EFFECTS OF COLOURED AGRONETS IN THE MANAGEMENT OF TOMATO (Solanum lycopersicum L.) PESTS AND TOMATO YIELD IN KENYA

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I56/CE/22781/10

A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science (Agricultural Entomology) in the School of Pure and Applied Sciences of Kenyatta University

October 2016
DECLARATION

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

Signature……………………………………………………… Date…………………………

Gacheri Virginia Kithinji (BED. Sc)
Department of Zoological Sciences

SUPERVISORS

We confirm that the work reported in this thesis was carried by the candidate under our supervision

Signature………………………………………………………Date…………………………

Prof. Jones M Mueke,
Department of Zoological Sciences,
Kenyatta University.

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

Dr. Muo Kasina,
National Sericulture Research Centre,
Kenya Agricultural Livestock Research organization.
DEDICATION

To the Almighty Father our God for his protection and guidance throughout the period of study. To my husband Boniface Kirugi, to my three daughters Nonzamo Mwende, Madkizella Kamathi and Emmy Kinya who supported me wholeheartedly during the period of the study. To my dad Janaro Kithinji, Mum Julieta Nkuru, relatives and friends who have contributed in one way or another to the completion of this study.
ACKNOWLEDGEMENTS

I am greatly indebted to my supervisors, Prof. Jones M. Mueke and Dr. Muo Kasina for their guidance, keen interest and advice during the course of the study. They gave constructive criticisms and advice to give the work its final quality. May the good Lord reward and richly bless them.

I also thank Prof. E. Kokwaro and Dr. J. Mbugi of the Department of Zoological Sciences for the encouragement during the research work. I am also grateful to all the field assistants especially Messers. Mbevi, Mulwa, Ongutu and Abel. I wish to express my sincere thanks also to Ms Ann the secretary Entomology Section (KALRO Kabete), Mr. Thuranira E.G, the biometrician for assistance and encouragement during the field work. To my fellow colleagues (Mrs Christine C.M., Messers. Kinoti and Okoth) may the good Lord reward and bless them abundantly.

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### ABBREVIATIONS AND ACRONYMS

<table>
<thead>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>CABI</td>
<td>Centre for Agriculture and Bioscience International</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organization</td>
</tr>
<tr>
<td>FAOSTAT</td>
<td>Food and Agriculture Organization Statistics</td>
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<td>HCDA</td>
<td>Horticultural Crops Development Authority</td>
</tr>
<tr>
<td>KALRO</td>
<td>Kenya Agricultural and Livestock Research Organization</td>
</tr>
<tr>
<td>MOA</td>
<td>Ministry of Agriculture</td>
</tr>
<tr>
<td>PAN</td>
<td>Pesticide Action Network</td>
</tr>
<tr>
<td>AVRDC</td>
<td>Asian Vegetable Research and Development Centre</td>
</tr>
<tr>
<td>USAID</td>
<td>United States Agency for International Development</td>
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<tr>
<td>ICIPE</td>
<td>International Centre of Insect Physiology and Ecology</td>
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<td>NARL</td>
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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a valuable vegetable crop in Kenya, grown mainly by small-scale farmers. It provides food security, nutrition and income for many small-holder farmers. Despite its economic importance, tomato production faces major challenges including scarcity of high quality fruits, insect pests and diseases. Currently farmers have relied on application of pesticides to manage the tomato pests. Pesticides are expensive to the farmer and have a negative impact to the farmer, consumer and the environment. Therefore, farmers need to evaluate other pest control strategies that are safe, effective and economically viable with the aim of minimizing the hazardous effects of pesticides residues. This study investigated the effectiveness of coloured agronets against tomato insect pests, their distribution within the crop and impact on yield. The field study was conducted on station at the Kenya Agricultural and Livestock Research Organization (KALRO) at Kabete in Nairobi County. The experiment comprised of two seasons each consisting of five months period. Riogrande tomato variety was grown in a nursery and the seedlings were transplanted on the fourth week after sowing. The effects of coloured agronets were investigated over two seasons. The experimental design was complete randomized block design with six treatments each with five replicates. The six treatments were blue, yellow, silver, rainbow and white coloured agronets and the control. Each replicate was a plot measuring 3m by 1m with twelve tomato plants with a spacing of 50 cm from one tomato plant to the other. Data collection involved counting the number of the major tomato pests and their distribution within the crop (top, middle and bottom plant parts). The total ripe fruits per plot were harvested eleven weeks after transplanting depending on the ripening. They were graded into marketable and unmarketable, and their total mean number and mean weight were obtained. The causes of unmarketable tomatoes were determined. The data obtained from the field experiment was entered in excel and exported to Genstat version 14. One way analysis of variance (ANOVA) was done to compare means across the treatments. Significance was sought at 95% level of confidence limit. Post hoc analysis was performed on the data found significant and the means were separated using the Least Significant Difference (LSD). Correlation of the total yield and the total pest number was also carried out. The rainbow, yellow and white agronets significantly reduced pest infestation levels compared with the control while whiteflies (*Bemisia tabaci*) prefered to infest the top of the plant canopy. However, the leaf mines were more abundant in the middle of the plant canopy. Tomatoes which were harvested under the rainbow agronet treatment were the most but not significantly different from those harvested under yellow and white agronets. The African bollworm (*Helicoverpa armigera*) was a major cause of yield loss on the control. The results of this study showed that colored agronet covers are potentially effective technology in improving tomato yields through the reduction of pest numbers on the crop. From the results obtained from this study it is recommended that use of agronets to be included in integrated management of tomato pests in tomato production.
CHAPTER ONE

INTRODUCTION

1.1 Background information

The tomato (*Solanum lycopersicum*) belongs to the Solanaceae family. The family includes black nightshade (*Solanum nigrum* L.) brinjals (*Solanum melongena* L.), potatoes (*Solanum tuberosum*) and capsicums (*Capsicum annuum*). It is one of the most valued vegetable crop; its origin is South America from where it spread to Europe in the sixteenth century and later to East Africa in the 1900 (Wamache, 2005). Several varieties have been developed for commercial purposes, for fresh market and the processing (MOA, 2009; Prasad and Kumar, 2010). Tomato is an important source of vitamin C, calories, phosphorous and calcium. It has been ranked as number two after potatoes as the most important vegetable in most regions of the world (FAOSTAT, 2005). A review on tomato production worldwide shows an average production of 126 million tons which was recorded in 2007 (FAO, 2007). In Kenya, the total production of tomatoes during the year 2011 was 407,374 Mt in 18,178 Ha (MOA, 2011).

In Kenya, tomato is ranked among the horticultural crops mainly grown under the rain fed conditions and under irrigation by small-scale farmers (HCDA, 2009). In Kenya, the crop is mainly grown in Kirinyaga County (Mwea Area), Meru Central (Mitunguu area), Isiolo, Nyeri, Nakuru and Taita-Taveta counties, with a total production of 3,476,028 tons (MOA, 2005). Due to unpredictable rainfall patterns, some small scale
farmers have started growing tomatoes in the greenhouses. In 2004, approximately 75,101 tons of tomatoes were produced in the central regions (Waiganjo et al., 2006).

Damage and yield losses due to insect pests attack have been reported in the East African region. The major insect pests on tomato include African bollworm (*Helicoverpa armigera*), red spider mite (*Tetranychus spp*), whitefly (*Bemisia tabaci*) and Thrips (*Ceratothripoides brunneus* Bagnall) (Varela et al., 2003).

In order to reduce yield losses, farmers rely on spraying synthetic chemical pesticides such as bifenthrin, permethrin, Malathion and carbaryl to reduce damage from pests. The over use of synthetic pesticides has several drawbacks which include elimination of natural enemies, development of resistance by pests, resurgence of pests and the development of secondary pests (Mathews, 2008). Chemicals are also toxic, expensive and leave residues in the environment (HCDA, 2011). Therefore, the farmers need to seek other alternative methods of pest management that are safe, effective and environmentally acceptable. Some of the alternative methods which are currently used include botanical methods, cultural practices like mulching, intercropping and recently the findings of agronet as very effective approach to pest management in horticulture farming systems. The current study aimed at investigating the effects of coloured agronets in the management of key pests of tomato, their distribution within the crop and their impacts on yield.
1.2 Problem statement

Tomato production is emerging as an important income generating activity in Kenya especially for small-scale farmers (HCDA, 2009). Despite its economic importance, tomato production faces major challenges including scarcity of high quality fruits, insect pests and diseases. Tomato yield losses in East Africa (including Kenya) can be as high as 88% of which pests account for 56% (CABI, 2004). Moreover, with limited knowledge and training in pest management techniques, farmers in sub-Saharan Africa often rely heavily on pesticides control. Nevertheless, pesticides have a negative impact on farmers, consumers and the environment. Apart from being expensive to the farmer, they destroy the natural enemies and pests develop resistance. In Africa insect-proof nets and particularly insecticide-treated nets have only been used as bed-nets in public health to prevent malaria morbidity and mortality (Hougard et al., 2002). Therefore, farmers need to seek alternative methods of pest management that are cheap, effective and environmentally acceptable such methods include use of agronets. The transparent (white) agronets have been tested against tomatoes and cabbage in Kenya and they have been found to effectively reduce pest infestations and are suitable for cost effective production of tomatoes (Bionet Agro, 2010). However, it is prudent to enhance the efficiency of these agronets, for instance, through the consideration of colour of the agronets. This study evaluated the effects of coloured agronets in controlling tomato pests.
1.3 Justification of the study

Tomato is a commonly used vegetable crop and is cultivated throughout the year for domestic and commercial purposes. Apart from its importance as a source of income, the tomato has a compound known as lycopene which is known to decrease the incidence of prostate cancer and age related disorders (AVRDC, 2003). Due to insect pests and diseases, there is low tomato production which does not meet the demand for consumption and marketing. Low productivity is a result of poor rainfall distribution, pests and diseases affecting the crop (MOA, 2010). The pests include red spider mite (Tetranychus ssp) whiteflies (Bemisia tabaci), thrips (Ceratothripoides brunneus) and the African bollworm (Helicoverpa armigera). In order to control the pests, growers mainly use chemicals, thereby creating a problem of the presence of the pesticide residue in and on the produce (Varela et al., 2003). Chemicals are also toxic, expensive and leave residues in the environment (HCDA, 2011).

Tomato consumers are enlightened on pesticides residue effects on their health and therefore, increasingly demand for clean and quality produce. Use of agronets in the tomato production is a good management practice aimed at increasing tomato production and minimizing losses from pests and adverse weather conditions. This technology has successfully been practiced in different countries of the world such as Benin, Burkina Faso, Netherlands and India (Esther et al., 1994). According to Bionet Agro, (2010) the use of agronets is new in Kenya and apart from pest control, the cover interferes with the micro-climate within the area which may enhance crop growth. The
nets have different mesh sizes and the best size for tomato was found to be 0.4mm while 0.9mm was found to be best for cabbage (Muleke et al., 2014). Specific insect pests have a preference for certain colors and this reduces their impact on crops. For instance, Ben Yakir et al. (2008) reported that whiteflies preferred to land on yellow nets compared to black nets. In their study, yellow sticky traps were placed under the yellow nets. These traps collected more adult whiteflies than the traps under the black netting (Ben Yakir et al., 2008).

This study was initiated to evaluate the effectiveness of coloured agronets as a pest management option that could be useful in reducing the indiscriminate pesticides application.

1.4 Research questions

i. What are the effects of colored agronets in the management of tomato pests?

ii. What are the effects of colored agronets in the distribution of tomato pests within the crop?

iii. What are the yields of tomatoes grown under colored agronets?

1.5 Hypotheses

(i) Colored agronets do not differ in the management of tomato pests in Kenya.

(ii) There is difference in pests’ distribution within the tomato crop across different agronets.

(iii) There is no difference in the yield of tomatoes grown under different colored agronets.
1.6 Objectives of the study

1.6.1 General objective

The overall objective of the study was to investigate the effectiveness of coloured agronets in the management of the major tomato (*Solanum lycopersicum* L.) pests in Kenya.

1.6.2 Specific objectives

i. To determine the effect of coloured agronets on tomato pests incidences.

ii. To determine the effects of coloured agronets on pest distribution within plant parts.

iii. To assess yield of tomatoes grown under coloured agronets.

1.7 Significance of the study

Tomato consumers are enlightened on pesticides residue effects on their health and therefore, there has been increasing demand for clean and quality produce. Use of agronets in the tomato production is a good management practice aimed at increasing tomato production, minimizes use of pesticides and losses from pests and adverse weather conditions. Agronets are safe, cheap, and they can be used for five years before replacing them.
CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and cultivation of tomato

The origin of tomato crop is South America from where it spread to Europe in the sixteenth century and later to East Africa in the 1900 (Wamache, 2005) . The wild relative tomato (Solanum lycopersicum L.) is native to western South America, including the Galapagos Island (Peralta et al., 2008) . Like the other horticultural crops, tomato was first introduced in Kenya in 1933 by the early European settlers (Atherton and Rudich, 1986).

Tomato (Solanum lycopersicum L) belongs to the Solanaceae family and it is a warm climate crop but it can be grown in cold climate under protection. The crop takes 3 to 4 months to mature but can also extend over a year particularly the indeterminate varieties. It grows best in fertile, well-drained soils with pH 6 (Obeng-Ofori et al., 2007) and ambient temperatures of about 25°C (Rice et al., 1987). Tomato is a popular crop in Kenya and in many parts of the world and it is an important source of vitamins, minerals and fiber for human diets globally (Naika et al., 2005; Ssekyewa, 2006). It has also been reported that tomato contains lycopene antioxidant which is important in fighting free radicals that interfere with the normal cell growth (Giovannucci, 1999; Naika et al., 2005). In Kenya, tomato is an important vegetable whose fruits are used in
salads, cooked as vegetable, processed into tomato paste, sauce and puree (MOA, 2009).

Tomato yields in the tropics vary widely between one to 23 tons per hectare compared to the temperate regions where yields of 10 to 20 tons per hectare have been realized (Lanny, 2001). Yields are lowest in tropical Africa as a result of both non-living and living components of which the latter include primarily insect pests, diseases and weeds (Tumwine et al., 2002). The total tomato production in the year 2009-2011 in Kenya is shown in table 2.1 while tomato production in the 1st ten counties in Kenya is shown in table 2.2. The tomato production increased from 354,356 Mt in 2009, 378,756 Mt in 2010 and 407,374 Mt in 2011 and the value also increased from 2009-2011.

**Table 2.1. Increased area under tomato production and estimated value in Kenya for the period 2009-2011**

<table>
<thead>
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<th>Area (Ha)</th>
<th>Production (Mt)</th>
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<td>2009</td>
<td>17,230</td>
<td>354,356</td>
<td>8,549,178,482</td>
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<td>2010</td>
<td>17,529</td>
<td>378,756</td>
<td>10,441,561,004</td>
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<td>2011</td>
<td>18,178</td>
<td>407,374</td>
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### Table 2. 2 Tomato production in the 1st ten counties in Kenya

<table>
<thead>
<tr>
<th>No</th>
<th>County</th>
<th>Area- ha</th>
<th>Qty (MT)</th>
<th>Value( million Kshs)</th>
<th>Area- Ha</th>
<th>Qty (MT)</th>
<th>Value( million Ksh)</th>
<th>Area - HA</th>
<th>Qty (MT)</th>
<th>Value (million Ksh)</th>
<th>% share</th>
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<td>1</td>
<td>Taita Taveta</td>
<td>1,485</td>
<td>61,481</td>
<td>1,343</td>
<td>70,328</td>
<td>1,508</td>
<td>1,508</td>
<td>1,702</td>
<td>70,743</td>
<td>1,769</td>
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<td>Migori</td>
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<td>628</td>
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<td>456</td>
<td>3.7</td>
</tr>
<tr>
<td>8</td>
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<td>15,802</td>
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<td>9</td>
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<td>386</td>
<td>7,140</td>
<td>83</td>
<td>218</td>
<td>1,410</td>
<td>55</td>
<td>312</td>
<td>22,000</td>
<td>438</td>
<td>3.5</td>
</tr>
<tr>
<td>10</td>
<td>Transzoia</td>
<td>376</td>
<td>8,640</td>
<td>87</td>
<td>289</td>
<td>8,624</td>
<td>110</td>
<td>470</td>
<td>10,620</td>
<td>367</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>17,230</td>
<td>354,356</td>
<td>8,549</td>
<td>17,529</td>
<td>378,756</td>
<td>10,442</td>
<td>18,178</td>
<td>407,374</td>
<td>12,354</td>
<td>100.0</td>
</tr>
</tbody>
</table>

(Source: MOA, 2013)

### 2.2 Tomato production in Kenya.

Tomato is a commonly used vegetable crop and is cultivated throughout the year to increase income for small scale farmers in rural areas, improve living standards and a source of employment (Ssejjemba, 2008). Tomato is mainly cultivated in the open field. However, in the recent past adoption of greenhouse, tomato growing technology is on the increase (Wachira et al., 2014). In the year 2012, tomato production covered 18,613 ha with a total production of 397,007 MT valued at 12.8 billion (HCDA, 2013). The major tomato producing counties in Kenya are Kirinyaga (13.7%), Kajiado (9.1%) and Taita Taveta (6.9%) (HCDA, 2013). Determinate variety is cultivated in the open field while indeterminate tomato variety is cultivated in greenhouses (Odame, 2009).
2.3 Challenges to tomato production in Kenya

Tomato production challenges experienced by farmers in Kenya are diseases, pests, poor quality seeds, high cost of inputs and adverse weather conditions (HCDA 2011).

Tomato production in Kenya is faced with many constraints which affect tomato yields. These include damage by insect pests and diseases, poor crop husbandry, low quality seeds and post-harvest losses among other factors (Varela et al., 2003). Tomato plant is damaged from the seedling stage of growth throughout its development by insect pests feeding directly and through transmitting disease causing organism (Lange and Bronson, 1981). Tomato yield losses in East Africa (including Kenya) can be as high as 88% of which pests account for 56% (CABI, 2004). Other challenges of tomato production include uncoordinated and unorganized marketing, exploitation by middle men and poor production planning leading to over-supply in some months hence low prices (MOA, 2011).

2.4 Pests affecting tomato production

A tomato plant is attacked by a wide range of pests such as Lyriomyza spp (leaf miners) Helicoverpa armigera, (African bollworms), Bemisia tabaci (whiteflies), Ceratothripoides brunneus (thrips) and Aphis gossypii (aphids). Red spider mite (Tetranychus evansi) and the tomato russet mite (Aculops lycopersici).Mites have been reported to cause high tomato yield losses (Gleason and Brook, 2006). They damage a crop by sucking cell sap from underside of leaves (Syngenta, 2011), stems and fruits. In addition they cause leaf defoliation, flower abortion, fruit russeting and cracking. The
seriously affected leaves turn pale and chlorotic (Syngenta, 2011), they curl, wither and
die. Consequently, only small bunches of the new growth remain at the tips of the plant
(Varela et al., 2003). When infestation is severe, mites cause stunted growth, drying and
falling of leaves, hence resulting to yield losses (Varela et al., 2003).

The African bollworm (*Helicoverpa armigera*) is a serious insect pest and has been
reported to cause damage in tomato production in Kenya (Wabule, 1997). *Helicoverpa
armigera* main damage is caused by old larvae which feed on flower buds, flowers and
by burrowing into the young tomato fruits (Syngenta, 2011) causing secondary infection
which is followed by rotting of the fruit. In addition, it attacks many other different
crops such as beans, pigeon peas, cotton, maize and different weeds (Jallow et al.,
2005).

Whiteflies cause direct crop damage when feeding because they injure the plant tissues
and suck nutritive plant sap and indirect damage by transmitting diseases to host plants
(Perring, 1995, 2001). The damage results to stunting, poor growth, defoliation, reduced
yields and sometimes death. Other forms of damages include chlorotic spot, yellowing,
branching of vegetative structures and irregular ripening of the tomato fruits which
result from defoliation. Whiteflies excrete honeydew, a clear sugary liquid which
supports growth of black sooty mould which decreases the photosynthetic rate
(Fenemore and Prakash, 2006; Gilbertson, 2008). Apart from direct damage, whiteflies
transmit economically important virus diseases.
Thrips belong to the Thripidae family but only a few species which are serious crop pests and these include *Ceratothripoides brunneus* (Bagnall) pest on tomato (Varela *et al.*, 2003). Thrips cause injury to flowers, stems, flower buds, fruits and leaves with their piercing and sucking mouth parts and ovipositor (Lewis, 1997). A characteristic of the feeding behavior of thrips is that they inject saliva into cells prior to sucking their content and this facilitates the ability of thrips to act as vectors of plant viruses (Moritz *et al.*, 2004). During oviposition, female thrips puncture plant tissues with their ovipositors causing destruction of epidermal and parenchyma cells which leave brown spots after drying.

### 2.5 Integrated pest management (IPM)

Integrated Pest Management (IPM) is an approach that can reduce the counterproductive pesticide applications (Wheeler, 2002). It focuses on long term prevention of damage to crops by pests through a combination of cultural, chemical, biological and physical controls to suppress pest population levels below those causing economic injury (Flint, 2012). The current trends in crop production are towards reducing the use of pesticides by applying multiple control tactics (Raini *et al.*, 2005). The approaches for the control of tomato pests in Kenya include biological, chemical, cultural and physical methods (Waiganjo, *et al.*, 2011).
2.5.1 Biological control

Biological control is defined as the use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be (Eilenberg et al., 2001). Microbial agents such as arthropod parasitoids and predators, entomopathogenic nematodes and microbial agents such as viruses, bacteria, protozoa and fungi) are increasingly becoming an important part of integrated pest management strategies (Van Driesche and Bellows, 1996; Van Lenteren, 2008). Horticultural farmers in Kenya have used predators, parasitoids and pathogens as part of an integrated strategy for insect pest management (Migiro et al., 2010). Biological control agents are good components of Integrated Pest Management because they are selective and produce little toxic or no toxic residues.

*Trichogramma* sp.nr. *Mwanza* (Schulten and Feijen) and *Trichogrammatoidea* sp.nr. *Lutea* (Girault) have been successfully utilized in Kenya as biological control against *H.armigera* infesting tomato crops (Kalyeb et al., 2015). International Center of Insect Physiology and Ecology (ICIPE) conducted surveys in Kenya between 2007 and 2008 which indicated the presence of various indigenous leafminer parasitoid species. The most important ones were *Diglyphus isaea* walker, *Hemiptarsenius varicornis* (Girault) (Hymenoptera Eulophidae) *Opis dissitus* Muesebeck (Hymenoptera: Braconidae) and *Neochothescharis Formosa* (Westwood) Hymenoptera: Eulophidae) (Chabi-Olaye et al., 2008). The parasitoids against whiteflies that have been successfully used worldwide are dominated by two genera of aphelenid hymenopterans, Encarsia and Eretmocerus
The parasitic wasp *Aphidius ervi* (Haliday) (Hymenoptera: Braconidae) is widely found in Kenya and are very efficient for the biological control of the aphid *Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae) in tomato crops (Kennedy, 2003; Digilio et al., 2012). Parasitic wasps have been used successfully to control greenhouse whiteflies in protected crops (Varela et al., 2003). A Phytosaide predator has been commonly used to control cassava green spider mites and has been widely practiced mainly in North America and Europe (Gerson et al., 2003, Ferrero et al., 2011).

### 2.5.2 Chemical control

Chemical control is the application of insecticides and pesticides to minimize pest populations infesting the crops. The chemical compound in the pesticides kills pests or inhibits their feeding, mating and other essential behaviors. Examples of chemicals are synthetic pesticides, botanical pesticides and semiochemicals (National Research Council, 1992).

#### 2.5.2.1 Synthetic pesticides

Categories of synthetic pesticides for agricultural use include organochlorine, carbamate, organophosphate and pyrethroids among others (Eldridge, 2008). Dimethoate, alpha-cypermethrin, abamectin, imidacloprid and cyfluthrin are the most common pesticides used against pests in vegetable production systems in Kenya (Gitonga et al., 2010). Beta cyfluthrin 9% SC+Imidacloprid 21% (at 15.75+36.75 g.a.i./ha) insecticides are very effective in the reduction of damage caused by *H.armigera*,
followed by monocrotophos 36 SL 450 g.a.i/ha, beta cyfluthrin 25 SC 18.g.i./ha, Imbda cyhalothrin 5% EC+ thiamethoxan 25 WG 15.62+31.25 g.a.i/ha imidacloripd 200 SL 42 g.a.i/ha (Ashokkumar and Shivaraju, 2005). Various methods are being used to reduce spider mites population such as chemical application of the recommended chemicals when the pest population is high (Varela et al., 2003).

The chemical should cover all the plants parts especially underside of the leaves where most spider mite life stages are located (Schuster et al., 2007).

### 2.5.2.2 Semiochemicals

A semiochemical is a chemical signal secreted by an organism leading to behavioral change in an individual of the same species or a different species. Insect hormones namely the kairomones and pheromones can be used with great specificity in the monitoring of pest populations to trap and kill pests, and also to confuse insect mating behavior (El-sayed et al., 2009). The tomato leafminer *Tuta absoluta* (Meyrick) (Lepidoptera:Gelechiidae) is not effectively controlled by convectional chemicals and pheromone lures are used for both monitoring and mass trapping in an integrated pest management program in Argentina, South America (Pereyra and Sanchez, 2006).

### 2.5.2.3 Botanical pesticides

These are naturally occurring chemicals extracted from plants and are used for pest management. They are safe to use and are friendly to the environment and to human health (Isman, 2006). The pyrethrum, rotenone, neem and essential oils are botanical
products which are used for insect control (Prakash and Rao, 1996). Neem seeds contain Azadirachtin a botanical insecticides from Azadirachtin indica Juss (Meliaceae) (Schmutterer, 2002). Azadirachtin indica is a strong anti-feedent, repellent and growth regulator of a wide variety of phytophagous insects (Mitchell et al., 2004).

Currently neem- based products are registered as pesticides in Kenya (Knapp and Kashenge, 2003) however these products have already proven to be effective against several insect pests such as Plutella xylostella, Brevicoryne brassicae l., Myzus persicae (Kalt) and Lipaphis erysimi (Sulz) in cabbage, Brassica oleracea var capitata, and Lyriomyza spp. on tomatoes and cut flow (Knapp and Kashenge, 2003; Waiganjo et al., 2011). The active ingredients found in the pyrethrum plant of the genus Chrysanthemum are pyrethrins and cinerin which are obtained from the dried flowers of the pyrethrum daisy(Tanacetum cinerariaefolium; Asteraceae) (Rajapakse and Ratnasekera, 2008). Pyrethrins insecticides knocks down the flying insects and causes convulsions in most insects however, they are unstable in light compared with the synthetic derivatives (Pyrethroids) (Isman, 2006).

2.5.3 Cultural control

Cultural control techniques used to reduce insect pest population include site selection, crop rotation, trap cropping, cultivar and seed selection, plant density and weed control (Jones, 2001). To minimize losses by pest outbreaks, data on pest distribution is among
the important factors to consider when selecting a suitable site for growing vegetable crops (Jackson, 1988).

Cultural practices may have negative effects on different crop pests (Glen, 2002). Consequently, selection of specific practices must be based on the overall pest risk assessment. For instance, an alternative cultural control of *H.armigera* is the control of over-wintering pupae bursting which has been used in several cropping areas (Duffield, 2004). Trap cropping and planting repellent hosts in strips or around the field, have been widely applied (Hokkanen, 1991). Damage to fruit by *H.armigera* could be reduced when the African marigold was planted intercropped with tomato (Hussain and Sheik, 2007). Crop rotation is the repetitive cultivation of an ordered succession of crops on the same land (Palanianppan, 1996). Growing tomatoes on the same field year after year will lead to the buildup of populations of organisms that feed on the crop (Atieri, 1993). Crop rotation practices reduce the populations of pests, particularly aphids and thrips, over successive seasons by breaking the life cycle (Stoddard, et al., 2010). An integrated pest management program for whiteflies is a good cultural practice which involves host free periods monitoring fields for any trouble spots, protecting natural enemies and using pesticides only when necessary (Schuster et al., 2007).
2.6 Use of agronets in tomato production

Different literature reviews have been written on the impact of agronets on aspects such as flowering, pest control and post-harvest yields. Oren-Shamir et al. (2001) showed that the use of nets has a great impact on post-harvest yield in horticultural crops. According to USAID, agronets are innovative in managing insect pests. This innovation is not only inexpensive but it is also reusable and safe for use by farmers. The nets provide a physical barrier for protecting vegetables against pests (Vincent et al., 2003; Boiteau and Vernon, 2004). This protection extends further to the associated viral diseases. Studies have also shown that agronets improve the microclimate of vegetables with notable improvements in temperature, relative humidity light and soil moisture (Muleke et al., 2014). These factors contribute towards improved production of vegetables (HCDA, 2011).

Agronets not only increase yields but also improve the quality of fruits and vegetables (Gogo et al., 2014a; Muleke et al., 2014). Agronets also have an impact on specific insect pests, insects have a preference for certain colors and this reduces their impact on crops. For instance, Ben Yakir et al. (2008) reported that whiteflies preferred to land on yellow nets compared to black nets. In their study, yellow sticky traps placed under the yellow nets collected more adult whiteflies than the traps under the black netting (Ben Yakir et al., 2008).
The effectiveness of agronets in crop production has been tested and proved in Africa. Tests have been done on the cultivation of crops such as cabbage (*Brassica oleracea* L. var. capitata L.) (Muleke *et al*., 2014). Results have shown that the agronets are effective in controlling crop pests including aphids, cucumber beetles (*Acalymma* and *Diabrotica* sp.) and whiteflies. (Bionet Agro, 2010). As a result of their pest exclusion ability, agronets present a potential tool for reducing application of pesticides in crop production (HCDA, 2011).

Research findings have also shown that crop production with agronets has a direct effect on the growth and development of plants, resulting in better yields (Elad *et al*., 2007; Gogo *et al*., 2012). In Kenya, successful use of agronets has been achieved in tomato production and cabbage transplant production (Liccardi *et al*., 2008). It has been recorded that the size of the mesh of agronets used has an impact on insect penetration and the microclimate around the crop (Muleke *et al*., 2013). The use of nets in microclimate modification has been tested in Kenya on cabbage (Muleke *et al*., 2014). The Agronets have been found to be effective in microclimate modification. Agronets significantly alter air temperature and soil moisture, and this influences plant growth through changing leaf characteristics, biomass accumulation and relative growth rate of plants, hence better yields and quality of the crop (Gogo *et al*., 2012). Studies carried out on Eco Friendly Nets in Kenya have concluded that agronets can help in reducing population of insects such as aphids, whiteflies, leafminer, cotton bollworms and thrips on tomato plants (Gogo *et al*., 2014b).
The use of nets in tomato production is also a technique that is cost effective (Saidi et al., 2013). Research has shown that farmers incur high costs in purchasing chemical pesticides some of which are host specific rather than broad spectrum. This makes the cost of producing tomato high. With the use of agronets, the cost of chemical pesticides is addressed. Addressing the challenge of pests with agronets is a technology that helps in maximizing profits from tomato (Joubert and Poissonie, 1991). Use of nets in tomato production also has a positive impact on the quality of tomato. As a physical barrier, nets provide an enabling environment for tomatoes to grow to maturity without disturbance from environmental factors and pests (HCDA, 2011). Pests such as rodents and some insects are known to cause physical damage to tomatoes hence undermining their quality. When agronets are used to cover tomato crops, the fruits are protected hence their quality in the market is enhanced (Shahak, 2008). Studies have shown that tomatoes that are produced under nets are less damaged (Victor, 2015). For instance, they have few scars and other deformities that arise from biotic and environmental factors. Farmers who use nets can therefore enjoy high quality tomatoes that can easily be sold in the market (Shahak, 2008).
CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted at KALRO Kabete (Figure 3.1). The station is located in Nairobi County. It is situated about 8km Northwest of Nairobi $36^\circ 41^1$E and $01^0 15^1$S and at an attitude of 1737m above sea level in the upper semi-humid agro-ecological zone UM3(Jaetzold and Schmidt, 1983). The rainfall is bimodal; the average received ranging from 600 to 2000mm per year. The area is reliable and favorable for agricultural activities, with the April-July period receiving 60% and October-November 40% of precipitation. It has two crop growing periods with a total of 150-214 days. The mean annual temperature ranges from 18.0°C to 21.9°C. Soils at KARLO, Kabete, are dominated by humic Nitisols (UNESCO, 1990) with a clay texture and are known locally as Kikuyu Red Loam.

3.2 Experimental materials

In this study, the knitted polyethylene coloured agronets used were provided by A to Z Textile mills Ltd., Arusha, Tanzania. The agronets were blue, yellow, silver, rainbow with 0.4mm pore mesh size and white agronet with 0.9mm pore mesh size and the control. The A to Z Textiles used synthetic dyes to colour the agronets. The coloured agronets were cut into 3×5×1.3m covers to protect the tomato plants in the field after transplanting. Pegs measuring 1.3m were used to suspend the nets so that when the tomato plants grew they did not come into contact with the net.
3.3 Study design and field experiments

The study was carried out in a randomized complete block design in a plot size of 3×1m replicated five times. The tomato variety Rio Grande with determinate growth habit was chosen based on the recommendation of KARLO. There were two trials, season one and season two, each lasting for six months. Nursery experimental plots measuring 1×2m were manually prepared using a hoe and the beds raised to 15cm above the ground to improve drainage. Seeds were grown in the nursery in drills of 20cm apart and 1cm deep thereafter; watering was regularly done using watering cans. During
sowing, NPK fertilizer was applied at a rate of 10g per hole and the seedlings were transplanted to the field after a month. The field was ploughed to a depth of approximately 19cm and later harrowed to a fine tilth using a disc plough and harrow. Transplanting holes were manually dug and diammonium phosphate fertilizer was applied at the rate of 10g per hole and thoroughly mixed with the soil.

Watering was done using a watering can regularly ensuring that an equal amount of water was applied to each plot. The thinning of seedling was carried out later to 7cm apart in rows. Weeds were uprooted using hands and any plants showing signs of disease were pulled out immediately and thrown away. All other management practices were carried out uniformly in all the plots. The experiment had six treatments replicated five times. The treatments included:

a) Blue Agronet 0.4mm mesh size
b) Rainbow Agronet 0.4mm mesh size
c) Yellow Agronet 0.4mm mesh size
d) Silver Agronet 0.4mm mesh size
e) White Agronet 0.9mm mesh size (Standard)
f) Uncovered plot (Control)
White agronet with mesh size 0.9mm was used in the study as standard. The allocation of the treatments was random within a block. The spacing from one plot (treatment) to the next was one meter apart and two meters between blocks. Each plot had 12 tomato plants with two rows of six tomato plants spaced at 50cm x 50cm (inter row and intra row spacing). Pegs measuring 1.3m were used to suspend the nets so that when the plants grew they did not come into contact with the net (Plate 3.1). The tomato plants were covered with coloured agronets throughout the experiment except during weeding and other management practices. One week immediately after transplanting, pests sampling started and was done on weekly basis on four randomly selected tomato plants in the plot. Four tomato plants represented 30% of the tomato plants in every plot. After maturity, the harvesting of ripe fruits started and was done twice per week from the 11th weeks after transplanting. Ripe fruits were harvested per plot in labeled polythene bags and were carried to the KARLO laboratory for grading as marketable and unmarketable tomatoes.
3.4 Effects of colored agronets on tomato pests incidences and their distribution

Experiments were carried out both in the tomato nursery and in the field after transplanting. Data was not collected on tomato pests’ incidences in the nursery. One week after transplanting data collection on tomato pests’ incidences commenced, thereafter four randomly selected tomato plants per plot were sampled for pests’ incidences (Plate 3.2). The four tomato plants formed 30% of the total tomato plants in each plot. Sampling of pests was carried out weekly by inspecting 30% of the tomato plants in each plot. The samples were taken from the top, middle and bottom plant canopy to assess the number of different tomato pests and their distribution (Plate 3.3).
The major tomato pests include *Helicoverpa armigera, Bemisia tabaci, Tetranychus evansi, Liryomyza* spp, *T.tabaci* and *F.occidentalis*. Pests were counted per agronet and recorded separately. Sampling was by hand picking, use of aerial nets for flying insects, small pests like aphids and thrips were counted with the aid of a hand lens and forceps. Leaf miner damage was assessed by counting the number of leaf mines made on the leaves of the tomato plant. Sampling of the pests was done early in the morning when most insects had low activity.

Plate 3. 2: Plot opened for data collection at KARLO –Kabete
Plate 3.3: Samples taken from top, middle and bottom canopy

3.5 Effects of colored agronets on tomato yield

Harvesting of ripe fruits after maturity was done twice per week from the 11\textsuperscript{th} week after transplanting. Fruits were harvested per plot in labelled polythene bags, carried to the KARLO laboratory where they were weighed using a spring scale balance (Plate 3.4). The total number and weight of the fruits were recorded per plot to get the total yields at each harvest for every trial. The harvested tomato fruits were categorized as marketable and unmarketable quality based on surface defects, insect damage displayed on the fruits, blight, blossom end rot, canker, sunscald, rodent and bacterial infection.
Plate 3.4: Spring scale balance used for weighing tomatoes at KARLO Laboratory, Kabete

3.6 Data analysis

The obtained data was subjected to one way analysis of variance (ANOVA) to determine the most effective agronets colors for managing major tomato pests using Gens tat statistical package. Comparison of means was carried out using Fischer’s protected least significant difference (LSD) at 95% level of confidence limit. Correlation of the total yield and the total pest numbers were also carried out.
CHAPTER FOUR

RESULTS

4.1 Effect of colored agronets on tomato pests incidences

The pest species identified during the field experiments included *Helicoverpa armigera*, *Bemisia tabaci*, *Tetranychus evansi*, *Lirymyza* spp, *Ceratothripoides brunneus* and *Aphis gossypii*. In the first trial the total number of *Bemisia tabaci* was 3183, *Aphis gossypii* was 3683, *Ceratothripoides brunneus* was 691, leafmines made on leaves were 2,117. In the second trial the total numbers of *Bemisia tabaci*, *Aphis gossypii*, *Ceratothripoides brunneus* and leafmines were 32912, 2350, 1034 and 3273 respectively. The majority of these pests were collected from unprotected tomato plants in the field. Generally, there were low numbers of tomato pests on tomato plants grown under coloured agronets compared to the pests on the unprotected tomato plants (Table 4.1). In the two trials the tomato plants grown during the second trial had a higher pest incidence compared to the tomato plants grown in the first trial. There was more harvest of tomatoes in the second trial compared to the first trial. Agronets provide visual barrier to pests, hence difficult to see or locate tomato plants under the agronets (Plate 4.1).
Table 4. Mean number of whiteflies, leaf mines, thrips, aphids and red spider mite infesting tomato plants grown under agronets at KALRO Kabete December 2012 to May 2013 and September 2013 to March 2014

<table>
<thead>
<tr>
<th>Treatments</th>
<th>White flies</th>
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<th>Leaf mines</th>
<th></th>
</tr>
</thead>
<tbody>
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<td>Season 1</td>
<td>Season 2</td>
<td>Total</td>
<td>Season 1</td>
</tr>
<tr>
<td>Blue Agronet</td>
<td>116.4 ±116.40ab</td>
<td>1520.0 ±143.70a</td>
<td>1637.0 ±130.60a</td>
<td>50.80 ±13.26b</td>
</tr>
<tr>
<td>No net</td>
<td>162.4 ± 12.83a</td>
<td>1526.0 ±199.10a</td>
<td>1689.0 ±203.40a</td>
<td>240.8 ±34.04a</td>
</tr>
<tr>
<td>Rainbow Agronet</td>
<td>101.4 ±12.89bc</td>
<td>763.0 ±108.50bc</td>
<td>864.0 ±114.40bc</td>
<td>29.6 ±4.11b</td>
</tr>
<tr>
<td>Silver Agronet</td>
<td>113.0 ±26.44abc</td>
<td>1076.0 ±154.60bc</td>
<td>1189.0 ±155.00bc</td>
<td>26.6 ±6.01b</td>
</tr>
<tr>
<td>White Agronet</td>
<td>79.6±5.75 bc</td>
<td>987±92.30 bc</td>
<td>1066.0 ±96.20bc</td>
<td>32.0±7.76b</td>
</tr>
<tr>
<td>Yellow Agronet</td>
<td>63.6 ±3.96c</td>
<td>711.0 ±114.30c</td>
<td>775.0 ±111.90c</td>
<td>43.6 ±11.54b</td>
</tr>
</tbody>
</table>

| P value | 0.016 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| LSD     | 52.44 | 338   | 332.8 | 44.82 | 72.7  | 80.6  |

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<td>Season 2</td>
<td>Total</td>
<td>Season 1</td>
</tr>
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<td>28.8</td>
<td>41.6</td>
<td>1</td>
</tr>
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<td>19.2</td>
<td>35.4</td>
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<td>71</td>
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<td>White Agronet</td>
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<td>24.8</td>
<td>21.8</td>
<td>46.6</td>
<td>589.8</td>
</tr>
</tbody>
</table>

| P value | 0.149 | 0.63 | 0.262 | 0.31 | 0.339 | 0.319 |
| LSD     | 23.23 | 46.36 | 51.16 | 598.7 | 454.5 | 683   |

<table>
<thead>
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</tr>
<tr>
<td>Blue Agronet</td>
<td>24.4</td>
<td>120.8</td>
</tr>
<tr>
<td>No net</td>
<td>0</td>
<td>51.2</td>
</tr>
<tr>
<td>Rainbow Agronet</td>
<td>34.2</td>
<td>190.8</td>
</tr>
<tr>
<td>Silver Agronet</td>
<td>5.4</td>
<td>431</td>
</tr>
<tr>
<td>White Agronet</td>
<td>3.2</td>
<td>89.6</td>
</tr>
<tr>
<td>Yellow Agronet</td>
<td>4.2</td>
<td>260.8</td>
</tr>
</tbody>
</table>

| P value | 0.147 | 0.23 | 0.232 |
| LSD     | 30.16 | 334.5 | 335   |

*Means followed by similar letters within a column are not significantly different, +/-SE
Tomato plants grown without agronet cover had significantly (p<0.05) higher *Bemisia tabaci* incidence in the first trial compared to the yellow, white and rainbow agronets, (Table 4.1) while the number of *Bemisia tabaci* recorded on silver and blue agronets were not significantly different (p>0.05). In season two, tomato plants which were grown without agronet cover and those under the blue agronet had a significantly higher *Bemisia tabaci* incidence compared to those tomato plants which were grown under other agronets (Plate 4.2). Tomato plants under the yellow agronet had the lowest whitefly incidence levels (775.0 ±111.90c) while the tomato plants under the blue agronet had the highest whitefly incidence levels (1637.0±130.60a) in the total. Yellow, rainbow and white agronets were not significantly different though the mean numbers varied.
Plate 4.2: The underside of a tomato leaf infested by whiteflies at KARLO-Kabete

The mean number of leaf mines made on the tomato plants grown without agronet cover were significantly (p<0.05) higher compared to those from the plants which were covered with the agronets (Table 4.1). The tomato plants grown under the rainbow agronet had the lowest mean number of leaf mines (65.0 ±6.78c) made on the leaves. In addition the mean number of leaf mines made on the leaves of tomato plants grown under the rainbow, silver, white and yellow agronets were not significantly different. In total, the unprotected tomato plants had the highest mean number of leaf mines (571.6±41.53a) made on the leaves. The mean numbers of Ceratothripoides brunneus (Thrips) on the tomato plants grown under various colored agronets was not significantly different (P> 0.05, Table 4.1). The tomato plants grown under the white agronet colour had the highest mean number of Ceratothripoides brunneus (87.0) while
those under the blue agronet colour had the lowest mean number of *Ceratothripoides brunneus* (41.6)) compared to the other agronets. The mean number of *Ceratothripoides brunneus* from the unprotected tomato plants was 35.4 in total. The mean numbers of thrips (Table 4.1) were not assigned the standard error since there were no significant differences in the mean number among the agronets in season one, season two and the total (p=0.149, p=0.63, p=0.262) respectively.

In the two trials there were no significant differences in the mean number of *Aphis gossypii* infesting tomato plants grown among the treatments (Table 4.1). In the first trial the mean number of *Aphis gossypii* infesting tomato plants grown under yellow agronet were considerably higher compared to other treatments (589.8). However, in the second trial, the mean number of *Aphis gossypii* infesting unprotected tomato plants was (424.0) higher compared to the other treatments. Tomato plants grown under the blue agronet had the lowest mean number of *Aphis gossypii* in the two trials (Table 4.1).

There were no significant differences in the mean number of *Tetranychus evansi* among the treatments in the two trials (p=0.232, Table 4.1). The tomato plants grown under silver agronet had the highest mean total number of *Tetranychus envansi* among the treatments (436.4) while the lowest mean total number was in the unprotected tomato plants (51.2). Tomato plants grown under the yellow agronet had a mean total number (265.0) while the rainbow agronet the mean total number was (225.0). The tomato plants grown in the first trial had fewer *Tetranychus envansi* compared to those of the second trial.
4.2 Effects of coloured agronets on pest distribution on the tomato plants

4.2.1 Whiteflies distribution on tomato plants grown under colored agronets

The *Bemisia tabaci* mean total numbers were considerably higher at the upper canopy of the tomato plants grown under the blue agronet (1310.2±121.2), uncovered (997±115.4), silver agronet (961.6±147.7) white agronet (802.8±82.6), rainbow agronet (708.0±97.2) and yellow agronet (623±91.9) compared to the middle and bottom canopy.

Whitefly infestations at the top canopy of tomato plant under the blue agronet had significantly (*p*=0.001) higher the total mean number compared to other treatments (Table 4.2). In season one the mean number of whitefly infestation levels at the top and bottom canopy of the plants were not significantly different (*p*>0.05) across all the treatments. In season one the mean number of whitefly infestation level at the middle canopy of the plants in the uncovered plot was significantly higher compared to the other treatments. Whitefly infestation levels at the middle canopy of the tomato plants was not significantly different among the yellow, white, rainbow and silver agronets in season one. The mean number of whitefly infestation levels at the middle and bottom canopy of tomato plants in the uncovered plot was significantly different compared to the other treatments in season two. Among the agronets, the blue agronet had the highest mean number of whiteflies infesting the top canopy of the tomato plants while
the yellow agronet had the lowest total mean number of whiteflies infesting the plants top canopy (1310.2±121.20a, 623.6±91.90d) respectively. Whitefly infestation levels were highest at the middle and bottom parts of the tomato plants in the uncovered plots in the total compared to the other treatments.
Table 4. Mean number of white flies infesting tomato plant at the top, middle and bottom parts grown under various treatments at KALRO Kabete December 2012 to May 2013 and September 2013 to March 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
<td></td>
</tr>
<tr>
<td>No net</td>
<td>52.00</td>
<td>72.4±3.71c</td>
<td>38.00</td>
<td>945.4±112.00b</td>
<td>489.4±81.92a</td>
<td>91.6±20.92a</td>
<td>997.4±115.40b</td>
<td>561.8±81.30a</td>
<td>129.6±23.90a</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>50.00</td>
<td>37.80±10.50bc</td>
<td>25.20</td>
<td>911.60±146.10b</td>
<td>151.80±15.00c</td>
<td>12.80±6.30b</td>
<td>961.6±147.70bc</td>
<td>189.6±22.20c</td>
<td>38.0±8.70b</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>45.60</td>
<td>43.40±9.33b</td>
<td>27.40</td>
<td>1264.6±125.70a</td>
<td>218.60±42.10b</td>
<td>37.00±26.00b</td>
<td>1310.2±121.20a</td>
<td>262.0±36.60b</td>
<td>64.4±25.90b</td>
<td></td>
</tr>
<tr>
<td>Rainbow</td>
<td>42.00</td>
<td>37.20±3.15bc</td>
<td>22.20</td>
<td>666.00±93.40c</td>
<td>87.00±15.97c</td>
<td>9.60±3.72b</td>
<td>708.0±97.20cd</td>
<td>124.2±16.50c</td>
<td>31.8±5.00b</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>27.00</td>
<td>30.20±2.99bc</td>
<td>22.40</td>
<td>775.80±80.80c</td>
<td>185.60±37.09c</td>
<td>25.40±12.21b</td>
<td>802.8±82.60bd</td>
<td>215.8±39.10c</td>
<td>47.8±6.20b</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>25.60</td>
<td>23.00±3.72c</td>
<td>15.00</td>
<td>598.00±91.80c</td>
<td>101.20±26.43c</td>
<td>11.80±3.68b</td>
<td>623.6±91.90d</td>
<td>124.2±25.10c</td>
<td>26.8±5.90b</td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.112</td>
<td>0.001</td>
<td>0.141</td>
<td>0.001</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>LSD</td>
<td>23.45</td>
<td>18.42</td>
<td>16.32</td>
<td>283.1</td>
<td>119.8</td>
<td>41.09</td>
<td>277.2</td>
<td>118.1</td>
<td>44.42</td>
<td></td>
</tr>
</tbody>
</table>

*Means followed by similar letters within a column are not significantly different (+/-SE)
4.2.2 Leaf mines distribution on tomato plants grown under colored agronets

In the uncovered plots there were differences in the mean number of leaf mines at the top, middle and bottom canopies of the tomato plants compared to the other treatments in both seasons (p=0.001, Table 4.3). The bottom canopy of the tomato plants had considerably higher mean number of leaf mines compared to the top and middle canopies in season one. In season two the middle and bottom parts of the tomato plants in the uncovered plots had significantly higher mean number of leaf mines compared to the other treatments. In the blue and silver agronets, there were no variations in the mean number of leaf mines at the top canopy of tomato plants (14.80±4.3ab, 14.60±3.8ab) respectively (Table 4.3). The white agronet had the lowest (31.0±8.4c) mean total number of leaf mines at the middle canopy of the plants while the rainbow agronet had the lowest (24.2±3.1b) mean total number of leaf mines at the bottom canopy of the tomato plants. The highest populations of leaf mines were recorded at the middle parts of the plants in all the treatments in season two. The total mean numbers of mines at the top canopy of the plants there were no significant differences among the blue, silver, white and yellow agronets. .
Table 4.3 Mean number of leaf mines at the top, middle and bottom parts of tomato plants grown under various treatments at KALRO Kabete, December 2012 to May 2013 and September 2013 to March 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
</tr>
<tr>
<td>No net</td>
<td>8.60±1.8a</td>
<td>99.60±9.5a</td>
<td>132.6±25.5a</td>
</tr>
<tr>
<td>Yellow</td>
<td>3.20±2.1b</td>
<td>10.20±2.2b</td>
<td>30.20±10.3b</td>
</tr>
<tr>
<td>Silver</td>
<td>1.40±0.8b</td>
<td>12.20±4.7b</td>
<td>13.00±2.2b</td>
</tr>
<tr>
<td>Blue</td>
<td>1.00±0.8b</td>
<td>1.00±0.77b</td>
<td>30.00±7.9b</td>
</tr>
<tr>
<td>White</td>
<td>0.80±0.4b</td>
<td>9.20±1.16b</td>
<td>22.00±6.8b</td>
</tr>
<tr>
<td>Rainbow</td>
<td>0.00±0.0b</td>
<td>13.00±3.9b</td>
<td>16.60±3.4b</td>
</tr>
</tbody>
</table>

Pvalue 0.001  0.001  0.001  0.002  0.001  0.001  0.001  0.001  0.001

LSD 3.436  15.75  33.52  9.41  51.71  36.2  9.99  52.3  59.39

*Means followed by similar letters within a column are not significantly different (+/-SE)
4.2.3 Thrips distribution on tomato plants

The mean number of thrips infestation levels at the top, middle and bottom canopy of the tomato plants were not significantly different (P>0.05) across all the treatments (Table 4.4). In season one, the white agronet had the highest mean number of thrips infesting the top, middle and bottom canopy of the tomato plants (11.40, 20.40 and 10.40) respectively. In season two, the middle canopy of the tomato plants had the highest mean number of thrips infestation across all the treatments compared to the top and bottom canopy of the tomato plants. The yellow agronet had the lowest mean number of thrips infesting middle canopy of the tomato plants in season two and the total (10.80, 20.00,) respectively. The blue agronet had the lowest mean number of thrips infesting the bottom canopy of the tomato plants (6.60) in the total (Table 4.4). The standard error is not indicated in all the tables showing no variations in all the treatments.
Table 4. Mean number of thrips at the top, middle and bottom parts of tomato plants grown in various treatments at KALRO-Kabete, December 2012 to May 2013 and September 2013 to March 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
</tr>
<tr>
<td>No net</td>
<td>0.81</td>
<td>5.00</td>
<td>10.40</td>
</tr>
<tr>
<td>Yellow</td>
<td>7.00</td>
<td>9.20</td>
<td>8.60</td>
</tr>
<tr>
<td>Silver</td>
<td>6.40</td>
<td>10.40</td>
<td>9.00</td>
</tr>
<tr>
<td>Blue</td>
<td>5.60</td>
<td>3.40</td>
<td>3.80</td>
</tr>
<tr>
<td>White</td>
<td>11.40</td>
<td>20.40</td>
<td>10.40</td>
</tr>
<tr>
<td>Rainbow</td>
<td>1.80</td>
<td>6.20</td>
<td>8.40</td>
</tr>
</tbody>
</table>

| P-value   | 0.076    | 0.144    | 0.885  | 0.493  | 0.699  | 0.739  | 0.202  | 0.369  | 0.815  |

4.2.4 Effect of coloured agronets on the aphid distribution on tomato plants

In both seasons, the mean number of aphids infesting tomato plants at the top, middle and bottom canopy of the plants was not significantly different (p>0.05) in all the treatments (Table 4.5). In season one, the yellow agronet had the highest mean number of aphids infesting the top, middle and bottom canopy of the tomato plants compared to the other treatments (251.2, 193.0, 146.0) respectively. Meanwhile the blue agronet had the lowest mean number of aphids infestation at the top, middle and bottom canopy of the plants compared to the other treatments in season one (0.4, 1.0 and 0.0) respectively. The yellow agronet had the highest total mean number of aphids infesting the top canopy of the tomato plants (258.4) while the blue agronet had the lowest mean total...
numbers of aphids infesting the top and bottom canopy of the tomato plants (4.0, 0.6) respectively. The white agronet had the lowest mean number (0.6) of aphids infesting the middle canopy of the plant in season two (Table 4.5). There was a considerably higher mean number of aphids in the unprotected tomato plants at the top, middle and bottom canopy of the tomato plants (154.0, 168.4 and 102.0) compared to the other treatments (Table 4.5) in season two. Generally in season one there were more aphids compared to season two. At the top canopy of the tomato plants under yellow agronet, there were more aphids (258.4) in total followed by the tomato plants in the uncovered plot which had a mean number of 163.2 aphids.
Table 4. 5 Mean number of aphids infesting the top, middle and bottom parts of tomato plants grown under various treatments at KALRO Kabete December 2012 to May 2013 and September 2013 to March 2014

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
</tr>
<tr>
<td>Yellow</td>
<td>251.2</td>
<td>193.0</td>
<td>146.0</td>
</tr>
<tr>
<td>Silver</td>
<td>15.0</td>
<td>17.0</td>
<td>39.0</td>
</tr>
<tr>
<td>No net</td>
<td>9.2</td>
<td>22.0</td>
<td>1.0</td>
</tr>
<tr>
<td>White</td>
<td>8.0</td>
<td>1.6</td>
<td>10.0</td>
</tr>
<tr>
<td>Rainbow</td>
<td>4.0</td>
<td>17.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Blue</td>
<td>0.4</td>
<td>1.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pvalue</td>
<td>0.165</td>
<td>0.409</td>
<td>0.481</td>
</tr>
<tr>
<td>LSD</td>
<td>221.1</td>
<td>212.5</td>
<td>175.1</td>
</tr>
</tbody>
</table>
4.2.5 Red spider mite distribution on the tomato plant

The mean number of *Tetranychus evansi* infestation at the top, middle and bottom canopy of the tomato plants were not significantly different (P>0.05) across the treatments. In season one the rainbow agronet had the highest mean number of *Tetranychus evansi* infesting the top, middle and bottom parts of the tomato plant (4.8, 10.48, 19.0) respectively compared to all other treatments (Table 4.6). In season two, the yellow agronet had the highest mean number (137.8) of the red spider mite infesting the top canopy of the tomato plants. The white agronet had the lowest mean number of red spider mites (20.4, p=0.435) infesting top part of the plants in season two. On the other hand, silver agronet had the highest total mean number of red spider mites (222.2) infesting the middle part of the tomato plant.
Table 4. 6 Mean number of the red spider mites at the top, middle and bottom parts of the tomato plants grown under various treatments at KARLO Kabete December 2012 to May 2013 and September 2013 to March 2014

| Treatment | Season 1 | | | | Total | | | |
|-----------|----------|----------|----------|----------|----------|----------|----------|
|           | Top      | Middle   | Bottom   | Top      | Middle   | Bottom   | Top      | Middle   | Bottom   |
| Blue      | 0.8      | 10.2     | 13.4     | 47.4     | 64.0     | 9.4      | 48.2     | 74.2     | 22.8     |
| Rainbow   | 4.8      | 10.4     | 19.0     | 72.4     | 78.2     | 40.2     | 77.2     | 88.6     | 59.2     |
| Yellow    | 0.2      | 2.2      | 1.8      | 137.8    | 95.2     | 27.8     | 138.0    | 97.4     | 29.6     |
| White     | 1.0      | 1.0      | 1.2      | 20.4     | 69.2     | 0.0      | 21.4     | 70.2     | 1.2      |
| Silver    | 0.0      | 5.2      | 0.2      | 135.2    | 217.0    | 78.8     | 135.2    | 222.2    | 79.0     |
| No net    | 0.0      | 0.0      | 0.0      | 24.4     | 27.0     | 0.0      | 24.2     | 27.0     | 0.0      |
| Pvalue    | 0.55     | 0.21     | 0.48     | 0.435    | 0.172    | 0.278    | 0.432    | 0.164    | 0.302    |
| LSD       | 6.012    | 10.74    | 24.95    | 154.2    | 146.2    | 76.7     | 153.2    | 146.5    | 81.8     |
4.3 The effect of coloured agronets on tomato production

The mean number of marketable tomatoes harvested from the rainbow agronet was highly significant (p=0.001) compared to other treatments in season one (Table 4.7). On the other hand the tomato plants grown without agronet cover had significantly (Plate 4.3, p<0.05) lower mean total number of the harvested marketable fruits compared to the covered tomato plants. In seasons one and two the unprotected tomato plants produced the lowest mean numbers of tomatoes (88.0±9.18c and 93.0±29.49b respectively). The produce of the unprotected tomato plants (unhealthy plants) was low due to the large number of pests, diseases and adverse weather conditions (Plate 4.3). During the first and second seasons the rainbow agronet produced the highest mean number of marketable tomatoes (237.2±25.08a, and 299.6±23.91a) respectively (Table 4.7). However, in season two, there were no significant differences in the mean number of marketable fruits grown under the rainbow, silver, yellow, white and the blue agronets. In season one both the blue and the uncovered plots had significantly (P<0.05) lower mean numbers of marketable tomatoes compared to those grown under the rainbow agronets. Healthy tomato plants under nets produced healthy tomato fruits thus increasing the yield (Plate 4.4).
Table 4. 7  Mean number of the harvested marketable tomatoes per sampling at KARLO-Kabete

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 1</th>
<th>Season 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>120.4 ±15.27bc</td>
<td>277.8±17.10a</td>
<td>398.2±19.93b</td>
</tr>
<tr>
<td>No net</td>
<td>88.0 ±9.18c</td>
<td>93.0±29.49b</td>
<td>181.0±28.41c</td>
</tr>
<tr>
<td>Rainbow</td>
<td>237.2a ±25.08a</td>
<td>299.6±23.91a</td>
<td>536.8±33.43a</td>
</tr>
<tr>
<td>Silver</td>
<td>152.65 ±15.74b</td>
<td>286.2±34.85a</td>
<td>438.8±37.96ab</td>
</tr>
<tr>
<td>White</td>
<td>165.8±11.53b</td>
<td>236.0±40.98a</td>
<td>401.8±43.34b</td>
</tr>
<tr>
<td>Yellow</td>
<td>159.0±22.65b</td>
<td>272.6±66.57a</td>
<td>431.6±69.9ab</td>
</tr>
</tbody>
</table>

P-value  
0.001  0.006  0.001

LSD  
51.95  107.1  126.6

Means followed by similar letters within a column are not significantly different (+/-SE)

Plate 4. 3 : Unhealthy tomato plants in open plot hence poor yield
4.4 The effect of coloured agronets on marketable tomato.

In the first season the mean weight of the harvested tomatoes in the rainbow agronet was significantly different compared to the blue, silver agronets and uncovered plots (p=0.004, Table 4.8). In season two, the mean weight of marketable tomatoes in the uncovered (control) plots was significantly different compared to the other treatments (p=0.006). The mean weight of marketable tomatoes in the rainbow agronet was not significantly different from the white and yellow agronets in season one (p>0.05). Nevertheless, the mean weight of marketable tomatoes under the blue agronet and the control were not significantly different from each other in season one (p<0.05).
Table 4.8 Mean weight (g) of marketable and unmarketable tomatoes damaged caused by *Helicoverpa armigera*, *Phytophthora infestans* and Blossom end rot at KARLO Kabete

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Marketable</th>
<th>Unmarketable - African bollworm</th>
<th>Unmarketable - blight</th>
<th>Unmarketable - Blossom end rot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Season 1</td>
<td>Season 2</td>
<td>Total</td>
<td>Season 1</td>
</tr>
<tr>
<td>Blue</td>
<td>13088±1347.00a</td>
<td>18442±1636.00b</td>
<td>570</td>
<td>585.0±381.70b</td>
</tr>
<tr>
<td>No net</td>
<td>4030±1475.00b</td>
<td>8046±1282.00c</td>
<td>3181</td>
<td>4761±465.20a</td>
</tr>
<tr>
<td>Rainbow</td>
<td>16200±1192.00a</td>
<td>25658±2082.00a</td>
<td>860</td>
<td>890.0±274.00b</td>
</tr>
<tr>
<td>Silver</td>
<td>11440±1861.00a</td>
<td>2117±2235.00ab</td>
<td>330</td>
<td>551.0±105.30b</td>
</tr>
<tr>
<td>White</td>
<td>12370±2802.00a</td>
<td>2000±2406.00ab</td>
<td>750</td>
<td>909.0±523.20b</td>
</tr>
<tr>
<td>Yellow</td>
<td>20013±2829.00ab</td>
<td>11970±3362.00a</td>
<td>2110</td>
<td>2186.0±1880.50b</td>
</tr>
<tr>
<td>P value</td>
<td>0.004</td>
<td>0.006</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>LSD</td>
<td>2595.4</td>
<td>2877.95</td>
<td>6477</td>
<td>362.7</td>
</tr>
</tbody>
</table>

Means followed by similar letters within a column are not significantly different (+/-SE)
In both seasons the rainbow agronet had the highest marketable tomato yield (Plate 4.5) while the control had the lowest marketable tomatoes (25658±2082.0a, 8046.0±12820c) respectively. Among the five agronet treatments, the blue recorded the lowest marketable tomatoes.

Plate 4. 5: Marketable tomato fruits at KARLO-Kabete

4.5 Causes of fruit yield losses

During the two trials the tomato plants and the tomatoes were infested by airborne microorganism like *Phytophthora infestans* which was partly responsible for reducing tomato yield. A few tomatoes were damaged by *Phytophthora infestans* blight together with canker and sunscald (Plate 4.6). Yield loss by the *Helicoverpa armigera* in the unprotected tomatoes was highly significant (P<0.01) compared to other treatments in season one and the total (Table 4.8).
4.5.1 African bollworm yield loss

The unprotected tomato plants had the highest yield loss (1579.4g) and (3181.0g) as a result of damage caused by *Helicoverpa armigera* in both seasons one and two respectively (Table 4.8). Moreover, the mean weight of unmarketable tomatoes damaged by *Helicoverpa armigera* in the uncovered plots was highly significant) compared to all

Plate 4. 6 : Unmarketable tomatoes due to damage by *Helicoverpa armigera*, *Phytophthora infestans* and Blossom end rot at KARLO Kabete
the other treatments in season one ((P=0.001 Table 4.8). The percentage of unmarketable tomatoes due to loss caused by *Helicoverpa armigera* was 48.2% (Table 4.9)

**Table 4.9 The percentage of marketable tomatoes and unmarketable tomatoes due to loss caused by *Helicoverpa armigera*, *Phytophthora infestans* and blossom end rot at KARLO**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Marketable</th>
<th>Unmarketable - African bollworm</th>
<th>Unmarketable - blight</th>
<th>Unmarketable - Blossom end rot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>16.3</td>
<td>5.9</td>
<td>10.6</td>
<td>11.5</td>
</tr>
<tr>
<td>No net</td>
<td>7.1</td>
<td>48.2</td>
<td>7.8</td>
<td>23.8</td>
</tr>
<tr>
<td>Rainbow</td>
<td>22.6</td>
<td>9.0</td>
<td>24.6</td>
<td>19.8</td>
</tr>
<tr>
<td>Silver</td>
<td>18.7</td>
<td>5.6</td>
<td>19.7</td>
<td>13.5</td>
</tr>
<tr>
<td>White</td>
<td>17.6</td>
<td>9.2</td>
<td>19.8</td>
<td>19.7</td>
</tr>
<tr>
<td>Yellow</td>
<td>17.7</td>
<td>22.1</td>
<td>17.5</td>
<td>11.7</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

In addition, the blue agronet treatment had the lowest mean weight of tomato loss due to bollworm damage in season one. In season two and the total, the silver agronet had the lowest mean weight as a result of the tomato damage by *Helicoverpa armigera* (330.0g, 551.0g ) respectively while the uncovered plot the highest mean weight of the tomato damaged by *Helicoverpa armigera* were 3181.0g and 4761.0g respectively. In the total the mean weight of unmarketable tomatoes due to the *Helicoverpa armigera* loss in the uncovered plots was significantly higher compared to the other treatments (p<0.01, Plate 4.7).
Plate 4.7: Damage made by *Helicoverpa armigera* to a tomato fruit at KALRO-Kabete

4.5.2 Blight yield loss

Yield loss by blight in the tomatoes under the blue agronet and the uncovered plot were significantly different compared to the other treatments in season one and the total (Tables 4.8 and 4.9). The mean weight of unmarketable tomatoes infested by *Phytophthora infestans* blight in the uncovered plot and the blue agronet were significantly different from the other treatments in season one and the total (p=0.05, Table 4.8). However, in season two the mean weight of unmarketable tomatoes infected by *Phytophthora infestans* under the rainbow agronet was significantly higher compared
to the other treatments (p=0.001). In season one and the total, the mean weight loss of tomato due to *Phytophthora infestans* blight infection was lowest in the uncovered plots. In season two, the mean weight of unmarketable tomatoes infected by *Phytophthora infestans* blight was lowest in the blue agronet (2800.0g), while the mean weight of unmarketable tomatoes in the rainbow agronet was highest (7440.0g, Table 4.8). The mean weight of the unmarketable tomatoes infested by the blight in the rainbow, silver and white agronets were not significantly different (P>0.05) in the total. Among the agronets, the blue agronet had the lowest mean percentage (10.6%) of unmarketable tomatoes infested by the blight in the total (Table 4.9). The *Phytophthora infestans* is an oomycete that causes the serious late blight which affected the tomatoes leading to decrease in the yield.

### 4.5.3 Blossom end rot yield loss

Tomatoes infested by blossom end rot without agronet cover had significantly higher mean weights in the first season compared to the other treatments (P=0.001). The tomatoes grown under the rainbow agronet and infested by the blossom end rot had the highest mean weight (3075.0g) compared to all other treatments in the second season (Table 4.8, Plate 4.8). Among the agronets, in season one the white agronet had the highest mean weight of unmarketable tomatoes infected by blossom end rot while the silver agronet had the lowest mean weight of the unmarketable tomatoes in season one. In season two, the mean weight of unmarketable tomatoes infested by blossom end rot
under the blue agronet had the lowest mean weight while the rainbow agronet had the highest mean weight of unmarketable tomatoes. In the total the rainbow agronet had slightly higher mean weight (3762.0g) of unmarketable tomatoes compared to the white agronet with 3744.0grams. Tomatoes infected by the blossom end rot disease from the uncovered plot had the highest percentage (23.8%; Table 4.9).

Plate 4. 8 : Tomatoes infested by blossom end rot at KARLO-Kabete

4.6 Correlation between leafminers, white flies and the yield in season 1

There was significant negative correlation (r=-0.4104, p=0.0243) between leaf mines and yield, and also there was a significant negative correlation (r=-0.4403, p=0.0149) between whiteflies and the yield (Table 4.10). There was no significant correlation between the other pests and the yield.
Table 4.10 Correlation between the number of leafminers, white flies and yield season 1 and 2.

<table>
<thead>
<tr>
<th>Pests</th>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>yield</td>
<td>p-value</td>
</tr>
<tr>
<td>Leaf miners</td>
<td>-0.4104</td>
<td>0.0243</td>
</tr>
<tr>
<td>White flies</td>
<td>-0.4403</td>
<td>0.0149</td>
</tr>
</tbody>
</table>

4.7 Correlation between leafminers, whiteflies and yield in season 2

Like in season 1, there was a high significant negative correlation \( r = -0.5363, p = 0.0022 \) between leafmines and yield and also there was a significant negative correlation \( -0.4947, p = 0.0055 \) between whiteflies and yield. (Table 4.10). There was no significant correlation between the other pests and the yield.

4.8 Correlation between the total number of leafminers, white flies and yield.

There was a very highly significant negative correlation \( r = -0.6659, p = 0.001 \) between leafminer and the yields in both seasons and there also was a significant negative correlation \( r = -0.3796, p = 0.0385 \) between whiteflies and the yield in the total (Table
4.11). The other pests thrips, aphids, red spider mite there were no variations or significant differences.

Table 4. 11 Correlation between the total number of leafminers, white flies and yield.

<table>
<thead>
<tr>
<th>Pest</th>
<th>Yield</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf Mines</td>
<td>-0.6659</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>White flies</td>
<td>-0.3796</td>
<td>0.0385</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

The findings of this study showed that agronets are effective in reducing populations of tomato pests. They prevent pests from seeing tomato plants and in addition, behavior of the insect is affected by the nets hence inability to fly around the plants, mate and lay eggs thus lowering populations of pests under netting. Victor (2015) reported that the white nets used could offer a visual barrier for flying pests such as *L. trifolii*, *H. armigera*, *B. tabaci* and *H. pyritosa*; distance their feeding and mating habits, hence lowering their populations under the covered treatments. The agronets which were used in the current study provided a physical barrier to pests hence; they prevented their access to the tomato plants during their growth. These results supported earlier findings by Weintraub and Berlinger (2004) who reported that nets mask crops thus deterring pests that detect their prey via visual signals. Similar findings have been reported by Gogo *et al.* (2012) who observed that tomato insect pests and diseases reduced in number under net covering (0.4mm pore diameter). The mean number of pests, mainly whiteflies infesting the unprotected tomato crop, was significantly higher compared to other treatments. Pest infestation levels of whiteflies, leaf miners and aphids on the tomato plants were lower in the agronets compared to pest infestation levels on the unprotected tomato plants. These results support earlier findings by Victor (2015) who reported reduced populations of *A. gossypii*, *B. tabaci* and *L trifoli* through physical exclusion under 0.4mm untreated nets.
According to Gogo *et al.* (2012) higher relative humidity which occur under the netting covers can also affect the feeding habits of sucking pests such as *B. tabaci* consequently lowering their population under netting. The blue agronet had the highest mean number of whiteflies among the five coloured agronets while the yellow agronet had the lowest mean number of this pest. The attraction of whiteflies to the blue colour is due to shorter wavelength and higher frequencies (Thomas, 1996). The blue agronets had the highest mean number of whiteflies this is in agreement with Thomas, (1996) who observed that most insect orders are attracted to blue and black lights. Tomato plants grown under the agronets had healthy foliar unlike the plants that were exposed to pests and other environmental conditions. Agronets modify microclimates which are under netting, thus causing increase in relative humidity, soil moisture and air temperatures leading to better growth by changing leaf characteristics, biomass accumulation and relative growth rate of plants. Saidi *et al.* (2013) reported that nets can be used effectively in the management of tomato pests by covering the plants thus minimizing pest infestations.

In season one, the yellow net was found to have considerably a higher mean number of aphids which might have resulted due to the absence of natural host plants and also by the fact that the microclimate under netting was suitable for the aphids. This is in agreement with Barbosa *et al.* (2011) who observed outbreaks of aphids during a hot season under netting as a result of the absence of natural host plants and by the absence of regulation by natural predators (ladybird) under the netting set up (James *et al.*,
2009). With reduced pests’ population, the application of insecticidal sprays may be minimized during tomato production. In other studies in the United States, the use of nets reduced the application of insecticidal sprays to one application on a selective insecticide (Martin et al., 2006). This was quite good in view of the fact that the current trends in crop production are towards reducing the use of chemical sprays and farmers are also encouraged to use selective insecticides.

The results on effects of coloured agronets on pests’ distribution on the tomato plants showed that the underside of the top canopy of the plants grown under blue agronet had the highest mean number of whiteflies compared to the other agronets in season two. The leaves at the top are succulent than those which are found on the lower sides. Whiteflies in all the treatments in season two were found in large numbers at the top of the crop compared to the mean number of whiteflies found at the middle and bottom canopy of the tomato crop. This suggest that whiteflies are more abundant on the top canopy of the crop as previously reported by Zurina et al., 2010). Similar results were reported by Zurina et al. (2010) who observed that the largest number of eggs of Bemisia tabaci and larvae infesting Capsicum annum were found in the upper strata than those which were found on the middle and lower plant strata. The leaf mines made by L trifolii on the leaves of tomato plants were found in large numbers at the middle canopy of the crop in all the treatments. This suggests leafminers (L trifolii) are more abundant on the lower plant strata compared to the upper plant strata.
The unprotected tomato plants had the highest mean number of leafmines made by *L. trifolii* on the lower plant strata. Among the five colored agronets, the tomato plants grown under blue agronet had considerably higher mean number of leaf mines at the middle canopy of the tomato plant whereas the top canopy had the least mean number of the mines. According to Parrella and Vincent (1984), *L. trifolii* (Leaf miner) prefers laying eggs at the middle part of the Chrysanthemum plant. Consequently this is where larvae can mostly be found. The other pests *Helicoverpa armigera, Tetranychus envansi, Ceratothripoides brunneus* and *Aphis gossypii* which were studied showed no variations on their distribution within the tomato plant.

Every farmer tries to focus, maximize yields and the quality of tomato fruits. In this study, it was found that there was an increase in weight of the marketable tomatoes which were harvested under agronets compared to those without agronet covers. The use of coloured agronets in tomato production improved the tomato yield. At harvest, the mean weight and the number of marketable fruits (not damaged by pests or disease) were higher for the tomatoes which were grown under net cover compared with the non-protected tomato plants. The high tomato yields could be attributed to the low damage of both the tomato plants and the fruits by pests and the microclimate under netting which enhanced growth of the tomato plants. Therefore, growing tomato plants under coloured agronets not only increased the mean fruit weight and their numbers, but it also produced fruits of higher quality. El-Aidy anaqd Sidars (1996) reported higher marketable tomato yields under protected compared to non-protected tomato plants.
Similarly, Nair and Ngouajio (2010) reported more total marketable of cucumber (*Cucumis sativus* L.) under nets compared with the control.

Muleke *et al.* (2014) observed that microclimate modification and insect pest exclusion using agronets improve pod yield and quality of French beans. These authors also observed a general increase in yield and quality of cabbage under netting. Tomatoes harvested under the rainbow agronet had the highest yield but not significantly different from those grown under the yellow and white agronets. Rainbow agronet had blue, white and yellow mixed colours and these resulted to better performance in tomato production. This agrees with Elad *et al.* (2007) findings on pepper with increased yields of two *Capsicum annum* cultivars when they were grown under shade nets compared to the uncovered control. The poor yield on the yellow agronets treatment which was observed in the study could have been the result of the light –reflectant characteristic: yellow reflects more red (photosynthetic), but less far-red photo morphogenetic) light of the spectrum (Coufal *et al.*, 1984; Decoteah and Friend 1991) and that may have resulted in the reduced yields. Based on these results, yellow agronet cannot be recommended for the growing tomatoes (Csizinszky *et al.*, 1995). Finally, net protection improved the crop yield due to a combination of the efficacy of the netting in blocking pests and the induced microclimate which was beneficial for the tomato growth.
The unmarketable tomatoes had deformities that were attributed to the damage caused by insect pest namely *H. armigera*, blight (*Phytophthora infestans* blight), blossom end rot (a nutrient deficiency) and unfavorable weather conditions. These deformities and damages lowered the quality of the harvested tomatoes mostly in the uncovered plots. These findings are consistent with those which have been reported by El-Aidy and Sidars (1996) that protected tomato plants had higher marketable tomato yield compared to the unprotected tomato plants which produced lower marketable tomato yield. The current study showed that the protection of tomatoes against insects with agronets may need to be complemented by application of fungicides due to the infection from airborne microorganisms like blight (*Phytophthora infestans*) which was partly responsible for reducing tomato yield under the netting covers. Without active ventilation, when the nets are permanently covered, they substantially increase temperatures and humidity which encourage disease development. In contrast, these findings differ that of Kashyap and Dhiman (2010) who used nylon nets in the management of alternaria blight and black rot in cauliflower seedlings. The tomato harvest from unprotected tomato plants had considerably lower blight infection compared to harvest from agronets. The colored agronets were provided by the A to Z Textiles Co Limited (Arusha, Tanzania) to KARLO Kabete, further studies should look at the full economic analysis of the production systems with the cost of the nets included when they become commercially available.
5.2 Conclusions

(i) Agronets were found to be effective and they successfully reduced levels of tomato pests.

(ii) Agronets did not have influence on the distribution of whiteflies and leafminers on the tomato plant parts.

(iii) Tomato plants grown under rainbow agronets had the highest yields but were not significantly different from those grown under yellow and white agronets.

5.3 Recommendations

(i) Due to agronets ability to reduce population levels of tomato pests, farmers should be advised to use them in order to enrich their yield.

(ii) Since rainbow agronets performed better on tomato yield than other agronets farmers should be encouraged to use them.

5.4. Suggestions for further study

(i) Further testing of colored agronets using different tomato varieties and different tomato growing ecological zones should be carried out because they would benefit the small hold farmers.
(ii) A full economic analysis factoring in the cost of purchase, installation and management of the colored agronets when they become commercially available.

(iii) An analysis on the effect of the colored agronets on the nutritive value and defects would also go a long way in promoting the consumption of net grown tomatoes.

(iv) An evaluation of the effect of colored agronets on the pollinators and natural enemies is an important factor.
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### Appendix 1: Plot Layout (non-treated trial)

<table>
<thead>
<tr>
<th>Block 1</th>
<th>white agro-net</th>
<th>Blue agro-net</th>
<th>Silver agro-net</th>
<th>Rainbow agro-net</th>
<th>No net</th>
<th>Yellow agro-nets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 2</td>
<td>Yellow agro-net</td>
<td>Silver agro-net</td>
<td>Blue agro-net</td>
<td>White agro-net</td>
<td>Rainbow agro-net</td>
<td>No net</td>
</tr>
<tr>
<td>Block 3</td>
<td>Blue agro-net</td>
<td>Yellow agro-net</td>
<td>No nets</td>
<td>White agro-net</td>
<td>rainbow agro-net</td>
<td>Silver agro-nets</td>
</tr>
<tr>
<td>Block 4</td>
<td>Rainbow agro-net</td>
<td>No net</td>
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<td>Yellow agro-net</td>
<td>White agro-net</td>
<td>Blue agro-net</td>
</tr>
<tr>
<td>Block 5</td>
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<td>Yellow agro-net</td>
<td>Rainbow agro-net</td>
<td>No nets</td>
<td>White agro-nets</td>
</tr>
</tbody>
</table>
Appendix 2: Measurement of the field layout