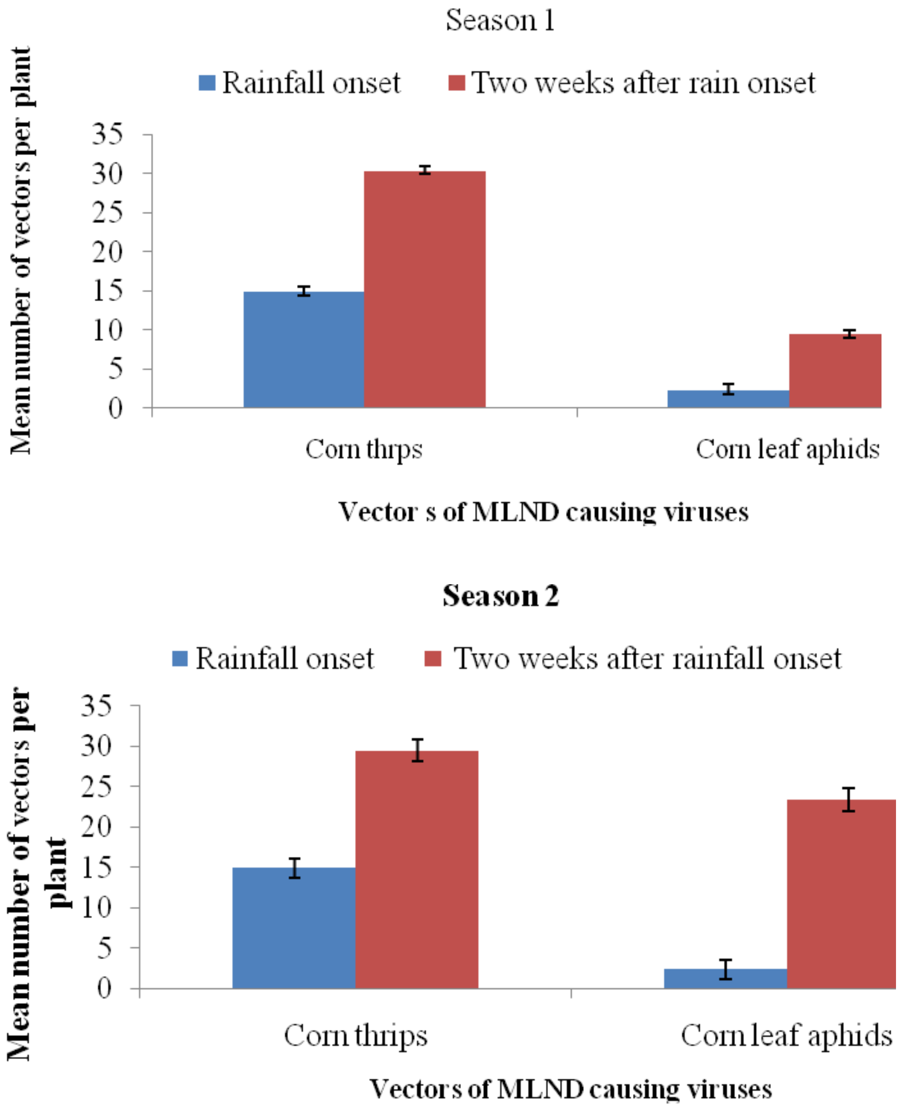


Figure 4. 27: Vector infestation in maize planted during the rain onset and two weeks after

During season one, all the varieties were MCMV positive except for H515 that was negative (Table 4.29). The MCMV viral load was significantly ($P<0.001$) higher in variety DK 8031 although the same variety tested negative for SCMV. The MCMV viral load in DK 8031 was not significantly different from the one in H614 and Olerai. Variety H614 was the only one that was positive for MCMV and SCMV. Therefore maize lethal necrosis occurred only in H614 maize variety among all the five varieties (Table 4.29).

During season two, all the varieties were MCMV positive (Table 4.29). The MCMV viral load was significantly ($P<0.001$) higher in varieties H614 and H515 compared to other varieties. Pannar and H515 were the only maize varieties that were SCMV negative and hence MLND free. Variety DK8031 and Olerai 22 had SCMV viral load that was significantly ($P<0.001$) higher than any other varieties. This viral load was not significantly different from the one found in variety H614 (Table 4.29).

Table 4.29: Maize lethal necrosis disease virus status in various maize varieties in Bomet County

Seasons	Maize Variety	MCMV load	MCMV status	SCMV load	SCMV status	MLND status
Season 1	DK 8031	0.3890a	Positive	0.1010cd	Negative	Absent
	Olerai 22	0.3163ab	Positive	0.1202bc	Negative	Absent
	H614	0.2923ab	Positive	0.1328b	Positive	Present
	Positive control	0.2810b	Positive	0.2060a	Positive	Present
	Pannar	0.2795b	Positive	0.1038bcd	Negative	Absent
	H515	0.2233bc	Negative	0.1145bcd	Negative	Absent
	Negative control	0.1440cd	Negative	0.1280bc	Negative	Absent
	Blank control	0.0890d	Negative	0.0850cd	Negative	Absent
	P value	<.001		<.001		
	Se	0.05		0.014		
	Maize varieties	MCMV load	MCMV status	SCMV load	SCMV status	MLND status
Season 2	H 614	0.9699a	Positive	0.2254ab	Positive	Present
	H 515	0.9600a	Positive	0.1507bc	Negative	Absent
	Olerai 22	0.8079ab	Positive	0.3189a	Positive	Present
	DK 8031	0.7595ab	Positive	0.3059a	Positive	Present
	Pannar	0.6896ab	Positive	0.1336bc	Negative	Absent
	Positive control	0.6280b	Positive	0.2430ab	Positive	Present
	Negative control	0.2378c	Negative	0.0910c	Negative	Absent
	Blank control	0.0840c	Negative	0.0890c	Negative	Absent
	P value	<.001		<.001		
	Se	0.142		0.062		

***** Means within column followed by the same letter are not significantly different at P= 0.05).

Amongst the landraces planted during the onset of rainfall, MLR 7, MLR 9, MLR 10 and MLR 15 tested negative for both MCMV and SCMV hence MCMV negative (Table 4.30). In addition, MLR 12 tested SCMV negative hence MLND negative (Table 4.30). Landraces that had significantly (P<0.001) lower MCMV viral load were MLR 12 while MLR 2 had significantly (P<0.001) lower SCMV viral load (Table 4.30). However, MLR 18, MLR 13, MLR 8 and MLR 4 had a significantly higher MCMV and SCMV viral load compared with rest (Table 4.30).

Table 4.30: Maize lethal necrosis disease virus status in various landraces grown on the onset of rain in Bomet County, Kenya

Landraces	MCMV viral load	MCMV status	SCMV viral load	SCMV status	MLND status
MLR 18	1.1618a	Positive	1.2782a	Positive	Positive
MLR 13	0.9715ab	Positive	0.7963b	Positive	Positive
MLR 8	0.8165abc	Positive	0.8480b	Positive	Positive
MLR 4	0.7477bcd	Positive	0.8565b	Positive	Positive
MLR 11	0.6790bcde	Positive	0.8355b	Positive	Positive
MLR 16	0.6747bcde	Positive	0.6425bc	Positive	Positive
MLR 3	0.6530bcde	Positive	0.7492bc	Positive	Positive
MLR 14	0.5740cdef	Positive	0.6002bc	Positive	Positive
Positive	0.555cdefg	Positive	0.5630bcd	Positive	Positive
MLR 6	0.4863cdefgh	Positive	0.4900bcdef	Positive	Positive
MLR 5	0.4670cdefghi	Positive	0.5240bcde	Positive	Positive
MLR 1	0.4525cdefghi	Positive	0.4475bcdef	Positive	Positive
MLR 17	0.4110defghij	Positive	0.4760bcdef	Positive	Positive
MLR 12	0.3588efghij	Positive	0.1395ef	Negative	Negative
MLR 2	0.2575fghij	Positive	0.3735cdef	Positive	Positive
MLR 10	0.2002ghij	Positive	0.1527ef	Negative	Negative
MLR 9	0.1725hij	Negative	0.3675def	Positive	Negative
MLR 7	0.1472hij	Negative	0.1517ef	Negative	Negative
MLR 15	0.1432hij	Negative	0.1492ef	Negative	Negative
Negative	0.1130ij	Negative	0.1210ef	Negative	Negative
Blank	0.0840j	Negative	0.0890f	Negative	Negative
P value	<.001		<.001		
Se	0.18		0.21		

***** Means within column followed by the same letter are not significantly different at P= 0.05.

Maize planted two weeks after the onset of rainfall tested negative for both MCMV and SCMV in landraces MLR 7 and MLR 9 (Table 4.31). In addition, MLR 1, 6, 11, 12 and MLR 15 were SCMV negative while MLR 10 was MCMV negative. All the fore mention therefore had no MLND. The landraces MLR 13, MLR 15 and MLR 16 had a significantly lower MCMV viral load while MLR2, MLR 17 and MLR 18 had significantly higher MCMV viral load (Table 4.31). Landraces MLR 4 and 18 had a significantly higher SCMV viral load while MLR 16 and MLR 17 had significantly lower SCMV viral load (Table 4.31).

Table 4.31: Maize lethal necrosis disease virus status in various landraces grown 2 weeks after the onset of rain in Bomet County, Kenya

Landraces	MCMV viral load	MCMV status	SCMV viral load	SCMV status	MCMV status
MLR 17	0.7072a	Positive	0.5138bcd	Positive	Positive
MLR 18	0.6867ab	Positive	0.8450a	Positive	Positive
MLR 2	0.6755ab	Positive	0.2700de	Positive	Positive
MLR 6	0.673ab	Positive	0.1225e	Negative	Negative
MLR 14	0.5833abc	Positive	0.6070abc	Positive	Positive
MLR 3	0.5673bcd	Positive	0.5617bcd	Positive	Positive
Positive	0.5630bcd	Positive	0.3777cd	Positive	Positive
MLR 1	0.5215cde	Positive	0.1188e	Negative	Negative
MLR 4	0.4982cdef	Positive	0.8585a	Positive	Positive
MLR 12	0.4977cdef	Positive	0.1897e	Negative	Negative
MLR 5	0.4810cdef	Positive	0.6268abc	Positive	Positive
MLR 11	0.4705cdef	Positive	0.1223e	Negative	Negative
MLR 8	0.4320dfg	Positive	0.7258ab	Positive	Positive
MLR 13	0.4040efg	Positive	0.6510abc	Positive	Positive
MLR 15	0.3700fg	Positive	0.1430e	Negative	Negative
MLR 16	0.3320g	Positive	0.5137bcd	Positive	Negative
MLR 7	0.1472h	Negative	0.1477e	Negative	Negative
MLR 9	0.1303h	Negative	0.1045e	Negative	Negative
MLR 10	0.1300h	Negative	0.7060ab	Positive	Negative
Negative	0.1210h	Negative	0.0990e	Negative	Negative
Blank	0.0890h	Negative	0.0900e	Negative	Negative
P value	<.001		<.001		
Se	0.06		0.15		

* Means within column followed by the same letter are not significantly differentat P= 0.05.

During season 1, variety H614 had a significantly (P<0.001) lower percentage cob fill compared with H515, DK 8031, Olerai and Pannar that did not differ significantly (Table 4.32). Similarly, variety H614 posted significantly (P<0.001) lower fresh weight and dry weight as well as weight of good seeds and weight of cobs per plot (Table 4.32). Varieties Pannar and Olerai posted significantly ($P<0.001$) more weight of cobs and fresh weight per plot compared to the rest. However, variety H515 had significantly more weight of diseased seeds compared to all the varieties (Table 4.32).

During season 2, Pannar had a significantly ($P<0.001$) high percentage cob fill and fresh weight per plot as compared with cob filling in Olerai, H515, DK 8031 and H515 (Table 4.33). A significantly ($P<0.001$) high cob weight, cob weight per plot and weight of good seeds ($P = 0.02$) were seen in variety Olerai compared to H515 variety that had significantly lower values (Table 4.33). Similarly yield characteristics such as percentage cob fill, weight of good seeds and dry weight per plot in H614 variety did not significantly differ from the one in H515 (Table 4.33).

Table 4.32: Mean weight and percentage of various yield characteristics of maize subjected to varietal treatments during season 1

Variety	Weight/ cob (g)	%cob fill	Weight of cobs in kg/11.25m^2	Fresh weight kg/11.25m^2	Weight/ grain (g)	Weight goods grain kg/11.25m^2	Weight of diseased grains kg/11.25m^2	Dry weight per plot kg
Olerai	74.05a	90.62a	5.85a	4.15a	0.5269a	4.24a	0.518ab	3.238a
Pannar	69.12ab	89.46a	5.53ab	4.139a	0.3063b	3.78a	0.4845ab	3.515a
H515	67.9ab	85a	5.432ab	4.047a	0.3226b	3.652a	0.772a	3.09a
DK 8031	56.61b	91.88a	4.529b	3.8866a	0.295b	3.272a	0.1226b	3.676a
H614	26.98c	41.25b	2.118c	1.396b	0.243b	1.074b	0.3621b	0.912b
P value	<.001	<.001	<0.001	<0.001	0.018	<0.001	0.03	<0.001
Se	6.5	6.11	0.6	0.5	0.08	0.627	0.2	0.4

***** Means within column followed by the same letter are not significantly different at P=0.05.

Table 4.33: Mean weight and percentage of various yield characteristics of maize subjected to varietal treatments during season 2

Variety	Weight/ cob (g)	%cob fill	Weight of Cobs in kg/11.25m^2	Fresh weight kg/11.25m^2	Weight/ grain (g)	Weight goods grain kg/11.25m^2	Weight of diseased grains kg/11.25m^2	Dry weight per plot kg/11.25m^2
Pannar	124.3b	84.38a	9.945b	8.86	0.261	7.73ab	0.78	7.869a
Olerai	167.2a	70.83ab	13.379a	8.47	0.838	8.101a	0.25	7.321a
DK 8031	107.7bc	66.25b	8.615bc	7.4	0.492	6.855abc	0.11	7.131a
H 614	105.4bc	72.5ab	8.436bc	7.99	0.273	5.671bc	1.54	5.921ab
H 515	82.6c	69.45b	6.61c	6.35	0.308	4.674c	0.51	4.744b
	0.001	0.12	<0.001	0.34	0.2	0.02	0.2	0.04
	0.6	7.2	1.596	1.91	0.6	1.21	0.75	1.1

***** Means within column followed by the same letter are not significantly different at P=0.05.

N/B To convert to tonnes per ha multiply Kg by 0.888; ((10,000/11.25)10000)

During season one, the sugar cane mosaic viral load was significant and negatively correlated to the weight per cob as well the weight of good grains per plot (r = -0.91, P = 0.03; r = -0.86, p = 0.025) (Table 4.34). Similarly the MCMV viral load was significant and negatively correlated to the bad grains (r = 0.94, P = 0.01). There was a significant and negative correlation between the SCMV viral load and the dry weight of the grains (r = - 0.88, P = 0.008) (Table 4.34).

During season 2, there was a significant strong and negative correlation seen between the MCMV viral load and the dry weight per plot (r = -0.91, P = 0.003) (Table 4.35).

Table 4.34: Correlations among vectors of MLND causing viruses and yield in different varieties during season 1

		1	2	3	4	5	6	7	8
Good grains	1	-							
MCMV load	2	0.1249	-						
SCMV load	3	-0.9117*	-0.3314	-					
Weight of good grains	4	0.9894	0.1622	-0.8653*	-				
Weight of diseased grains	5	0.1903	-0.942**	-0.0042	0.1343	-			
Dry weight	6	0.9815	0.2308	-0.8866*	0.9809	0.0677	-		
Corn leaf aphids	7	-0.8401	-0.4312	-0.9643**	-0.8085	0.1119	-0.7973	-	
Corn thrips	8	0.7118	0.5624**	-0.5187	0.6609	0.7772	0.6547	-0.3391	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

Table 4. 35: Correlations among vectors of MLND causing viruses and yield in different varieties during season 2

		1	2	3	4	5	6	7
Weight goods Grain	1	-						
Weight of cobs	2	0.845	-					
Corn leaf aphids	3	0.525	0.494	-				
Corn thrips	4	0.563	0.512	0.9985***	-			
Dry weight	5	0.9565**	0.659	0.55	0.59	-		
MCMV viral load	6	-0.84	-0.453	-0.2	0.22	-0.9117**	-	
Weight per cob	7	0.8658*	0.997***	0.55	0.57	0.695	0.473	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

Landrace planted during the onset of rainfall showed MLR 12 showing a significant % cob fill, cob weight, weight of good grains as well as the fresh and dry weight. This was not significantly different from yield characteristics observed in MLR 1, MLR 3 and MLR 9 and MLR 11 compared to the rest. Landraces MLR 5 and MLR 4 had significantly lower yield characteristics compared with the others (Table 4.36). Additionaly, MLR 1 had significantly more weight of bad grains compared with the others (Table 4.36).

Landraces planted two weeks after the onset of rainfall had significantly higher yield characteristics in MLR1, MLR 9 and 15. These three landraces showed significantly more percentage cob fill, weight per cob, weight of good grains, fresh weight and dry weight compared to the other landraces (Table 4.37). However, significantly lower % cobs fill, cob weight and weight of good grains was observed in MLR 4, MLR 5, MLR 18 and MLR 10 (Table 4.38). Fresh weight was significantly lower in landraces MLR 4, MLR 5, MLR 10 and MLR 16 while dry weight was significantly lower in MLR 10 (Table 4.37). Weight of bad grains was significantly higher in MLR 1, MLR 16 and MLR 18 while MLR 4, MLR 5, MLR 10, MLR 13, MLR 14 and MLR 17 had significantly less weight of bad grains (Table 4.37). There was no landrace effect on the weight per grain in both landraces planted during the onset and two weeks after the rain onset (Table 4.36 and 4.37).

Table 4.36: Yield properties of different landraces of maize planted during the onset of rainfall

Landraces	%fill	Cob Weight in per 2.5m^2 in kg	Weight per seed in g	Weight of good seeds per 2.5m^2 in kg	Weight of bad grains per 2.5m^2 in kg	Fresh weightper2.5m^2 in kg	Dry weight per 2.5m^2 in kg
MLR 12	41.82a	4.714a	0.1204	3.226a	0.621bc	3.636ab	3.18a
MLR 11	36.33ab	4.675ab	0.1499	2.801ab	0.1979c	2.999bc	3.365a
MLR 9	35abc	2.464cdef	0.9334	2.205abc	1.0463b	3.251abc	1.851abcd
MLR 1	34.39abcd	4.396abc	0.9201	3.19a	1.8767a	4.875a	3.019ab
MLR 14	34.17abcde	2.724bcdef	0.196	1.998abc	0.322c	2.32bcde	1.943abcd
MLR 2	32.01abcde	2.419def	0.1274	1.63bc	0.2475c	1.578cde	1.548cd
MLR 3	30abcde	3.702abcd	0.2069	2.692ab	0.2335c	2.925bc	2.623abc
MLR 6	27.93abcde	2.431def	0.2133	1.623bc	0.4006bc	1.904cde	1.764bcd
MLR 18	26.8bcde	2.497def	0.1652	1.806bc	0.1856c	1.8cde	1.697cd
MLR 10	26.44bcdef	3.538abcd	0.604	2.608ab	0.3101c	2.605bcd	2.602abc
MLR 17	25.98bcdef	1.894def	0.2358	1.284bc	0.2529c	1.477cde	1.346cd
MLR 8	25.54bcdef	2.264def	0.0997	1.737bc	0.2273c	1.606cde	1.802bcd
MLR 7	25.01bcdef	3.2abcde	0.1088	1.577bc	0.4762bc	1.782cde	1.136d
MLR 13	23.2bcdef	2.048def	0.1876	1.424bc	0.2948c	1.419cde	1.557cd
MLR 15	22.5bcdef	2.03def	0.2079	1.49bc	0.1313c	1.622cde	1.574cd
MLR 4	21.87bcdef	1.707ef	0.0925	1.017c	0.183c	0.961de	1.328cd
MLR 16	18.33cef	1.832def	0.2893	1.433bc	0.0209c	1.454cde	1.387cd
MLR 5	11.42f	0.945f	0.2215	0.718c	0.2136c	0.513e	0.573d
Pvalue	0.04	<.001	0.3	0.01	<.001	0.01	0.004
Se	8	0.9	0.04	0.6	0.6	1.75	0.74

***** Means within column followed by the same letter are not significantly different at P= 0.05.

N/B Toconvert to tones per ha multiply by 4; ((10,000/2.5)/1000)

Table 4.37: Yield properties of different landraces of maize planted 2 weeks after the onset of rainfall

Landrace	% cob fill	Cob weight / 2.5m^2(Kg)	weight per grain(g)	Weight of good grains / 2.5m^2(Kg)	weight of bad grains/ 2.5m^2 (Kg)	Fresh weight / 2.5m^2(Kg)	Dry weight / 2.5m^2(Kg)
	46.67a	5.888ab	0.2092	0.351ab	0.007715a	0.4251a	0.3477a
	43.5ab	5.174abc	0.2334	0.371a	0.002709bcde	0.3883abc	0.3481a
MLR 15	41.87ab	4.692abcde	0.2079	0.3689a	0.002723bcde	0.3961ab	0.3417a
MLR 14	40.62abc	6.317a	0.196	0.3279abc	0.001262de	0.34abcd	0.3028ab
MLR 3	36.62abcd	5.012abcd	0.2069	0.268abcd	0.006111abc	0.3283abcd	0.2629abc
MLR 6	30.37abcde	3.203cdefg	0.2133	0.2371abcde	0.001799cde	0.2546abcde	0.2343abcd
MLR 13	30.25abcde	2.997cdefg	0.1876	0.2105abcde	0.000281e	0.2158bcde	0.203abcd
MLR 11	30bcde	2.631cdefg	0.1499	0.1816bcde	0.002579bcde	0.2073bcde	0.187abcd
MLR 8	29.57bcde	3.589bcdef	0.0997	0.2322abcde	0.002558bcde	0.2578abcde	0.2395abc
MLR 2	27.32bcde	3.816abcdef	0.1274	0.2352abcde	0.005245abcd	0.2876abcd	0.256abc
MLR 7	27.12bcde	2.689cdefg	0.1088	0.1728bcde	0.001708cde	0.1914de	0.163bcd
MLR 17	25.25cde	1.435fg	0.2358	0.1951abcde	0.000661e	0.2017cde	0.1973abcd
MLR 12	25cde	2.404defg	0.1204	0.1448bde	0.002851bcde	0.1729de	0.1349cd
MLR 18	24.12de	1.2011fg	0.1652	0.1677cde	0.006634ab	0.217bcde	0.1366bcd
MLR 5	21.88de	1.1973fg	0.2215	0.1386de	0.001259de	0.1512de	0.1382bcd
MLR 10	21.5de	1.03g	0.0604	0.071e	0.00079e	0.0787e	0.0688d
MLR 16	21.38de	2.564cdefg	0.2893	0.1854bcde	0.006855ab	0.1939de	0.1948abcd
MLR 4	20e	2.071efg	0.0925	0.1535bcde	0.000519e	0.1587de	0.1451bcd
P value	0.012	<001	0.37	0.037	0.002	0.014	0.022
Se	8.3	1.34	0.5	0.092	0.001	0.09	0.09

***** Means within column followed by the same letter are not significantly differentat P= 0.05.

N/B Toconvert to tones per ha multiply by 4; ((10,000/2.5)/1000)

Weight of the yield characteristics were significantly higher in landraces planted during the rain onset as compared to those planted two weeks after the onset of rainfall ($P < 0.001$) (Figure 4.28). However weight of bad grains were significantly lower in landraces planted during the rain onset compared with those grown two weeks after the rain onset ($P < 0.001$) (Figure 4.28).

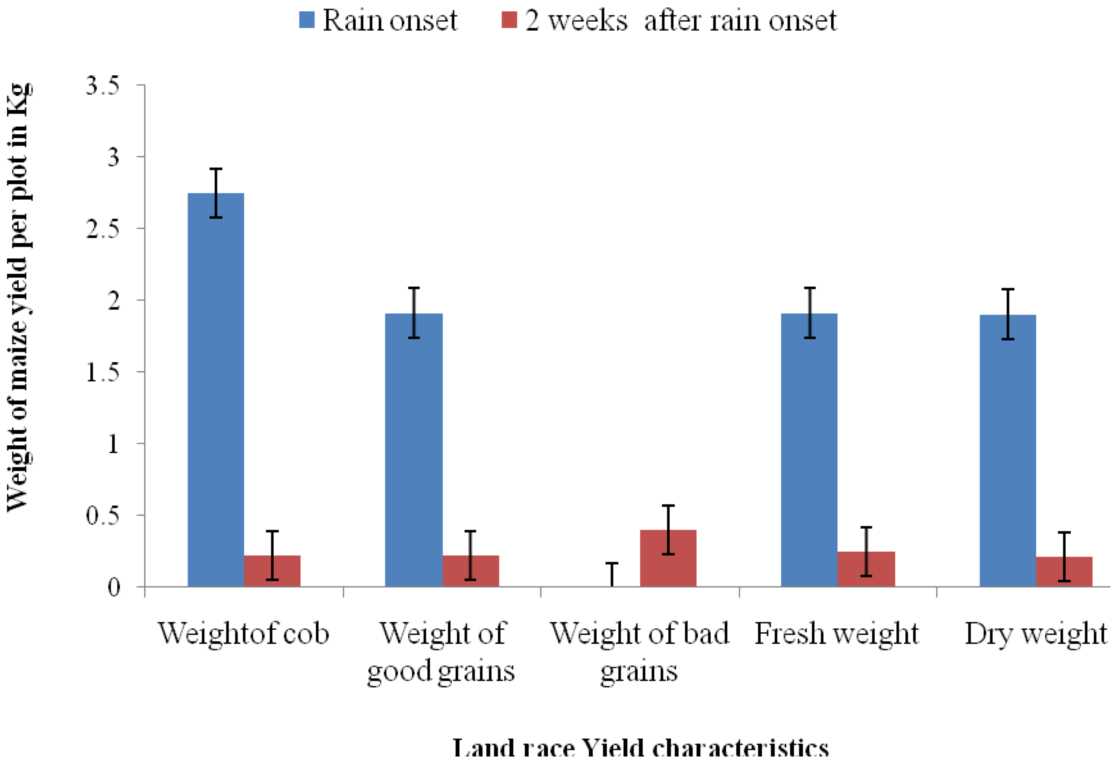


Figure 4.28: Weight of several yield characteristics in maize landraces planted during the onset and two weeks after the rain onset

4.6. Management of vectors of maize lethal necrosis disease causing viruses using cropping system approach in Kenya

There were no significant differences in corn thrips, corn thrips damage and Corn leaf aphids' infestation on maize grown under various cropping systems during season 1 and 2 (Table 4.38).

Table 4.38: Mean infestation levels of Corn thrips and Aphids and Corn thrips damage on maize grown under various polycultures cropping in Bomet County Kenya

	Season one			**Season two**		
Treatment	Corn thrips	Corn leaf Aphids		Corn thrips	Corn leaf Aphids	
Maize in elephant grass border	18.6	13.3	1.273	17.5	5.9	2.72
Maize in sorghum border	18.1	20.3	1.419	16	2.2	3.03
Maize intercropped with coriander	16.1	18.4	1.214	15.5	4.6	2.59
Maize intercroped with sorghum	15	12.2	1.331	16.6	5.5	2.84
Maize in millet border	13.5	14.7	1.404	21.9	6.2	3.1
Olerai maize monocrop	11.6	15.6	1.346	15.2	3.5	2.87
Maize in coriander border	11.2	17.1	1.273	18.9	6.5	2.71
Maize intercropped with millet	10.4	16.7	1.492	16.1	5.7	3.18
Maize intercropped with elephant grass	10.3	14.4	1.521	18.2	2.1	3.25
P value	0.47	0.7	0.4	0.6	0.4	0.54
Se	8.1	7.8	0.29	6.2	3.9	0.69

* Means within column followed by the same letter are not significantly different at P = 0.05.

Corn thrips infestation in companion crops significantly differed for both seasons (P<.001). Maize monocrop had significantly higher infestation of corn thrips compared with the entire companion crops (Table 4.39). Amongst the companion crops, coriander border and coriander intercrop had significantly higher corn thrips infestation. All the other companion crops recorded significantly lower infestation levels (Table 4.39). There was no significant difference among the corn leaf aphids infestation on all the companion crops during season 1.

However, corn leaf aphids' infestation was significantly (P = 0.013) higher on coriander grown both as an intercrop and a border crop during season 2 (Table 4.39). This did not vary significantly with the corn leaf aphid infestation on maize intercropped with sorghum and maize monocrop. The lowest corn leaf aphid infestation was observed in millet border and elephant grass border (Table 4.39).

Table 4.39: Mean number of vectors of MLND causing viruses on companion crops grown under various Cropping systems in Bomet County

	Season One		Season Two	
Treatment	Corn thrips	Corn leaf Aphids	Corn thrips	Corn leaf Aphids
Olerai maize monocrop	39.6a	9.6	43.2a	8.2ab
Coriander border	18.9ab	9.5	9.1b	14.9a
Coriander intercrop	17.7b	19.7	6.6bc	16.5a
Sorghum intercrop	8.6abc	4.1	2.3d	8.6ab
Millet intercrop	7.9bc	3.5	2.1d	9ab
Millet border	7.0bc	4.2	2.1d	5.4ab
Elephant grass intercrop	5.5bc	7.1	2.2d	2.4b
Sorghum border	3.9c	3.3	3.2cd	9.4ab
Elephant grass border	3.8c	5.6	2.6cd	2.9 b
P value	<.001	0.4	<.001	0.013
Se	9.2	6.3	3.2	9.8

* Means within column followed by the same letter are not significantly different at P= 0.05.

Maize grown under the different cropping systems tested positive for MCMV. However the positive control registered a significantly ($P \leq 0.001$) higher viral load as compared to the other treatments (Table 4.40). Maize surrounded by millet and the one intercropped with sorghum had significantly lower MCMV viral load compared with all the maize treatments. Sugarcane mosaic virus was absent only in maize surrounded by coriander and the one intercropped by coriander resulting to no MLND. Maize surrounded by Sorghum had a significantly (P=0.003) higher SCMV viral load compared to the other systems (Table 4.40).

Table 4. 40: Status of MLND causing viruses in maize grown under various cropping system in Bomet County of Kenya

Cropping system	MCMV load	Viral status	SCMV load	Viral status	MLND Status
Positive	0.69a	+	0.5955bcd	+	Positive
Maize intercropped with millet	0.4705b	+	0.9103abc	+	Positive
Coriander border	0.4442bc	+	0.272cd	-	Negative
Maize in Sorghum border	0.4383bc	+	1.4592a	+	Positive
Maize in E. grass border	0.431bc	+	1.034ab	+	Positive
Maize intercropped with E. grass	0.4233bc	+	0.8105abcd	+	Positive
Maize intercropped coriander	0.423bc	+	0.2053d	-	Negative
Olerai Maize	0.3775cd	+	0.6558bcd	+	Positive
Millet border surrounding maize	0.3652d	+	0.8975abc	+	Positive
Maize intercropped with sorghum	0.3618d	+	0.9918ab	+	Positive
Negative	0.163e	-	0.172d	-	Negative
Blank	0.099e	-	0.112d	-	Negative
p value	≤0.001		0.003		
Se	0.04		0.3		

* Means within column followed by the same letter are not significantly different at P= 0.05.
- Negative + Positive

Sorghum was the only companion crop that was positive for MCMV (0.2918). However, it tested negative for SCMV (Table 4.41). Maize had a significantly higher viral load compared with sorghum while the companion crops from all treatments tested SCMV negative hence MLND negative (Table 4.41).

Table 4.41: Status of MLN causing viruses in companion crops grown under various cropping system in Bomet County of Kenya

Cropping system	MCMV load	Viral status	SCMV load	Viral status	MLND status
Positive	0.69a	+	0.5955a	+	Positive
Maize	0.4163b	+	0.559a	+	Positive
Sorghum border	0.2918bc	+	0.115b	-	Negative
Coriander border	0.2642cd	-	0.1202b	-	Negative
Coriander intercrop	0.259cd	-	0.1547b	-	Negative
Sorghum intercrop	0.2438cd	-	0.1138b	-	Negative
Millet intercrop	0.2345cd	-	0.131b	-	Negative
Millet border	0.2157cde	-	0.1212b	-	Negative
Elephant grass intercrop	0.1997cde	-	0.1145b	-	Negative
Elephant grass intercrop	0.1915cde	-	0.1138b	-	Negative
Negative control	0.163de	-	0.172b	-	Negative
Blank control	0.099e	-	0.112b	-	Negative
P value	<.001		<.001		
Se	0.056		0.07		

* Means within column followed by the same letter are not significantly differentat P= 0.05.
- Negative, + Positive

During season 1, maize intercropped with sorghum had significantly (P< 0.001) higher % cob fill while the one intercropped with coriander had significantly more cob weight than all the other treatments (Table 4.42). Weight of good grains and fresh weight was significantly higher in maize monocrop compared with maize grown with other companion crops. However, dry weight was significantly higher in maize surrounded by coriander as well as the maize monocrop ((Table 4.42).

During season 2, significant differences were only realized in % cob fill and weight of bad grains. Higher % cobfill was seen in maize surrounded by sorghum border although this did not significantly differ with maize grown as a monocop as well as the one grown under millet intercrop (Table 4.43).

Pooled data shows maize surrounded by sorghum as having a significantly higher ($P< 0.001$) % cob fill, higher cob weight per plot as well as more fresh and dry weight per plot. However this was not significantly different from the yield characteristics found in Olerai maize variety (Table 4.44). In addition, maize surrounded by sorghum border had significantly ($P= 0.007$) lower weight of bad grains in comparison to the other treatments (Table 4.44). The least yield characteristics were found in maize intercropped with Elephant grass and millet.

Table 4.42: Mean grain yield data of maize grown under various border and intercrops cropping system in season 1

Cropping system	% Cob fill	Cob weight / 16.69 m^2	Weight of good grains / 16.69 m^2	Bad grains / 16.69 m^2	Fresh weight / 16.69 m^2	Dry weight / 16.69 m^2
Maize intercropped sorghum	87.5a	15.07bcd	5.139cd	0.0434	5.182cd	4.704cd
Maize in millet border	84.78ab	13.01cde	5.187cd	0.1357	5.323cd	4.773cd
Olerai Maize alone	81.25ab	14.4cd	8.588a	0.2021	8.79a	7.667a
Maize intercropped coriander	81.25ab	18.23ab	8.759a	0.0077	8.767a	6.938a
Maize in Sorghum border	79.86bc	18.75a	7.112bc	0.0962	7.208ab	5.759ab
Maize in Elephant grass border	77.67bc	13.65cde	7.703b	0.0569	7.76a	5.968b
Maize in coriander border	72.62c	15.43bc	6.802bc	0.0592	6.861bc	5.6bc
Maize intercropped Elephant grass	71.88c	11.81de	4.142d	0.1293	4.271d	3.059d
Maize intercropped millet	53.85d	11.08e	4.302d	0.0516	4.353d	4.187d
P value	<.001	<.001	<.001	0.13	<.001	<.001
Se	9.2	4.64	1.5	0.5	1.5	1.5

Table 4.43: Mean grain yield data of maize grown under various border and intercrops cropping system in season 2

Maize in Sorghum border	88.75a	5.9198	3.8565	0.4885b	4.345	3.924
Olerai Maize alone	83.62ab	5.9949	4.0718	0.2795b	4.3513	3.929
Maize intercropped millet	80abc	5.8752	3.132	1.0935a	4.221	3.6788
Maize in millet border	75bcd	6.2561	3.5929	0.3838b	4.1164	3.5503
Maize intercropped sorghum	72.22abcd	6.7275	2.9875	1.0276a	4.0151	3.4025
Maize intercropped coriander	70.83bcde	4.5033	2.7244	0.5007b	3.2064	2.8687
Maize intercropped E. grass	66.45de	6.6639	3.0363	1.0565a	4.0928	3.645
Maize in Elephant grass border	60.81e	6.0397	3.0527	0.3262b	3.3789	2.8801
Maize in coriander border	60.61e	5.4636	2.3973	0.5729ab	2.9702	2.4982
P value	<.001	0.2	0.4	0.009	0.37	0.23
Se	6.1	0.86	0.69	0.27	1.28	1.16

* Means within column followed by the same letter are not significantly different P= 0.05.

Table 4.44: Pooled mean grain yield data maize grown under various border and intercrops cropping system in Bomet County Kenya

Cropping System	%cob fill	Cob weight (tones/h)	Weight/grain (grams)	Bad grains (tones/h)	Good grains (tones/ha)	Fresh weight (tones/ha)	Dry weight (tones/ha)
Olerai Maize alone	82.25ab	6.1ab	0.2	0.2c	4.5a	4.9a	4.2a
Maize in E. grass border	68.36d	5.3bc	0.2	0.1c	3.5abc	3.6bcd	3.1c
Maize intercropped with Elephant grass	67.46d	4.8c	0.2	0.5a	2.3e	2.8d	2.4c
Maize in Sorghum border	84.54a	6.8a	0.3	0.2c	3.7ab	3.9b	3.4bc
Maize intercropped with sorghum	77.68bc	5.5bc	0.2	0.5a	2.5cd	3.0cd	2.6c
Maize in coriander border	73.9bcd	5.3bc	0.6	0.3bc	2.8bcd	3.8bc	3.5bc
Maize intercropped with coriander	65.28d	4.8c	0.2	0.2c	3.1bcd	3.3cd	2.9c
Millet border surrounding maize	78.69ab	5.0bc	0.2	0.2c	2.8cd	3.1cd	2.7c
Maize intercropped with millet	69.70cd	4.5c	0.2	0.5a	2.4e	2.9cd	2.5c
P value	<0.001	0.01	0.4	0.007	<0.001	<0.001	<0.001
Se	3.1	0.9	0.1	0.2	0.7	0.6	0.8

***** Means within column followed by the same letter are not significantly different P=0.05.

MCMV viral load on companion crops had a significant and positive correlation with the percentage cob fill ($r = 0.59$, $P \leq 0.05$), fresh weight in maize ($r = 0.86$, $P \leq 0.001$) (Table 4.46). However, MCMV viral load on maize showed a significant negative correlation with the percentage cob fill ($r = -0.59$, $P \leq 0.05$) (Table 4.45). A significant negative correlation was registered between corn leaf aphid infestations on companion crops and the corn thrips infestation on maize ($r = -0.66$, $P \leq 0.05$). Similarly a significant negative correlation was registered between the corn leaf aphids infestation on maize and MLND severity ($r = -0.63$, $P \leq 0.05$) (Table 4.45).

Corn leaf aphids on maize had a significant positive correlation with corn thrips infestation on maize ($r =0.63$, $P \leq 0.05$) while the corn thrips infestation on companion crops registered a similar relation with the weight of good grains in maize ($r = 0.81$, $P \leq 0.01$) (Table 4.45). A significant positive correlation was seen between the corn thrips infestation on companion crops and the fresh weight of maize ($r = 0.83$, $P \leq 0.01$) and the dry weight of grains ($r = 0.86$, $P \leq 0.01$). Contrary to this the infestation of maize by corn thrips had a significant negative correlation with MLND incidence in maize ($r = - 0. 60$, $P \leq 0.01$). A highly significant positive correlation was found between MCMV on companion crops and the fresh weight of maize ($r = 0.86$, $P \leq 0.001$) (Table 4.45). This would probably explain why maize under the sorghum border had superior yield properties.

Table 4.45: Correlation between vector infestations, MLND infection and yield characteristcs in maize under different cropping systems

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	-													
2	0.002	-												
3	0.16	-0.45	-											
4	0.45	0.61	-0.22	-										
5	-0.03	-0.66*	0.63*	-0.41	-									
6	0.52	0.52	-0.14	0.86***	-0.26	-								
7	0.69	0.29	0.05	0.83**	-0.23	0.92	-							
8	0.61*	0.46	-0.09	0.95***	-0.34	0.87	0.91***	-						
9	-0.59*	-0.12	-0.1	-0.51	-0.04	-0.31	-0.42	-0.52	-					
10	-0.08	-0.31	-0.12	-0.55	0.39	-0.46	-0.56	-0.53	-0.05	-				
11	-0.31	0.27	-0.63*	0.14	-0.5978*	0.13	0.08	0.01	0.36	-0.41	-			
12	0.54	0.42	-0.1	0.96	-0.35	0.83	0.89***	0.9	-0.5	-0.57	0.085	-		
13	0.34	-0.88	0.5	-0.452	0.68	-0.21	-0.01	-0.24	0.06	0.31	-0.44	-0.27	-	
14	0.66	0.31	0.12	0.81**	-0.19	0.93	0.99	0.86***	-0.4	-0.57	0.09	0.84	-0.03	-

*=Significant at P<0.05 **=Significant at P<0.01 ***=Significant at P<0.001

1; %cob fill, 2; Corn leaf aphid companion, 3; Corn leaf aphids on maize 4; corn thrips on companion 5; Corn thrips on maize, 6; Dry weight, 7; fresh weight, 8; MCMV on companion, 9: MCMV on maize, 10; MCMV on maize, 10; MLND incidence, 11; MLND severity, 12; SCMV on companion, 13; SCMV on maize 14; Weight of good grains

4.7. Management of vectors of MLND causing viruses using biological control in Bomet County of Kenya

More vectors were significantly (P<0.001) recorded on maize at 7 weeks after germination compared to the other maize stages. Maize sampled during the first and third week after germination had significantly lower vectors (Figure 4.29). However, no corn leaf aphids were present on maize from the 1st to the 5th weeks after germination.

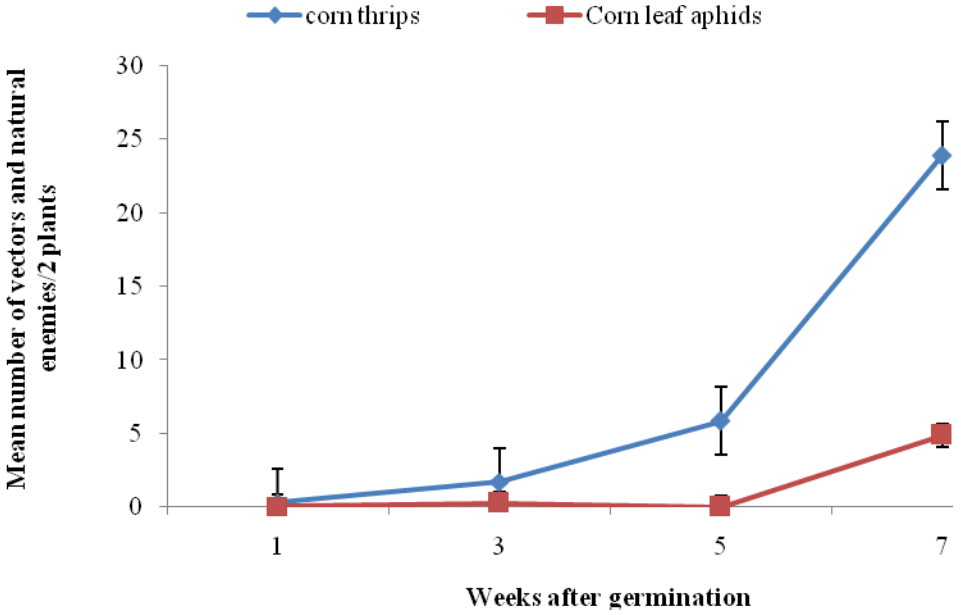


Figure 4. 29: Trends of vectors of MLND causing viruses on maize under biological treatment at different growth stages of maize in season 1

During season two, the corn thrips infestation was significantly higher on maize during the first week after germination (P<0.001). Thereafter a significant increase was observed at week five after germination followed by a significant drop at seven weeks after germination (Figure 4.30). Contrary to this, the corn leaf aphids' infestation was significantly higher at one week after germination followed by 5 WAG. A significantly (P<0.001) lower infestation of corn leaf aphids was observed when the crop was seven weeks after germination (Figure 4.30).

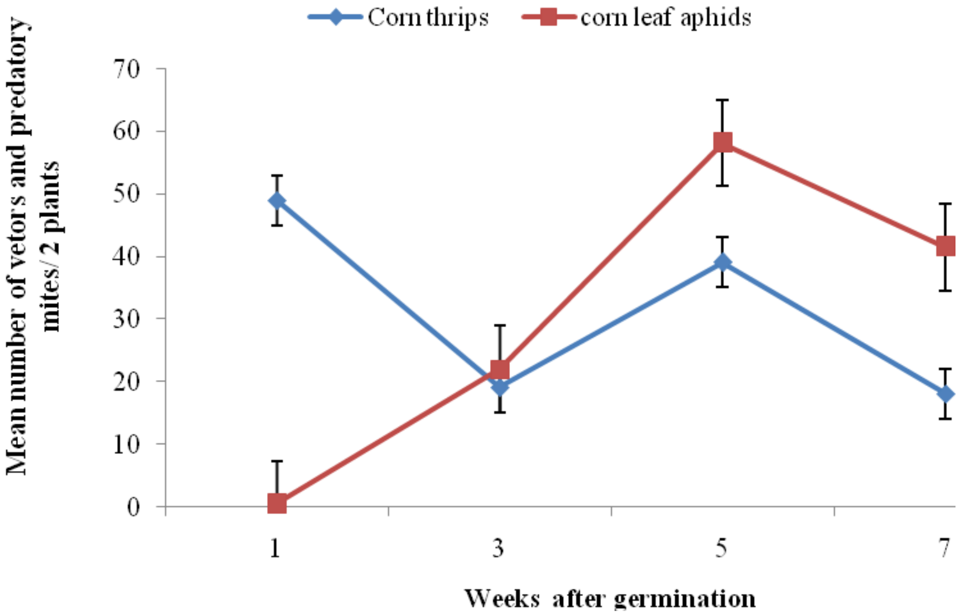


Figure 4.30: Trends of vectors of MLND causing viruses on maize under biological treatment at different growth stages in season 2

The biological control strategies applied had no effect on the number of corn thrips and corn leaf aphids as well as the corn thrips damage level (Table 4.46). However the highest number of corn thrips was recorded on maize that had not been sprayed and the one treated with entomopathogenic fungi while the least was recorded on maize treated with predatory mites. More corn leaf aphids were also recorded on maize that treated with predatory mites although no significant differences were realized. Similar trends were also observed in thrips damage level with no significant differences (Table 4.46).

Table 4.46: Mean number of vectors of MLND causing viruses on maize under various biological control Season 1

	Corn thrips	Corn leaf aphids	Thrips damage level
Entomopathogenic fungi	10.3	1.4	2.325
Control	10.3	1.2	2.325
Thunder	8	1.04	2.2
Garlic extract	7.6	1.4	2.125
Predatory mites	7.1	1.5	2.2
P value	0.42	0.44	0.81
Sed	3.81	0.35	0.165

***** Means within column followed by the same letter are not significantly different P= 0.05.

The biological control strategies applied had no effect on the number of corn thrips and corn leaf aphids as well as the corn thrips damage level (Table 4.47). However the highest number of corn thrips was recorded on maize sprayed with entomopathogenic fungi while the least was recorded on maize sprayed with garlic extract. More corn leaf aphids were recorded on maize that had been sprayed by ecotech although they did not differ significantly. Similar trends were also observed in thrips damage level with no significant differences (Table 4.47).

Table 4.47: Mean number of vectors of MLND causing viruses on maize under various biological control season 1

Biocontrol strategy	Corn thrips	Corn leaf aphids	Thrips damage
Entomopatogenic fungi	33.8	33.2	3.875
Control	32.6	29.3	3.75
Predatory mites	31.4	27.4	3.781
Garlic extract	28.6	34.5	3.688
P value	0.9	0.9	0.3
Se	6.9	6.4	0.22

Maize treated with the different types of bio control methods and sampled at three weeks after germination tested positive for both MCMV and SCMV (Table 4.48). However the

MCMV viral load in maize sprayed by ecotech was significantly (P<.001) higher than any other treatment. Similarly, the SCMV viral load in maize that was not sprayed was significantly (P<.001) higher than any other treatments (Table 4.48). Maize under entomopathogenic fungi and predatory mites had significantly lower levels of MCMV and SCMV viral loads (Table 4.48).

Table 4.48: MLND Status in maize sampled at 3 weeks after germination under various biological controls

Biocontrol method	MCMV 3WAG	MCMV Status	SCMV 3 WAG	SCMV Status	MLND Status
Garlic extract	0.6135a	Positive	0.427b	Positive	Positive
Predatory mites	0.5705ab	Positive	0.356bc	Positive	Positive
Entomopathogenic fungi	0.5645ab	Positive	0.2873cd	Positive	Positive
Control	0.552ab	Positive	0.5357a	Positive	Positive
Positive	0.328c	Positive	0.243d	Positive	Positive
Negative	0.091d	Negative	0.091e	Negative	Negative
Blank	0.084d	Negative	0.089e	Negative	Negative
P value	<.001		<.001		
Se	0.03		0.044		

***** Means within column followed by the same letter are not significantly different at P=0.05.

At seven weeks after germination, maize tested positive for both MCMV and SCMV across the treatments hence maize from all the treatments was affected by maize lethal necrosis disease (Table 4.49). Although the MCMV viral load did not differ significantly, the SCMV viral load was significantly higher in maize from plots that remained untreated and those sprayed by ecotech (Table 4.50). Lower SCMV viral load was recorded in maize sprayed with water and hypotech (Table 4.49).

Table 4.49: MLND Status in maize sampled at 7 weeks after germination under various biological controls

Biocontrol method	MCMV 7WAG	MCMV Status	SCMV 7WAG	SCMV Status	MLND Status
Garlic extract	0.7225a	Positive	0.4898b	Positive	Positive
Predatory mites	0.6232a	Positive	0.3722bc	Positive	Positive
Control	0.6085a	Positive	0.7117a	Positive	Positive
Entomopathogenic fungi	0.5575a	Positive	0.4493ab	Positive	Positive
Positive	0.328b	Positive	0.343bc	Positive	Positive
Negative	0.091c	Negative	0.091c	Negative	Negative
Blank	0.084c	Negative	0.089c	Negative	Negative
P value	<.001		0.002		
se	0.08		0.14		

***** Means within column followed by the same letter are not significantly different at P= 0.05.

The bio control agents had no effect on all the yield characteristics of maize (Table 4.50). However, maize sprayed by ecotech had more weight in all the yield characteristics while maize applied with hypotech recorded the least (Table 4.50). However, there was no significance difference in all the treatment applied (Table 4.50).

Table 4.50: Mean of yield characteristics in maize under various biological Control

Bio control agent	% Cob fill	Weight per grain in g	Weight of good grains	Fresh weight per plot	Dry weight per plot
Garlic extract	62.614	0.6614	6.301	6.3	5.49
Entomopathogenic fungi	61.905	0.4948	4.77	4.77	4.44
Control	61.875	0.5566	4.94	4.94	4.72
Predatory mites	54.167	0.5962	4.628	4.63	3.95
P value	0.9	0.5	0.8	0.7	0.9
se	6.5	0.63	0.9	1.52	1.5

CHAPTER FIVE

5.0. DISCUSSION

5.1. Farmers knowledge and practices against vectors of MLND causing viruses in Bomet East Sub County.

The most active population in maize farming from this study was found to be within the age group ranging between 21 to 50 years. These results are similar to those reported by Samson *et al.* (2014) in Kisii County. However most maize farmers in Bomet Sub County were aged between 21 to 30 years. This may have been attributed to the majority of respondents being youthful and having the strength to work in the farms. Respondents above fifty years were very few indicating that they had either given up on maize farming or got involved in other economic activities that could generate more income than maize. There is a probability that low literacy levels as shown in the education levels results, might have contributed to the spread of MLND and lack of proper control strategies. The fifty seven percent of respondents that had only attained education up to primary level results were similar to those reported by Kipng'eno. (2012) in Nyamarambi Division, Kisii County. The level of education among farmers is likely to determine the kind of agronomical practices and the adoption of control measures towards the control of MLND. Education is therefore used as a proxy to more skills in handling and managing MLND vectors and viruses. Less educated farmers may not be able to understand information and make informed decisions (Mahuku *et al.,* 2015).

The 36% of farmers who depend on maize as part of their main source of income as well the 12.1 % who rely fully on maize for their income are likely to encounter income deficit if MLND was to wipe out the whole crop or cause 100% yield loss as stated by Wangai *et al.* (2012) and Adams *et al.* (2013). The 54% of respondents who get their income from other sources other than maize and 24 % who do not rely on maize for income, represents famers in Bomet East Sub County whose crops totally fail due to MLND (Wangai *et al.,* 2012; Lukanda *et al.,* 2014). The bare minimum agronomic practices carried out by farmers might also predispose the crops to high MLND incidences and severity due to poor health as reported by Kinyua *et al.* (2015).

The positive and significant correlation between the type of agronomical practices and the farmers' knowledge on vectors of MLND causing viruses give an indication that farmers who were aware of the vectors may use agronomical practices such as early spraying to reduce the vectoring mechanism. This may eventually lead to low occurrences of MLND. According to Kinyua *et al.* (2015), a combination of proper agronomic practices such as the use of fertilizer and chemical sprays encourages the robust development of the crop which can escape the virulence of the virus as well as the damage caused by corn thrips. More knowledgeable farmers are likely to adopt control measures that will discourage the spread of MLND hence reduce MLND severity (Samson *et al.,* 2014). This is in agreement with better understanding of the vectors of MLND causing viruses as stated in the conceptual Frame work in Figure 1.1.

The 90% awareness among farmers on MLND and its effect on maize is similar to the findings reported by Samson *et al.* (2014) when 95.9% of farmers in Kisii County reported MLND on their farms. The dismal 3% of respondents who correctly identified the vectors of MLND disease causing viruses is evidence that information on corn thrips and corn leaf aphids as vectors of MLND causing viruses is limited.

5.2. Field dispersal and movement of *Frankliniella williamsi* and *Rhopalosiphum maidis* in a maize field

The findings that blue sticky traps are better in trapping corn thrips compared with the yellow cards is the first report globally and provides important information about monitoring and control of this vector. The findings are similar to what has been reported for other thrips pests infesting other crops such as the cow pea and French beans (Tang *et al.,* 2016; Muvea *et al.,* 2014; Kasina *et al.,* 2009). Other studies have reported on the efficiency of both blue and yellow sticky traps in monitoring thrips population numbers and mapping their spread in a given area (Thongjua *et al.,* 2015; Broughton and Harrison, 2012). The lack of preference by corn leaf aphids on neither blue or yellow sticky traps contrasts with the one reported by Nigel *et al.* (2011) that yellow sticky traps captured significantly higher *Elatobium abietum* (green spruce aphid) on spruce plantation. However, this may be due to the differences in the aphid species.

The sticky traps oriented at 90° (vertically positioned to the ground) attracted more corn thrips compared with other orientations. Similar findings by Tian-Ye *et al.* (2004) reported on the efficiency of vertically positioned yellow fluorescent traps attracting more thrips compared to other placements. Vectors trapped at various phenological stages of maize varied significantly with the mid and late whorl stages (when the collar of the eighth and twelfth leaf was visible respectively) attracting more vectors compared to the other younger stages. It is presumed that these stages of maize provide adequate cues that lure more vectors. The different hues of colors in maize stages, possibility of trap materials as well as the reflectance of the sticky trap could have contributed to the attraction of high numbers of vectors during the mid and late whorl stages (Kaas, 2005). The fewer corn thrips trapped at the one to two leaf stages (1WAG) concide with those reported on onions where infestation at four weeks after transplanting was 15 times less than those found on older plants at 12 weeks after transplanting (Ibrahim and Adesiyun, 2009). Corn leaf aphids were significantly higher during the late whorl stage. This is likely to be the optimal time that the sugarcane mosaic virus interacts with maize chlorotic mottle virus to cause MLND. This kind of vector movement and trends provides best approaches that can initiate control strategies which may prevent population explosion and reduce the interaction chances of the MCMV and SCMV viruses.

Compass directions of traps had no effect on the capture rates of neither corn thrips nor the corn leaf aphids. This suggests that direction does not influence the aerial dispersal patterns of corn thrips and corn leaf aphids. This agrees with Hoddle *et al.* (2002) who found out that direction had no effect on the capture of *F. occidentalis* and *Scirtothrips persicae*. Vectors movement into the maize field was significantly higher compared with those leaving the maize field. This indicates that from the time the crop is one to two leaves till the late whorl stage, the crop becomes a target for the vectors. This dispersal pattern of corn thrips is of fundamental importance because it can be used for vector forecasting in areas where vector outbreak is likely to occur. According to Pedego and Rice (2009) such information can also be used for creating pest sampling plans and management tactics.

Sampling is critical in estimating the infestation level of the vectors in the field. Therefore the choice of sampling orientation is critical. In this study, sampling alongside the maize rows provided the best estimate of corn thrips infestation levels. Albrecht (2010) reported similar results when he used the the same pattern to sample for the turf grass grubs. Planting along the North- South orientation favored the movement and spread of corn thrips compared to planting along the East- West slopes. The behavioral pattern of the corn thrips in this manner should be investigated further and exploited by farmers as an intervention measure against the spread of MCMV and eventually MLND.

The most effective region for estimating corn thrips infestation level on maize is the upper region. The thrips could have preferred this region due to its succulence nature that was easy to feed from. In this region the corn thrips are able to easily suck sap and cause scarification of the plant (Ssemwogerere *et al.*, 2013). These areas could also be offering an excellent protection area from the harsh weather and insecticides. Similarly, Razmojou and Golizadeh (2010) reported infestation of *R. maidis* on all the above ground plant parts. This study thus provides information that can be used to optimize spraying towards the control of the two vectors.

Scouting and monitoring results show that the most reliable time for scouting of vectors is either between 8.30 to 10.30 am or 3.30 to 5.30 pm. This is the first report on scouting and monitoring of corn thrips and corn leaf aphids on maize. However, a similar study carried out by Pizzol *et al.* (2006) reported more flower thrips (*Frankliniella occidentallis*) trapped just before noon and then decreased through the afternoon. Findings by Atakan *et al.* (2001) also reported more corn thrips being captured by sticky traps between 8.00 am to 2.00 pm. Results from this study agree with those of Atakan *et al.* (2001) during the morning hours but not the afternoon time. In this study, the scouting of *F. williamsi* and *R. maidis* was done by visually identifying vectors on examining the leaves while sticky traps were used for *F. occidentalis*. This may account for the time sampling differences in corn thrips and corn leaf aphids especially in the afternoon. In conclusion, all the scouting and monitoring techniques found in this study provides more information that will make the process more effective before control strategies are employed as stated in figure 1.1.

5.3. Effect of sticky rolls in management of vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

Results obtained from this study show the potential of blue and yellow sticky rolls trapping more corn thrips and corn leaf aphids respectively. This is the first report on sticky roll efficiency in managing and controlling the vectors. Previous studies by Sampson *etal.* (2013) shows that blue sticky rolls are highly effective in controlling western flower thrips (*Frankliniella occidentallis*) on straw berry. In addition, Idris *et al.* (2012) and Mwangi, (2015) similarly reported that yellow colored sticky traps have the potential to reduce the number of black bean aphid, *Aphis fabae*. Moreover, Baoyu *et al.* (2012) demonstrated the effieciency of yellow sticky traps in controlling the Tea aphid (*Toxoptera aurantii*). The ability of the blue sticky rolls in trapping more corn thrips in this study is similar to the one reported by Tang *et al.* (2016) who found that more thrips *Megalurothrips usitatus* were attracted to the blue sticky traps compared to the other colors. The green spruce aphids were majorly attracted to the yellow sticky rolls compared to the other color as reported by Nigel *et al.* (2011). This concides with results from this study where more corn leaf aphids were attracted to the yellow sticky rolls. It is also key to note that, whether the sticky rolls were installed at germination, 1 or two weeks after germination, the vector trapping did not significantly vary within the regimes for both the blue and yellow sticky rolls. This indicates that the sticky rolls do not lose their trapping efficiency as time elapses.

The absence of MCMV and SCMV virus in maize sampled at 3 WAG indicates that the virus had not fully incubated and it's manifestation in the crop was still weak. However, as the crop matures the virus innoculum increases and this leads to higher chances of MLND occurring. It is therefore possible, that most of the corn thrips that were already carriers of MCMV had been trapped or attracted to the blue sticky roll (Tang *et al.*, 2016) while more of the SCMV carrier corn leaf aphids had equally been trapped or attracted to the yellow sticky roll (Sampson*et al.*, 2013). This is supported by results in this study which clearly shows that maize protected by yellow sticky rolls were SCMV negative and MCMV positive while those protected by blue sticky rolls were MCMV negative and SCMV positive. The presence of MLND in maize in the control experiments where no sticky rolls were installed shows the blue and yellow sticky rolls having the potential to interrupt the MCMV and SCMV interaction for MLND not to occur (Adams *et al.*, 2014). Cabanas *et al.* (2013) clearly found out that MLND can only occur when the two virus co infects the maize plant.

The significant ($P<0.05$) and negative correlation between the corn thrips trapped versus MCMV viral load and MLND severity on maize could be used to explain the absence of MCMV from plots protected with blue sticky rolls. It is also possible that most of the corn thrips trapped by the sticky rolls were the infected ones. Corn thrips require enough time to feed in order to acquire and semi persistently transmit the virus from an infected plant to a healthy one (Nelson *et al.*, 2011; Cabanas *et al.*, 2013). There is a possibility that the presence of blue sticky roll interfeared with the virus transmission by trapping the thrips. These results show that maize under sticky rolls was protected from mass infestation by corn thrips and corn leaf aphids. However, it seems that the blue and yellow sticky rolls prevented inoculated corn thrips and corn leaf aphids from infecting the crop either by MCMV or SCMV respectively by trapping the vectors (Muvea, 2011; Mwangi, 2015). The trapped corn thrips and corn leaf aphids showed a significant and negative correlation with MLND severity. This simply means that the possibility of transmission of MCMV by corn thrips and SCMV by corn leaf aphids to cause MLND was likely to be lower when both vectors trapped by sticky rolls were more in number. Similarly, the significant and negative correlation between the corn thrips trapped by sticky rolls and those found infesting maize clearly indicates that maize was protected by sticky rolls from the vector infestation.

The behavioral responses of the corn aphids to stimuli of different colors in relation to virus transmission as explained by Doring and Chittka (2007) can be related to the behavior of corn leaf aphids in this study when maize protected by yellow sticky traps tested negative for SCMV which is transmitted by the vector. The corn thrips infestation on maize negatively and significantly correlates with the weight per seed, fresh weight and weight of cobs per plot. This means that corn thrips infestation has an effect on the performance and yield of maize. Ssemwogerere *et al.* (2013) reported on how thrips suck and deplete plant nutrients, this eventually leads to yield loss while Nyasani *et al.* (2012) and Kasina *et al.* (2009) reports similar results when they showed that Western flowerthrips *F.occidentalis* causes massive yield losses on French beans. Sticky roll management of the vectors and viruses causing

MLND will lead to minimal disease spread and this will eventually result into improved maize yield as shown in the conceptual frame work (Figure 1.1).

5.4. Action threshold level of vectors transmitting Maize Lethal Necrosis Disease causing viruses

Results from the threshold study confirm the effectiveness of thunder (Imidacloprid and Cyhalothrin) in controlling corn thrips as reported by Kasina *et al.* (2015). Similarly, studies by Nderitu *et al.* (2008) show the potential of Cyhalothrin insecticide towards the control of *Megalurothrips sjostedti* on French beans. Although findings from this study showed that more frequent sprays (10 sprays of thunder/ weekly sprays) significantly reduced corn thrips infestation, the economic returns from the same plots indicated otherwise. Plots that received fewer sprays had more marginal rate of returns as compared to those that received more sprays. The implication of these results is that farmers are better off using fewer applications of thunder although they have to accept some level of vector density. Similar results have been reported by Nault and Shelton *et al.,* 2010 on the use of fewer sprays that result to higher marginal rate of returns. Nderitu *et al.,* (2008) also reported higher economic returns in French beans that were sprayed twice as compared with those that were sprayed six times. Fewer applications of insecticides have both economic and health benefits. They give better marginal rate of returns to the farmer; reduce pesticide residue levels as well as favoring the establishment of natural enemies among others.

Action threshold level is the average number of vectors per plant that will cause economic yield loss if the infestation is not controlled. Findings from this study show that six corn thrips and three corn leaf aphids per plant would warrant the use of thunder to bring the infestation lower. Therefore it is imperative that farmers should monitor vector build up during the season and only use thunder when the vectors attain the action threshold level. These results agree with those reported by Nault and Shelton, (2010) when an action threshold of three thrips was reported on onions. The action threshold for corn thrips on maize in this study seems higher than the one found on onions. This could be attributed to the difference in crop size and plant architecture as explained by Gill *et al.* (2015). From this study, emphacies is put on monitoring of corn thrips and corn leaf aphids on maize to ensure that farmers are guided by population build up instead of using calendar sprays.

It was also noted that although most frequent sprays indirectly reduced MCMV and SCMV viral load, the monthly spray regime equally worked well with all thunder sprayed plots testing negative for MLND during the first season. These results are confirmed by those reported by Kinyua *et al.* (2015) who found that maize plots that were sprayed on a fortnight basis had lower MLN disease severity levels compared to those not sprayed. Therefore, less frequent sprays are suggested to safeguard economic returns. In this study, it is also confirmed that crops infested by corn thrips are affected by the corn thrips damage as well as the MCMV virus that it transmits. Regression analysis shows that both affect yield negatively. This is confirmed by Beres *et al.* (2013) who reported on the damage caused by corn thrips and their ability to transmit MCMV. Although thunder had no effect on corn leaf aphids, regression analysis indicate that their presence causes a significant increase in SCMV infection. This could probably explain how the interaction of the two viruses occurs for MLND to manifest itself (Cabanas *et al.,* 2013; Nelson *et al.,* 2011). Proper action threshold levels for the corn thrips and corn leaf aphids will enable farmers to spray or take control when there is need. This will ensure that optimal yield will be realized from maize as well as better economic rates which will result into improved food security and the people's livelihoods as mentioned in Figure 1.1.

5.5. Varietal tolerance to vectors of maize lethal necrosis disease causing viruses in Bomet County, Kenya

The lack of preference by vectors to hybrid maize varieties and the landraces planted during the rain onset indicates that no tested variety had resistance to the vectors. However the low corn thrips infestation on landraces MLR 11 planted two weeks after the onset of rain might suggest lack of preference by corn thrips to the particular landrace. The high corn thrips damage seen in landraces MLR 13, 17 and 4 could also indicate that the varieties might be good feeding hosts for the vectors. Moreover, the lower vector infestatiom in landraces planted during the rain onset could be attributed to inadequate suitable hosts and breeding sites for the vectors. Maize being the main and only ntural host of corn thrips (Jiang *et al.*, 1990; Cabanas *et al.,* 2013) was limited hence initial infestation was low. These populations subsequently build up as the season progressed. This is clearly seen in maize planted two weeks after the rain onset. Ogah (2011) similarly reported an increase of Yam bean flower thrips as the season progressed.

The susceptibility of variety H614 to MLND could explain the lower yield properties observed in this variety compared with the others. This is in agreement with Samson *et al.* (2014) who found out that MLND causes extensive yield losses. Another possibility for the poor yield performance and susceptibility in H614 could be explained by Wang *et al.* 2017 findings that chloroplasts in cells co-infected with MCMV and SCMV contained much smaller starch grains than that in the MCMV-infected cells, this suggested that photosynthesis in particular cells was impeded resulting into poor yield. The weather conditions and other abiotic stresses in the region might also have exacerbated the MCMV infection as reported by (Redinbaugh and Zambrano-Mendoza, 2014). The absence of SCMV virus in Pannar and H515 for both seasons contributed to both varieties testing MLND negative. This might have led to the high yield properties in variety Pannar compared with the rest. These results are similar to those reported by Castillo and Herbert. (1974); Claflin. (1978) and Uyemoto *et al.* (1981) on mild effects of MCMV compared with the MLND severe ones. Despite the absence of MLND in variety H515 during both seasons, lower yields were recorded and this might have been as a result of inherent characteristics in H515 coupled with the prevailing weather conditions. The MCMV resistance/ tolerance seen in pannar maize variety could be compared to the one reported by Nelson *et al.* (2011) on MCMV resistance in maize inbred lines in Hawaii. This was in contrast to the report on artificial inoculation of MLND causing virus in Kenyan varieties which later succumbed to MLND (Mahuku *et al.*, 2015). However this differences may be expected because field conditions coupled with natural pressures may not have beeen sufficient enough to break the tolerance in Pannar and H515 leading to their MLND negative status. Moreover, this could also be attributed to the differences in abiotic stress Zambrano *et al.* (2014).

The high yield characteristics observed in MLR 1, MLR 9, and MLR 15 landraces planted during and two weeks after the onset of rain might have been due to the landraces testing negative for MLND. However MLR 1 was more tolerant to MCMV and MLND in maize planted during the rain onset and still posted better yield characteristics. According to Nelson *et al.* (2011), MCMV was found to be a quantitative trait that widely varied among pure lines with some tropical maize grain stocks showing superior resistance to MCMV. Hence this could have been the case for MLR 1. Better yield properties for both landraces planted during the rain onset and two weeks after the rain onset were consistently observed in MLR 1 and MLR 9. These varieties could be considered for breeding as per the report given by CYMMIT (2012) and CABI (2013) on the possibility of breeding varieties that are resistant to both MCMV and SCMV. Therefore MLR 1, MLR 9 and MLR 15 could probably be tested further as a potential source of germplasm for breeding MLND resistant varieties as earlier reported by Wangai *et al.* (2012) and Fatma *al.* 2016. Poor yield in landraces MLR 4, MLR 5, MLR 10 and MLR 18 could be attributed to the presence of MLND in all the landraces for both seasons except for MLR 10 that was susceptible to MCMV during the first season and SCMV during the second season. These results are consistent with those reported by Samson *et al.*, 2014 who reported on the extensive yield losses experienced in Kisii County due to maize lethal necrosis disease.

Despite the low corn thrips infestation and thrips damage level registered in MLR 5, MLR 10, MLR 2, MLR 3 and MLR 4, the landraces still posted low yield properties. Moreover, the MLND negative status in MLR 10 did not neccessarily result into better yield properties. This means that even without MLND manifestation in the landrace, it still performed poorly yield wise. Superior yield properties would have been expected especially from these landraces that harbored significantly lower thrips infestation and damage levels. Therefore, this shows that the three landraces MLR 5, MLR 4 and MLR 10 were inferior landraces as compared to the other landraces in terms of yield. Similar to these results, Ogah (2009) reported low yied produce in Yam bean variety despite the lowinfestation of *Megalurothrips sjostedti*. These poor yields were attributed to the genetic makeup of the landrace (Ogah, 2009). Development of resistant crops to the vectors and viruses of MLND is the most economical and viable approaches towards curbing the MLND menace (Kumar *et al.*, 2004; Fatma *et al.*, 2016; Mengistu, 2016). The Pannar maize varieties, MLR1 and MLR 9 landraces provides an opportunity for breeders to develop germplasm that can provide resistance to the vectors and viruses that cause MLND. This agrees with the conceptual framework (Figure 1.1) on effective control stragies that will eventually result into improved maize yield by reducing the disease effects.

5.6. Management of vectors of maize lethal necrosis disease causing viruses using cropping system approach in Kenya

Both corn thrips and corn leaf aphids preferred maize as their main host plant when grown together with other companion crops. This was expected for corn thrips as reported by Gordon *et al.* (1984) and Nelson *et al.* (2011) about maize being the main host for corn thrips. Tian *et al.* (2012) and Souza *et al.* (2004) found similar results when they reported the lack of beneficial effects of intercropping in maize towards the control *R. maidis* infestation and damage. However, it is also clearly noted that a significant number of both corn thrips and corn leaf aphids found their habitat on coriander.Results show coriander harboring these vectors more than the other companion crops (millet, sorghum and Sorghum). Namikoye *et al.* (2015) similarly reported on coriander ability to host corn leaf aphids and corn thrips. This could be advantageous to maize as the transmission process is interfered with since it is non persistent transmision. Since the companion crops were planted two weeks earlier than the target maize crop, the corn thrips and corn leaf aphids are likely to inhabit the coriander, feed on it and in the process reduce the innoculum or lose it before they invade the maize. Similarly, Adams *et al.* (2013) and Mengistu, (2016) reported the use of quarantine (the viral innoculum will be retained in the companion crop with little being vectored to the main crop) in the reduction of the virus innoculum. In this case coriander may provide host that will reduce viral inoculation in maize

The high yield properties found in maize surrounded by sorghum, might be due to the the sorghum sharing part of the MCMV innoculum. It is possible that the corn thrips first landed on sorghum border and transmitted the MCMV before transmitting the virus on maize found in sorghum border. This is confirmed when sorghum border was the only companion crop that tested positive for MCMV. Achon *et al.* (2017) and Hoffmann *et al.* (2016) similarly reported *Sorghum halepense* as a host to MCMV virus. The transmitted virus subsequently did not affect the yield as in the case of yield from other cropping systems. The same trend is seen on maize surrounded by elephant grass border. Elephant grass is likely to posse's chemical cues that not only repel the vectors but also reduce the virulence nature of the virus. Khan *et al.,* 2004 and Cook *et al.,* 2007 had similar results when Elephant grass successfully controlled *Chilo partellus* through push and pull mechanism.

The infestation levels of the corn leaf aphids on coriander were significantly similar to the one on maize. This is also proved when maize planted with coriander as an intercrop and a border tests negative for sugarcane mosaic virus. This simply means that maize intercropped with coriander and surrounded by coriander had no maize lethal necrosis disease. It is also key to note that lack of a significance variance in the infestation levels of corn leaf aphids on both coriander and the maize could be exploited in the control of the maize lethal necrosis disease. In the presence of both coriander and maize, aphids have a similar probability of feeding on either crop. This may greatly reduce the virulence nature of sugarcane mosaic virus and reduce its interaction chances with the MCMV virus. Eventually, MLND levels may greatly be reduced in maize planted as a polycultures even though the number of vectors remains the same. Since aphids transmits SCMV non-persistently (Gwendolyne *et al.,* 1996), It is possible for disruption of the virus transmission on maize to occur especially if the corn leaf aphids land on companion crops and feed before infesting maize. This might have been the case in explaining the absence of SCMV in maize grown with coriander.

All the maize look similar visually and may also have had similar chemical stimuli leading to attraction of significantly similar numbers of corn thrips (Parker *et al*., 2013). The low infestation in Elephant grass, millet and sorghum hosts indicates that sorghum could be used as repellant companion crop which can probably disrupt the normal chain of host crop selecting behaviors (Finch *et al.,* 2003) among the vectors. However, coriander may turn out to be a good trap crop for the thrips. Coriander harbours the vectors more than any other companion crop. It is also confirmed that coriander is neither a host to MCMV nor SCMV. Despite corianders preference by corn leaf aphids, it may be having chemicals that discourage the incubation and development of the SCMV as a virus. Coriander offers one of the control strategies that can trap the vectors as well as prevent SCMV from occurring. This is in agreement with the conceptual framework (Figure 1.1) on minimizing the disease spread.

5.7. Management of vectors of MLND causing viruses using biological control in Bomet County of Kenya

The lack of effect of beauvitech, hypotech and ecotech on infestation of corn thrips, corn leaf aphids and yield in maize implies that they may not be a suitable component of an integrated management strategy against these vectors. Previously, Messelink *et al.* (2011) reported ineffectiveness of the predatory mite, *Neouseillus cucumeris* in controlling the western flower thrips (*Frankliniella occidentalis*). This infectiveness might have been caused by the predator being generalists that feeds on more than one prey. Therefore there is a possibility that the *Hypoaspis miles* were also feeding on other insects in the ecosystem. According to Messelink *et al.* (2013) they attribute these phenomena to the interaction between the thrips predators and the natural enemies of aphids.

According to Bloemhard and Ramakers (2008) the inability of the predatory bugs to control aphids has been noted. While most bio agents are specific, most predators are generalists and this are expected to contribute to the pest management. Hypotech effects would have been reduced due to non timely application carried in this study. The predator feeds mainly on thrips pupae that falls in the soil while most of the thrips larvae and adults are found on the younger succulent leaves. These results are different from the one reported by Jandricic *et al.* (2016) who reported on the predatory mite *Neoseilus cucumeris* reducing *Frakliniella occidentalis* by 54 to 78%. The ineffectiveness of *Beauveria basiana* on the corn thrips as well as the cornleaf aphids contradicts reports by Jessica (2015) and Wu *et al.* (2014) who used *B. bassiana* to control *F. occidentalis.* Similarly, garlic extract ineffectiveness on the control of corn thrips and corn leaf aphids' infestation is the first report although Mwangi, (2015) also reported the ineffectiveness of the botanicals such *Diversifolia spp on* aphid's infestation. In most cases garlic has successfully been used as intercrop to successfully control thrips and aphids (Waiganjo *et al.* 2007; Mwangi, 2015) but not as a spray. This might explain its ineffectiveness as a spray.

CHAPTER SIX

6.0. CONCLUSIONS, RECCOMMENDATIONS AND FURTHER RESEARCH

6.1. Conclusions

1. Farmers are aware about MLND but know very little about the vectors.
2. Corn thrips sampling efficiency is affected by angle orientation of blue sticky traps, planting orientation of maize as well as the time and region of sampling.
3. A sticky roll significantly reduces vector infestation as well as protecting maize from MLND.
4. Spraying thunder on a monthly spray regime coupled with an action thresh hold level of 6 corn thrips leads to a higher marginal rate than any other spray regime.
5. Pannar maize variety has a higher resistance level of MLND and performs better yield wise.
6. Coriander is a good trap crop for both vectors and is able to protect maize from being infected with MLND while maize protected by sorghum had relatively better yield characteristics.
7. Beauvitech, hypotech and the ecotech extract had no effect on corn thrips and corn leaf aphids.

6.2. Recommendations

1. There is an urgent need for dissemination of information on vectors of MLND causing viruses to the people of Bomet East Sub County.
2. Farmers and researchers are recommended to sample corn thrips alongside the rows on the upper regions of the plant and use blue traps at 90° to best estimate vector

infestation levels in maize.

iii. Farmers are recommended to adopt the use of blue and yellow sticky rolls for mass trapping of corn thrips and corn leaf aphids as well as for prevention of MLND.

iv. Farmers are recommended in adopting a monthly spray regime coupled with an ATL of 6 corn thrips to realize a higher marginal rate.

v. Pannar is recommended for use by farmers, however it could be tested in various ecological zones to determine its stability

vi. Farmers could consider planting Sorghum around maize plots as a trap for MCMV as well as Coriander for trapping vectors and SCMV**.**

vii. Farmers should not use Beauvitech, Hypotech and the Ecotech extract to control corn thrips and corn leaf aphids.

6. 3. Further Research

i. Pannar maize variety, Landraces MLR 1, MLR 9 and MLR 15 could be tested further for their source of resistance and as a potential source of germplasm for breeding MLND resistant varieties

ii. Studies are required to determine the chemical cues found in coriander which deters the development of the SCMV and MCMV.

iii. Sorghum should be studied further to investigate its effect on vector transmission of MCMV and how its yield is affected by MLND.

iv. A combination of all the monitoring aspects and control strategies in this work should be tested for their combined effect on vectors of MLND causing viruses

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APPENDICES

Appendix 1

Explanation

These set of questions are meant to generate truthful information from farmers of Bomet County where we have had trials since 2012.The results will be used to inform policy on how to enhance the control of vectors of MLND causing viruses in the country.The report will not be based on individual responses and will not be individualized. Please do truthful information.

Qsn		
	Part 1.General information	
1.1	Date	
1.2	Enumerator/data collector	
1.3	Start time	
1.4	County	
1.5	Sub county	
1.6	Ward	
1.7	Area/Village	
1.8	Coordinates	
	Part 2. Social capital characteristics	
2.1	Name of respondent/farmer [if any]	
2.2	Position in the household/farm [household head,spouse,child,other]	
2.3	Age of respondent [no. of years]	
2.4	Number of households	Male= Female=
2.7	Percentage of farming to income of Household/farm.	Up to 25% [1 Up to 50% [1 Up to 75% [1 Up to 100%]
	Part 3. Maize status	
	Area under maize	
	Age [months] after germination	
	Agronomic practices applied	
	1.Fertilizer: Yes {1 no {1 how many times?	
	2.Weeding: Yes {1 no {1 how many times?	
	3.Herbicide: Yes {1 no {1, list………….	
	4.Pestcide: Yes {1 no {1, list…………..	
	5.Fungicide: Yes {1 no {1,list…………..	

	Pest seen during the crop growth	
	Pest	
	Diseases seen during the crop growth	
3.5	Disease	
	Disease incidence and severity in 10 randomly picked plants	

3.6	Plant no.	Present {Yes/No}	Severity MLND Scale { 1-5 }
	1.		
	2.		
	3.		
	4.		
	5.		
	6.		
	7.		
	8.		
	9.		
	10.		
	Overall	{ % }	

	Part 4: Yield data per crop { record number of cobs }					
4.1	Plant no.	No ear	Small	Medium	Large	Diseased
	1.					
	2.					
	3.					
	4.					
	5.					
	6.					
	7.					
	8.					
	9.					
	10.					
	End time of the activity					

APPENDIX II

Abstract for Paper accepted for Publication in the East African Agricultural and Forestry Journal

Cropping System intensification as a Management method against vectors of viruses causing Maize lethal necrosis disease in Kenya

Namikoye, E. S.[1, 2*], Kariuki, G. M.[1], Kinyua, Z.M.[2], Githendu, M.W.[1] and Kasina, M.[2*]

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[2]Kenya Agricultural and Livestock Research Organization, P.O. Box 14733-00800, Nairobi
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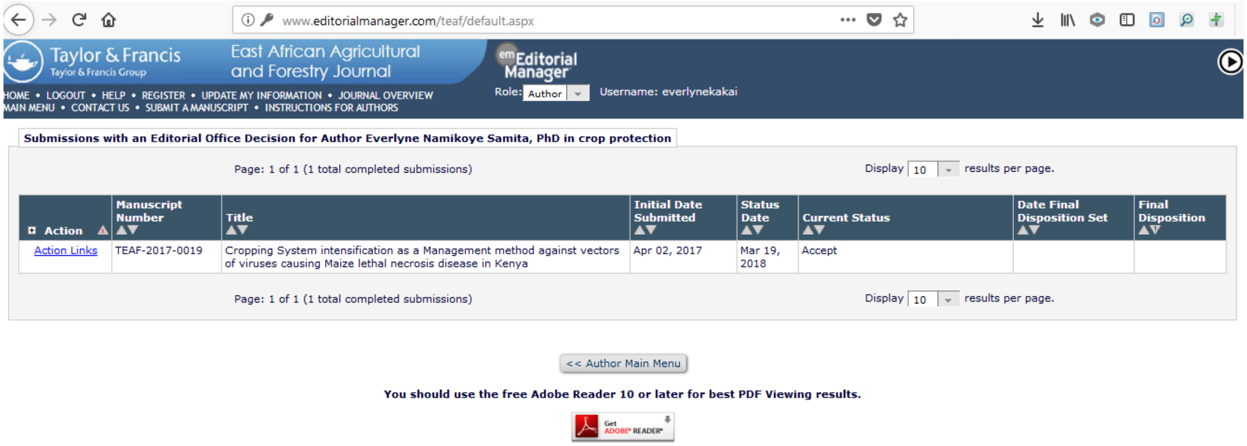
Abstract

Maize lethal necrosis disease (MLND) has emerged as a great threat to maize production in East Africa. The disease is caused by a synergistic infection of maize by sugarcane mosaic virus (SCMV) and maize chlorotic mottle virus (MCMV). This study was carried out in Bomet County, Kenya, to determine the potential of various cropping systems in managing vectors of MLND causing viruses. Plots measuring 7.5 m x 5.25 m were planted with maize (*Zea mays* L.) intercropped or bordered by elephant grass (*Pennisetum purpureum*), coriander (*corriandium sativum*), pearl millet (*Pennisetum glaucum*) and Gadam sorghum (*Sorghum bicolor*). Maize monocrop was used as a control treatment; the nine treatments were arranged in a randomized complete block design and replicated four times for two seasons (Dec, 2014 to Apr 2015 and Apr 2015 to Sept 2015). Data of corn thrips and corn leaf aphids infestation, MLND severity and incidence, MCMV and SCMV viral load, and yield was taken. Sorghum border was the only companion crop that tested positive for MCMV and none tested positive for SCMV. Maize intercropped with elephant grass had significantly ($P<0.01$) the least disease incidence. However, it recorded significantly lower yields ($P<0.01$). Coriander was the only companion most preferred by both corn thrips and corn leaf aphids ($P<0.001$). Maize from all cropping systems tested positive for MCMV ($P<0.001$) while maize grown with coriander tested SCMV negative ($P<0.001$). Yield from plots surrounded by sorghum and coriander were significantly similar to the one from maize monocrop plots. These findings suggest that maize should be intercropped with coriander due to its potential to trap the corn leaf aphids and protect maize from SCMV. In addition maize should be grown surrounded by sorghum border to maximize on yield performance in areas prevalent to MLND.

Key words: Intercropping, border cropping, mono cropping, corn thrips, corn leaf aphids

Appendix III

Acceptance evidence



Role: Author

Username: everlynekakai

Submissions with an Editorial Office Decision for Author Everlyne Namikoye Samita, PhD in crop protection

Page: 1 of 1 (1 total completed submissions)

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Action	Manuscript Number	Title	Initial Date Submitted	Status Date	Current Status	Date Final Disposition Set	Final Disposition
Action Links	TEAF-2017-0019	Cropping System intensification as a Management method against vectors of viruses causing Maize lethal necrosis disease in Kenya	Apr 02, 2017	Mar 19, 2018	Accept		

Page: 1 of 1 (1 total completed submissions)

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Subject: (East African Agricultural and Forestry Journal) Your submission has been accepted
To: "Everlyne Namikoye Samita" <namikoye.samita@ku.ac.ke>
Cc:
Mar 19, 2018
Ref.: Ms. No. TEAF-2017-0019R1
Cropping System intensification as a Management method against vectors of viruses causing Maize lethal necrosis disease in Kenya
East African Agricultural and Forestry Journal

Dear Ms Samita,
I am pleased to tell you that your work has now been accepted for publication in East African Agricultural and Forestry Journal.
It was accepted on Mar 19, 2018

Thank you for submitting your work to this journal.

With kind regards
Jack Ouda
Editor-in-Chief
East African Agricultural and Forestry Journal

Welcome to NISC Production: East African Agricultural and Forestry Journal 1456298

20 Mar 2018

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Yours sincerely,

Mike Schramm

Email:mike@nisc.co.za

APPENDIX IV

Abstract for a paper published in the conference proceeding," *KAPAP conference proceedings at KALRO Westlands* 10-12th June 2015; pp 88-91

Namikoye, E. S., Kariuki, M. G., Kinyua, Z. M., Githendu, M. W. and Kasina, M. (2015). Effects of companion crops on population dynamics of maize lethal necrosis disease vectors in Bomet County of Kenya.*Paper KAPAP conference proceedings at KALRO Westlands* 10-12th June 2015; pp 88-91

Effects of companion crops on population dynamics of Maize Lethal Necrosis Disease vectors in Bomet County, Kenya

Namikoye, E. S.[1, 2*], G. Kariuki[1], Z.M. Kinyua[2], M.W. Githendu[1] and M. Kasina [2]
[1]Department of Agricultural Science and Technology, Kenyatta University, P.O. Box 43844-00100, Nairobi.
[2]Kenya Agricultural and Livestock Research Organization-Kabete, P.O. Box 14733-00800, Nairobi
[*]Correspondence: Muo.Kasina@kalro.org

Abstract

Maize is the most consumed staple food crop in Kenya with a per capita of 110 kg. It is equally an important commercial crop particularly in high potential areas. Currently, the presence of Maize lethal necrosis disease (MLND) has constrained its production. The disease is challenging to manage because it is a co-infection of maize by two viruses, the Maize chlorotic mottle virus and Sugarcane mosaic virus, which are vectored mainly by corn thrips (*Frankliniella williamsi)* and corn leaf aphids (*Rhopalosiphum maidis*), respectively. This study was carried out to assess the potential for companion crops to act as traps or repellents for these vectors, thus contributing to vector management. Trials were carried out in farmers' fields in Bomet County. Treatments included napier, coriander, millet, sorghum and maize, arranged in a randomized complete block design with four replicates for two seasons, November 2014-April 2015 and April-August 2015. Each crop was planted either as an intercrop or a border crop with maize as the main crop. We present results from the first season. There were significant differences ($P < 0.001$) in the presence of corn Thrips among the companion crops although intercrops (21.53) recorded a slightly higher significant figure than border crops (10.28). Coriander trapped the highest number of corn thrips (27.6), followed by sorghum (22.2). Napier and millet trapped the lowest mean number of thrips, 9.1 and 4.7, respectively. However, in comparison with maize (85.96), companion crops had significantly lower corn thrips. Coriander hosted the highest number of aphids (132.6) compared with napier (45.9) and sorghum (30.8) while millet recorded the lowest (5.6). The number of aphids in coriander and maize (60.4) was not significantly different from each other but was significantly higher compared with those registered in other companion crops ($P=0.0021$). This preliminary study shows that both napier and millet may act as repellent crops for Corn Thrips mainly as border crops while coriander and sorghum could act as trap crops majorly as intercrops.

APPENDIX V

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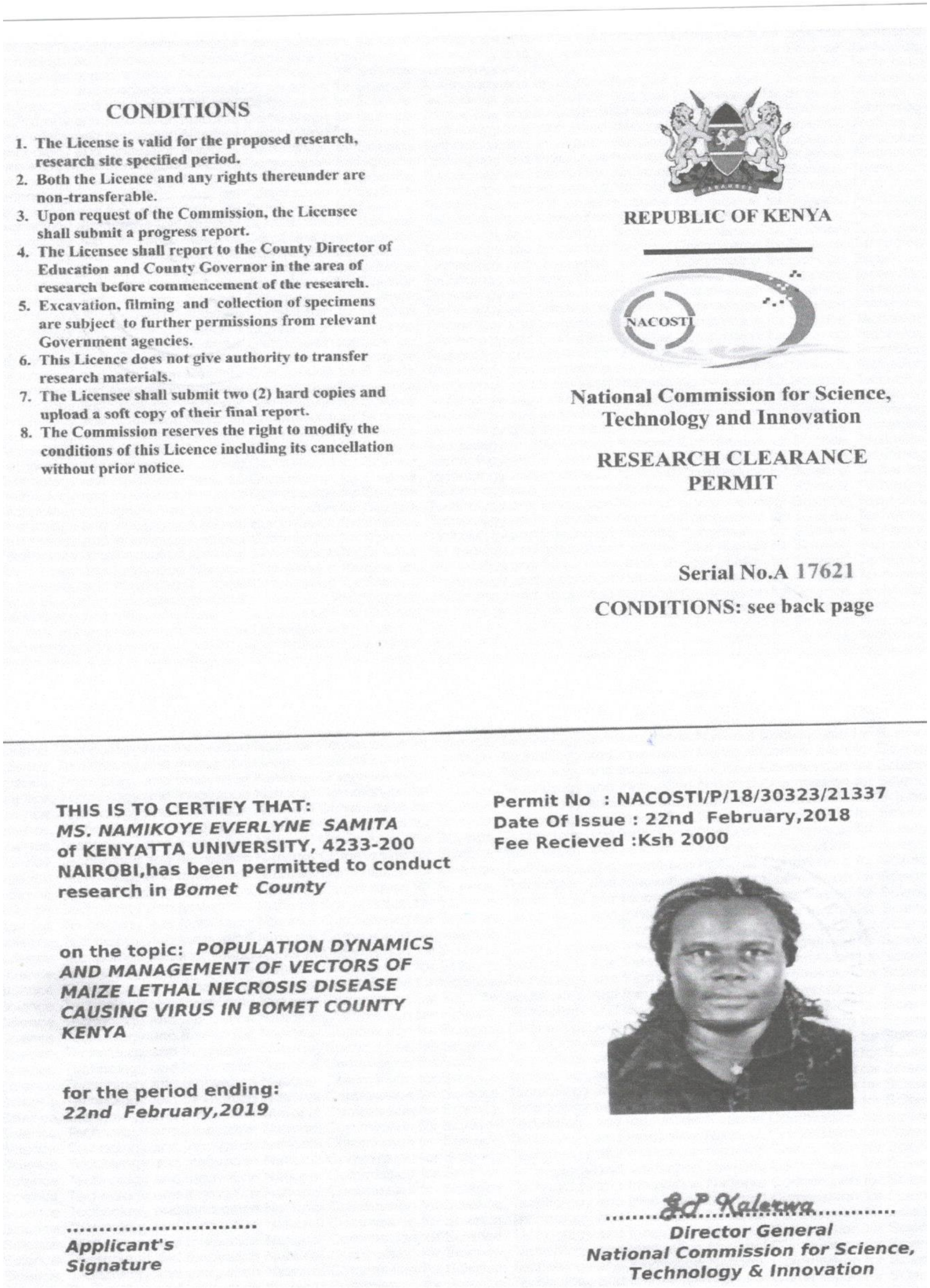

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NAIROBI,has been permitted to conduct
research in *Bomet County*

on the topic: *POPULATION DYNAMICS AND MANAGEMENT OF VECTORS OF MAIZE LETHAL NECROSIS DISEASE CAUSING VIRUS IN BOMET COUNTY KENYA*

for the period ending:
22nd February,2019

Permit No : NACOSTI/P/18/30323/21337
Date Of Issue : 22nd February,2018
Fee Recieved :Ksh 2000

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Applicant's Signature

GP Kalerwa
Director General
National Commission for Science, Technology & Innovation

APPENDIX VI

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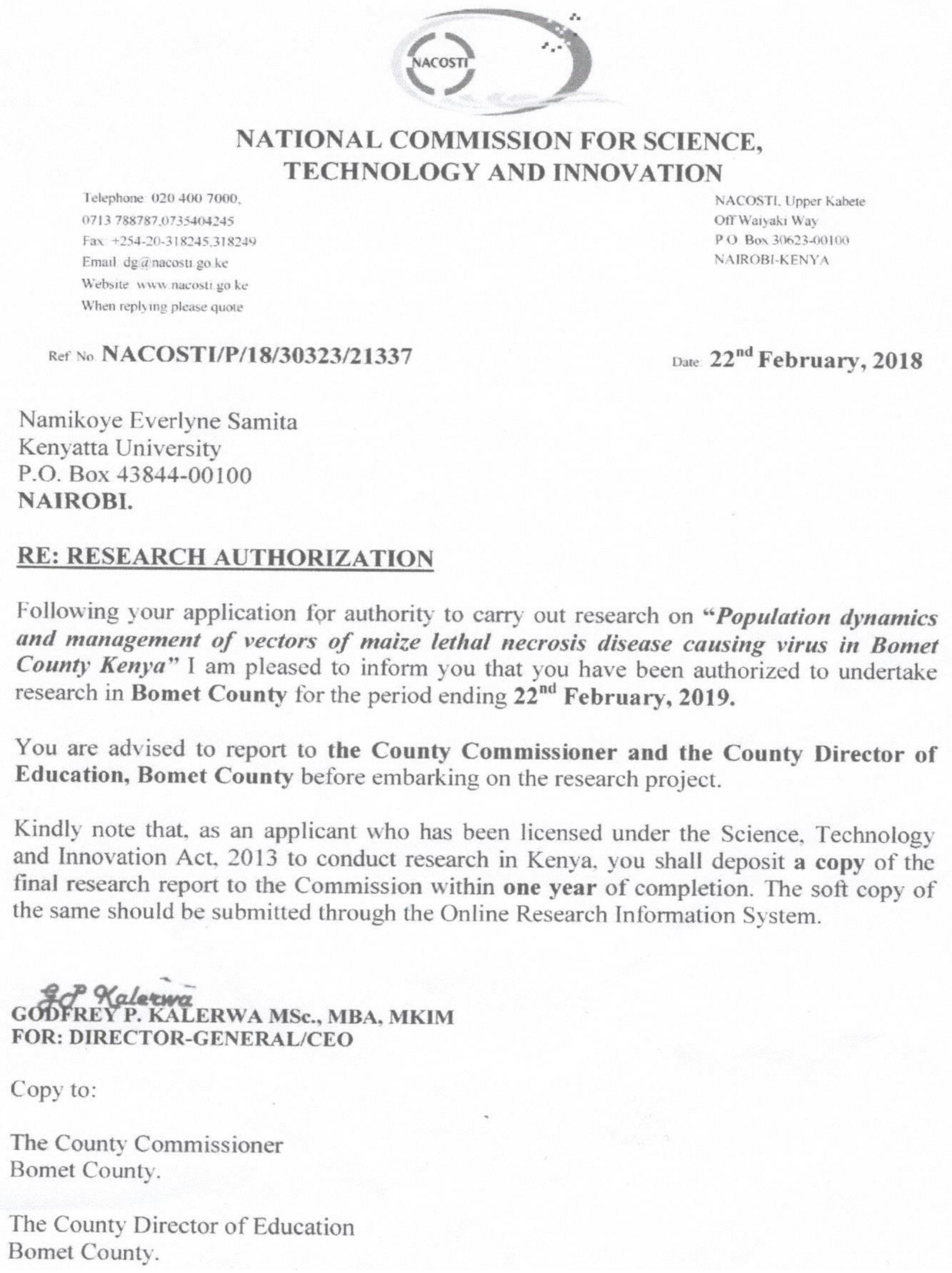

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Date: **22nd February, 2018**

Namikoye Everlyne Samita
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on **"*Population dynamics and management of vectors of maize lethal necrosis disease causing virus in Bomet County Kenya*"** I am pleased to inform you that you have been authorized to undertake research in **Bomet County** for the period ending **22nd February, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Bomet County** before embarking on the research project.

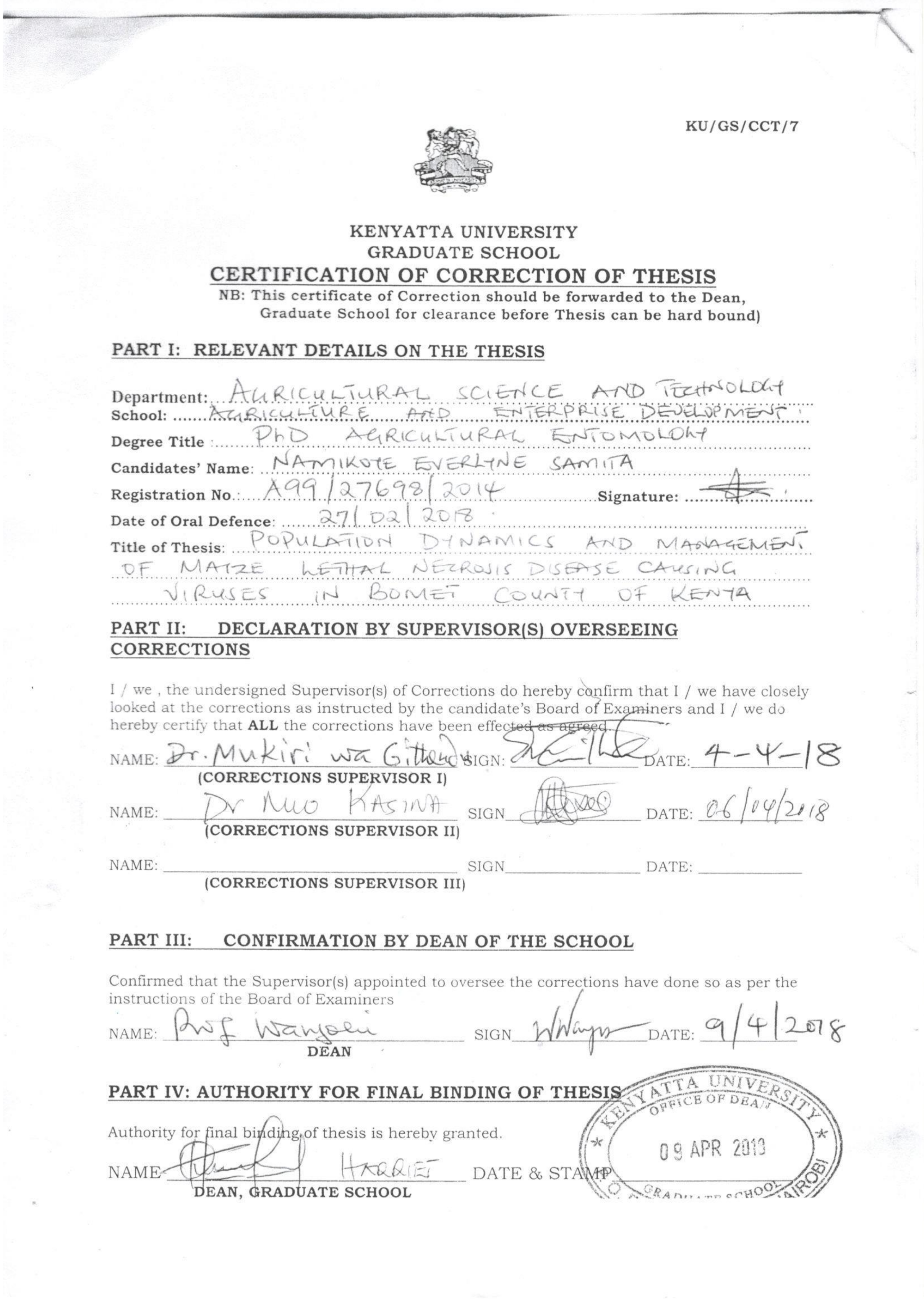
Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

G.P Kalerwa
GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Bomet County.

The County Director of Education
Bomet County.



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Candidates' Name: NAMIKOYE EVERLYNE SAMITA
Registration No.: A99/27698/2014 **Signature:**
Date of Oral Defence: 27/02/2018
Title of Thesis: POPULATION DYNAMICS AND MANAGEMENT OF MAIZE LETHAL NECROSIS DISEASE CAUSING VIRUSES IN BOMET COUNTY OF KENYA

PART II: DECLARATION BY SUPERVISOR(S) OVERSEEING CORRECTIONS

I / we , the undersigned Supervisor(s) of Corrections do hereby confirm that I / we have closely looked at the corrections as instructed by the candidate's Board of Examiners and I / we do hereby certify that **ALL** the corrections have been effected as agreed.

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