**DETERMINATION OF DISEASE PREVALENCE, BEST TREATMENT COMBINATIONS AND TEST OF INTEGRATED MANAGEMENT ON TOMATO (*Solanum lycopersicon* Mill) PROTECTED FROM CROP PESTS USING AGRONETS IN KENYA**

**TOO ABEL KIPCHIRCHIR**

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# DECLARATION

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Sign………………………………..Date………………………………..

**Too Abel Kipchirchir**

Registration: SC/PGB/013/10

**Approval by Supervisors**

This Thesis has been submitted for examination with our approval as University supervisors

1. **Prof. Ezekiel Kiprop**……………………....……Date……………………

University of Eldoret

1. **Dr. Muo Kasina** ………………………………..Date…………………….

Kenya Agriculture and Livestock Research Organization -National Agricultural Research Laboratories, Nairobi

1. **Dr. Lusike Wasilwa**…………………………….Date…………………….

Kenya Agriculture and Livestock Research Organization Head Quarters, Nairobi

# DEDICATION

I dedicate this work to all those whom have loved me, cared for me and inspired me to whom I am today. To my family for their support and encouragement during my time of study

# ABSTRACT

Tomato is an important economic and food security crop in Kenya grown under rain fed and irrigation systems mainly by small-scale farmers as source of income, vitamins A, C, Lycopene and alicin strong anti oxidants that fight free radicals. Diseases and pests are major constraint to tomato production in Kenya. However, Agronets have been successfully used in control of pests in Kenya. Agronet use is a new agro technology that aims at preventing pest attack by acting as exclusion barrier in addition to microclimate creation that enhances crop growth. Studies on Agronets efficiency and influence to plant physiology have been done before. However, research regarding the effect of Agronets microclimatic modification in influencing disease development and possible management strategies have not been carried out hence there was need to carry out such studies that would give comprehensive package on the technology. This research was carried out to determine prevalence and severity on tomato grown under Agronet in the nursery and field condition, test of integrated management on severity and determining the best treatment combination. The study was carried out on-station at KARI, Kabete. Factorial design was used in the study, where two factors; Agronets and management strategies. Each factor had different levels in nursery and field conditions. Agronets had five levels in nursery; insecticide impregnated 0.9 mm Agronet, non impregnated 0.9 mm mesh Agronet, 0.4 mm mesh Agronet, shading with grass (common farmers practice) and the no net (control). Integrated management had three; seed dressing, seed dressing plus monitored sprays and no application (control). Data was collected on weekly basis for the disease incidence, severity and pest population was entered into excel sheet format and Means sort by subjecting data to ANOVA using Genstat software. Significance was tested at 95% level and means separated using Fisher’s Protected Least Significant difference. Data was transformed using square root transformation (x+0.05)0.5to normalize. Results showed that significant (P<0.05) microclimatic conditions were observed across the Agronet levels in the nursery and field conditions. Four major diseases; early blight, damping off, tomato yellow leaf curl disease and late blight were prevalent in the nursery. Severity of TYLCD varied significantly (P<0.05) across the Agronet levels with control and shading recording high severity compared to Agronet covered plot which had lower severity levels. With additional management, significant difference (P<0.05) on severity of the diseases was recorded except for damping off in season 1. In the field, prevalent diseases included; late blight, tomato yellow leaf curl virus, bacterial leaf spot and Septoria leaf spot. Significant (P<0.05) variation across Agronet were observed in TYLCD, bacterial spot and tomato mosaic disease. With additional management, severity varied significantly (P<0.05) across the management strategy for powdery mildew, early blight, and late blight. There was no significant (P>0.05) interaction of Agronet and additional management. Both Agronet and management factors had significant (P<0.05) effect on yield while similar significant interaction of the factors was observed to influence the yield effect. Best treatment combinations were observed with use of Agronet with drenching plus monitored sprays which resulted to higher quantity of marketable yields. From this study, it was concluded that Agronets and management acted independently and that using Agronet technology calls for scouting for diseases at all stages of tomato growing.

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# LISTS OF ABBREVIATIONS AND ACRONYMS

|  |  |
| --- | --- |
| AYVB: | Ageratum Yellow Vein Betasatellite |
| CAN: | Calcium Ammonium Nitrate |
| cm: | Centimeter |
| CO2: | Carbon dioxide |
| DAP: | Diammonium Phosphate |
| ELISA: | Enzyme-Linked Immunosorbent Assay |
| g: | Grams |
| GOK: | Government of Kenya |
| Ha: | Hectare |
| HORTCRSP: | Horticultural Collaborative Research Support Program |
| ICIPE: | International Centre for Insect Physiology and Ecology |
| IDM | Integrated Disease Management |
| IPM: | Integrated Pest Management |
| KARI: | Kenya Agricultural Research Institute |
| KES: | Kenya Shillings |
| m: | Meter |
| mg: | Milligram |
| mm: | Millimeter |
| MOA: | Mode of Action |
| MT: | Metric Ton |
| NA: | Nutrient Agar |
| NARL: | National Agricultural Research Laboratories |
| PDA: | Potato Dextrose Agar |
| TYLCD | Tomato Yellow Leaf Curl Disease |
| USAID: | United States Agency for International Development |
| WAT: | Week after Transplanting |

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# CHAPTER ONE

## INTRODUCTION

## 1.1 Background

Tomato (*Solanum lycopersicon* Mill.) is one of the mostly grown vegetable in the world (Odome *et al.,* 2008). It is a widely cultivated vegetable in Africa, including Kenya where it forms part of major component of daily diet due to its nutritional value as source of vitamins A and C (Dobson *et al.*, 2002). It is a rich source of lycopene, caratenoids and alicin antioxidants, reported to fight free radicals in human bodies hence reducing the chances of cancer infection, interference of the body physiological activities and premature aging (Nkondjock *et al.,* 2005). The fruit is also a source of minerals and fibres. In East Africa, tomatoes form a dependent cash crop for small scale farmers (Ortiz and Hartmann, 2003). In Kenya’s agriculture, horticultural sub sector to which the tomato falls, statistics reveals that cultivation of tomato has been on the rise for fresh market demand (Odome *et al.,* 2008) and as a source supply of raw materials to the agro based industries, employment for people and generation of foreign exchange among others. Tomato production has been practiced under irrigation and rain fed systems. Farmers have further adopted modern technologies including greenhouse cultivation, glass house, high tunnel cultivation and the most recent, Agronet technology (Martin *et al.,* 2006). All these have been embraced by small scale farmers with the aim of improving crop yield and quality which consequently lead to both food sovereignty and food security that is able to satisfy the consequent population.

Agronet technology is a modern technology that aims at providing physical barrier towards pests that attack protected crops. Agronets offers a strong physical barrier based on size of the pores in relation to the size of the insects and stature. Apart from protecting the crop from damages caused by the insect pests, they also provide protection to the plants from injuries resulting from animal grazers and natural calamities such as hailstones (Pérez *et al.,* 2006). The crops are also protected from excessive sun radiation that may cause scorches on the plant surfaces. Colored nets have been used to repel insect pests and protect the plant from specific insect infestation since specific color shave been found to repel or attract some insects, for instance blue coloured Agronets repels the aphids while yellow ones attracts white flies (Ben-Yakir *et al.,* 2008). Agronets also do promote plant vigor and plant stand through modification of the surrounding environment thus creating conducive microclimate (Gogo *et al.,* 2012; Fajinmi and Fajinmi, 2010). Modification of microclimate results from raised temperature and increased humidity which leads to change in plant physiological activities through increased photo assimilates and increased co2 assimilation thus resulting in rapid plant growth (Tietel *et al.,* 2008). In the nursery plants, net technology has been found to improve and reduce the pre-emergence period of seedlings from eight to six days translating to 25 % in time reduction (Gogo *et al.,* 2012). Furthermore seedlings covered under the net take relatively shorter time to achieve the recommended transplant height hence the technology proves appropriate to farmers who engage in seedling enterprise since this benefit them through reduction of farm management expenses involved and avoiding bad weather (Muleke *et al.,* 2013).

Most farmers aim at increasing the quality and yields of their crops and quality through adoption of various technologies. However, lack of knowledge and inadequate research that provides sufficient guidelines and back up to the new technologies are key challenges to realization of their goals. Among the challenges in Agronet technology are diseases and insect pests (Elad *et al.,* 2007). Identification of diseases incidence, severity and possible management strategies under Agronets is key to boost the technology to further achievements since there are limited studies that pertains to the management of the diseases in this technology in Kenya. The greatest challenge faced by the technology is how to counter the interaction of the microclimate modification to plants growth and the disease causing pathogens. The increased temperature and relative humidity inside the net, leads to improved plant growth as well that of disease causing pathogen (Elad *et al.,* 2007). This is a critical challenge that faces the technology and appropriate strategies have to be developed to address the shortcomings.

## 1.2 Problem statement

Agronet technology represents a new agro-technological concept which aims at providing physical protection of plants from insect pests (Ilic *et al.,* 2010) that comes hand in hand with microclimate modification that enhances plant growth and development, quality of the plant produce and the general plant canopy size (Gogo *et al.,* 2012). Agronet technology has been applied in numerous plants with much success achieved in its use for instance in ornamentals, (Nissim-levi *et al.,* 2008), cabbages (Kiptoo, 2012), fruit trees (Shahak *et al.,* 2004) and vine yards. Netting is frequently used to protect agricultural crops from excessive solar radiations as referred to as shade nets and also to improve the thermal climate while aiding on soil moisture retention else referred to as micro climate modification (Kittas *et al.,* 2009). Under the net cover, mean daily temperature and relative humidity are significantly higher (Gogo *et al.,* 2012). These microclimate modification has effect on crop physiological activity through carbon dioxide assimilation and consequently contributing to crop rapid development (Teitel *et al.,* 2008). The Agronet also has been noted to enhance seedling emergence and growth the net cover through microclimate modification (Gogo *et al.,* 2012). It is also evident that the use of the Agronet result in microclimate modification which translates to better physiological performance and with high chlorophyll content leading to photo assimilates translocation that guarantees improved seedling growth (Adams *et al.,* 2001). Agronet technology concept has been effective in ensuring quality of produce is achieved so as to avert damages that are inflicted on the plant during development in the nursery and field condition. They are also effective in protecting crops from excessive solar radiations that would cause sun scalds, sheltering from strong winds, hails and bird predators (Tietel *et al.,* 2008). In insect pest control, shade nets have been found to be effective in controlling infestation levels especially aphids and white flies in tunnels covered by either yellow or pearl net with consistently two to three times lower than in tunnels covered by black or red nets. The incidence of cucumber mosaic virus in pepper grown under black or red nets, ranged between 35 and 85% (Ben-Yakir *et al.,* 2012). Tomatoes are grown in Israel under fine mesh nets of 50mm mesh clear nets to protect them from sweet potatoes white fly, *Bemisia tobaci* and the tomato yellow leaf curl virus (Berlinger *et al.,* 2002). Colored photoselective nets shading nets have been developed with the aim of improving crop production through their optical properties in addition to their physical protective properties to the plants that are covered inside it. Recent studies have demonstrated that growing vegetables, fruits, and ornamental crops under specific colored nets lead to increase in production with influence in quality and quantity improvement (Shahak *et al.,* 2008; 2009). In pepper production, colored nets improves productivity by 18% compared to full sunlight exposure. However studies on influence of the micro climate modification on pathological aspect have remained silent. In addition nothing has been done to determine interaction between net treatments and disease severity both in the nursery and in the field. Further studies on diseases affecting tomato crop covered with agro net to exclude insect pests with their management has not been established. Therefore this study was designed to evaluate and determine the influence of the Agronet on disease development. Further to test the possible integrated management of the disease development using integrated control that will enable farmers gain from the new technology to reduce on costs and improve on benefits of the integrated management.

## 1.3 Justification

Tomato is considered both as vegetable and a fruit thus forming an integral part of the fruit vegetables round the globe, it can be eaten either cooked or raw as salad. Economically in Kenya, tomato is an important enterprise crop for the low income household’s for income generation and supplying the urban population with the commodity (FAO 2007, 2012). In 2007 tomato the value stood at Ksh. 14 billion with Nyanza, Rift valley and Central regions contributing 80 % (Odome *et al.,* 2008). The growing demand for reduction of the chemical inputs in agriculture and increased resistance to insecticides have provided great impetus to the development of alternative forms of insect pest and disease control methods (Sardul *et al*., 2012), among them is the use of Agronet technology. However this new technology has been under studies mostly with cabbage, tomato, capsicum and cucumbers regarding their efficiency in pest control and their effect in yield (Ben-Yakir *et al.,* 2012) in different parts of the world. However, Diseases pose a major threat to food security and production of tomato in Kenya (Odome *et al.,* 2008). No studies had been carried out on the disease management aspects on tomato plants that are covered with the low cover Agronet hence there was need to design research study that is geared to developing comprehensive background regarding disease prevalence, possible management and treatment combinations since such modalities are lacking before adopting blindly the new technology that may lead to huge losses while compromising the quality and the quantity of the produce. Options to avert these factors are limited and thus there was need to such strategies.

## 1.4 Hypotheses

1. There are no infections on tomatoes grown using Agronet technology in the nursery and field conditions.
2. There is no significant interaction in the use of integrated control strategies in disease management with the use of Agronet technology.
3. There are no significant treatment combinations that give higher yields under Agronet technology in the field conditions.

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## 1.5 Objectives

### 1.5.1 Main objective

To determine the disease prevalence on tomato (*Solanum lycopersicon* Mill*)* possible management strategies and best treatment combinations on tomatoes protected from crop pests using agro-nets in Kenya.

### 1.5.2 Specific objectives

1. To determine disease prevalence and severity on tomato crop grown under Agronet technology in nursery and field conditions.
2. To test the possible integrated management strategies of tomato diseases grown under Agronet technology in nursery and field conditions while determining the interaction of Agronets and the management regimes.
3. To determine the best treatment combinations of Agronets and possible management that give higher yields of marketable tomato under Agronet technology in field conditions.

CHAPTER TWO

## LITERATURE REVIEW

## 2.1 Tomato natural history

Tomato is classified taxonomically under plant kingdom as an angiosperm and ranked under the order solanales, genus *Solanum* and species name being *Solanum lycopersicon*of family solanaceae*.* Its synonym is *Lycopersicon esculentum*.

Tomato (*Solanum lycopersicon*) is an herbaceous annual crop that can grow up to 3m (3-10 feet) in height. The stems are weak, woody, hairy, with strongodours (Jay, 2000). The terminal bud usually becomes an inflorescence and growth is by an auxiliary bud. The flowers grow up to 2cm in diameter and borne in inflorescence of 4-12 flowers. The leaves are spirally arranged up to 3cm long and 10-15cm across. The leaf blade is lobed and divided. The calyx is short and remains green when the fruit ripens. The six petals are yellow and grow to a height of 1cm. Tomato has main tap root that grows alongside vigorous fibrous roots that anchor the plant strongly to the soil and aiding in absorption of water and mineral salts.

Tomato is an important vegetable grown in Africa believed to have originated from Central America (Dobson *et al.,* 2002) and was distributed to various parts of Africa by the colonialist (Figure 1). The word tomato was derived from the word tomatt in Nahuatt language and its specific name *lycopersicum* means “wolf peach” or the “wolf apple” and they are major food candies in South America (Jay, 2000). It was introduced to Kenya by early European settlers in 1900’s (Odome *et al.,* 2008). Tomato is a warm season crop that is sensitive to frost at any growth stage. The optimal soil temperature for seed germination is 20°C or above. Germination below 16°C is extremely low. Daily maximum temperature of 25-30°C is ideal for vegetative growth, fruit setting and development. With adequate soil moisture, tomato plants can tolerate temperature well in excess of up to 38°Cbut beyond pollen meiosis is disrupted thus affecting fruit setting (Hartz *et al.,* 2008). The best temperature for tomato is between 15°C to 18°C at night while below +10°Ctomato stops growing. Tomato plant is a sensitive to photoperiodism and demands a lot of sunlight exposure particularly when flowering begins

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**Key:**Tomato growing regions in Africa

**Figure 2.1: Geographic distribution of tomato grown areas in Africa. Source: Google scholar.**

## 2.2 Production constrains of tomato in Kenya

Horticultural subsector is faced with a number of challenges that are both biotic and abiotic factors (FAO, 2005; GoK, 2010).It faces a number of problems which include diseases and pests (Maerere *et al*., 2006). The biotic factors include temperature and humidity fluctuations in long and short seasons that are favorable conditions for pathogens to develop, lowering yields in the season. Further this factor promotes the development of a variety of diseases (Masinde *et al.*, 2011).

Tomato production in Kenya is further crippled by great dependency on rainfall. Rain dependency has been a great challenge to small scale holder farmers since they are subjected to producing the crop only during the beginning of the short and long rains thus doing production seasonally. These posses a great challenge to food security and consequently low market value due to the glut production of the produce at particular period of the year. Farmers have taken this challenge seriously by adopting and accessing modern irrigation facilities and schemes. However the number of small scale farmers who have embraced the new irrigation facilities is still low and currently stands at 30% (Minotand Ngigi, 2003). Choice of variety, use of substandard seeds or inappropriate seed materials and variety form part of the production constraints. Due to lack of adequate knowledge, research, and provision of extension services, farmers have faulted the process by recycling the same varieties using local untested or uncertified seeds while others depend on old research findings that are often out of date with the market value and demand (Maerere *et al.,* 2006). Although in Kenya there is no variety screened against effective resistance to diseases, pests and drought( Masinde *et al.,* 2011) some seed providers have failed in advising the farmers on the screened attributes such as yield , resistance and tolerance, that forms baseline towards good production practice. Other breeders do only consider specific attributes during selection for breeding contrary to a wide criterion that assures plants survive under wide climatic conditions. Amongst the list of selection criteria are; taste, size of the fruit, seed purity, disease tolerance, yield , marketability, shape of the fruit, harvesting period, pest tolerance, labour costs , storability, colour, and growth period (Kimani, 2000). Reduction in land size and diminishing arable space is another factor that slows tomato production in Kenya. The area under tomato production between 2005 and 2007reduced drastically from 20,743 ha to 18,926ha representing 9% reduction. With the national average yield of 16.7MT/HA (Mutukuand Tshirley, 2004).Common tomato diseases, pests and high expenses of their control hamper tomato production in Kenya. Common diseases are caused by both a abiotic and biotic factors which when coupled clears the crop. Common diseases and pests include early blights, late blights, bacterial wilts, fusarium wilts, leaf moulds , bacterial canker, blossom end rots, buckeye leaf Septoria among others. African bollworm, aphids, whiteflies, thrips, systate beetles, cut worms and leaf hoppers form the insect pest group (Dobson *et al.,* 2002). In addition to causing direct damage to the plants, these insect pests transmit complex viral diseases to the plants (Lawrence *et al.,* 2000). Lack of training sites and facilities to train farmers on propagation and other cultural practices is part of constrains that contribute to low production in Kenya. Inadequate field space to conduct field trials and demonstrations contribute majorly to this. The problem of plant diseases particularly in developing nations is exaggerated by the paucity of the quality and quantity of the resources devoted to their study and the overall logistic aspects. In some part this may be as a result of poor governance but also arises from the difficulty in quantifying plant diseases and relating it to the failure of the crop to reach achievable yields. This implication shows that plant pathology is underfunded in relations to its importance (Strange and Scott, 2005). Under funding through agricultural ministries to improve production and value addition provision also affects the growth of the production, profitability and income opportunities (Odome *et al.,* 2008).

Poor infrastructure, inadequate storage facilities and poor hygiene is leading to wastes is a great challenge faced by retailers and other traders. This curtails the effort of delivering fresh produce to the market leading to compromise in quality as well. This problem is synonymous to Kenyan retailers who access the produce from the local farmers who live in the interior parts of the country who lack knowledge of proper storage of the produce (Odome *et al.,* 2008).

Value addition of tomato has been critical in the production chain because it affects the growth, profitability income opportunities of large number of farm households who are involved in tomato cultivation and sale of the produce. Presently this attribute is unavailable to the small scale farmers (Odome *et al.,* 2008). Value addition can be undertaken through processing of the produce or cold storage which demands for government intervention for their acquisition or through farmer cooperative societies which are apparently inexistence. This deny farmers significant benefits during the peak seasons while the cold storage facilities could turn farmers to an advantage state during the glut periods and providing an opportunity to get relatively higher prices thus helping in boosting the agricultural gains.

## 2.3 Important diseases of tomato

### 2.3.1 Early blight

Early blight is a devastating fungal disease that has been found to be a major constrain in tomato production (Tumwine *et al.,* 2002, Waiganjo *et al.,* 2006). Early blight is caused by *Alternaria solani.* Early blight influences general plant health during germination and even during plant establishment (Bisdorf, 2005, Pandey *et al.,* 2006). It causes significant destruction both qualitatively and quantitatively at any stage of the plant growth (Gilbertson *et al.,* 2012) including fruit setting and seed formation (Tewari and Vishuvant, 2012). Early blight is also destructive during storage period and posses critical danger to tomato production leading to reduction in economic fruit yield (Haggag *et al.,* 2007). The disease is favored by warm temperature and wetness. The high extend may be due to high precipitation of the surrounding environment, dew, crowded plantation and excess rainfall (Tewari *et al.,* 2012).

Early blight is most destructive disease in tropical and subtropical countries because of the environmental conditions. Leaf blight, fruit rot and stem blight are the common damaging symptoms of early blight. In regions with high rainfall, high temperature range between 24°C-29°C and high humidity epidemics can occur (Chaerani and Voorrips, 2006).

### 2.3.2 Tomato yellow leaf curl virus

Tomato yellow leaf curl virus is a disease that threatens both the small scale, large scale field and home production of pepper (*Capsicum annuum*) and tomato (*Lycopersicon esculentum*), (Salati *et al.,* 2010, Czosnek *et al.,* 1997) in tropical and subtropical regions.

Tomato yellow leaf curl virus belongs to the family geminiviridae (Gottlieb *et al.,* 2010). It is transmitted by adult silver leaf whitefly (Bemicia *tabaci*) and can be rapidly transmitted (Czonek 2007) in circular form(Uchibora *et al.,* 2013).Begomoviruses are complex circular, single-stranded DNA plant geminiviruses (Grimstad *et al.,* 1980) that replicates and transcribe in the host cell nucleus. TYLCV replicates by double strand DNA intermediate and induces RNA silencing in infected plants (Vanitharani *et al.,* 2003)

### 2.3.3 Powdery mildew

It is a leaf disease that is of high concern to tomato production in different parts of the world. Powdery mildews is caused by fungus belonging to Erysiphe family; the major being *Oidium neolycopersici.* Tomato powdery is common in the fields and the greenhouse-grown tomatoes all over the world (Khodaparast *et al.,* 2012). It is caused by four different species of erysiphaceae including *Oidiumneolycopersici*, *Golonivomyces orontii, Leveillula taurica* (Jones *et al.,* 2001; Kiss *et al.,* 2001). *Golovinomyces orontii* is most common to many plants in the tropics and temperate region and the only ectophytotic fungus in tomato producing long chains of conidia (Kiss *et al.,* 2005). The fungus reproduces by means of spores that can be transmitted by strong wind blowing from an infected host plant to a clean susceptible plant. For infection to take place high humidity is or moisture with high temperature is a requirement (Dobson *et al.,* 2002). Powdery mildew has a wide range of host plants among them are; egg plant, cucumber, pepper and beans which have exhibited high susceptibility (Hoseinkhanial *et al.,* 2012). The first symptoms appear on the leaves as bright yellow spots. The spots then broaden and enlarge and eventually turning brown (Hoseinkhanial *et al.,* 2012). The brown patches finally merge and make the leaf dry and coating of the spores on the surface render the leaves white (Dobson *et al.,* 2002). However, there is a degree of sensitivity among various host plants based on different isolates of the Erysiphe. Powdery mildew is distinct to a particular host although they can infect plants belonging to the same family. Difference in reaction is due to the difference in the host plants genotypes, the race of the pathogens and the general prevailing environmental conditions (Hoseinkhanihal *et al.,* 2012).

### 2.3.3.1 Management

Constant irrigation to plants helps reduce the drought stress of the aging plant leaves and thus it helps lower the chances of infection. Removal and destruction of crop debris through burning after harvest help in reducing the quantity of the inoculum available for overwintering with the plant debris in the soil.

Crop rotation for plants is a requisite that helps breakdown the disease cycle. Planting plants belonging to different family reduces the chances of infection and the process the virulence of the pathogen is weakened.

When mildews incidence and severity in a plantation is high, fungicidal application is recommended as the immediate solution since it gives effective mode of control to the *Erysiphe*.

## 2.3.4 Late blight

Late blight is caused by heterothallic stramenopile, *Phytopthora infestans* (Mont) de Barry. It is a common destructive disease of Solanaceae family that it includes tomatoes and potatoes worldwide (Fry *et al.,* 1993). Late blight causes fruit, stem, leaves and flower rot to tomato (Lievens *et al.,* 2004). Late blight is an important disease and thatis worth noting due to its destructive nature. In 1845, late blight caused significant damage to Irish potatoes and led to death of close to one million people in Ireland (Strange, 2003). Infected plants exhibit typical water soaked brown lesions on the leaf surfaces, necrotic spots with white sporulation on the surface of the fruits and stem (Strange *et al.,* 2005). Late blight organism is an obligate parasite that survives inside a living tissue. They survive in seeds of infected plants, compost piles and volunteer plants that may remain inside soil at the time of harvest from the previous season.

Late blight is transmitted by means of spores which have mechanisms of rapid spread. They are best transmitted when the environmental conditions are favorable. Cool and wet conditions are ideal conditions for the disease establishment. Water splash as a result of overhead irrigation, rainfall and surface water run offs are the main transmitting agent of the spores. Strong winds also contribute to the dispersal of the spores from an infected plant to a potential host or from an epidemic colonized area to a disease free area (Dobson *et al.,* 2002). Volunteer crops left in the soil during the time of harvest may be a new source of inoculum the following planted crops in the field when conditions are favourable.

### 2.3.4.1 Management

Currently there is no commercially available variety that has complete resistance to late blight disease (Odome *et al.,* 2008)although continuous research by breeders have developed transgenic varieties that have slight resistance but not complete resistance to the disease due constant mutation of the *Phytopthora* strains.

Fungicidal applications have been majorly the appropriate control methods for the disease especially during the wet weather. Application of fungicides schedule is strictly followed if positive gains on control are to be realized. Fungicidal applications follow a systemic order with considerations based on their mode of action (MoA) application of fungicides start with the application of contact fungicides followed by trans laminar and finally systemic (Dobson *et al.,* 2002).

Cultural techniques have also helped in controlling late blight risks and out breaks. Cultural techniques are part of the integrated disease management (IDM) and integrated pest management (IPM). Cultural activities such as pruning extra suckers facilitates free air movements thus reducing humidity and good spray penetration of the fungicides. Modern technologies such as drip irrigation and change of irrigation regimes from evenings to the heat of the day time allows the plant to dry before the night falls (Odome *et al.,* 2008) help in avoiding disease development.

Mulching of the crop also help reduce the chances of infection through water splash. Staking tomatoes help reduce the risk of blight disease by helping the plant and the fruits off the soil.

Rotational practices away from the solanaceae family plants such as tomatoes and a potato for a period of three to four years is also recommended to break the disease cycle (Dobson *et al.,* 2002). However this approach is limited by the fact that the neighboring farms should be free from the disease or the volunteer crops. Complete removal or deeply dig in old crops after harvest is recommended

## 2.4 Agronet technology

Agronet represents new agro-technological concept which aims at physical protection of plants from insect pests (Ilic *et. al.,* 2010) that comes in aid with quality of plant produce, enhanced growth and development. The Agronet application has been evaluated on numerous agricultural crops and among the crops include; cabbages (Gogo *et al.,* 2014) vegetables (Fallik *et. al.,* 2009, 2010), fruit trees and vineyards (Shahak *et al.,* 2004). Netting is frequently used to protect agricultural crops from excessive solar radiations. This has been practically applied in Serbia due to very high temperatures during summer season with average temperature range of 35-42°C. These aids in improving thermal climate while retaining soil moisture otherwise referred to as microclimate modification (Kittas *et al.*, 2009). The mean daily and relative humidity are significantly higher under netting treatments as compared to the open (Gogo *et al.,* 2012).The microclimate modification has effect on plant growth through the influence of carbon dioxide assimilation that consequently contributes to rapid plant growth (Teitel *et al.,* 2008).In the nursery; it has been evident that Agronet do influence seed germination and seedling emergence. Seeds covered with net take relatively 6 days to germinate compared to those which are not covered which take at least 8 days to germinate. These translate to 26 % reduction in time and therefore good for farmers that do seedling business and disease avoidance (Gogo *et. al*., 2012). Seedlings under agronet cover do express vigor and steady growth due to enhanced climate modification .The number of leaves, the size of the stem and the size of their roots are significantly large compared to those of the seedlings that are not covered. They show better physiological performance with high chlorophyll content (Gogo *et al.,* 2012) thus leading to photo assimilates translocation and thus guaranteeing improved seedling growth (Adams *et al.,* 2001).

Agronet technological concept has been effective in ensuring quality of produce is achieved so as to avert damages that are inflicted on the plant during development in the field. Agronet are consequently effective in protecting agricultural crops from excessive solar radiations that would cause sun scalds, sheltering from wind hails and exclusion from birds that feed on the crop (Teitel *et al.,* 2008).Consequently covering of crops with agro net is efficient in reducing insect transmitted viral diseases(Yakir *et al.,* 2012) , efficient against insect pests control with the infestation levels of aphids and white flies in tunnels covered with either yellow or pearl nets having consistently two to three times lower than in tunnels covered with black or red nets. The incidences of cucumber mosaic virus in pepper grown black or red nets ranged between 35 and 89% (Yakir *et al.,* 2012). Tomatoes have been grown under the net in Israel under fine mesh nets usually 50-mesh clear nets to protected against sweet potato white fly (*Bemicia tabaci)* and the Tomato Yellow leaf curl virus (TYLCV) (Berlinger *et al.,* 2002).

Colored (photoselective) shading nets are being developed with the aim of improving crop production by their optical properties in addition to their physical protective properties (Ben-Yakir *et al.,* 2012). Recent studies have demonstrate that that growing vegetables , fruits and ornamental crops under certain colored shading nets led to increase in production with influence in quality improvement (Shahak *et al.,* 2008, 2009).Uses of color-shade nets improve productivity by moderating climatic extremes (Ilic *et al.,*2012). In studies using pepper, production has been found to be increased by 18% compared to full sunlight exposure (Ilic *et al.,* 2012).

# CHAPTER THREE

## MATERIALS AND METHODS

## 3.1 Study site

The study was conducted on station at Kenya Agricultural Research Institute-National Agricultural Research Laboratories, Kabete from July to December 2012 and repeated from February to June 2013.KARI-NARL is located 8 km Northwest of Nairobi, 36041’E and 010 15’S with an altitude of 1737 m above the sea level (Jaetzold *et al*., 2005). The mean annual temperature ranges from 11°Cto 23°C with bimodal rainfall ranging from 600 to 2000mm per year. The soil are well drained, very deep dark-reddish brown to dark-red, friable clay classified as a Humic Nitisols, according to the Soil Map of the World, and known locally as the Kikuyu red clay loam (Jaetzold *et al*., 2005, FAO/UNESCO, 2009). The rainfall is reliable and favorable for agricultural activities, with the April-July period receiving 60% and October-November 40% of precipitation, It has two growing seasons per year with a total 150 -214 days (Jaetzold *et al*., 2005; Kassam*et al*., 1991) .

Land was prepared prior to sowing by ploughing with tractor disc plough to a depth of approximately 20cm and harrowed to fine even soil. Nursery plots were raised to approximately 25cm. Agronomical practices sowing and transplanting were performed with the use of Diammonium phosphate (18% N, 46% P2O5) mixed with soil at the rate of 5g per plant. Watering of the crop in the nursery and the field were performed to supplement the rains.

Weeding was done after two weeks to keep the plots free from the weeds. Top dressing using Calcium of Ammonium Nitrate was carried out 4 weeks after transplanting in the field at a rate of 5g per plant.

## 3.2 Nursery trial

## 3.2.1 Experimental design and treatments

Factorial design was used in the nursery to facilitate maximum interaction between the Agronet and disease management strategy factors. Agronet as a factor had five levels; insecticide impregnated net of 0.9 mm mesh, non impregnated 0.9 mm mesh net, non impregnated 0.4 mm mesh net, shading with grass that represented the farmers practice and non covered plots acting as the control. The impregnated nets were treated with cypermethrin which is an insect repellant. Management factor had three levels; seed dressing plus monitoring, seed dressing without monitoring and control. Seed dressing was done with Apron star45 WS® (a product with a combination of thiamethoxam, mefonoxam and difeconazole) while monitoring was done using broad spectrum systemic fungicides, Ridomil Gold® (metalaxyls, mancozeb). Plots were arranged such that there was interaction across the treatments in the factors. For example, all disease management factors were replicated within the Agronet factor levels.

## 3.2.2 Layout

Nursery plots had raised beds measuring 200cm by 70cm (Figure 3.1 left) with a space of 50cm between them and an alley of 1m maintained between adjacent Agronet levels (Figure 3.1 Right).

Tomato variety Rio Grande® a common grown determinate variety in Kenya was used. Seeds were sown at the spacing of 1 cm within a row (50 seeds per row) and 10 cm between rows. Sowing was done on 27th July 2012 and 1st February 2013 for season one and season two, respectively and nursery trial lasted for one month. Two metal rods (220 cm x 30 cm) were used to suspend the nets (3 mx2 m) and permanently covered using soil. Wooden Pegs, 1 m high, were used to suspend grass shading to represent farmer practice used at nursery establishment



**Figure 3.1: Layout of nursery plots (left) and raised beds in the nursery at KARI, Kabete (right). (Source: Author,2014)**

## 3.2.3 Data collection

Data collection on germination (Figure 3.2 left) and plant stand count (Figure 3.2 right) started from the 1st emergence of the seedlings all through to the 2nd week after sowing with the use of telecounter for accuracy purposes.



**Figure 3.2: Germination of seedlings (left) and plant stand count (right) at KARI, Kabete. (Source: Author, 2014)**

Five random plants in each plot were sampled for disease incidence and severity levels recorded in excel data sheet format with the score scale adopted and modified from Ullasa *et al*. (1981).The score scale ranged from 0 to 4; 0 represented the plants that were free from the disease and do not show any symptoms, 1 represented the plant that showed disease infection from 1 to 25 %, 2 represented plant infection of 26 to 50 %, 3 represented disease infection of 51 to 75 % symptoms while 4 represented disease severity infection of up 100% or dead plants. Insect pests were counted from a sample of 5 plants in each plot by carefully turning the underside of the leaves *in situ*. Unknown insect pest species were collected for further identification at KARI-NARL Entomology laboratory.

Disease identification was based on the symptoms while the unknown diseased samples were taken to KARI-NARL, Plant Pathology Laboratory for further diagnosis and Kotch’s postulates confirmation. Temperature and humidity were recorded using data loggers mounted at the centre of each bed to monitor relative humidity and the surrounding air temperature (Figure 3.3). Data recorded was downloaded after every week to avoid data loss and the average relative humidity and air temperature were calculated.



Data logger logger

**Figure 3.3: Tomato seedling in the nursery plots ready for transplanting and data logger (Thermo hygrometer) placed at the centre of the bed. (Source: Author,2014)**

On the monitored plots prophylactic applications were done, these were based on disease presence. Mancozeb, metalaxyl (both systemic and broad spectrum) and soap solution against pests.Application was done on the second week after sowing for both seasons on the monitored plots. Data collection was done weekly from 9 am to 12 noon for a period of three weeks before the termination of the nursery experiment.

## 3.3 Field trial

## 3.3.1 Experimental design and treatments

Factorial design was used in the field experiment with two factors. Agronet factor had four levels; Insecticide impregnated net 0.9 mm mesh size net, non impregnated 0.9 mm mesh size net, non impregnated 0.4 mm mesh size net, and non covered acting as the control. The treated nets are impregnated with alpha cypermethrin which is an insect repellant. Integrated management strategies levels included: drenching at transplanting only, drenching plus monitored sprays and no drenching (no application) that served as the control. The arrangement of the Agronet levels was random and the levels of integrated management were randomly arranged within each level of the Agronet.

## 3.3.2 Layout

Plots measuring 4.2 m x 2.0 m were used and tomato seedlings were spaced at a spacing of 60 cm x 60 cm was maintained between plants in a row. An alley of 1m was also maintained between plots levels of each Agronet level and the management levels.

Healthy tomato seedlings were transplanted from the nursery plots protected by nets to ploughed, fine tilled main experimental plots on 6th September 2012 and 6th march 2013 for season one and two, respectively. During transplanting, Diammonium Phosphate (DAP) fertilizer was applied at the rate of 50g per planting hole and mixed with the soil uniformly before placement of the seedlings. Transplanting of the seedlings was done in the evening(Figure 3.4) when sun intensity was low and 50-75 % of the seedling height was buried into the soil to provide the tomato seedlings with a developmental boost and one gallon of water was given immediately to each plant.



**Figure 3.4: Transplanting process of the tomato seedling to the field plots in Kabete. (Source: Author, 2014)**

After watering, drenching with carbamendazim 50DF (Bavistin®) was done on respective plots. Metal rods with arches of 1.5m high were raised to suspend Agronets which were used to cover the plants in respective plots by burying to the soil.

Staking of the plants (Figure 3.5) was done three weeks after planting using ribbon threads supported by wooden pegs.



**Figure 3.5: Staking of tomatoes in the field at KARI, Kabete. (Source: Author, 2014)**

## 3.4 Data collection

Data collection was done from 9 am to 2 pm on weekly basis for a period of 12 weeks when the trial was terminated. Eleven plants were randomly sampled in the three rows for both diseases and pests. The severity of the disease were recorded on excel data sheet based on designated standardized score scale adopted and modified from Ullasa *et al.,* 1981. The scale consist of five categories ranging from 0 – 4; zero represented clean or no symptoms, 1represented 25% of the plant is infected, 2 represented 26-50% infection, 3 representing 50-75% infection while 4 represented 76-100% dead or absolutely infected plants.

Severity of the disease were taken from the plants with score scales of 1-4 denoting infection while zero representing uninfected plants. Disease diagnosis in the field was done based on the symptoms exhibited by the plant while the unidentified diseases were taken with the diseased plant samples, well wrapped in polythene bags to KARI-NARL Plant Pathology Laboratory for further identification. Isolation of disease pathogens were obtained from the diseased plant samples and cultured on artificial media and subsequently subcultured till pure cultures were obtained to be used for pathogenecity tests in the green house to determine Koch’s postulates. Enzyme-linked Immunosorbent Assay (ELISA) was used in determination of the viral pathogens.

The assessment of insect pest species and identification was done carefully to ensure all the species diversity counted. The insect pests observed were identified, counted and recorded using voucher specimen at KARI-NARL entomology section while the unknown insect pests were referred to ICIPE for further identification.

Climatic data were recorded using a data logger (thermo hygrometer, HM; 9 Shanghai Precision and Scientific Instruments Company, Shanghai China) which was mounted on a wooden stick and placed at the centre of each bed as was in (Figure 4). Data recorded by the instrument was downloaded after a fortnight to avoid data loss and the average temperature and relative humidity were obtained by averaging the daily values recorded.

Yield data was achieved by harvesting tomato fruits at pink stage twice a week for a period of three weeks. In each harvest, fruits were sort based on market standards hence classified as marketable and non marketable. Weight and number of both marketable and non marketable tomato were recorded with further classification of unmarketable according to the causal agents.

## 3.5 Data analysis

All the data collected was recorded on excel data sheet. Data cleaning was carried out before analysis. Transformation of data was performed on skewed data before analysis was performed using square root transformation. Means of the disease severity were sought by analysis of variance and the means separated using Fischer’s protected test at 95% confidence level while interaction of factors were determined by correlation using Genstat Discovery 4th edition program version 16.

# CHAPTER FOUR

## RESULTS

## 4.1 Climatic conditions on tomatoes grown under Agronets in nursery and field at Kabete

## 4.1.1 Climatic conditions as influenced by Agronets in the nursery at Kabete, from august to September 2012 and February to march 2013

Agronet covered plots recorded the high significant (p< 0.001) mean temperature (Table 4.1) in the two seasons compared to shading (farmers practice) and no cover (control). Generally, shading recorded the lowest average temperature while control recorded the lowest relative humidity levels. During season 1, mean temperatures were lower compared to season 2 while relative humidity was high in season 1 compared with season 2 ( Table4.1). For the Agronets, 0.4 mm mesh Agronet recorded the highest temperature followed by 0.9 mm mesh treated net, 0.9 mm mesh untreated Agronet, control and shading which recorded the least temperature.

During the two seasons, relative humidity across the Agronets were high in 0.4 mm mesh Agronet,0.9 mm mesh treated net, 0.9 mm mesh untreated Agronet compared with shading and the control respectively but did not vary significantly (p> 0.05) from each other.

**Table 4.1: Mean weekly temperature (°C) and relative humidity (%) on plots planted with tomatoes under different treatments in nursery level at Kabete from August to September 2012 and February to March 2013**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | | **Season 1** | |  |  |  | | | **Season 2** | |  |
| Treatment | Average  (°C) | % increase of temp. from control | | Relative Humidity (%) | % increase of humidity from control |  | Average  (°C) | % increase of temp. from control | | | Relative Humidity (%) | % increase of humidity from control |
| 0.4 mesh | 21.46a | | 8.8 | 80.04 | 18.6 |  | 25.95a | | 16 | | 55.60 | 2.9 |
| 0.9 mesh Treated | 20.81a | | 5.5 | 72.70 | 7.7 |  | 24.97a | | 11.6 | | 53.92 | - 0.2 |
| 0.9 mesh Untreated | 19.96a | | 2.4 | 73.30 | 9.2 |  | 25.58a | | 14.4 | | 54.10 | 0.2 |
| Shading | 17.53b | | - 11.1 | 68.90 | 2.1 |  | 20.71b | | - 7.4 | | 54.91 | 1.7 |
| Control | 19.72b | | 0 | 67.50 | 0 |  | 22.37b | | 0 | | 54.01 | 0 |
| P Value | <0.001 | |  | 0.177 |  |  | <0.001 | |  | | 0.795 |  |
| LSD | 1.665 | |  | 11.290 |  |  | 1.675 | |  | | 3.560 |  |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at P = 0.05 based on control.

## 4.1.2 Climatic conditions on tomatoes grown under Agronets in the field at Kabete from September to December 2012 and March to June 2013

High significant (P<0.001) mean temperature were recorded inside the Agronet covered plots during season 1 compared with the control (Table 4.2). Across the Agronets covered plots, 0.4 mm mesh Agronets recorded the highest temperature means although it did not vary significantly (p> 0.05) with that of 0.9mm mesh treated Agronet and 0.9 mm mesh untreated Agronets. During season 2, temperatures did not vary (p>0.05) across the Agronets levels but the plot covered with the Agronets registered higher mean temperatures compared with the control (Table 4.2).

Relative humidity did not vary significantly (p> 0.05) across the Agronet levels during the two seasons (Table 4.2). However, higher relative humidity was recorded in the Agronet covered plots compared with the control. Agronet 0.4 mm mesh Agronet registered higher humidity in comparison with 0.9 mm mesh Agronets either treated or untreated but did not vary significantly (P>0.05) from each other.

**Table 4.2: Mean weekly temperature (°C) and relative humidity (%) on tomatoes grown under different treatments in field conditions at Kabete from August to September 2012 and February to March 2013**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Season 1** | | |  |  | **Season2** | |  |
| Treatment | Average Temp(°C) | | % increase | Relative Humidity (%) | % increase | Average Temp(°C) | % increase | Relative Humidity (%) | % increase |
| 0.4 mm | 23.25a | | 27.8 | 69.58 | 8.4 | 21.46 | 5.1 | 72.09 | 2.8 |
| 0.9 mm Treated | 22.67a | | 25 | 70.08 | 9.1 | 21.47 | 5.2 | 72.53 | 3.4 |
| 0.9 mm Untreated | 23.53a | | 29.4 | 67.23 | 4.7 | 21.62 | 5.9 | 72.56 | 7.7 |
| Control | 18.18b | | 0 | 64.21 | 0 | 20.41 | 0 | 70.15 | 0 |
| P value | <0.001 | |  | 0.146 |  | 0.081 |  | 0.493 |  |
| LSD | 1.125 | |  | 5.522 |  | 1.030 |  | 3.600 |  |

Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at P = 0.05 based on the control.

## 4.2 Pest infestation levels on tomato grown under Agronets

## 4.2.1 Pest infestation in nursery

During season 1, high pest pressure was recorded in grass shaded and the control treatments compared with the Agronet covered treatments (Figure 4.6).

Significant (p<005) difference on white flies, leaf hoppers, leaf miners and thrips were observed across the treatments during the season (Figure 4.6). Leaf hoppers inside 0.9 mm mesh untreated

Agronet were not expected as they are big in size than the size of the Agronet pores but the presence was atrributed to entry of the pest during the time of data collection.

**Figure 4.6:Pest infestation levels of tomatoes in the nursery at Kabete during season 1 from August to September 2012.**

In season 2, white flies, leaf miners and leaf hoppers were only recorded during the season. White flies varied significantly (P<0.05) across the Agronet treatments with control and grass shaded plots recording high infestations compared with agronet covered plots (Figure 4.7). Leaf hoppers were only recorded on the grass shaded and the control plots, while no incidence of the same were recorded on Agronet covered plots.

**Figure 4.7:Pest infestation levels of tomatoes in the nursery at Kabete during season 2 from February to March 2013**

## 4.2.2 Pest infestation levels in the field

During season 1, high significant (P<0.05) difference were observed on Agonet covered plots compared to control plots for white flies, leaf hoppers and leaf miners (Figure 4.8). Aphids and red spider mites (RSM) had higher count recorded on 0.4 mm mesh agronets compared to the rest of the agronet treatments.

**Figure 4.8: Pest infestation levels of tomatoes in the field during season 1 at Kabete from September to December 2012**

In season 2, white flies infestations were significantly (P<0.05) different across the Agronet levels with Agronet covered plots recording higher presure compared with the control which was lower (Figure 4.9).

Thrips varied significantly(P<0.05) Agronet covered plots recorded high thrips presure compared with the control plots. Aphids were only recorded in control plots compared with the Agronet covered plots (Figure 4.9)

**Figure 4.9: Pest infestation of tomatoes in the field during season 2 at Kabete, March to June 2013**

## 4.3 Disease incidence and severity on tomatoes as influenced by different Agronet treatments in the nursery and field conditions

## 4.3.1 Expression of diseases on tomatoes grown under different Agronet levels in the nursery at Kabete

Four major diseases were recorded on tomatoes grown under different treatments in the nursery (Figure 4.7 and 4.8). These were early blight (caused by *Alternaria solani*), damping off (caused by *Pythium ultimum*), Tomato Yellow Leaf Curl Virus and late blight (caused by *Phytopthora infestans*). Early blight severity was significantly high (at P≤0.05) on tomato seedlings covered with Agronets compared with those underno cover and those grown under grass shade in season 1 (Figure4.7). Damping off was not significantly (P>0.05) different across the treatments. The severity of tomato yellow leaf curl disease varied significantly (P<0.05) across the Agronet treatments. Incidence and severity was high on the non covered plots (no net) and shading and did not vary significantly (P>0.05) from each other.

**Figure 4.10: Disease incidence and severity on tomatoes grown under Agronets at KARI Kabete from August to September 2012**

During season 2, early blight did not vary significantly (P>0.05) across the Agronet levels but high incidences were recorded on 0.9 untreated Agronet and no net treatments (Figure 4.11). Damping off disease did not vary significantly across the four Agronet levels. Tomato yellow leaf curl virus varied significantly (P<0.05) across the Agronet levels. No net cover and shading with grass recorded the highest severity levels and varied significantly (P<0.05) with those of the Agronet covered plots experiencing low infections. Late blight was only observed in 0.4 mm mesh Agronet but absent in the rest of the treatments.

**Figure 4.11: Disease incidence and severity on tomatoes grown under Agronets at KARI Kabete from February to March 2013**

## 4.3.2 Expression of diseases on tomatoes grown under different Agronet levels in the field at Kabete

Tomato yellow leaf curl disease was highly significant (P<0.001) across the Agronet levels. No net plots recorded the highest severity mean of 0.153. Similarly, no net recorded significantly the highest prevalence of 0.023. Late blight was observed across the four Agronet levels during the season but no significant difference across the treatments.

Incidence of Septoria was recorded with 0.4mm (0.0346 ) mesh net recording the highest severity of followed by no net (0.039), 0.9 mm mesh net (0.0303 ) and 0.9 mm mesh treated net (0.013) respectively(Table 4.3). However, there was no significance differences observed across the treatment. Powdery mildew did not vary significantly (P>0.05) across the Agronet levels (Table 4.3). However, severity was higher in net covered crops in comparison to the control. Prevalence was high in 0.9mm mesh net with prevalent mean of 0.063 followed by 0.4 mm mesh net with prevalence mean of 0.4mm mesh net with 0.058 mean while followed by 0.9 mm mesh treated net with 0.024 while no net had the least severity prevalence of 0.019. Generally, severity mean of powdery mildew was high inside the covered plots compared to the open (control)

Early blight was also observed during this season with no net recording the highest severity mean of 0.450 followed by 0.4 mm mesh net with 0.407, On 0.9 mm mesh treated net the score was 0.339 while 0.9 mm mesh net scored least severity (Table 4.3).

Bacterial leaf spot was also observed during the season and significant (P<0.05) variation observed between the net covered plots with the control. Control plots recorded higher severity levels compared to the net covered plots (Table 4.3).

Tomato mosaic virus was also recorded during the season with significant severity levels recorded across the Agronet levels. No net recorded high prevalence compared to rest of the Agronet levels.

**Table 4.3: Disease incidence and severity on tomatoes grown under different Agronet levels season 1(September to December, 2012) at Kabete**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Agronet | Late blight | Tomato yellow leaf curl disease | Bacterial spot | Septoria leaf spot | Powdery mildew | Early blight | Tomato mosaic disease |
| No net | 0.450 | 0.154a | 0.097a | 0.039 | 0.019 | 0.450 | 0.024a |
| 0.9T | 0.338 | 0.013b | 0.013b | 0.013 | 0.024 | 0.338 | 0.000b |
| 0.9UT | 0.329 | 0.002b | 0.009b | 0.030 | 0.063 | 0.329 | 0.000b |
| 0.4UT | 0.407 | 0.000b | 0.015b | 0.034 | 0.058 | 0.407 | 0.000b |
| P value | 0.556 | <0.001 | 0.003 | 0.734 | 0.059 | 0.556 | 0.026 |
| LSD | 0.1939 | 0.0514 | 0.055 | 0.049 |  | 0.193 | 0.019 |

Key: Means followed by the same letters within a column are not significantly different according to the least significant difference test at P = 0.05; severity index: 0= clean, 1=1 to 25 % infection, 2=26 to50 % infection, 3=51 to75 % infection, 4=above 75 % infection

In season two, powdery mildew was observed but was not significantly different (P>0.05) across the Agronet levels (Table 4.4). The covered plot with 0.9 mm mesh Agronet recorded the highest severity mean of 0.053 followed by 0.4 mm mesh Agronet with 0.0253, 0.9 mm mesh treated Agronet had 0.0202, while no Agronet (control) had the least severity mean of 0.0126 (Table 4.4). No significant variation in the level of powdery mildew infection through the entire season across the Agronet levels.

Infection of late blight did not vary significantly (P>0.05) across the four Agronet levels during the season. However, tomatoes covered with 0.4 mm mesh net recorded the highest level of severity (mean 1.666) followed by 0.9 mm mesh net (1.667). No net recorded a mean severity of 1.578 while 0.9 mm mesh treated net recorded the least severity mean of 1.503.

High level of significant (P<0.01) was for tomato yellow leaf curl disease in season 2 across the Agronet levels (Table 4.4). No net recorded high severity (0.11616) compared with records of 0.9mm mesh treated Agronet, 0.9mm mesh Agronet and 0.4 mm mesh Agronet. Bacterial spot was observed only in control but the results did not vary with those of the net covered tomatoes.

Tomato mosaic disease incidence was also noted during the season but the severity did not vary (P>0.05) across the Agronets levels during the season. However, no net recorded higher severity mean in comparison to net covered crops where there were no incidence.

High significant difference (P<0.001) on severity of Septoria leaf spot was observed across the Agronet levels during season 2 (Table 4.4). Mean severity of Agronet covered plots varied with that of the control which recorded higher severity compared with the net covered plots.

**Table 4.4: Disease incidence and severity in the field during season 2 (March to June, 2013) at Kabete**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | Late blight | Tomato yellow leaf curl disease | Bacterial spot | Septoria  Leaf spot | Powdery mildew | Early blight | Tomato mosaic disease |
| No net | 1.578 | 0.11616a | 0.0152 | 0.19949a | 0.0126 | 0.083 | 0.0025 |
| 0.9 mm treated net | 1.503 | 0.00505b | 0.000 | 0.0303b | 0.0202 | 0.169 | 0.0000 |
| 0.9 mm net | 1.677 | 0.00253b | 0.000 | 0.0505b | 0.053 | 0.144 | 0.0000 |
| 0.4 mm net | 1.699 | 0.01515b | 0.000 | 0.00253b | 0.0253 | 0.149 | 0.0000 |
| P value | 0.572 | <0.001 | 0.395 | <0.001 | 0.389 | 0.534 | 0.3950 |
| LSD | 0.3118 | 0.058 | 0.02121 | 0.0855 | 0.049 | 0.1209 | 0.0035 |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at *P* = 0.05; severity index: 0= clean, 1=1 to 25 % infection, 2=26 to 50 % infection, 3=51 to 75 % infection, 4=above 75 % infection

## 4.4 Disease incidence and severity as influenced by integrated management

## 4.4.1 Effect of integrated management in the nursery

During season 1, early blight was observed across the three management strategies (Table 4.5). However, high severity was recorded in plots where there was no treatment(37.9 %) followed by seed dressing with 27 percent mean score while seed dressing plus monitoring only had the least disease severity (23.3%).Seed dressing plus monitoring showed relatively lower severity levels compared to no application and seed dressing only.

Damping off had high significant(P<0.01) difference with no treatment recording the highest severity mean percent of 33.9 %, while seed dressing and seed dressing plus monitoring had the least severity(3.64 % and 3.28 %) respectively.

No significant difference was observed on Tomato yellow leaf curl disease across the three treatments during the season (Table 4.5). However, where no treatment was applied, highest severity mean of 26.3 % was recorded followed by seed dressing only and closely by seed dressing plus monitoring which had 25.9 % and 25.1 % respectively.

**Table 4.5: Mean severity percent scores of diseases recorded on tomatoes grown under different management levels in nursery at Kabete from August- September 2012**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Early blight | Damping off | TYLCD |
| No application | 37.9 | 33.9a | 26.3 |
| Seed dressing | 27 | 3.64b | 25.9 |
| Seed dressing plus monitoring | 23.3 | 3.28b | 25.1 |
| P value | 0.661 | <0.001 | 0.985 |
| LSD | 34.040 | 15.730 | 15.240 |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at P = 0.05

In season two, significant (P<0.01) difference was observed only on early blight and tomato yellow leaf curl diseases (Table4.6). Early blight had highest severity percent on untreated plots(mean 2.933 %) followed by seed dressing (0.4 %) while seed dressing had no infection. Damping off recorded highest severity of (7.7%) on no application management followed by seed dressing with 4.3 % and seed dressing plus monitoring which recorded the least severity of 2.5 % (Table 4.6).

Tomato yellow leaf curl disease prevalence was high in no application with (12.667 %). No incidence and severity of late blight was observed for the entire season two as it was in season one.

**Table 4.6: Mean severity percent scores of diseases recorded on tomatoes grown under different managements at Kabete in season 2 from February to March, 2013.**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Early blight | Damping off | TYLCD |
| No application | 2.933a | 7.7 | 12.667a |
| Seed dressing | 0.4b | 4.3 | 6.4b |
| Seed dressing plus monitoring | 0b | 2.5 | 5.467b |
| P value | 0.024 | 0.159 | 0.037 |
| LSD | 2.254 | 5.43 | 5.94 |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at P = 0.05

## 4.4.2 Effect of integrated management in the field

Severity of Late blight, Septoria leaf spot and early blight were highly significant (P<0.001) on tomatoes grown under different management levels (Table 4.7). No application level recorded the highest effect on disease severity. Late blight recorded the highest level of severity on no application, followed by drenching only and drenching plus monitoring with 0.9464, 0.914 and 0.1623 respectively.

Significant difference (P<0.05) was observed across the management levels on tomato yellow leaf curl disease (Table 7). No application and drenching did not vary significantly (P>0.05) but varied significantly (P<0.05) with drenching plus monitoring. However drenching and drenching plus monitoring did not vary significantly from each other.

The results of the managements on bacterial spot were not significantly different (P>0.05) from each other during the season.

Septoria leaf spot showed high significant (P<0.001) effect across the management levels during the season. Control and drenching plus monitoring didn’t vary significantly (P>0.05) from each other but the two varied significantly (P<0.05) with drenching only. The severity of powdery mildews across the three management levels didn’t however vary significantly (P>0.05).

High significance (P<0.001) of early blight severity was observed during season one with no drenching recording the highest severity mean of 0.513 and did not vary significantly(P>0.05) with that of no application with 0.4481. Drenching and monitoring recorded the least mean severity of 0.1818.

Tomato mosaic disease was only prevalent in control and drenching but not significantly (P>0.05) different was recorded across the three management levels.

**Table 4.7: Effect of management strategies on disease severity in the field during season 1 (September to December, 2012)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Management | Late blight | Tomato yellow leaf curl virus | Bacterial spot | Septoria  Leaf spot | Powdery mildew | Early blight | Tomato mosaic virus |
| Control | 0.946a | 0.079a | 0.021 | 0.002a | 0.075 | 0.448a | 0.005 |
| Drenching | 0.914a | 0.041ab | 0.061 | 0.003b | 0.045 | 0.513a | 0.013 |
| Drenching plus monitoring | 0.162b | 0.006b | 0.018 | 0.08a | 0.003 | 0.182b | 0.000 |
| P value | <0.001 | 0.006 | 0.128 | <0.001 | 0.125 | <0.001 | 0.279 |
| LSD | 0.4889 | 0.0445 | 0.0945 | 0.0844 | 0.0691 | 0.1679 | 0.0323 |

Key: Means followed by the same letters or no letters within a column are not significantly different according to the least significant difference test at P = 0.05; severity index: 0= clean, 1=1 to 25 % infection, 2=26 to 50 % infection, 3=51 to 75 % infection, 4=above 75 % infection.

During season 2, high significant effect (P<0.001) of the management strategies were observed on late blight and early blight diseases (Table 4.8). Significant effect (p<0.05) was also observed on powdery mildew. On late blight and early blight, no application and drenching only varied significantly with that of drenching plus monitored sprays.

Tomato yellow leaf curl recorded high severity on no application, followed by drenching plus monitoring and lastly, drenching only. The results were not expected as drenching plus monitored sprays recorded higher severity mean compared to drenching only.

Severity due to Bacterial spot was only prevalent on no application treatment while drenching and drenching plus monitored sprays had no infection.

No significant difference was observed on Septoria leaf spot disease across the three management strategies. Unexpectedly, drenching plus monitored sprays recorded higher severity followed by drenching only and finally no application. High severity of Septoria disease on tomatoes covered with the Agronet, drenched and monitored with sprays is as a result of the high plant vigor and that creates a big canopy that reduces the wind movement and air circulation thus providing an optimal environment for the pathogens to proliferate.

Tomato mosaic disease severity was only recorded on drenching plus monitored sprays management strategies only. This was attributed to the plant vigour as the crops under drenching only and no application had been all wiped out by the diseases at the late stages. Interestingly, the infection of tomato mosaic virus disease remained below the economic threshold.

**Table 4.8: Effects of management strategies to disease severity in the field during season 2 (March to June, 2013)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Management | Late blight | Yellow leaf curl virus | Bacterial spot | Septoria | Powdery mildew | Early blight | Tomato mosaic virus |
| Control | 2.150a | 0.053 | 0.011 | 0.027 | 0.057a | 0.08 b | 0.000 |
| drenching | 2.091a | 0.011 | 0.000 | 0.030 | 0.023ab | 0.055b | 0.000 |
| Drenching + monitoring | 0.602b | 0.032 | 0.000 | 0.093 | 0.003b | 0.292a | 0.002 |
| P value | <0.001 | 0.202 | 0.371 | 0.059 | 0.047 | <0.001 | 0.371 |
| LSD | 0.2700 | 0.0458 | 0.0183 | 0.0613 | 0.0848 | 0.1168 | 0.0031 |

Key: Means followed by the same letters or no letters within a column are not significantly different according to the least significant difference test at P = 0.05; severity index: 0= clean, 1=1 to 25 % infection, 2=26 to 50 % infection, 3=51 to75 % infection, 4=above 75 % infection

## 4.5 Interaction of Agronet and integrated disease management strategies in nursery and field conditions at Kabete

## 4.5.1 Interaction effect in the nursery level

No significant (P>0.05) seasonal interaction of Agronet and management practices were recorded across the two seasons for the early blight disease (Table 4.9). There was high significant (P<0.001)interaction for Damping observed in season one but these was not observed during season 2 probably due to high temperature and relative humidity in season 1 compared to season 2.

There was no significant interaction (P>0.05) of Agronet and the management strategies observed on tomato yellow leaf curl disease (Table 4.9).

**Table 4.9: P values for the interaction effect of Agronet cover and management levels on the diseases of tomatoes in nursery at Kabete in season 1 and 2**

|  |  |  |  |
| --- | --- | --- | --- |
| **Season** | **Early blight** | **Damping off** | **TYLCV** |
| **Season 1** | 0.567 | <0.001 | 0.865 |
| **Season 2** | 0.297 | 0.964 | 0.458 |

## 4.5.2 Interaction effect in the field level

High interaction effects of Agronet and the additional disease management strategies was recorded for tomato yellow leaf curl disease only during season one but no interaction was observed at season two (Table 4.10). The Interaction of the two factors was expected but the deviation on the second season was attributed to prevailing climatic conditions. No significant interaction was observed for late blight, bacterial spot, Septoria, early blight, and tomato mosaic virus diseases for the two seasons implying that Agronet and management strategies acted independently against the diseases establishment.

**Table 4.10: P value for the interaction on the effects of Agronet cover and management practice on the diseases of tomatoes at Kabete in season 1 and 2 in the field (September to December, 2012 and March to June, 2013)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| season | Late blight | Tomato yellow leaf curl virus | Bacterial spot | Septoria  Leaf spot | Powdery mildew | Early blight | Tomato mosaic disease |
| Season 1 | 0.926 | <0.001 | 0.999 | 0.936 | 0.652 | 0.821 | 0.267 |
| Season 2 | 0.770 | 0.148 | 0.429 | 0.904 | 0.961 | 0.947 | 0.000 |

## 4.6 Disease trends of on field grown tomatoes under different treatments

## 4.6.1 Trends of important diseases in the field during season 1 (September to December 2012)

### 4.6.1.1 Late blight

High late blight prevalence was observed in plots covered with 0.4 mm mesh Agronet and the control up to the 11th week after planting (Figure 4.12). However, during the 12th week, there was sharp increase in severity of late blight. Thereafter this slightly reduced in 13th week on Agronet covered plots maintained high severity of the disease.

**Figure 4.12:** Late blight development under Agronet at Kabete

Considering management strategy, drenching and control recorded high severity means with drenching registering higher severity during the first nine weeks (Figure 4.13). From the ninth week, prevalence rose sharply for the control up to the 14th week. Infection prevalence on drenching plus monitored sprays plots remained low throughout the season compared with the rest of the treatments.

**Figure 4.13: Mean weekly severity of Late blight under different management strategies on tomatoes at Kabete from September to December 2012**

### 4.6.1.2 Powdery mildew

Powdery mildew was high in plots that were not covered with Agronet during the first week after transplanting (Figure 4.14). Infections remained low in Agronet covered plots until the 7th week when there was gradual development of the disease. This was attributed to the increase in humidity and rise in temperature resulting from microclimatic conditions. Agronet covered plots infection were high at the 11th week and gradually fell gradually through to the 14th week. Infection under the no net level remained low which is attributed to low humidity levels since the plant surfaces is blown by wind thus resulting to the plant dryness.

**Figure 4.14: Mean weekly severity of Powdery mildew under different Agronet levels on tomatoes at Kabete.**

Considering management (Figure 4.15), high severity were recorded on plots under drenching only during the first week after transplanting (Figure 4.14) this as well as control was attributed to the infected plants transplanted from the nursery. Drenching plus monitored sprays recorded lower disease severity all across the season except during the 12th week when infections were influenced by rise in rainfall.

**Figure 4.15: Powdery mildew disease under management strategy at Kabete**

### 4.6.1.3. Tomato yellow leaf curl virus

Tomato yellow leaf curl disease severity remained low under all treatments until the fifth week when it was registered in no net plots and 0.9 mm mesh net. No net level recorded high severity levels of the disease to the 14th week (Figure4.17). However, Agronet covered plots with 0.9 mm mesh initial infection may have resulted from plants transplanted with infection from the nursery. Infections on no net plots were as a result of exposure of the plants to the vectors since it was not protected.

**Figure 4.16: Tomato yellow Leaf curl virus development under the net during season one**

Considering the management strategies, severities of drenching plus monitored sprays remained low across the season (Figure 4.17). However severity rose from the 9th week to 11th week due to influence by the prevailing high rainfall which raised the humidity levels. Drenching recorded high prevalence of tomato yellow leaf curl disease during the season with high severity recorded in the 13th week. Control recorded severity pattern that was of similar to that of drenching but lower in severity than that of drenching.

**Figure 4.17**: Tomato yellow leaf curl disease under management strategy at Kabete

### 4.6.1.4 Early blight severity

Early blight severity in Agronet treatments remained low until the 5th week where infections were noted (Figure 4.18). Prevalence rose gradually in no net in comparison to covered crop with low prevalence but from 12th week no net had high infection compared to Agronet covered plots.

**Figure 4.18: Early blight development under the net during season one**

Early blight severity was progressively high under drenching and control plots during the season (Figure 4.19). Infection remained low until the 6th week when severity rose gradually. Severity under drenching plus monitored sprays remained low throughout the season.

**Figure 4.19: Early blight disease under management strategies at Kabete**

## 4.7 Yield effect

All Agronet covered plots had significantly (P<0.05) higher yields compared with control (Table4.11). More weight of marketable tomatoes was recorded in covered plots compared to open plots (no nets). The result was however expected due to the effect of the microclimate modification that the nets maintain high humidity and temperature in addition to pest control effect. High percentage increases from no Agronet plots (NN) were observed to be high in net covered plots (Table4.11) compared to the control plots in the two seasons. During season 1, Agronet 0.4 mm mesh Agronet recorded high percentage increase from the control. In season 2, in 0.9 mm mesh Agronet highest percentage increase was recorded compared with the rest of the Agronets but did not vary significantly from each other but varied significantly (p< 0.05) from that of the control.

**Table 4.11: Mean yield (g) of tomatoes grown under different Agronet treatments at Kabete during seasons 1and 2(September to December 2012 and March to July, 2013)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Agronet | Season 1 | % increase from the control | Season 2 | % increase from the control |
| 0.4UT | 1317.8a | 317.82 | 920.8a | 748.66 |
| 0.9T | 1270a | 302.66 | 1387.5a | 1178.80 |
| 0.9UT | 1039.6a | 229.61 | 1033.3a | 852.35 |
| NN | 315.4b | 0 | 108.5b | 0 |
| P Value | 0.030 |  | 0.010 |  |
| LSD | 744.9 |  | 736.3 |  |

Key: Means followed by the same letters within a column are not significantly different according to the least significant difference test at P = 0.05.

## 4.7.1 Effect of management regimes on marketable yields in the field

High significant (P<0.001) effect of management was observed across the three management strategies for the two seasons (Table 4.12). Drenching plus monitored sprays strategy recorded the highest weight of marketable tomatoes compared to drenching only and no sprays during the two seasons.

High percentage increase from that of the control was recorded in drenching plus monitored spray management strategy. Drenching plus monitored sprays recorded high percentage increase from control during season 2 (27394.68 %) while in season 1, it still recorded high percentage increase of 1831.48 %.( Table 4.12). Drenching only recorded smaller deviation from the control compared with drenching plus monitored sprays that was extremely high.

**Table 4.12**: Tomato yield under different management regimes during seasons 1and 2(September to December, 2012 and March to July, 2013) in Kabete

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Management regime | Season 1 | | % increase from control | Season2 | | % increase from control |
| Drenching plus Monitored spray | | 2655.8a | 1831.4 | | 2575.1a | 27394.6 |
| Drenching only | | 163.8b | 19.1 | | 9.4b | 67.0 |
| No sprays | | 137.5b | 0 | | 3.1b | 0 |
| P value | | <0.001 |  | | <0.001 |  |
| SED | | 227.6 |  | | 221.6 |  |
| LSD | | 645.1 |  | | 637.7 |  |

Key: Means followed by the same letters or no letters within a column are not significantly different according to the least significant difference test at P = 0.05

## 4.7.2 Factor (Agronet and management regimes) interaction effect on marketable tomato yields

There was significant (P<0.05) interaction (Table 4.13) of Agronet and management strategies observed during the two seasons. In season 1, (P=0.004) the interaction of the factors was noted while in season 2, (P=0.002) was recorded. This implied that each factor had influence on the yield performance in the field

**Table 4.13: P values for Agronet and management factor interaction on marketable yields at Kabete.**

|  |  |  |
| --- | --- | --- |
|  | **Season 1** | **Season2** |
| **P values** | 0.004 | 0.002 |

## 4.7.3 Causes of unmarketable tomatoes

Diseases and pests contributed immensely to loss of tomato productions in the field in both seasons. High severity of diseases and pests led to the loss of the tomato as observed in season 1 compared to season 2 (Figure 4.20). Blight had the largest loss during the two seasons and varied significantly (P<0.05) from each other. Tomato mosaic virus was also recorded to cause economic losses of tomato yields during the two seasons with no significant (p> 0.05) difference across the two seasons. However, high prevalence was recorded during season 1.

Bacterial leaf spot varied significantly (P<0.05) with high volume of unmarketable tomatoes in season 1 compared with season 2. Canker loss was high in season 1 compared to season two as well and varied significantly(P<0.05) with each other, while blossom end rot was averagely low for the two seasons and varied significantly as well. High pest damage that resulted to fruit loss was observed to be caused by lasser army worms during the two seasons and did not vary significantly (P>0.05) from each other. African Boll worm loss was also recorded in the two seasons.

**Figure 4.20: Main causes of unmarketable of tomatoes at Kabete from September to December 2012 and March to June 2013**

## 4.7.4 Determination of the best treatment combination

The best treatment combination based on the yields of marketable tomatoes (Table 4.14) were observed on plots that were covered with 0.4 mm mesh, 0.9 mm mesh treated and 0.9 mm mesh Agronets drenched plus monitored sprays carried out(Table 4.14). No significant difference (P>0.05) across the three treatment combinations was observed but varied significantly (P<0.05) with those of the same Agronet drenched and no sprays(control) and those of the no net with either drenching plus monitoring, drenching only and no sprays (Table 4.14).

**Table 4.14: Mean marketable yield for treatment combinations for season 1 in Kabete, from September to December, 2012**

|  |  |
| --- | --- |
| **Treatment combinations** | **Means(weight in g)** |
| 0.4UT drenching + monitored sprays | 3911.7a |
| 0.9T drenching + monitored sprays | 3381.7a |
| 0.9UT drenching + monitored sprays | 2733.3a |
| NN drenching + monitored sprays | 596.3b |
| 0.9 T drenching only | 261.7b |
| NN drenching only | 208.3b |
| 0.9UT no sprays | 200.0b |
| 0.9UT drenching only | 185.3b |
| 0.9T no sprays | 166.7b |
| NN no sprays | 141.7b |
| 0.4 UT no sprays | 41.7b |
| 0.4UT drenching only | 0.0b( No yield) |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test, at P = 0.05

In season two, 0.9 mm mesh net and 0.9 mm mesh treated drenched and monitored Agronet recorded the best treatment combinations and were not significantly at (P>0.05) different from the treatment combinations of 0.4 mm mesh Agronet drenched and monitored (Table 4.15). Despite use of the Agronet with drenching only, low yields were recorded compared with those which were covered and monitored with sprays while those which were not covered (NN) and monitored with sprays recorded significantly (P<0.05) higher yields compared to those of the same non covered not sprayed with lower yields or nothing at all harvested.

**Table 4.15: Mean marketable yield for treatment combinations for season 2 in Kabete, from March to July, 2013**

|  |  |
| --- | --- |
| **Treatment combinations** | **Mean(weight in g)** |
| 0.9T drenching + monitored sprays | 4162.5a |
| 0.9UT drenching + monitored sprays | 3100.0a |
| 0.4UT drenching + monitored sprays | 2712.5a |
| NN drenching + monitored sprays | 325.5b |
| 0.4UTno spray | 37.5c |
| 0.4UT drenching | 12.5c |
| 0.9T drenching | 0.0c |
| 0.9T no spray | 0.0c |
| NN drenching | 0.0c |
| NN no spray | 0.0c |
| 0.9UT drenching | 0.0c |
| 0.9UT no spray | 0.0c |

Key: Means followed by the same letter(s) within a column are not significantly different according to the least significant difference test at P = 0.05

# CHAPTER FIVE

## DISCUSION

## 5.1 Climatic conditions on tomatoes grown under different Agronets in nursery and field at Kabete

High microclimatic conditions of temperature and relative humidity were recorded under Agronet covered plots compared to shading and the control for the two seasons in the nursery. Similar results were also observed in tomatoes transplanted to the field during the two seasons. The results were attributed to modification of the climatic conditions resulting from the thermal radiations of the net. Results obtained corroborated the earlier studies by Gogo *et al.* (2012) on Agronet studies of microclimate modification using eco-friendly net for high quality tomato transplant production at Egerton Njoro; Shahak *et al*. (2004) while using different nets in management of pests.

Temperature under net cover however, varied from those of control and shading in the nursery level with a margin of 1°C to 3°C. These findings were found to corroborate earlier findings by Melinkovic *et al.* (2012) that plastic shaded house received maximum and minimum daily variance are 1°Cto 3°C warmer than outside while working on yield and pepper quality as affected by light intensity using colour shade nets.

In the field conditions under the Agronets, 0.4 mm mesh Agronet recorded the highest microclimatic conditions than 0.9 mm mesh Agronet. The net treatments whether treated or untreated did not influence the microclimatic conditions but rather the fineness of the Agronet based on the size of the pore size influenced the microclimatic conditions as seen in 0.4 mm mesh Agronet in comparison with 0.9 mm mesh nets(large mesh pore Agronets). However, microclimatic conditions during season 1 varied with that of season 2 in consistency and the variations were attributed to the prevailing environmental conditions because season 1 was carried out during short rains(September to December) while season 2 was carried out during long rains( March to June). Findings of this study complimented earlier findings by Gogo *et al*. (2012) that Agronet technology effect is dependent on the prevailing conditions. It was notable that as the temperature increased, the relative humidity decreased and vice versa.

Relative humidity was inversely proportional to the mean temperature across the two seasons whether short rains period or long rains. Similar findings were observed by Gogo *et al.* (2012) in microclimate modification using ecofriendly nets for high quality tomato transplant production.

## 5.2 Disease incidence and severity on tomatoes grown under different Agronets in the nursery at Kabete

Tomato yellow leaf curl virus was significantly higher on grass shading of the Agronet level and the control compared with those under Agronet covered plots. The significant differences was attributed to the efficiency of the nets that acted as the physical barrier to the entry of vector pest that transmit begomoviruses to the plant inside the nets whilst those which were not covered gave easy access of the vector pests to transmit the viral pathogens this findings confirmed earlier findings by Berlinger *et al*. (2002) while working on exclusion screens to prevent white flies transmitting Tomato yellow leaf curl virus.

Insecticides impregnated nets did not show any significant difference from those that were untreated indicating lack of comparative advantage in preventing vector pest’s entry. This could be due to the molecule used for impregnating the nets considering earlier findings by Gogo *et al.* (2012) that impregnation could enhance repellency and thus Agronet efficiency.

Damping off was prevalent in the nursery especially under the net covered crops in season 1. This was attributed to high humidity and temperature within the Agronets which could have resulted in enabling environment for damping off which is known to increase in severity within the ranges of above 25°C and 70% relative humidity. However, prevalence on the control plots registered higher severity which was not anticipated. The deviation from the expected results was attributed to the prevailing ambient conditions as it was during the long rains season and due to the prevailing high relative humidity and mean temperature Pythium pathogens caused severity that could translate to economic losses through loss of the crops in the control plots. Similar findings were reported by Gogo *et al.* (2012), that the microclimatic conditions are dependent on prevailing weather conditions and agro-ecological zones.

During season 2, damping off incidence was recorded on net covered plots, shaded and the control plots. These findings corroborate earlier findings by Muleke *et al.* (2013) whom while working on assessment of ecofriendly nets for sustainable cabbage seedling in Africa stated that damping off is the major disease experienced under Agronets in the nursery. However incidence of damping off were not expected on the control and the shaded plots because the aeration of the plots was not interfered as those of the plots covered with the Agronets that reduce the wind speed resulting to aeration and the success of the disease epidemic could have resulted from the dynamics of the canopy architecture and host receptivity to infection over time of growth as reported by Tivoli *et al.* (2012) while working on canopy architectural traits that reduce the expression and development of epidemics.

Late blight was observed on 0.4mm mesh Agronet only in season 2 but was absent in the rest of the Agronet levels. These results were attributed to the fineness of the Agronet that restricted air circulation leading to high build up of relative humidity and temperature that led to increased microclimatic conditions of temperature and relative humidity by 16% and 2.9% respectively from that of the control. These findings contradicted earlier findings by Gogo *et al*. (2012) who reported reduction in incidence and severity of late blight on using similar Agronets. However, Gogo worked in colder areas of Njoro, where 0.4 mm mesh Agronet resulted to stable microclimatic conditions for growing tomato.

## 5.3 Effects of the integrated management on disease development in the nursery at Kabete

Damping off was highly significant across the three management levels with the seed dressing plus monitored sprays recording the least severity mean which did not vary with that of seed dressing but both significantly different with that of the control. These results translated that coupling of the Agronet with seed dressing and seed dressing plus monitored sprays management strategies had influence on damping off severity. The importance of seed dressing plus monitored sprays in plants covered with Agronets was effective and that a blanket assumption should not be made on the use of Agronets against diseases since from the results it was evident that the net and the management factors did not work independently from each other.

During season 2, the result were not expected as there were no significant variation recorded on the management levels but seed dressing plus monitored sprays recorded the least severity means compared to the seed dressing and the control. These results showed that seed dressing with systemic fungicide plus monitoring with fungicides offers good management strategy for damping off for tomato seedlings in the nursery.

Significant differences across the three management levels were observed in season 2 for early blight and tomato yellow leaf curl virus disease. Seed dressing and seed dressing plus monitored sprays severities varied significantly with that of control. Although in season 1, results were not significantly different since seed dressing and seed dressing plus monitoring recorded the least severity compared with control. Low severity levels of early blight on seed dressing and seed dressing plus monitored sprays was attributed to the effectiveness of the broad spectrum systemic fungicide; Thiamethoxam 20%, 20% difeconazole and 2% metalaxyls (Apron star®) and monitored spays of mancozeb and metalaxyl(Ridomil Gold®) used during seed dressing and monitored sprays respectively. This finding support the earlier findings by Nashwa, (2011) that Ridomil reduced early blight disease severity by 74.2% in field tomato while working on control of early blight in green house and field grown tomatoes using foliar sprays.

## 5.4 Interaction of the integrated management and the Agronet levels in the nursery tomatoes at Kabete

Damping off recorded the highest interaction of Agronet and management strategies during season 1 compared with season 2. These results were attributed to the influence of the Agronet to create microclimatic conditions of high humidity (cool and wet) and increase the temperature thus favoring disease development. These findings supported previous studies by Muleke *et al.* (2013) that damping off is prevalent in Agronet covered cabbage seedlings. Gogo *et al*. (2012) stated that disease development under Agronet cover is influenced by the general surrounding environmental conditions and climatic conditions. Early blight, late blight and tomato yellow leaf curl virus never recorded any significant interactions between the Agronet and the management strategies implying that the Agronet and management strategies operate independently and that appropriate disease scouting is important when Agronets are used to avert crop loss resulting from disease development influenced by optimum environmental conditions from the microclimate modification.

## 5.5 Disease incidence and severity on tomatoes grown under different Agronets in the field at Kabete.

High significance results on tomato yellow leaf curl virus were observed on various Agronet levels. The result implication was that the Agronets worked effectively in management of tomato yellow leaf curl virus as it provided a physical barrier to entry by white fly vectors. Similar results were observed on tomato mosaic virus disease. These results confirmed earlier findings by Berlinger *et al.* (2002) who reported that the physical barrier provided by the net reduced the transmission of tomato yellow leaf curl virus to plants as the white flies transmitting begomoviruses are not permitted. However, the results of the second season did not conform to that of the first season and it was not expected but the deviation was attributed to the prevailing weather conditions which were not favourable (low temperatures and high humidity) to the viral vectors which rendered it in active for pathogen transmission. Similar results have been reported by Shelat *et al*. (2014).

Bacterial leaf spot varied significantly across the Agronet levels in season one but did not vary during season two. Significant variations in season one may have resulted from mechanical damage on the plants leading to infection during cultural practices such as weeding, watering and harvesting. The efficiency of the nets was well observed as the crop covered with nets expressed low severity levels.

Powdery mildew did not vary significantly across the Agronet levels but results indicated that high prevalence was within the net covered plots. This was attributed to the effect of the microclimate modification and shading effect resulting in proliferation of erysiphe spores due to presence of optimal conditions inside the net.

Septoria leaf spot was highly significant across the Agronet levels during season two in comparison to season one. Control varied significantly from the covered plots and the variations were attributed the dependency of the microclimatic conditions. The variations of season one and season two were attributed to cool and wet conditions during the second season while season one was warm and wet.

There was no significant effect of Agronet technology on early blight during the two seasons. However, high severity was observed on the control plots compared to the covered plots in season one compared to season two. The results of season two were expected as the general climate of warm and wet were offered by the nets. These results were only observed before the formation of the plant canopy but later changes were observed as cool and wet conditions contributed by plant canopy and the net shade were experienced. These findings confirmed earlier findings by Tivoli *et al.* (2012) that plant architecture strongly impacts the microclimatic conditions within a canopy. Late blight was observed across the three Agronet levels but did not vary significantly. The levels of infection inside the net covered crops were high compared to the control in season two. This was attributed to the modified microclimate that favored the plant vigour leading to big canopy formation that trapped high humidity below the plant on the covered crops compared to those in the control with smaller canopies that did not provide enough shade to trap humidity due to wind that caused aeration under the plant cover. These finding corroborate findings by Tivoli *et al.* (2012) who reported that the success of disease establishment depended on climatic conditions, dynamics of canopy architecture and the impact of plant growth on the development of plant disease epidemics. In addition Geisler *et al*. (1996) reported the effect of leaf wetness duration, relative humidity and temperature over time. During season one, high severity observed in the control plots was expected but it was not anticipated during season two. These were attributed to the transfer of the inoculums from the infected seedlings from nursery to the field during transplanting period.

## 5.6 Effect of integrated management strategies on disease severity in the field

Late blight was observed across the three management levels and drenching plus monitoring varied significantly with drenching and the control. The result of the study confirmed that drenching plus monitoring worked effectively against late blight complimenting earlier findings by Erinle and Quinn (1980) while working on the epiphytotic management of late blight in Nigeria. Drenching plus monitoring with pesticides worked effectively in managing late blight on crops covered with Agronets.

High significance difference was observed across the two seasons. Drenching plus monitoring varied significantly with drenching and control. Drenching plus monitoring recorded the least severity mean across the two seasons. Low severity of early blight on drenching plus monitoring was attributed to the efficiency of the pesticides used for drenching and regular monitoring compared to drenching only during the time of planting and the control which had no application.

On tomato yellow leaf curl virus, significant difference on management levels were observed in season one, while no significance across the management levels in season two. The deviation in season two were attributed to changes in climatic conditions of cool and wet resulting from long rains experienced that influenced the pest vector population that transmit the virus as most pests are inactive during cold period compared to warm season.

Bacterial leaf spot did not vary significantly across the management levels during the two seasons. The results were attributed to inefficiency of the broad spectrum fungicides (metalaxyl and mancozeb) to control the bacterial diseases but rather copper based fungicides could have been used.

Septoria leaf spot varied significantly across the three levels of management in season one, control and drenching plus monitoring varied with that of drenching only. These results were not expected and the deviation from the expected results were attributed to effect on health plant vigor and huge canopy that led to provision of a conducive environment for disease development a product of the microclimate that was created. Similar findings were recorded earlier by Maerere *et al.* (2010) Although no significance of the disease was observed during season two, it was noted that drenching plus monitored sprays recorded relatively high severity mean compared to drenching and control, the spores of the pathogen could have been introduced to the drench and monitored plot during handling of the crop data collection and cultural practices such as staking and weeding.

Powdery mildew disease did not vary significantly across the three levels of management in season one. However, the mean severity of the disease remained low under the drenched plus monitored plots compared to drenching and control. In season two, significant difference were observed across three management levels and drenching plus monitored sprays proved effective in the control of the powdery mildews, compared to drenching and the control. The low severity levels under drenching plus monitored sprays attributed to the efficiency of the broad spectrum fungicides used. These results confirmed earlier survey by Maerere *et al.* (2006) that 89% reliance on powdery mildew management on tomato crop is dependent on foliar sprays with broad spectrum fungicides.

Tomato mosaic virus recorded high mean severity under the control and drenching only during season one. However, the severity levels of the disease was not observed under drenching plus monitored sprays but the severity mean did not vary significantly across the three levels. These results confirmed that drenching plus monitored sprays are effective in managing tomato mosaic virus. The results obtained in season two were not expected. Control and drenching only did not record any severity mean compared to drenching plus monitored sprays and the results were attributed to late application of fungicides during the season where plants had already been infected with the virus.

## 5.7 Interaction of Agronet and management in the field

Significant interaction of Agronet and the management strategies were observed during season one on tomato yellow leaf curl virus disease, from these results it was established that the coupling of the net technology and good management practices (drenching plus monitored sprays) gave the best control of the begomoviruses especially during the short rains season. In season two no interaction was observed. The result of season two were not expected but could be attributed to change in prevailing climatic conditions (long rains) that inhibited the activities of pest vectors (*Bamicia tabaci*) thus, inability to vector virus. During season one, the nets provided physical barrier to the entry of vector that transmits the virus while those vectors which gained entry by default during the opening of the plots at the time of data collection, were suppressed by the monitored sprays done. These results confirmed the findings by Bextine *et al.* (2001) who while working on the effect of insect exclusion on incidence of the yellow vine disease found that excluded and associated bacterium in squash.

Significant interaction of Agronet and management strategies was observed on tomato mosaic virus during the second season. The coupling of technology and the management proved effective, similar results were achieved by Majumdar (2010) while working on large scale net house for vegetable production to study pest management success and challenges for new technology in Alabama. However, the results of season one did not compliment the results of season two and the deviation was attributed to the high pest population during the season that favored by the warm weather.

No significant interaction of Agronets and management were observed on late blight, early blight, bacterial sports, septoria leaf spot, and powdery mildew diseases. The findings of this study indicated that success can be achieved by use of Agronet and management on managing viral diseases while the rest of the diseases, it is not advisable to assume a blanket solution since each (Agronet and management) acts independently on disease epidemics.

## 5.8 Yield effect

High produce of marketable tomato were obtained from the net covered crops compared to the control. These findings supports the earlier findings by Gogo *et al*. (2013) who found out that growing tomato under the same Agronets caused significant increase in number of marketable yields and quality of tomato compared to non covered plots while working on Agronets also referred to as ecofriendly nets and floating row covers to reduce pest infestation and improving tomato yields in Kenya. The ability of the net covers to provide microclimate modification of temperature and humidity facilitated increased photo assimilates intake as reported by Gogo *et al.* (2012). The findings of these studies corroborate earlier findings by MilenKovic *et al.* (2012) who reported increased yield and quality of pepper by shedding nets. Higher percentage increase of marketable tomatoes from that of the control were recorded inAgronet covered crop with a deviation greater than 200%.Al- Eidy and Sidaros, (1996) reported similar results where more marketable tomatoes were recorded in net covered crops compared to lower non-marketable yield under non-covered plants.

Higher significant differences across the management strategies were also recorded. Drenching plus monitored sprays gave huge quantity of marketable tomatoes which was over 1800% increase from the control for the two seasons. Similar results were documented by Nashwa, (2011) who reported that fungicides treated plots recorded high fruit yields of tomato by 85.7% compared to control while working on control of tomato diseases using aqueous plant extracts and conventional fungicides.

Significant interaction of Agronets and management strategies was also established to influence the quantity yield of marketable field grown tomatoes in the two seasons. The result implication is that coupling of the Agronets with appropriate management practice that is drenching plus monitored sprays is more profitable and leads to realization of the profits from the Agronet technology.

High volumes of unmarketable tomatoes were caused by diseases during the two seasons. Blights, bacterial leaf spot, tomato mosaic disease blossom end rot and bacterial canker are among the main contributors alongside major pests such as African bollworm, Lasser army worm and red spider mites. The high volumes of unmarketable yields were evident as attributed to pest and diseases. Similar findings were documented by UMADEP (2003) in a base line survey in Tanzania.

Based on the marketable yields, the Agronet covered crops with drenching plus monitored sprays, gave the best treatment combination for growing tomatoes in field conditions while utilizing the benefits of the technology. However across the Agronet drenched plus monitored sprays, 0.4 mm mesh Agronet best suited short rains period with higher mean of marketable yields although with no significant difference with those of 0.9 mm mesh Agronets. While 0.9 mm mesh Agronets drenched with monitored sprays performed well during long rainy period, recording higher marketable means though with no significant difference with those of 0.4 mm mesh and Agronet drenched plus monitored sprays. Though there was no significant variation on the result of the above on these treatment combinations, the variations in means between 0.9 mm mesh Agronets and 0.4 mm mesh Agronet were attributed to the size of the pores on the Agronets which influences the microclimate modification of relative humidity and temperature. The larger pores possessed by 0.9 mm mesh Agronet allows wind through the Agronet which leads to evaporation of the moisture thus lowering the humidity while those of 0.4 mm mesh Agronet are smaller thus reducing wind speed responsible for evaporation thus resulting to high humidity build up which is well utilized by the crop during short rains period while during long rains, high relative humidity within the net coupled with high temperature led to proliferation of diseases thus reducing yield during this period. These results confirms earlier findings by Maerere *et al*. (2006) that tomato yields vary greatly in tons/ ha depending on integrated managements of pests and diseases ascribed to.

**CHAPTER SIX**

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

Nursery plots covered with Agronets and at the field recorded high levels of temperature and relative humidity resulting from microclimate modification inside the Agronet cover compared to the control and shaded plots. Under Agronet cover, 0.4 mm mesh Agronets record better microclimatic conditions compared to 0.9 mm mesh Agronet but the net treatment does not affect the efficiency of the Agronets.

Damping off, late blight tomato yellow leaf curl virus diseases were the most prevalent diseases under Agronet technology grown tomatoes in the nursery. Agronet influenced the disease development and manifestation of late blight, powdery mildews but help in the management of viral diseases such tomato yellow leaf curl virus.

Significant results were obtained with the use of different management strategies with seed dressing plus monitored sprays being the most effective. There were no significant interactions of Agronets and management strategies except for viral diseases.

In the field conditions, Agronets were efficient in controlling and managing the viral disease; tomato yellow leaf curl virus and tomato mosaic viruses. However no interaction of Agronets and management strategies were observed in the field conditions implying each acted independently. Use of Agronets combined with good management strategies like drenching plus monitored sprays in the field gave perfect combinations for the higher yields on marketable tomatoes compared to control.

## 6.2 Recommendations

1. Agronet should be used in nursery for economical benefits to ensure clean planting material is used in the field transplants
2. Scouting for diseases and monitoring of the crop using appropriate management strategy should be done at all stages as the Agronet does not offer solution to disease control except on viral diseases.
3. Use of Agronets lead to microclimate modification of relative humidity and temperature compared to non covered plots, hence Agronets should be adopted by tomato growers to reap the from benefits that come alongside the technology but scouting for diseases to avert crop loss.
4. Value addition of net treatment with impregnated insecticides does not influence the disease management hence use of either is recommended.
5. The 0.4 mm mesh Agronet is best suitable during the short rains season while 0.9 mm mesh Agronet is best suited during long rains period, though with no much significant difference between the two based on the quantity of marketable yield.
6. Best treatment combination of Agronets and seed dressing plus monitored sprays in the nursery should be considered in growing tomatoes in the nursery while Agronets and drenching plus monitored sprays may be considered for the field grown tomato

# REFERENCES

**Adams S. R., Cockshull K. E. and Cave C. R.**(2001). Effect of temperature on the growth and development of tomato fruit. *Ann. Bot*. (Lond) 88:869-877

**Al-Eidy F. and Sidaros S. A**. (1996). The effect of protected tomato seedlings on growth and yield of late summer tomato in Egypt. *Cah. Options Mediterr*. 31.385-389

**Andarkwa Isack**.(2011). Assessment of the postharvest handling of six major vegetables in two selected districts in Ashanti region of Ghana. M. Sc. Thesis. Kwameh Nkurumah University of Science and Technology.

**Ben-Yakir D. M. D., Hadar Y., Offir M. C. and Tregeran**. (2008). Protecting crops from pest using Optinets® screens and chromatin® shading nets. *Acta Hort*. 770: 205-212

**Ben-Yakir D., Antignus Y., Offir Y. and Shahak Y**. (2012). Colored shading nets impede Insect Invasion and decrease the incidence of insect- transmitted viral diseases in vegetable crops

**Berlinger M. J., Taylor R. A. J., Lebiush – Mordechi, Shalhevet S. and Spharim I**. (2002). Efficiency of insect’s exclusion screens for preventing white fly transmission of tomato yellow leaf curl virus of tomatoes in Israel. *Bulletin of Entomology Research* 92: 367-373.

**Bextine B., Wayadande A**. (2001). Effect of insect exclusion on incidence of Yellow Vine disease and associated Bacterium in squash. *Journ.Plant Dis*. 85. 875- 878

**Biratu K. S., Silvaraj T. and Hunduma T**. (2013). In vitro evaluation of Actionbacteria against Tomato Bacterial Wilt (*Ralstonia solanacearum*) in West Showa, Ethiopia. *J. Plant. Pathol and Micr*. 4 (160)

**Bissdorf J. (**2005). Field Guide to non Chemical Pest Management in Tomato Production. Pesticide Action Network (PAN) Germany, Harmburg, Germany, PP 1-48

**Chaerani R. and Voorrips R. E. (**2006). Tomato early blight (Alternaria solani): The, genetics and breeding for resistance. *Journal of Gen. Plant Pathol.*72:335-447

**Czosnnek H. and Laterrot H. (**1997). A world wide survey of yellow leaf curl viruses .*Arch virol.*142: 1391-1405

**Dai F. M., Zeng R., Chen W. J. and Lu J. P. (**2011). First report of tomato yellow leaf curl virus infecting cowpea in China. *J. of Plant Dis*. 95(3)

**Dobson H., Jerry C., Walter M., Karuma J., Chumba W. (**2002). Integrated Pest Management. Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent ME4, UK

**Elad Y., Messika Y., Brand M., David D. R., and Sztejnberg A**. (2007). Effect of colored nets on pepper powdery mildew (*Leveillula taurica) Phptoparasitica.* 35:285-299

**Erinle, I. D., and J. G. Quinn**. (1980). An epiphytotic of late blight of tomatoes in Nigeria. *Plant Disease* 64:701-702.

**Fajinmil A. A. and Fajanmil O. B**. (2010). Incidence of Okra Mosaic Virus (*Abelmoschus esculentus*) under tropical conditions. *J. of Mol. Virol.* 1:21

**FAO** ( 2007). Profitability and Sustainability of Urban and Peri-urban Agriculture. Agricultural Management, Marketing and Finance Occasional Paper No. 19. United Nations Food and Agriculture Organization, Rome.

**FAO** (2012). Growing Greener Cities in Africa: First Status Report on Urban and Periurban

**FAO (2005).FAOSSTATS**. [*Http://faostat.fao.org.(2007)Accessed*](Http://faostat.fao.org.(2007)Accessed) *on 19th July,2014.*

**Gogo E. O., Saidi M., Itulya F. M., Martin T. and Ngouaji M**. (2013). Eco-Friendly nets and floating row covers reduce pest infestation and improve tomato (*Solanum lycopersicon* L.) yields for small scale farmers in Kenya. *Journ. of Agro.* 4:1-12

**GOK. (**2010). Ministry of Agriculture, Economic Review of Agriculture prepared by: Central Planning and Project Monitoring Unit. (CPPMU) Nairobi, Kenya. PP1-76

**Gottliet Y., Zchori-Fein E., Moses- Daube N., Kontsedalov S., Skaljac M., Brumin M. andGhamin M. (**2010) . The transmission efficiency of tomato yellow leaf curl virus by the whitefly (*Bemisia tabaci*) is correlated with the presence of a specific

**Grimstad P., Ross Q. and Graig G. (**1980). *Aedes triseratus* (Diptera: Culicidae and La  *cross*e *virus*. Modification of mosquito feeding behavior by virus infection. *J. of Med. Ento.*17:1-7

**Haggag W. M., and Saber M. S. M.** (2007). Suppression of early blight on tomato and purple blight on onion by foliar sprays of aerated and non aerated compost teas. *J. of Food, Agri. and Env.*5(2)302-309 Horticulture in Africa. United Nations Food and Agriculture Organization,Rome.

**Ilic Z., Milenkovic L., Durovka M. and Kapoulus N**. (2010). The effect of color shade nets on the green house climate and pepper yield.

**Jay J. M**. (2000). Modern Food Microbiology. Aspon Publishers, inc. Gaithersburg, Maryland. 2000. A wolters Kluiver Company. *http//www.aspenpublishers.com*. Library of Congress catalog Card Number: 99-054735.ISBN: 0-8342-1671-X.

**Kiptoo J**. (2012). Use of insecticide impregnated nets to manage pests of cabbage in Kenya. Masters of Science Thesis, Moi University.

**Kittas S., Rigakis N., Katsoulas N. and Bartzanas T**. (2009). Influence of shading Screens on microclimate, growth and productivity of tomato. *Acta. Hort*. 807:97- 102

**Lawrence J. L., Edwards C. A., Schroeder M., Martin R. D., Mcdonald F. D., Gold- Smith J. (**2000). An Integrated Approach for managing hot pepper pests in Caribbean*. Proceedings of the BCPC Conference,* 13-16 November 2000, Brighton, UK

**Maerere A. P., Sibunga K. P., and Mwajombe K. K. (**2006). Baseline Survey Report of Tomato Production in Mvomero district – Morogoro region, Tanzania. Sokoline University of Agriculture Facility of Agriculture, Morogoro. Pp31

**Maerere A.P., Sibuga K.P., Bulali J.E., Mwatawala M.W. Kovach J., Kyamanywa S., Mtui, H.D. and Erbaugh M**. (2010). Deriving appropriate pest management technologies for smallholder tomato (Solanum lycopersicumMill.) growers: A case study of Morogoro, Tanzania.*J. of Animal & Plant Sciences*. 2010. Vol. 6, Issue 3: 663- 676.

**Majumdar A**. (2010). Large scale net-house for vegetable production: pest management successes and challenges for new technology. *Alabama Cooperative Extension Systems*: Aubium, AL, USA. Pg 350

**Martin T., Assogba-Komlan F., Houndete T., Hougard J. and Chandre F**. (2006). Efficacy of mosquito netting for sustainable small holders Cabbage production in Africa. *J. Econ. Ento*. 99:450-454

**Masinde A. O., Kwambai K. T., and Wambani N. H. (**2011). Evaluation of tomato (*Lycpersicon esculentum* L.) Variety tolerance to foliar diseases at Kenya Agricultural Research Institute Centre –Kitale in North West Kenya. *African Journ. of Plant Sci.*5(11)676- 681

**Milenkovic L, Ilic Z. S., Durovka M., Kapoulus N. and Fallik E**. (2012). Yield and pepper quality as affected by light intensity using colored shade nets. *J. of Agri. and Forestry*.58. (1):19-33

**Minot N. and Ngigi N. (**2003). Are Horticultural Exports A Replicable Success Story? Evidence from Kenya and Cote de Ivoire. Conference Paper presented in Went, IFPRI, NEPAD,CTA Conference . Success in African Agriculture, Pretoria, South Africa

**Muleke M. E., Saidi M., Itulya F. M., Martin T. and Ngouajio M**. (2013). Assessment of eco-friendly nets to ensure sustainable cabbage seedling production in Africa. *J. of Agro.*3:1-12.

**Mutuku K. and Tschirley D. (**2004). Improving Kenya’s Domestic Horticultural Production and Marketing Systems: Current Competitiveness, forces of change and challenges for the future. Working paper No. 08A/2004.Tegemeo Institute of Agriculture Policy and Development, Egerton University, Kenya

**Nalka S., Jeude J. L., Goffau M., Hiloni M. and Darn B**. (2005). Cultivation of tomato Production; Processing and Marketing. Agromisa Foundation and CTA, Wageningen, Netherlands.

**Nashwa M. A**. (2011). Control of tomato Early Blight disease by aqueous plant extracts and Ridomil.*Journ. ofPlant Pathol.* 10: 187-191.

**Nissim-Levi A., Farkash L., Humburger D., Ovadia R., Forrer I., Kigan S. and Oren-Shamir M**. (2008). Light -scattering shade nets increases branching and flowering of ornamental pot plants. *Journ. Hort. Sci. Biotech*. 83:9-14

**Nkondjock A., Ghadirian P., Johnson K. C. and Kwewski D**. (2005). Dietary intake of Lycopene is associated with reduced pancreatic cancer risk. *Jorn. Nutrition*. 135:592-597

**Nkondjock A., Ghadirian P., Jonhson K. C. and Krewski D**. (2005). Dietary intake of lycopene is associated with reduced pancreatic cancer risk. *Journ. Nutr.*, 135:592 -597

**Odome H., Musyoka P. and Kere J**. (2008). Report on how National Public Policies encourage or impede in agribusiness innovation: Cases of Maize, Tomato and Dairy in Kenya. A component of the world Bank Institute , Government of Denmark and Ireland.

**Ortiz R. and Hartmann P**. (2003). Beyond crop protection: the challenge for African Rural Development; International Institute of Tropical Agriculture (IITA): Ibadan, Nigeria. Pg. 46

**Pandey Y. R., Pun A. B. and Upadhyay K. P.(**2006)**.** Participatory Varietal Evaluation of Rainy Season Tomato under plastic House Condition. *Nepal Agric. Res. Journ.* 7:11-15

**Perez M., Plaza B. M., JimenezS., Lao M. T., Barbero J. and Bosch J. L**. (2006). The radiational spectrum through ornamental net houses and its impact on the climate generated. *Acta Hort*. 719: 613- 636

**Salati R., Shorey M., Briggs A., Calderon J., Rojas L. F., and Palmieri M. (**2010).First report of tomato yellow leaf curl virus infecting tomato, tomatillo and peppers in Guatemala. *Journ. Plnt. Dis.*94(4) 482-482

**Shahak Y., Gal E., Offir Y. and Ben-Yakir D**. (2008). Photoselective shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. *Act.Hort.* 797:75-80

**Shahak Y., Gussakovsky E. E., Gal E. and Ganelevin R**. (2004). Color nets: Crop protection and lighting quality manipulation in one technology. *Acta. Hort*. 659:143-151

**Shelat M., Murari S., Sharma M., Subramanica R., Jummana H. J., and Jarullah B**. (2014). Prevalence and distribution of Tomato yellow leaf curl virus in major agro climatic zones of Gujarat. *Journ.ofAdvances in Biosci. and Biot*. 5, 1-3.

**Strange R. N. (**2003). Introduction to plant pathology. Chichester, UK:Wiley

**Strange R. N. and Scott P. R. (**2005). Plant disease: A threat to Global Food Security. *Annual Review of phytopathology.*43:83-116

**Teitel M., Liron O., Haim Y. and Seginer I**. (2008). Flow through inclined and Concertina-Shape Screens. *Acta. Hort*.801:99-106

**Tewari R. and Vishuvanat K. (**2012). Management of Early blight (*Alternaria solani*) in tomato by integration of fungicides and cultural practices. *Inter. J. of Plant. Prot.* 5(2):201-206

**Tivoli B., Richard B., and Andrion D**. (2012). Current knowledge on plant canopy and architectural traits that reduce the expression and development of epidemics. *J. of Plant Pathol.*135:471-478

**Tumwine J., Frinking H. D. and Jeger M. J.**(2002). Integrating Cultural Control Methods for Tomato Late blight (*Phytopthora infestant*) in Uganda. *Ann.Appl. Biol.*2002:225-236

**Uchibori M., Hirata A., Suzuki M. and Ugaki M.(**2013). Tomato yellow leaf curl virusaccumulates in vesicle-like structures in descending and ascending midgut epithelial cells of the vector whitefly (*Bemicia tabaci*), but not in those of non vector whitefly (*Triaheurodes vaporariomon*). *J. of Gen. Plant Pathol.*1-8

**Ullasa B.A., Rawal R. D., Solai H. S., Singh D. P. and Joshi M. C**. (1981). *Plant Dis*. 65: 600-601

**UMADEP**  (Uluguru Mountains Agriculture Development Project): (2003). Baseline Survey Report for Mlali Division. Tanzania.

**Vanitharani R., Chellappan P. and Fauquet C. M**. (2003). Short interference of gene expression and vital DNA accumulation in cultured plant cells .*Prec. Natc. Acad. Sci.USA*. 100: 9632-9636

**Waiganjo M. M., Wabule N. M., Nyongesa D., Kibaki J. M., Onyango I., Wepukhulu S. B. andMuthoka N. M. (**2006). Tomato Production in Kirinyaga District, A Baseline survey report. KARI, Nairobi, Kenya.1-43p