EFFICACY OF INSECTICIDES USED FOR COTTON INSECT PESTS MANAGEMENT IN MASWA DISTRICT

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ABSTRACT

The efficacy of insecticides used for cotton insect pests management were investigated in Maswa district from November 2018 to April 2019. The aim was improvement of cotton productivity through use of appropriate insecticides at recommended rates of application. The experiment was laid out as factorial in Randomized Completely Block Design (RCBD) with three replications in different locations, i.e. Shanwa primary, Maswa girls and Binza Secondary. The main plots consisted of three different insecticide concentrations, i.e. 0.8 of actual, 1.0 actual, and 1.2 of actual, mls while the subplots constituted the nine types of insecticides. These insecticides were applied three times according to the recommended application regime and the economic thresholds of each major cotton insect pest observed. Data collected were subjected to the ANOVA technique using SAS 9.3 statistical software and followed by Least Significant Difference ($LSD_{0.05}$) means separation. Cotton insect pests dominant were Aphids followed by ants, which was one a beneficial. All the insecticides and rates of application tested decreased cotton insect pests densities and boll damage resulting in increased seed cotton yield when compared with control. Attakan, Confidor, Thunder and Duduba were highly effective against sucking insect pests of cotton. Based on Economic threshold (ET), dominant insect pests were; Aphids (20% of infested plants) and American bollworm (0.5 flared squares per plant) which was determined in order to initiate control measures which lead to increases in seed cotton production per area. ET rationalizes the use of insecticides to overcome inappropriate choices of insecticides, wrong timing of application, poor dosages and limited knowledge on scouting pests and decision making largely contribute to ineffectiveness of insecticides. Insecticides application therefore should be rotated in order to lower insect pest abundance.

DECLARATION

I, MASALU SHIBIRITI LUSANA, do hereby declare to the Senate of the Sokoine University of Agriculture that the content of this dissertation my original work done within the period of registration and that it has neither been submitted no being concurrently submitted in any other institution.

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DEDICATION

To my parents Lusana Shibiriti and my lovely late Poru Gashule for sending me to school, my wife Dyness Lushina, my Sons David and Faustine for their love and endurance.

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LIST OF ABBREVIATION, SYMBOLS AND ACRONYMS

%	Percentage
<	Less than
>	Greater than
≤	Less than or equal to
a. i.	Active ingredient
a.s.l	Above sea level
ANOVA	Analysis of Variance
ARI	Agricultural Research Institute
CDTF	Cotton Development Trust Fund
cm	Centimeter
df	Degree of freedom
e.g.	For example
ECGA	Eastern Cotton Growing Area
et al.,	And others
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
g	Gram
ha	Hectare
i.e.	That is
IPM	Integrated Pest Management
Kg	Kilogram
m	Meter
ml/ℓ	milliliter per liter
NPK	Nitrogen Phosphorus and Potassium

SE	Standard error
TCB	Tanzania Cotton Board
UNCTAD	United Nations Conference on Trade and Development
WCGA	Western Cotton Growing Area

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Cotton (*Gosssypium hirsutum* L.) is the most important natural fibre crop grown in the tropical and sub tropical regions (Shah *et al.*, 2017a). The plant belongs to the genus Gossypium in the family Malvaceae (Mshana, 2014). It is a cultivated annual shrub with broad three-lobed leaves and seeds in capsules or cotton bolls. Each seed is surrounded with white downy fibre which is easily spun (Kabissa, 2015). Before cotton's fluffy bolls emerge, the plant produces large white flowers which attract a wide range of insects, including bees, flies, butterflies and beetles, which visit the flowers to collect nectar and pollen as food and act as pollinators, moving pollen between flowers. Plants make seeds after male-produced pollen grains and female plant ovaries unite after fertilization. Some plants are self-pollinating, but others need pollinators to help the process and lead to increase cotton production both in conventional and organic farm by more than 12% for fibre weight and over 17% for seed number heavier than self pollinated bolls (Pires *et al.*, 2014; Cusser *et al.*, 2016).

The commercial cotton varieties have the ability to compensate for early loss of fruiting points caused either by physiological stress or by bollworm damage; and therefore early sowing, together with a blanket spraying regime, is recommended to minimize the damage caused by this bollworm (Nyambo, 1985; 1988; 1989b). Compensatory response could be increase in fruit set, increase in number of fruiting sites, setting of heavier fruits, and increased rate of late flowering (Barman and Parajulee, 2013).

Germans introduced Cotton into Tanzania since the 19 century (Baffes, 2004; Altenbuchner *et al.*, 2016). Currently, in Tanzania, land devoted to cotton production ranges from 3.5 x $10^5$to 5 x 10^5 ha (Tanzania Cotton Board, 2018) mainly small holder farmers in 49 district of 17 regions, with total production of cotton seeds of 150,000 and cotton lint of 78,000 tones (FAOSTAT, 2020). Among other products, seed cotton is the major source of cotton cake, which is important for animal feeds and organic manure (Busi, 2008; Iqbal *et al.*, 2014). Cotton seed oil used for human consumption and soap manufacturing and waste used for industrial applications, such as polishing clothes and wipers. In addition, cotton stalks can be used in the production of: pellets and briquettes for heating; mushroom; compost; manure; particle board; pulp, paper and corrugated boxes (Kabissa, 2016; UNCTAD, 2017). Cotton contributes about US$90 million to export earnings and provides employment to half a million rural households and about 31.7% of the GDP (CDTF, 2011; Poulton and Maro, 2009; Altenbuchner *et al.*, 2016; Kaur *et al.*, 2017).

The crop is grown in two agricultural zones, mostly under rain fed conditions. The Western Cotton Growing Area (WCGA) contributing 95% of the total production and 5% from the Eastern Cotton Growing Area (ECGA). The WCGA include; Mwanza, Shinyanga, Simiyu, Geita, Mara, Kigoma, Tabora, Kagera, Singida, Katavi and parts of Dodoma regions, while the ECGA covers Morogoro, Kilimanjaro, Manyara, Tanga, Coast and parts of Iringa regions (Busi, 2008; Nyambo, 2009; Mulashani, 2016; Altenbuchner *et al.*, 2016; Tanzania Cotton Board, 2018).

1.2 Problem Statement and Justification

In Maswa district, the productivity of seed cotton is low (0.56-0.75 t ha^{-1}) as compared to other districts e.g. Meatu and Bariadi, which is 0.75-1.2 t ha^{-1} (Geoffrey, 2015). One of the factors contributing to such low productivity cotton in the district is insect pests attack

(Lusana *et al*., 2019). They account for 30 to 50 % of the yield losses (Kabissa *et al*., 1997; Aslam *et al*., 2004; Asi *et al*., 2008; Deguine *et al*., 2008; Asif *et al*., 2016; Sahito *et al.*, 2016; Shah *et al*., 2017a). The incidence of cotton insect pests was on increase regardless of increased insecticides dosages. The abundance of insect pests is attributed to failure of farmers to follow manufacturer's guidance on the right dosage to use, in ability to diagnose the type and stage of the insect pests, stage of crop development and mixing insecticides (Badii and Asante, 2011; Saeed *et al*., 2016).

Previous studies, (Kabissa, 2015) on the efficacy of insecticides used in the WCGA were done at ARI-Ukiriguru with only five insecticides that are distributed by the Cotton Development Trust Fund (CDTF) system, namely; Duduall 450 E.C (chloropyrifos 300 g/ℓ + cypermethrin 150 g/ℓ), Ninja 50 E.C (labdacyhalothrin 50 g/ℓ), Zetabestox 10 E.C (zeta-cypermethrin 100 g/ℓ), Agrothrin 10 E.C (Alpha-cypermethrin 100 g/ℓ and Bamethrin 2.5% E.C (Deltamethrin 25 g/ℓ. These studies, however, did not include evaluation of insecticides' effectiveness in managing cotton insects, which are distributed both within and outside the CDTF system in Maswa. The current study was expected to provide information on: cotton insect pests and their composition, proper application rates for various insecticides, Economic threshold of dominant insect pests on the crop and enable farmers to have a wide selection of insecticides in the management of insect pests without building up resistance. In order to achieve this, a study involving several insecticides was conducted to identify the best ones for managing the insect pests with a view to increase yields of cotton from the current 0.75 to 1.5 tha^{-1} in Maswa District.

1.3 Objectives

1.3.1 Overall objective

The overall objective of the study was improvement of cotton productivity through use of appropriate insecticides at recommended rates of application in Maswa District.

1.3.2 Specific objectives

(i) To determine cotton insect pests abundance and its composition.

(ii) To determine the proper application rate and time among selected insecticides.

(iii) To assess different economic thresholds of dominant insect pests on cotton plants.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cotton Insect Pests

The major cotton pest particularly in the WCGA includes *Helicoverpa armigera* (Hubner), *Aphis gossypii* (Glover) and *Dysdercus spp* (Herrich-Schaeffer) (Kabissa, 1989). There are other pests but of minor significance such as *Empoasca spp Dysdercus sidae* (Herrich-Schaeffer), *Thrips tabaci* (Lindeman), *Bemisia tabaci* (Genn*) Tetranychus spp,* and *Phenacoccus solenopsis* (Tinsley). All these insect cotton pests they causes seed cotton yield losses among from 30 to 50 % (Ashfaq *et al.,* 2011; Mrosso *et al.,* 2014; Asif *et al*., 2016; Kabissa, 2015).

2.1.1 American Bollworm (*Helicoverpa armigera* (Hubner))

The American bollworm is the major cotton pest. It also attacks several crops grown in a relay intercropping system practiced by small scale farmers in western Tanzania (Nyambo, 1985; 1988; 1989a, b). Not surprisingly, many of their hosts are field crops including; cotton, sorghum, sunflower, chickpeas, soybeans, tobacco, maize and wheat; and horticultural crops such as tomatoes, lettuce, capsicum, various bean crops, and flowers: chrysanthemums, gladioli and roses (Nyambo, 1988; Alavo, 2006; Deguine *et al*., 2008; Kriticos *et al*., 2015; El-Bassouiny, 2017). High polyphagy, wide geographical range, mobility, migratory potential, facultative diapause and high fecundity are factors that have strongly contributed to the pest status of *H. armigera* and make it able to adapt to various cropping systems (Nyambo, 1988; Alavo, 2006). The moth is stoutly built and is yellowish brown. There is a dark speck and a dark area near the outer margin of each forewing. The fore wings are marked with grayish wavy lines and black spots of varying size on the upper side and a black kidney shaped mark and a round spot on the underside. The hind wings are whitish and lighter in color with a broad blackish band along the outer margin (Bohmfalk *et al*., 2011; Kabissa, 2015). The incidence and abundance of *H. armigera* on its host were directly and indirectly related to rainfall, with adequate and well-distributed rainfall often associated with heavy infestations in all host. Sufficient early season rainfall favored establishment and growth of early maize and sorghum crops on which early large *H. armigera* populations built up before they dispersed to cotton (Nyambo, 1988).

2.1.1.1 Biology

Adult can lay several hundred eggs in just 10 days from emergence which are spherical shaped, 0.4 to 0.6 mm in diameter and have a costate surface, white coloured later becoming greenish on upper aside of tender foliage of the plants (Plate 1). The eggs usually are distributed on various parts of the plant. Under favourable conditions, the eggs can hatch into larvae within three days and the whole life cycle can be completed in just over a month. The larvae take 12 to 22 days to develop, reaching up to 40 mm long in the sixth instars. Their colouration is variable but mostly greenish and yellow to red-brown. The head is yellow with several spots. Three dark stripes extend along the dorsal side and one yellow light stripe is situated under the spiracles on the lateral side. The ventral parts of the larvae are pale. They are rather aggressive, occasionally carnivorous and may even cannibalize each other. If disturbed, they fall from the plant and curl up on the ground. The pupae develop inside a silken cocoon over 7 to 15 days in soil at a depth of 4–10 cm or in cotton bolls or maize ears (Kabissa, 2015; Mohan *et al.*, 2014).

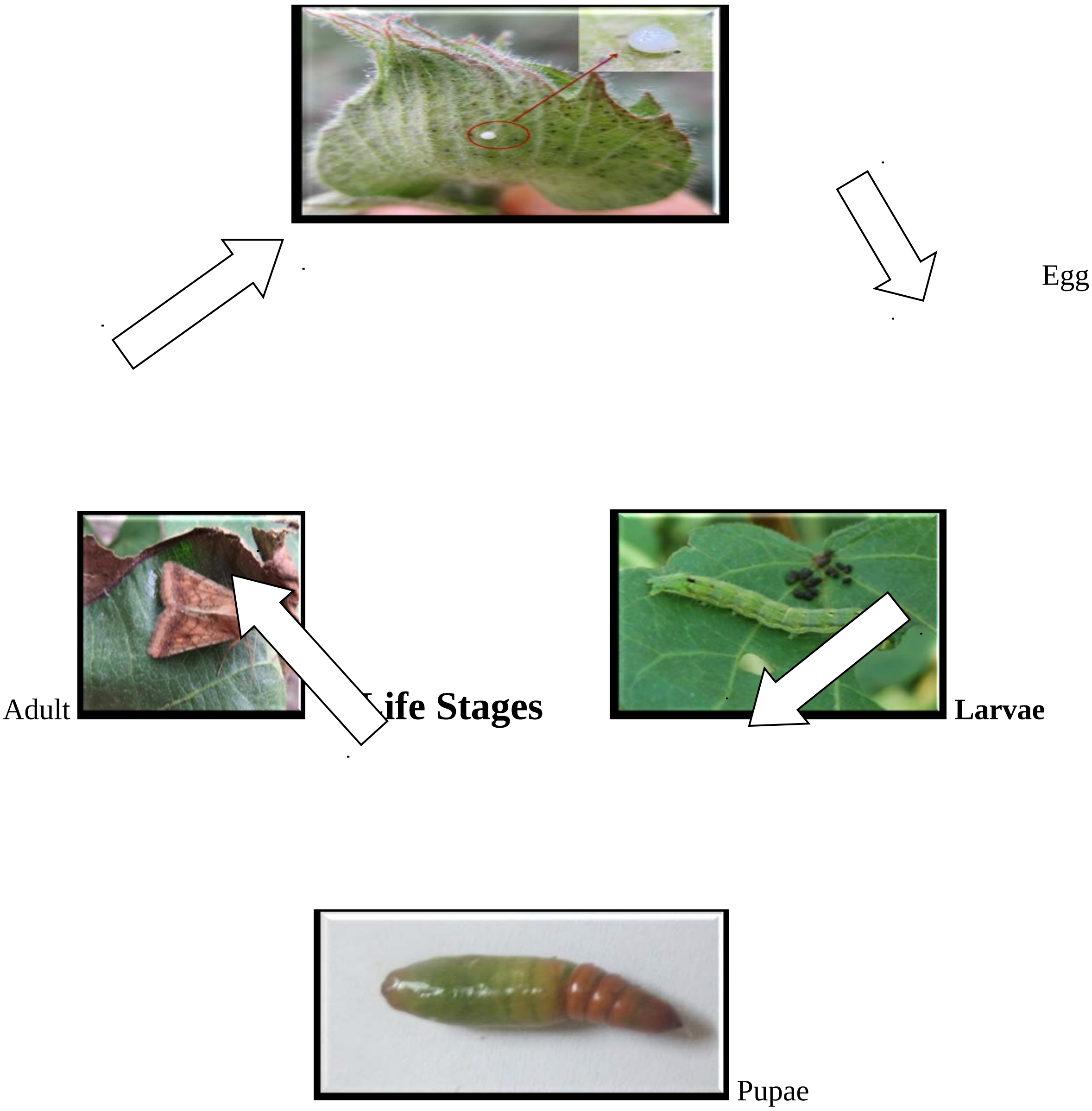


Plate 1: American bollworm, *Helicoverpa armigera* life cycle (Bohmfalk *et al*., 2011; Boyd *et al.*, 2004)

2.1.1.2 Damage

Damage to cotton plants occurs through feeding by the larvae. Single larva of *H. armigera* consumes 6.00-6.26 fruiting bodies of cotton during its larval stage and the damages are very high during larva instars 3, 4 and 5. As larva feeds on leaves, buds, growing points, flowers, square and fruit leaves are damaged and slows down plant growth because the leaf area index for effective photosynthesis is reduced as results, assimilates partitioning to the sink is reduced and consequently productivity of the cotton (Kabissa, 2015; Asif *et al*., 2016; El-Bassouiny, 2017). Feeding on flowers prevent fruits formation and feeding on fruit causes the main economic damages to cotton productivity as seed cotton will not be produced and if any then the quality of lint is affected. The holes serve as entry points for secondary infection by disease causing pathogens that lead to fruit decay (Plate 2) (Kanyeka *et al.,* 2007; Mohan *et al.,* 2014; Mrosso *et al.,* 2014; Kabissa, 2015; Asif *et al*., 2016; El-Bassouiny, 2017; Abudulai *et al.,* 2018a, b).

Plate 2: *H. armigera* larva feeding on cotton bolls (Bohmfalk *et al*., 2011; Mohan *et al*., 2014)

2.1.2 Cotton aphid (Aphis gossypii (Glover))

Aphids are generally found in the upper and middle parts of the plant possibly due to the softness of the leaf tissue, which substantially facilitates the carbohydrate extraction by aphids (Fernandes *et al.,* 2013). Both the adult cotton aphid and the immature stages are soft-bodied approximately 0.26 cm long and sucking insects. They range from light yellow to dark green and in many cases are almost black (Jones, 2004). Early in the season they are a darker color when feeding on new growth of cotton terminals. Later in the season, when their feeding is restricted to the underside of mature leaves (Plate 3), they are a lighter, yellowish colour and are smaller. The immature or nymph stage looks like the adult stage, only smaller. Most adults are wingless. There are no eggs as the young are born alive (Bohmfalk *et al*., 2011; Kerns *et al.*, 2015; Kabissa, 2015). Darker coloured forms of the cotton aphid have been associated with outbreaks. Dark coloured cotton aphids also appear to positively correlate with increasing nitrogen fertility, and decreasing temperature and leaf moisture (Fernandes *et al.*, 2013; Han *et al.*, 2014; Kaleem *et al*., 2014; Kerns *et al.*, 2015).

a)  b) 

Plate 3: Cotton aphids (a) Aptera adult (b) Alate adult (Boyd *et al.*, 2004; Bohmfalk *et al*., 2011)

2.1.2.1 Biology

The biology of the cotton aphid is unique. All adults are females. Female cotton aphids are able to reproduce both with and without mating (Fernandes *et al.*, 2013; Wilson *et al.*, 2013). When environmental conditions are favorable females that have not mated will give birth to live nymphs. In contrast, in unfavorable conditions such as high plant stress or increasing aphid numbers more male and egg-laying females are produced. Egg-laying females have wings so they can spread to new host plants to lay eggs. These females live and produce young on growing plants year round. Aphids reproduce rapidly. One female may produce as many as 80 young females that mature within 8 to 10 days. Thus, it is possible for aphids to have as many as 50 generations per year. These generations also occur as frequently as every 5 to 7 days under optimum conditions. The total life cycle is completed in 9 to 64 days with an average of 28 days (Kaleem *et al.*, 2014; Mohan *et al.,* 2014; Allen *et al.,* 2018).

2.1.2.2 Damage

Aphids are a phytophagous, cosmopolitan and polyphagous species that are found on cotton plants during the development phase of cotton plants (Fernandes *et al.,* 2013; 2018; Allen *et al.,* 2018). Both young and adult cotton aphids suck plant sap. Cotton aphids have been shown to reduce cotton yields by as much as 168 kg of lint per ha where aphids exceeded 50 per leaf (Wilson *et al.*, 2013; Kerns *et al.,* 2015). Infested plants become weak and the tender shoots, leaves fade gradually and may become blighted due to appearance of sooty mould on middle canopy leaves in case of severe attack. Dry conditions favor rapid increase in pest population and younger plants are more susceptible than the older ones. Aphids deplete cell contents of the foliage by feeding on sap, and inject toxins into plant tissues along with their saliva, which causes “hopper burn” symptoms in plants. Infested plants suffer from impaired photosynthesis and transportation of nutrients and water, reducing yield quantity and quality. Heavy aphid populations at Squaring and Boll Production can decrease the size of bolls, stunt plant growth, and may increase square and boll shedding. These sucking insects not only directly damage cotton plants but also act as vectors of viral diseases **(**Amin *et al*., 2016). They commonly appear on the underside of leaves where they suck the sap (Plate 4), causing leaves to curl and sometimes shed. Cotton aphids cause leaves to curl downward and "cup under,” which is in contrast to the upward curling caused by thrips. Aphids excrete honeydew, a sticky substance easily seen on cotton plants. A black sooty mouldy may grow on the honeydew during periods of high humidity. If aphid populations are high at harvest, lint may become sticky with honeydew and interfere with ginning and spinning. Aphids serve as an important food source for natural enemies of other cotton pests (Jones, 2004; Kanyeka *et al.,* 2007; Bohmfalk *et al*., 2011; Kaleem *et al*., 2014; Mohan *et al.,* 2014 Mrosso *et al.,* 2014; Sahito *et al*., 2017; Yang *et al.,* 2017; Allen *et al.*, 2018).

Plate 4: Aphids on flared square and leaf (Boyd *et al.,* 2004)

2.1.3 Cotton Stainer Bug (*Dysdercus sidae* (Herrich-Schaeffer))

Cotton stainer is the most destructive sucking pest present throughout the country (Nyambo, 2009; Kabissa, 2015). Besides cotton it also feeds on okra, potato, and some wild plants like family Bombacaceae. The adults spend much of their time coupled in copulation. The adult cotton stainer is a "true bug" with piercing, sucking mouthparts. The head and pronotum are bright red; the remainder of the body is dark brown crossed with pale yellow lines. The length is 1.5cm or slightly longer (Plate 5). Immature stages (nymphs) are smaller but resemble adults without wings (Bohmfalk *et al*., 2011; Kabissa, 2015).

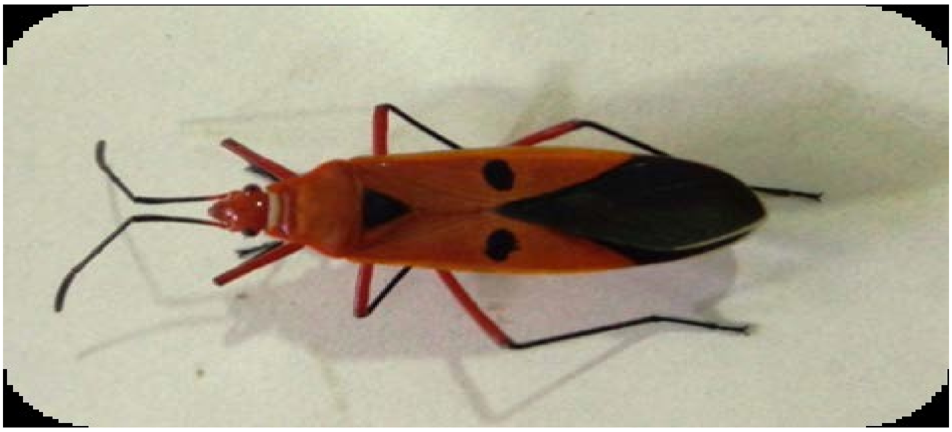


Plate 5: Adults' cotton stainer (Mugini, 2010; Bohmfalk *et al*., 2011)

2.1.3.1 Biology

The female lays about 15 yellowish eggs on the undersurface of the leaves, embedding them into the leaf veins. They suck cell- sap from the undersurface of leaves and pass through six stages of growth in 7-21 days. On transformation in winged adults, they live for 5-7 weeks, feeding constantly on the plant juice. The first instar immature is usually found congregating near the egg shell after emergence. The second and third instars feed gregariously on the bolls. Later instars wander freely over the plant. Adults are about 3 mm long and greenish yellow during the summer, acquiring a reddish tinge in the winter. The winged adults jump or fly away at the slightest disturbance and are also attracted to light at night (Mugini, 2010; Bohmfalk *et al*., 2011; Noman *et al*., 2016).

2.1.3.2 Damage

Both adult and nymph stages feed on seed inside the boll and produce the stains on the lint (Noman *et al*., 2016). It attacks flower buds, small immature and mature bolls. It inserts the stylet inside the bolls, reach to the seed; thus, causing reduction in size and finally the fruiting body may abort and drop to the ground. Feeding by large populations of the cotton seed bug can cause a significant decrease in cotton seed weight (up to 15%) (Mugini, 2010; Wilson *et al.*, 2013). The ability of seeds to germinate is also significantly reduced, potentially as much as 88%. Plate 6 shows, yellow staining on lint may be evidence of watery faeces as bugs feed in the open bolls and damage to bolls resulting in tight-locking (bolls that do not fluff out) (Nyambo, 2009; Mwatawala, 2010; Wilson *et al.*, 2013; Shah, 2014). During feeding, a fungus, which stains and weakens the cotton lint, is often injected into the bolls. When the boll opens cotton frequently sticks to the boll wall and is stained. Also the weight of seed cotton and ginning percentage are reduced. The damage caused by the fungus (Nematospora spp) is more pronounced in wet, humid weather. Young stainers can only feed on seeds, so multiplication in cotton does not begin until the first boll splits and expose the seed cotton. This is of importance when the seed is to be used for sowing the next season (Kanyeka *et al.*, 2007; Mugini, 2010; Bohmfalk *et al*., 2011; Kabisa, 2015; Noman *et al*., 2016).

Plate 6: Cotton bolls affected by Cotton Stainer (Shah, 2014)

2.1.4 Whiteflies (*Bemisia tabaci* (Genn))

They have two pairs of pure white wings and prominent long hind wings. The adult whitefly is about 0.16 cm long and snowy white (Mohan *et al.*, 2014). These moth-like insects are very active and fly readily when disturbed. The immature stage is a flat, scale-like insect usually about 0.08 cm long (Plate 7). The immature flies usually are found on the underside of leaves. Whitefly eggs are only visible under magnification (Bohmfalk *et al*., 2011; Mohan *et al.*, 2014).

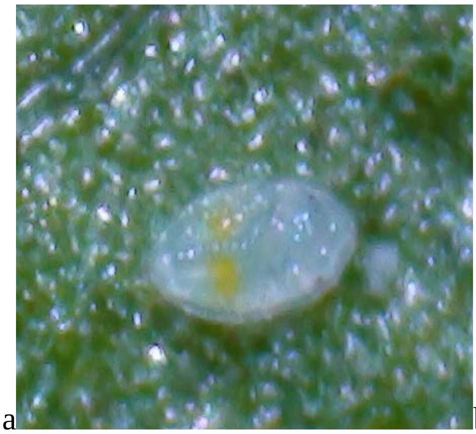
a  b) 

Plate 7: Cotton whiteflies (a) Nymph (b) Adults (Boyd *et al.*, 2004)

2.1.4.1 Biology

Whiteflies are active throughout the year on alternate hosts. Adults mate immediately after emerging from pupae. Eggs are laid on fully opened leaves in the terminal. These eggs require about 5 to 6 days to hatch. The nymphs, also called crawlers, move short distances, but after they insert their mouthparts into the leaves they become immobile. They feed for 5 or 6 days during the first three growth stages. Another 5 or 6 days are spent in a pseudo-pupae stage where no feeding occurs for the last 2 days. After this stage the adult emerges ready to produce eggs within 32-39 days. The adult female lays an average of seven eggs a day for 3 weeks. Peak whitefly numbers usually occur early in the season and during high humidity periods (Bohmfalk *et al*., 2011; Mohan *et al.*, 2014).

2.1.4.2 Damage

Whitefly both nymph and adults feeds on the plant sap and causes plants to wilt, drop leaves and under severe pest pressure, plants may die. Honeydew promotes sooty mouldy, which reduces potential crop yield by blocking sunlight and reducing assimilation of nutrients for plant growth (Ahmed *et al.*, 2002; Wilson *et al.*, 2013; Shah *et al*., 2017). Honeydew contamination effects processing of the lint as it causes the lint to stick to spinning machinery and results in severe price and reputation penalties (Wilson *et al.*, 2013). Cotton whitefly constantly sucks the cell sap, resulting in 50% reduction in boll production and acts as a vector of Cotton leaf curl virus (CLCuV) disease (Bohmfalk *et al*., 2011; Mohan *et al.*, 2014; Shah *et al*., 2017a; Gangwar and Gangwar, 2018).

2.1.5 Jassids (*Empoasca spp*)

Jassid adult is tinny insect oval in shape, green in color with four wings (Plate 8). Adult male is smaller in size than female. The pest usually rests under side of the leaves during the day hours. Population of Jassids is found throughout the due to the continuous availability of alternative hosts. The importance of different true alternative host plants belonging to the families Malvaceae and Euphorbiaceae were the most exploited by both nymphs and adults (Mohan *et al.,* 2014; Saeed, 2015).

a)  b) 

Plate 8: Cotton Jassids (a) Nymphs (b) Adult (Bohmfalk *et al*., 2011; Mohan *et al.*, 2011)

2.1.5.1 Biology

Females lay eggs on underside of the leaves inside midrib, large veins and lamina in a depression made by the ovipositor. Eggs hatching take place in 4-11 days. Nymphs look like adults but smaller, paler and wingless, and molt 5 times to become adult in 6-28 days. Adults are small, elongate and wedge shaped, 3 mm long that live for 5-7 week (Mohan *et al.,* 2014; Saeed, 2015).

2.1.5.2 Damage

Both nymphs and adults suck the plant sap and introduce salivary toxins that impair photosynthesis by blocking xylem and phloem and produce hopper burn disease. The affected leaves curl downwards, turn yellowish then brown before drying (Plate 9). Its infestation not only reduces plant height and number of bolls but also deteriorates lint quality (Saeed, 2015; Amin *et al*., 2016; Sahito *et al*., 2017). The infestation occurs after 45 days from sown date. The adult feeds by piercing and sucking the under surface of the leaf leads to leaves turning red and eventually drop off. A severe attack will stunt the plant cause complete crop failure and Seed cotton yield losses are estimated to be over 37% (Saeed, 2015; Shah *et al*., 2017b).

Plate 9: Cotton crop damaged by Jassids (Bohmfalk *et al*., 2011)

2.1.6 Thrips (*Thrips tabaci* (Lindeman))

Thrips are slender, straw-colored insects about 0.5 to 5 mm long, with piercing-sucking mouthparts (Plate 10). Adults are winged and capable of drifting long distances in the wind. Thrips are a common, early-season pest of cotton. Although thrips occur on cotton throughout the growing season, only young seedling plants are susceptible to injury by Thrips. Thrips injury to young seedling plants can stunt growth and reduce yield potential. As a result, most cotton is treated with an in-furrow insecticide or seed treatment to prevent the development of damaging populations. Fields through wind assisted flight (Mohan *et al.,* 2014; Siebert *et al.*, 2016). Thrips are the major mite predator in cotton (Wilson *et al.*, 2013; Allen *et al.,* 2018).

Plate 10: Adult Thrips (Boyd *et al.*, 2004; Bohmfalk *et al.*, 2011).

2.1.6.1 Biology

Thrips insert their eggs into the plant using a sharp ovipositor. Eggs hatch into wingless larvae, which complete two instars before entering a non-feeding pre-pupa stage which develops into a pupa. Pupae may occasionally occur on plants, but most are found in the soil. The time required to develop from the egg to the adult stage varies greatly with temperature, but may be as little as 15 days under optimum conditions (Mohan *et al.,* 2014).

2.1.6.2 Damage

Thrips have punch and suck or piercing-sucking mouthparts. A stout needlelike mandible is used to puncture plant tissue and cellular fluids are then sucked in through the maxillary stylets (Mohan *et al.,* 2014; Siebert *et al.,* 2016; Kaur *et al.,* 2017). When it occurs on leaves and other plant parts that have already expanded, this type of injury causes little or no significant harm to the plant. However, when such injury occurs within the terminal bud, on tiny developing leaves and fruiting structures, the effect can be quite different.

When Thrips feed on the young undeveloped leaves within the terminal bud, the resulting damage is magnified as those leaves develop and expand. This is because the damaged tissue fails to develop properly, while undamaged tissue continues to grow. After prolonged feeding or feeding by high numbers of thrips, seedlings have a ragged appearance, with visible silvery feeding sites on cotyledons and terminal leaf tissue. Over time these silvery areas will become brown in color (Mohan *et al.,* 2014; Siebert *et al.,* 2016). Heavily injured leaves usually have a crinkled, tattered appearance and often curl upward at the margins (Plate 11). Seedlings exhibiting this type of injury are often described as "possum eared cotton" (Mohan *et al.,* 2014; Shah *et al*., 2017a). Heavy thrips populations can stunt growth, cause death of the terminal bud (resulting in “crazy cotton”), delay fruiting and reduce stand. Thrips damage often is magnified by cool weather or drought, which can slow plant growth and/or lengthen thrips’ developmental time and increase the probability of seedling damage. Seedlings that emerge under warm, favorable growing conditions are much less susceptible to thrips injury than are those that emerge under conditions conducive to slow seedling development. Cotton seedlings become relatively safe from economic injury by thrips once they reach the 4- leaf stage (Mohan *et al.,* 2014; Siebert *et al.,* 2016; Kaur *et al.,* 2017; Shah *et al*., 2017a, b).

Plate 11: Young cotton leaves damaged by thrips (Boyd *et al.*, 2004)

2.1.7 Mealy bugs (*Phenacoccus solenopsis* (Tinsley))

Mealy bugs are cottony in appearance, small oval, soft-bodied sucking insects. Adult mealy bugs are found on leaves, stems and roots and are covered with white mealy wax, which makes them difficult to eradicate (Plate 12). They form colonies on stems and leaves developing into dense, waxy, white masses (Tanwar *et al.*, 2007).

Plate 12: Mealy bugs attacking different parts of cotton (Tanwar *et al.*, 2007)

The success of Mealy bug as a devastating pest of cotton owes to its wide range of Morphological traits and ecological adaptability. The pest status of these species was first time reported from Texas, America which later on spread throughout the world (Tanwar *et al.*, 2007; Ali *et al.*, 2014). Host Range Cotton Mealy bug has a wide range of host plants ranging from herbaceous weeds to woody plants. *Phenacoccus solenopsis* has been recorded as pest of 154 host-plant species out of which 20 are field crops, 64 weeds, 45 ornamental plants and 25 shrubs and trees, belonging to a total of 53 plant families (Khuhro *et al*., 2012; Ali *et al.*, 2014; Noureen *et al.*, 2016).

2.1.7.1 Biology

Cotton Mealy bug is a polyphaguous sucking pest with incomplete metamorphosis. It is an exotic pest with a wide host range, a waxy protective coating on the dorsal side which counters potential mortality factors, having high reproductive rate, and ability of overwintering (Egg and adult female stage) aid insect becoming a serious pest of many commercially important crops (Tanwar *et al.,* 2007; Mohan *et al.,* 2014). It has shown sexual reproduction, producing live young ones instead of laying eggs by a phenomenon of ovoviviparity. Mealy bug, soft body insect, reproduces mostly parthenogenetically, female lays eggs in ovisacs containing 150-600 eggs in their life time (Noureen *et al.,* 2016). Hatching takes place in 3-9 days into nymphs (Crawlers) which lasts for 22-25 days finally growing into adults in 25-30 days under optimum conditions. They can produce hundreds of nymphs in one generation with the capacity to lay up to 6000 eggs per generation. Adults (0.25 — 0.63 cm long) are soft, oval distinctly segmented insects that are usually covered with a white or gray mealy wax. Small nymphs, called crawlers, are light yellow and free of wax. They are active early on, but move little once a suitable feeding site is found. Found in warmer growing climates. Mealy bugs are soft-bodied, wingless insects that often appear as white cottony masses on the leaves, stems and fruit of plants (Tanwar *et al.,* 2007; Mohan *et al.,* 2014; Noureen *et al.,* 2016).

2.1.7.2 Damage

They suck a large amount of sap from leaves and stems with the help of piercing/sucking mouth parts, depriving plants of essential nutrients. The excess sap is excreted as honeydew which attracts ants and develops sooty mouldy (Plate 13), inhibiting the plant’s ability to manufacture food (Tanwar *et al.,* 2007; Noureen *et al.,* 2016). The presence of large number of Mealy bug individuals on various parts of host plant is one of the most important clue indicating pertinent crop losses. The major signs of cotton Mealy bug infestations are wrinkled leaves and shoots, distorted and bushy branches, white powdery substance on leaves, shoots and stem, presence of honey dew, less number of bolls, unopened flowers, chlorosis, stunting, deformation and death of plants (Tanwar *et al.,* 2007; Khuhro *et al*., 2012; Ali *et al.,* 2014; Mohan *et al.,* 2014; Noureen *et al.,* 2016).

Plate 13: Cotton plant affected by Mealy bugs (Tanwar *et al.*, 200)

2.2 Cotton Insect Pests Management

All major and minor cotton insect pests are controlled by any insecticides except spider mite which does not belong to insect class (Ahmed *et al.,* 2002). Also, these insect pests could be managed by an IPM (Integrated Pest Management) where is the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM package including; using resistant varieties, managing for early crop maturity, use various cultural practices, managing for insecticide resistance, using economic thresholds, scouting thoroughly, and applying insecticides in a timely manner when needed (Hoque *et al*., 2000; Hafeez *et al.*, 2006; Mwatawala, 2010; Bohmfalk *et al*., 2011; Khater, 2012; Mohan *et al.,* 2014; Noureen *et al.,* 2016; Sharma and Summarwar, 2017).

2.2.1 Cultural practices

Cultural technique is often found in association with low-tillage systems, resulting in a very highly modified physico-chemical environment for cotton growth. In addition to improving the structure and porosity of soils there is an increase in the diversity and abundance of living organisms in the fields, both of vertebrates and invertebrates (Deguine *et al*., 2008). Cultural controls embody an array of potential pest-control tactics, ranging from initial cultivar selection to a sequence of agronomic practices starting before planting and ending after harvest. Many of these strategies are singularly effective against one or more cotton insect pests, and may become particularly potent when used in conjunction with other cultural practices in an organized community-wide pest-management effort (Hoque *et al*., 2000; Kanyeka *et al.,* 2007; Mohan *et al.,* 2014; Noureen *et al.,* 2016).

2.2.1.1 Cultivation

Early cultivation to destroy insect pupae in soil is one of the most widely adopted cultural control techniques. This reduces the first generation of these pests in the following year. Cultivation and weeding using hand hoes between the rows also reduces the number of *Heliothis* and *Spodoptera* pupae where they are crushed in the soil and exposing the underground pupae to the surface where they desiccate and dry up. Good cultivation will not leave any food for the larvae and they die within 10 days (Javad, 1995; Summy and King, 1992; El-Wakeil and Abdallah, 2012).

A cotton seed weevil (*Apion soleatum*) was known to build up large populations in perennial and ratooned cotton in East Africa, until it was controlled by annual cultivations. Cultivation also affects the eggs of grasshoppers (*Zonocerus* spp.) (Javad, 1995; Mohan *et al.*, 2014). Moreover, deep ploughing may significantly reduce the incidence of certain cotton pathogens, e.g. bacterial blight, *Xanthomonas malvacearum*, and root rot, *Phymatotrichum omnivorum* and manipulate pest densities to advantage within the crop ecosystem (including native vegetation and unrelated crop species) and or to increase the effectiveness of natural enemies (Kabissa, 2015). Cultivation is also an important component of IPM, which can provide refuges for natural enemies or other beneficial arthropods that can then disperse into adjacent cotton fields. Such measures can reduce the dosage and frequency of insecticide sprays and further increase the control capacity of natural enemies against insect pests in cotton fields especially at the seeding stage (Summy and King, 1992; Choate and Drummond, 2011; Luo *et al*., 2014).

2.2.1.2 Time of sowing

Adjustment of planting time to escape pest damage is the most important means of keeping pest damage bellow economic levels. For examples early planting is perhaps the most effective means of control against steam borers in sorghum and maize in many countries and widely practiced by farmers. The correct time for planting can help the crop to avoid the infestation of some pests. In Egypt, the early cultivation of cotton is recommended to escape from the pink bollworm and the American bollworm infestation as the boll will be formed before early generation of this pest (El-Wakeil and Abdallah, 2012).

In Tanzania, early sowing preferably between the mid of November and the end of December is strongly recommended (Nyambo, 2009; 1985). In seasons when American bollworm builds up early, the early sown cotton may lose its bottom crop, but can compensate later by producing a crop during the main rains of March and April. Thus, sowing date and the compensatory ability of the UKM 08 varieties both contribute to minimizing the damage caused by American bollworm (Tanzania Cotton Board, 2018; Nyambo, 1985; 1989b). Early sowing is generally recommended to avoid a massive end of season buildup of some insect pests. Furthermore, early planting after the closed season reduces populations of *Diparopsis*, *Heliothis* and other key pests of Cotton in Zambia, Botswana and Tanzania (Summy and King, 1992; Javad, 1995; Hoque *et al*., 2000; El-Wakeil and Abdallah, 2012; Mohan *et al.*, 2014; Kabissa, 2015).

2.2.1.3 Fertilizer application

Excessive use of fertilizers is conducive to the outbreak of certain pests such as jassids, aphids and whiteflies due to lower the resistance of the plant against diseases caused by fungus and greater attractiveness to insect (Rajan *et al*., 2005). Plant nutrients may affect disease susceptibility through plant metabolic changes, thereby creating a more favorable environment for disease development. When a pathogen infects a plant, it alters the plant's physiology, particularly with regard to mineral nutrient uptake, assimilation, translocation, and utilization. Pathogens may immobilize nutrients in the soil or in infected tissues (Rajan *et al.*, 2005; El-Wakeil and Abdallah, 2012; Aslam *et al.*, 2004). They may also interfere with translocation or utilization of nutrients, inducing nutrient deficiencies or toxicities. Still other pathogens may themselves utilize nutrients, reducing their availability to the plant and thereby increasing the plant's susceptibility to infection. Soil borne pathogens commonly infect plant roots, reducing the plant's ability to take up water and nutrients. The resulting deficiencies may lead to secondary infections by other pathogens. Plant diseases can also infect the plant's vascular system and impair nutrient or water translocation (El-Wakeil and Abdallah, 2012; Mohan *et al.*, 2014).

2.2.1.4 Irrigation

In some countries like Sudan and Egypt, irrigation is also applied to the cotton crop to reduce the over-wintering populations of *Pectinophora* and *Diparopsis*. A late season increase in whitefly populations is also reduced if irrigation is stopped early. Early termination of irrigation accelerates crop maturity and is important in the control of late bollworm attack (Summy and King, 1992). Infestations of thrips (*Calothrips*) in Sudan were minimized by reduction in the interval between irrigations so that water-soaked pupae in clay soils prevented adult emergence (El-Wakeil and Abdallah, 2012). However serious cutworm infestations are associated with irrigated areas where the larvae can survive on a variety of crops throughout the year. Also, whitefly populations are able to survive better where irrigation increases the overall areas of hosts such as okra, cucumber, beans, tobacco and tomatoes in Sudan (Summy and King, 1992; Mohan *et al.*, 2014).

2.2.1.5 Weed control

Weeds can harbor pests which act as vectors of plant viral diseases and increases cost of production in case of controlling. Cotton seedlings are very sensitive to insect pests and competition, particularly during the first six weeks (El-Wakeil and Abdallah, 2012). Weeds, besides competing with seedling plant for light and nutrition, represent the alternative host for most of the cotton pest which start infestation on weed and move to the cotton. Delayed weed removal leads to strong insect pests and viral diseases to spread, competition for light, water and nutrients, between weeds and young seedlings, including the rhizosphere, frequently resulting in excessive internodes elongation, leggy, weak plants and loss of the bottom fruiting bodies, promoting vegetative growth. The crop should be maintained weed free for at least 8 – 9 weeks after sowing till canopy stars closing in by timely inter – culture (Summy and King, 1992; Mohan *et al.*, 2014; Luo *et al*., 2014).

2.2.1.6 Closed season

The use of the closed season is one of the most important cultural practices for the management of cotton insect pests in Africa. It generally lasts for two to three months between harvesting and sowing of the next crop (El-Wakeil and Abdallah, 2012). In East Africa legislation has been passed to ensure that there is a closed season for cotton growing in order to prevent population buildup of pink bollworm (*P. gossypiella*), which is oligophagous on Malvaceae. This legislation stresses that all cotton plants should be uprooted and destroyed (or burned) by a certain date and quite clearly no seed would be planted until the following rain arrives. This approach to pest control tends to be more applicable to the tropics where insect development and crop production may be more or less continuous. In temperate regions, there is already established very firmly a close season for virtually all crops, namely winter. During this period, all growth from old cotton is destroyed. The farmers are advised to uproot their cotton crops by early June in order to reduce populations of Diparopsis and Dysdercus in Botswana (Summy and King, 1992; Javad, 1995; El-Wakeil and Abdallah, 2012; Mohan *et al.*, 2014).

2.2.1.7 Stalk destruction

Destruction of stalks at the end of the cotton season is considered to be important in many countries to reduce the carryover of pests to the next crop. In many African countries, the dates of uprooting, shredding and ploughing in the cotton crop are prescribed by law in order to control various insect pests (Javad, 1995). All cotton residues must be uprooted and burnt in Tanzania which supported with by laws; State that, all cotton plant residuals must have been uprooted and burnt by 15th September for the Western Cotton Growing Area (WCGA) and early November for the East Cotton Growing Area (ECGA) (Tanzania Cotton Board, 2018). Early destruction of cotton stalks was among the initial and most adamant recommendations for control of American bollworm. The rationale of stalk destruction in temperate environments is similar to that discussed for harvest-aid chemicals, i.e. to destroy the food resources required for initiation of adult diapause in boll weevil and larval diapause in pink bollworm. It provides one of the few means available of curtailing or eliminating boll weevil reproduction and over-winter survival in desiccated bolls also destruction is best exemplified by the experience with 'stub' or 'rattoon' cotton in the southwestern United States, which has invariably generated major outbreaks of both species (Mugini, 2010; Mohan *et al.*, 2014).

2.2.1.8 Varietal resistance

Defined as the components of host plant resistance as follows: (1) antibiosis, i.e. factors that reduce pest survival, prolong developmental time, or produce other effects detrimental to the pest; (2) non-preference, i.e. factors that tend to reduce the incidence of pest attack relative to a more susceptible counterpart, and (3) tolerance, i.e. factors that allow a cultivar attacked by the pest to produce a yield greater than that of a less tolerant counterpart. Several resistance characters have involved modifications of the floral structures and levels of second plant substances, i.e. allelochemicals. Examples of the former include male sterility (reduction in anthers), which confers resistance to boll weevil yellow or orange pollen mutants, which exhibit resistance to tobacco budworm (Deguine *et al*., 2008; Mwatawala, 2010). Cotton with very hairy leaves is resistant to jassids attack, apparently because the hairs interfered with the feeding, movement and oviposition of these insects. Later, the length and density of the hair on the underside of the leaf were reported to be equally important factors in determining resistance levels (Nyambo, 1985). The resistance commercial glabrous varieties produced in Tanzania at Ukiriguru Agriculture Research Institute since 1939 were resistance to Jassids (*Empoasca* spp) (Nyambo, 1985; Mohan *et al.*, 2014; Amin *et al*., 2016).

2.2.1.9 Trap cropping (strip-cropping)

Defined as the inter-planting of primary crops with uniform parallel strips of secondary crops in sufficient density to harbour beneficial insect populations which combat insect pests of the primary crop. Recommended the planting of certain cultivated crops (e.g. cowpeas) and native vegetation (e.g. dewberries) in close proximity to cotton as a means of generating field nurseries of boll weevil parasites also Cotton + Cowpea, Cotton + Soybean, Cotton + Groundnut and Cotton + Pulses (Green gram /Black gram) (Nyambo, 1988; Deguine *et al*., 2008; Mohan *et al.,* 2014). It has been suggested that tasselling maize may act as a trap crop for Heliothis because it is said to be more attractive for Heliothis oviposition than cotton. The bollworm infestation may be reduced if cotton and maize are planted close together, in such a way that the vulnerable young boll formation stage of cotton coincides with the tasseling stage of maize. Use of trap crops like okra, Canabinus, castor, marigold (Tagets), early Pigeon pea, coriander, jowar, maize crops is recommended. Insects feeding on these crops must be removed and destroyed (Deguine *et al*., 2008; Mugini, 2010; Luo *et al*., 2014; Li *et al*., 2018). Interspersing cotton with trap crops such as alfalfa and mung bean not only can attract plant bugs, but also provide habitat for natural enemies, thus enhance naturally occurring biological control of plant bugs and other pests in cotton (Luo *et al*., 2014). Through intercropping with sunflower in cotton fields, as sunflower acts as a trap crop and attracts insects (Altenbuchner *et al.,* 2016).

2.2.1.10 Crop rotations

Crop rotations are important cultural techniques for the control of many crop pests. If a rotation is followed, the diapausing pupae of Diparopsis in the soil will have to search for new cotton fields (Altenbuchner *et al.,* 2016). However, cotton's rotation with maize may increase the risk of a heavier infestation of certain pests such as Heliothis which survives on a wider range of hosts. If a sequence of irrigated crops is available for 12 months the whitefly population generally increases (Javad, 1995; Hoque *et al*., 2000; El-Wakeil and Abdallah, 2012; Mohan *et al.,* 2014).

2.2.1.11 Planting density and row configuration

Recommendations for planting configuration at the turn of the century generally stressed relatively low plant densities and wide row spacing as a means of increasing mortality of developing boll weevils by direct exposure to or of enhancing the effectiveness of indigenous natural enemies. Eventually, the advantages of relatively high plant densities and narrow row spacing were recognized (as a means of enhancing earliness) and the conventional 100cm row configuration widely and narrow-row 75 cm configurations have been shown to accentuate the effect on earliness and are becoming increasingly common place as the appropriate implements become available from industry. High crop density can significantly affect overall cotton quality and quantity by increasing the plant's susceptibility to arthropod pests. Dense stands can stress the crop via intra specific competition among individual cotton plants. The plants compete for optimum growing conditions involving space, water, and nutrients. An excessively dense stand results in delayed fruit initiation and maturity, thus increasing exposure to late-season insects (Nyambo, 1988; El-Wakeil and Abdallah, 2012; Mohan *et al.,* 2014).

2.2.1.12 Quarantine

A quarantine zone prohibiting the growing of cotton in the southern districts of Tanzania, bordering Mozambique and Zambia, has been in force for many years since 1946 to prevent the spread of red bollworm, *Diparopsis castanea* (Hmps.), northward to the major cotton areas in the east and west of the country. Recent investigations found red bollworm on cotton grown in the southern part of the quarantine zone, showing that it was essential to enforce the non-cotton zone to protect the major cotton growing areas elsewhere in Tanzania (Kabissa and Nyambo, 1989; El-Wakeil and Abdallah, 2012).

2.2.2 Biological control

2.2.2.1 Natural enemies

Pests control strategy which involves making use of living natural enemies, antagonists, competitors or other biological control agents. These includes; classical, augmentation and conservation of natural enemies of pests such as insect predators, parasitoids, pathogen and weed feeders (Deguine *et al*., 2008; Mwatawala, 2010; El-Wakeil *et al.,* 2013; Luo *et al*., 2014; Colmenárez *et al.,* 2016; Noureen *et al.,* 2016). Predators are one type of natural enemies which tend to keep the population of their prey in check. They catch and eat other insects and mites, including pest species. Parasitoids are another type of natural enemies (Mwatawala, 2010; El-Wakeil and Abdallah, 2012; El-Wakeil *et al.,* 2013). They lay eggs in or on other species of insect (called hosts) and the larval stage kills the host as it feeds on it and develops. Pathogens are fatal or debilitating diseases to arthropod pests and include fungi, nematodes, bacteria, viruses, and other microbes. Fungi, particularly Deuteromycetes, can infect pests externally under favourable conditions, but other pathogens must be ingested to be effective as control agents. Pathogens are very specific to their hosts. Pathogens can be used as bio pesticides because they can be applied in similar ways to chemical interventions (Ashfaq *et al.,* 2011; Sarwar and Sattar, 2016).

2.2.2.1.1 Classical biological control

Classical biological control has been defined as deliberate introduction and distribution of natural enemies of destructive pests into areas where they did not exist previously and mostly employed against pests of exotic origin. It is the intentional introduction and permanent establishment of an exotic biological agent for long-term pest control (Ahmad *et al*., 2003; Deguine *et al*., 2008; Amin *et al*., 2008; Mwatawala, 2010; El-Wakeil and Abdallah, 2012; Mohan *et al.,* 2014).

2.2.2.1.2 Augmentation

Augmentation and Inundation involves mass culture and local release of parasites, predators or pathogens to provide biological control of pest species i.e. the practice of augmenting the numbers of naturally occurring biological control agents, such as predators and parasites, by making releases. It is based on enhancing the numbers of natural enemies, largely by mass production and release/ deployment. Augmentation normally target individual farms and it is not an area-wide strategy (Ahmad *et al*., 2003; Amin *et al*., 2008; Mwatawala, 2010; El-Wakeil and Abdallah, 2012; Luo *et al.*, 2014).

2.2.2.1.3 Conservation

Conservation deals with systems that minimize the disruption as well as promote the in situ activity and abundance of natural enemies' e.g. reduced application of insecticides, planting hedge plants that could serve as refuges in farm boundaries which assist parasitoids and predators during off-season, planting of flowers that could provide nectar/ pollen for beneficial insects etc (Ahmad *et al*., 2003; Amin *et al*., 2008; Mwatawala, 2010; El-Wakeil and Abdallah, 2012).

2.2.2.2 Insect pathogens and toxins

Three insect pathogens are known to regulate cotton bollworm populations. These include the entomopathogenic fungus *Beauveria bassiana*, *H. armigera nucleopolyhedrovirus* (HaNPV) and the soil bacterium *Bacillus thuringiensis* (Bt) (Alavo, 2006; Mohan *et al.*, 2014; Abudulai *et al.*, 2018a, b). Bt cotton is highly effective against cotton bollworm, pink bollworm and other lepidopteran species, and has lead to significant reductions in insecticide use in the Chinese cotton system (Mohan *et al.*, 2014). Population increases of natural enemies in Bt cotton fields can effectively prevents outbreak of cotton aphids in late season traps (Mwatawala, 2010; Luo *et al*., 2014).

2.2.2.3 Pheromones

A pheromone is a chemical that mediates behavioural interactions between members of the same species. Compounds that cause mating disruption of lepidoperan insects such as female sex pheromone of *H. armigera* have been carried out and efficacy of pheromone was compared to conventional insecticides used to control that pest. The most common examples are sex pheromones which are involved in mating, but aggregation and alarm pheromones are also known from cotton pest species (Alavo, 2006; Mwatawala, 2010; Luo *et al*., 2014).

2.2.2.4 Sterile insect technique (SIT)

A sterile insect is an insect that, as a result of appropriate treatment, is unable to produce a viable offspring (Mwatawala, 2010: El-Wakeil and Abdallah, 2012). Sterile insect technology is effective in many insect species because the female only mates once during her lifetime. She carries her mate's genetic material with her for the rest of her life and may lay several batches of eggs, but in many cases, she only receives genetic material from a male a single time during her life. If the genetic material she receives from the male fails to produce offspring, then the female will be unable to lay eggs that hatch into young insects. The SIT technique was used successfully to eradicate the tsetse in Zanzibar Island in Tanzania (Vreysen *et al.,* 2000; El-Wakeil and Abdallah, 2012), flies in Various biological and operational factors precluded the successful application of SIT to the two former species/groups but the method has been used annually since 1968 to mitigate the establishment of pink bollworm on cotton in the Central Valley of California and is a component of the current pink bollworm eradication program (Mwatawala, 2010; El-Wakeil and Abdallah, 2012).

2.2.3 Chemical control

Pesticides are comparatively better option to avoid economic damage to this high value crop. Chemical control action is based on need and is determined using the economic injury level and action threshold decision-making tools. However, chemicals pesticides may cause health hazards, environmental pollution, resistance development in insects, resurgence of new insect pests and toxicity to natural biological agents (House *et al.,* 1985; Khater, 2012; Iqbal *et al.,* 2014; Mohan *et al.,* 2014; Altenbuchner *et al.,* 2016; Colmenárez *et al.*, 2016; Shah *et al*., 2017b; Amera *et al.,* 2017). However chemical control should be used as a last resort. Since the chemical use intervention will remain in the IPM program many efforts was done to produce more safer and selective chemical insecticides derived from microorganism i.e. Agrin, Dipel 2X, BioGaurd from *Bacillus thuringensis*, Spinosad from *Saccharopolyspora spinosa* , Mectin from *Streptomyces avermitilis* or plant extract i.e neem oil, garlic, eucalyptus and datura. Plant extracts, datura and neem at 2% concentrations were effective in reducing the population of *Empoasca spp*, *Dysdercus sidae* (Herrich-Schaeffer), *Thrips tabaci* (Lindeman), *Bemisia tabaci* (Genn.*)* thereby enhancing the yield, safer and environment friendly (Khan *et al.,* 2013; Altenbuchner *et al.,* 2016). It is applied ONLY when the pest's damaging capacity is nearing to the threshold (Kanyeka *et al.,* 2007; Mwatawala, 2010; El-Wakeil and Abdallah, 2012; Khater, 2012; Luo *et al*., 2014; Noureen *et al.,* 2016).

2.2.4 Physical and mechanical practices

Physical and mechanical controls are the measures to kill the insect pest, disrupt its physiological or adversely the environment of the insect pest El-Wakeil and Abdallah, 2012; El-Wakeil *et al.,* 2013). These differ from cultural control in that the devices or actions are directed against the insect pest instead of modifying agricultural practices. For examples, hand picking of cotton stainers from cotton plants, banana weevils from banana pseudostems, tailed caterpillars from coffee, killing stem borers in coffee or American bollworm from tomato plants are the forms of physical control while use of a fly swatter against annoying flies is a form of mechanical control (Mwatawala, 2010; Mohan *et al.*, 2014). Common physical and mechanical control methods include the utilization of high and low temperature for instant hot water treatment of banana planting materials for control of nematodes, sun drying of stored grains, cool storage of maize grain, reducing humidity, utilizing insect attraction to light traps Armyworm and cotton bollworm (Noureen *et al.,* 2016).

IPM strategies aim to reduce reliance on pesticides as a single curative tactic by integrating a range of other actions to reduce pest pressure, enabling insecticides to be used as a last resort. IPM can be implemented through; correct pest identification**-** what pests and stages are causing the damage, understanding of pest and crop dynamics, planning preventive strategies**-** as the preferred management strategy in IPM, monitoring - involves periodic assessment of pests, natural control factors, crop characteristics, and environmental factors to the need for control and the effectiveness of any management action, decision, selection of optimal pest control tactics to manage the problem while minimizing economic, health and environmental risks, implementation and evaluation (Mohan *et al.*, 2014; Noureen *et al.,* 2016; Sharma and Summarwar, 2017; Wilson *et al.,* 2018).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Duration

The studies was conducted in Maswa District, which lies between latitudes 2^0 45′ and 3^0 15′S and 33^0 0′ and 34^0 1′ E and altitudes of 1200 and 1300 m above mean sea level. The experiment was conducted from November 2018 to April 2019.

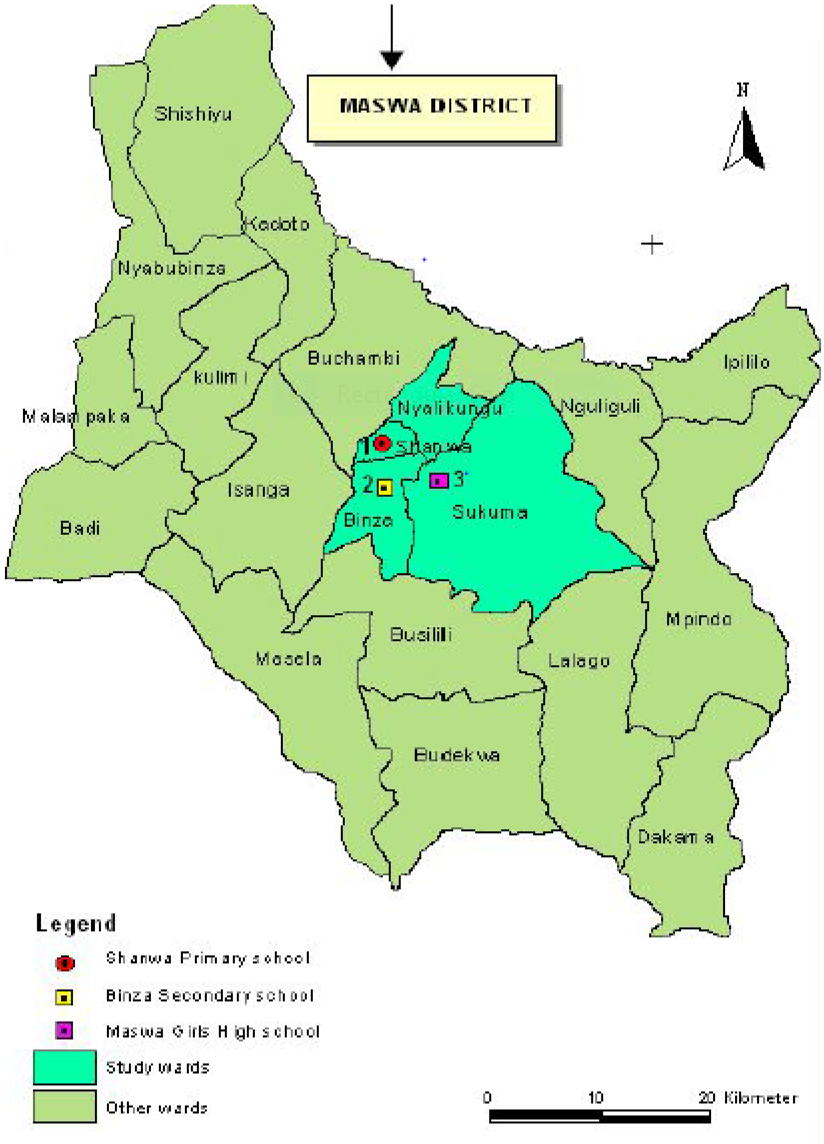


Figure 1: Location of research sites

3.2 Weather and Soil Patterns

Maswa district has a semi-arid climate with bimodal rainfall pattern of between 450 and 1000 mm with an average of 750 mm. The average rainfall decreases from north to south and from west to east. The short rains start in mid-November to mid-January and the long rains start early March to May. The average temperature is 26°C. The topography of the district is characterized by flat, gently undulating plains covered with low sparse vegetation. The area is dominated by heavy black clay soils with areas of red loam and sandy soil. Large parts of the district have hardly and vegetative cover and the soil fertility in large tracks of the district are medium to poor soil.

3.3 Materials, Experiment Design and Layout

A field experiment was established on 15th November 2018 due to 15th November to 15th January is a recommended for cotton planting date, using UKM-08 seeds which is a communal widely grown cotton variety for the WCGA. It was chosen because of its high yielding and good fibre characteristics. The experiment was laid out as split plots in a Randomized Complete Block Design (RCBD) as described by Gomez and Gomez (1984) with three replications at different locations (Maswa Girls, Binza Secondary and Shanwa Primary school). The main plots consisted of three different insecticide concentrations, i.e. 0.8 of actual, 1.0 actual and 1.2 of actual ml while the subplots constituted the types of insecticides tested namely; Bamic 20EC, Banophos 720EC, Attakan C344SE, Thunder 150OD, Confidor 200SL, Belt 480SC, Duduba 450 EC, Karate 5EC, Cypermethrin 200 EC (Table 1). In determination of cotton insect pests abundance factor A was location and species for factor B, where effect of insecticides used on insect pests composition A was rates and insecticides for factor B.

Where; 1or 100%= any actual recommended rate of insecticides by manufacturer

0.8or 80%= any of the recommended rate of insecticides minus by 0.2 or20%

1.2or 120= any of the recommended rate of insecticides added by 0.2or20%

Table 1: Type, rate and time of application of insecticides

Insecticides	Trade name and active ingredient	Insecticides detailed application rate per hectare

A_1	Bamic 20EC-Abamectin 20 g/ ℓ	Applied from seedlings emergence to first Square; 0.03 ℓ /ha, Mode of entry; contact. Mode of action nervous system and post synapse.
B_1	Banophos 720EC-Profenophos 720 g/ ℓ	Applied from seedlings emergence to first Square; 0.5 ℓ/ha, Mode of entry; contact. Mode of action: anti-choline esterase enzyme.
C_1	Attakan C344SE-imidacloprid200 g/ℓ+Cypermethrin144 g/ ℓ	Applied from seedlings emergence to first Square; 0.5 ℓ /ha, Mode of entry; contact and systemic. Modes of action are both peripheral and nervous system also ant-choline esterase enzyme.
A_2	Belt 480SC-flubendiamide phthalic acid diamide 480 g/ ℓ	From square to flowering and boll formation; 0.05 ℓ /ha, Mode of entry: systemic. Mode of action: axon poison.
B_2	Confidor 200 SL -imidacloprid 200 g/ ℓ	From square to flowering and boll formation; 0. 5 ℓ /ha, Mode of entry; Contact, ingestion and systemic. Mode of action ant-choline esterase enzyme.
C_2	Thunder 150 OD-Imidacloprid + Betacyfluthrin 100+45 g/ ℓ	From square to flowering and boll formation; 0.2ℓ /ha, Mode of entry; contact and systemic. Mode of action ant-choline esterase enzyme.
A_3	Duduba 450EC-Cypermethrin 10% + chlorpyrifos 35%	Boll formation to boll splitting; 0.2 ℓ /ha, Mode of entry; contact. Mode of action both peripheral and nervous system and ant-choline esterase enzyme.
B_3	Cypermethrin 200 EC-Cypermethrin 200 g/ℓ	Boll formation to boll splitting, 0.3 ℓ /ha, Mode of entry; contact and ingestion. Modes of action are both peripheral and nervous system
C_3	Karate 5EC-Lambdahalothrin 50 g/ ℓ	Boll formation to boll splitting; 0.3 ℓ /ha, Mode of entry; contact and ingestion. Mode of action axon poison.
D_0	Control	Untreated

These insecticides were applied three times according to the recommended application regime by manufacturer, phenology stage associated with insect pests and the economic thresholds level of each major cotton insect pest observed. The application of insecticides was done by using knapsack sprayer with volume 16L of water. Spraying of insecticides was done as top and bottom of leaves during the morning, from 7:30 am to 10:00 am. Also selecting of certain insecticides was based on the mode of insecticides action and presence of insect pests on or in plant parts e.g during flare square formation to bolls formation systemic insecticides were used due to some insect pests feeding on and in the reproductive parts of the plant. The insecticides abbreviated with letters A_1-$C_{1,}$ were applied in first session, A_2-C_2 second session, and A_3-C_3 in the third session, where D_0 was control sub plots (unsprayed). The sub-plots consisted of six rows each with 12 plants a spacing of 0.5 x 0.8 m. Thus sub-plots size was 3x6.8 m and main plot was 36 x 6.8 m resulting into an area of 244.8 m^2. The distance between sub plots was 0.5 m. Thus, the experimental sub plots were 36 with total area of 246.84 m^2. All recommended agronomic practices for cotton were adhered during the course of the experiment such as; farm yard manure (FYM) application at a rate of 10 t/ha during or just after land preparation in October, 125 kg NPK/ha applied six weeks after sowing, four-five seeds were directly sown per hill at 2.5 cm depth, thinning and weeding were done manually three times during crop growth.

3.4 Data Collected

3.4.1 Composition of insect pests

During determination, six plants were selected at random in each sub-plot and labeled with plastic tags at actual weekly intervals. Scouting, observation and counting were done early in the morning 7:30 am-10:00am, starting from three weeks of cotton seedling growth. Observation was done early morning due to most cotton insect pest nymph and adult were seen easily and were not hidden to escape predator and direct sunlight also their idle due to dews which developed during night so they cannot fly easily. This was done based on the actual individual count of sucking insects from top, middle and bottom on three leaves of the selected plants (Nemade *et al.*, 2018). The number and type of all insects observed was identified and counted using identification key, biology, and evidence of infestation and nature of damage key of pests, also for too small insects were counted by assistance of magnifying glass (Mwatawala, 2010; Bohmfalk *et al.*, 2011). Some of insect pests were identified by number and types of damage caused to plant parts such as; leaves flowers, flare squares and bolls affected (Pérez-Lachaud *et al.*, 2014; Luo *et al.*, 2014). The insect pests composition was taken from unsprayed sub plots then means and proportion of insect pests composition were calculated for different locations and phases using the formula below;

$$Composition = \frac{Total\ number\ of\ individuals\ of\ the\ same\ species}{Total\ number\ of\ insects\ found} x100$$

…………(1)

3.4.2 Effects of insecticides used on insect pests composition

The number and types of all insects on leaves, flowers, squares and bolls affected was counted from the six plants selected randomly in each treatment a day before spraying, three and seven days after spraying (Rudramuni *et al.*, 2012). The species which were actually observed and counted were aphids, jassids, whiteflies, thrips, cotton stainer and mealy bugs also beneficial insect included; ants, spider, ladybird beetle, green lacewing, praying mantis and damsel bugs while other species were observed and counted damaging reproductive parts of cotton plant such as American boll worm but syrphids and fungal pathogen beneficial pathogens was identified through sign and symptoms on different parts of cotton plants (Boyd *et al.*, 2004; Pérez-Lachaud *et al.*, 2014; Luo *et al.*, 2014).

3.4.3 Effects of economic threshold of insect pests on parameter of seed cotton yield

Scouting for American bollworm, by using the peg board whereby 0.5 flared squares per plant i.e. 15 flares per 30 sampled plants. This was determined by sampling cotton plants in one-replicate area along two diagonals. First, a one- replicate area is selected. This was cut across with two diagonals. Within each diagonal, fifteen plants were examined for flared squares (buds). The first three plants in a diagonal are neglected to remove border effects.

The fourth plant should be the first to be examined. Every seventh or eighth plant is examined along the diagonal until the number reaches 15. Thereafter seven paces neglected to next examination of seven or eight plants. The same procedure was repeated along the other diagonal so that the total number of examined plants was 30 and same applied to other two replicates. The number of flared squares was summed up and divided by total number of plants assessed. This gave the number of flared squares per plant to determine whether the control threshold had been reached (Mwatawala, 2010; Kabissa, 2015; Mohan *et al.,* 2014). For aphids, 20% of infested plants were randomly selected which its population ranged from 20-30 aphids per leaf. Scouting, observation and counting was facilitated by using magnified lens (Mwatawala, 2010). The proportion of insect pests composition was calculated to determine whether the control threshold had been reached (Ahmed *et al.,* 2002; Kanyeka *et al.,* 2007). During bolls splitting, number of bolls per plant, plant height, number of branches and seed cotton yield were determined and recorded (Verma *et al.,* 2017).

3.5 Data Analysis

Data collected were subjected to the ANOVA technique using SAS 9.3 software employing the following model:

$$\mathbf{Y_{ijk}=\mu+R_i+A_j+B_k+(AB)_{jk}+\varepsilon_{ijk}} \quad \ldots\ldots(2)$$

Where;

μ= the general mean,

R_i= the effect of i^{th} level of factor (replication),

A_j = the effect of j^{th} level of factor (Main plot)

B_k = effect of k^{th} level of factors B (sub plot factor),

$(AB)_{jk}$= the interaction effect between factors A & B and

ε_{ijk}= is the Experimental error (Residual error).

Then, Least Significance Difference ($LSD_{0.05}$) was done as means separation.

CHAPTER FOUR

4.0 RESULTS

4.1 Cotton Insect Pests of Maswa

The various insect pest species of cotton at different cotton crop growth stages are described in Table 2. It was clear that there were two categories of insects in the study locations, viz., insect pest and beneficial species.

However, the contribution of each insect species to the insect population were calculated and presented in Table 3, 4, and 5. The results of species composition for the three phases of cotton growth indicated variations within location (Table 3, 4, 5). In this study the dominant pest species were Aphids among locations and phases (Tables 3, 4, 5). Significant differences among locations in different phases were observed ($F_{2, 261} = 13.74$, $p < 0.0001$), ($F_{2, 362} = 10.65$, $p < 0.0001$) and ($F_{2, 426} = 147.12$, $p < 0.0001$) for phases one, two and three, respectively.

In phase one, Shanwa had higher number of species than Biza and Maswa (Table 6) while in phase two, Binza had the highest numbers of species compared to Maswa and Shanwa (Table 6). The same observation was noted for phase three whereby Biza also had higher number of species composition compared with Maswa and Shanwa (Table 6). Significant differences between species in different phases were observed ($F_{7, 261} = 80.53$, $p < 0.0001$), ($F_{10, 362} = 201.85$, $p < 0.0001$) and ($F_{12, 426} = 232.04$, $p < 0.0001$) for phase one, two and three, respectively. In all the three phases, Aphids were the most dominant insect pests followed by Ants. Other insect `species contributed less (Table 7).

Table 2: Observed cotton insect pests and beneficial species in each growth stage of cotton plant

Cotton growth stage	Pest insects	Beneficial species
Seedling emergence to first square	Aphids, Jassids, Whiteflies and Thrips	Ladybird beetles, Ants, Syrphids, Praying mantis and Spiders
Square formation to bolls formation	Aphids, American bollworm, Jassids, Cotton stainer, Whiteflies and Thrips	Ladybird beetles, Ground beetles, Ants, Syrphids. Praying Mantis, Tinichid flies, Spiders and Fungal pathogen
Bolls formation to bolls splitting	American bollworm, Aphids, Mealy bugs, Cotton stainer and Jassids,	Ladybird beetles, Ground beetles, Ants, Syrphids (Hover flies), Praying matis, Tinichid flies, Spiders**,** Fungal pathogen, Green lacewings, Damsel bugs

Table 3: Cotton insect and beneficial species abundance and composition per plant in the study sites phase one

	Shanwa Primary school		Location Maswa Girls		Binza Sec school	
Species	**Number**	**%Contribution**	**Number**	**%Contribution**	**Number**	**%Contribution**
Aphids *(Aphis gossypii)*	1371	86.44	536	81.58	559.5	67.45
Jassids (*Empoasca spp)*	98.5	6.21	2	0.30	1	0.12
Whiteflies (*Bemisia tabaci*)	16.5	1.05	0	0	0	0
Ants (*Oecophylla spp.)*	33	2.08	111	16.89	267	32.19
Ladybird beetle (*Hippodamia spp*)	16	1	5	0.76	2	0.24
Syrphids/hover flies *(Eupeodes confrater*)	21	1.32	3	0.45	0	0
Praying mantis (*Sphodromantis viridis*)	26	1.64	0	0	0	0
Spider (*Chiracanthium inclusum*)	4	0.26		0	0	0
Total	**1586**	**100**	**657**	**100**	**829.5**	**100**

Table 4: Cotton insect and beneficial species abundance and composition per plant in the study sites phase two

Species	Location Shanwa Primary School Number	 % Contribution	 Maswa Girls Number	 % Contribution	 Binza Sec School Number	 % Contribution
Aphids (*Aphis gossypii*)	1138	93.06	1745	94.72	1973	76.21
Whiteflies (*Bemisia tabaci*)	9.32	0.76	0.67	0.04	0	0
Thrips(*Thrips tabaci*)	2.34	0.19	2	0.11	0	0
Jassids (*Empoasca spp*)	27.7	2.27	3.99	0.22	1.67	0.06
American bollworm (*H. armigera*)	14.3	1.17	25	1.36	6.66	0.26
Cottonstainer(*Dysdercus sidae*)	1	0.08	3	0.16	0	0
Ladybird beetle(*Hippodamia spp*)	8.3	0.68	43.9	2.38	1.32	0.05
Ants (*Oecophylla* spp.)	15.6	1.28	10.7	0.58	595	22.98
Syrphids/hover flies (*Eupeodes confrater*)	6.33	0.52	4.66	0.25	7.65	0.30
Praying mantis (*Sphodromantis viridis)*	0	0	3.32	0.18	1.65	0.06
Spider(*Chiracanthium inclusum)*	0	0	0	0	2	0.08
Total	**1222.89**	**100**	**1842.24**	**100**	**2588.95**	**100**

Table 5: Cotton insect and beneficial species abundance and composition per plant in the study sites phase three

Species	Location Shanwa Primary school Number	 %contribution	 Maswa Girls Number	 %Contribution	 Binza Sec School Number	 %Contribution
Aphids (*Aphis gossypii*)	197.4	76.10	218.9	80.80	1235	88.95
American bollworm (*H. armigera*)	5.41	2.09	8.96	3.31	4.08	0.29
Cottonstainer (*Dysdercus sidae*)	5.98	2.31	0.99	0.37	0.11	0.01
Jassids (*Empoasca spp)*	3.3	1.27	0.33	0.12	0.33	0.03
Mealy bugs (*Phenacoccus solenopsis*)	4.99	1.92	0	0	9.34	0.67
Ants (Oecophylla spp.)	1.44	0.56	0.33	0.12	108	7.78
Ladybird beetle(*Hippodamia spp*)	5.3	2.04	5.74	2.12	2.64	0.19
Fungal pathogen (*Neozygites fresenii*)	24.6	5.27	21.56	7.96	8.98	0.65
Syrphids /hover flies(*Eupeodes confrater*)	10.63	4.10	13.66	5.04	18.9	1.36
Spider (*Chiracanthium inclusum*)	0.11	0.04	0	0	0.33	0.02
Green lacewing (*Chrysopa spp*.)	0.22	0.08	0	0	0.33	0.02
Damsel bugs (*Nabis spp*.)	0	0	0.33	0.12	0	0
Praying mantis (*Sphodromantis viridis*)	0	0	0.11	0.04	0.33	0.02
Total	**259.38**	**100**	**270.91**	**100**	**1388.37**	**100**

Table 6: Effect of location and growth stage of cotton on insect species abundance

Location	Phase one	Phase two	Phase three
Shanwa	8.13^{a}	4.70^{b}	0.46^{b}
Binza	4.32^{b}	8.58^{a}	4.12^{a}
Maswa	2.49^{b}	5.28^{b}	0.59^{b}

*Means with the same latter(s) within columns and rows are not significantly differently

Species	Phase one	Phase two	Phase three
Aphids (*Aphis gossypii* Glover)	32.8^{a}	58.25^{a}	19.76^{a}
Ants (*Oecophylla spp.)*	5.18^{b}	8.36^{b}	1.16^{b}
Jassids *Empoasca spp)*	0.75^{c}	0.24^{c}	0.06^{c}
Praying mantis *Sphodromantis viridis* **(**Forskal)	0.50^{c}	0.02^{c}	0.01^{c}
Syrphids *Eupeodes confrater* (Wiedemann)	0.19^{c}	0.14^{c}	0.35^{bc}
Ladybird beetle *Hippodamia spp*	0.17^{c}	0.34^{c}	0.16^{c}
White flies *Bemisia tabaci* (Genn.)	0.14^{c}	0.12^{c}	0^{c}
Spider (*Chiracanthium inclusum*)	0.11^{c}	0.07^{c}	0.00^{c}
American bollworm *Helicoverpa armigera* (Hubner)	0^{c}	0.46^{c}	0.21^{bc}
Thrips *Thrips tabaci (*Lindeman**)**	0^{c}	0.05^{c}	0^{c}
Cotton stainer (*Dysdercus sidae* (Herrich-Schaeffer)	0^{c}	0.02^{c}	0.68^{c}
Fungal pathogen (*Neozygites fresenii* Nowakowski*)*	0^{c}	0^{c}	0.57^{bc}
Mealy bugs *Phenacoccus solenopsis* (Tinsley).	0^{c}	0^{c}	0.03^{c}
Damsel bugs (*Nabis spp.*)	0^{c}	0^{c}	0.01^{c}
Green lacewings *Chrysoperla carnea (*Stephens)	0^{c}	0^{c}	0.01^{c}
P-Value	0.0001	0.0001	0.0001

Table 7: Number of species in different phases

*Means with the same latter(s) within columns and rows are not significantly differently

4.2 Effect of Insecticides Used on Insect Pests Composition

4.2.1 Effects of insecticides on the abundance of insect pests and predators associated with the cotton plant at different cotton growth stages

Population of insects was significantly different from emergence to square formation ($p < 0.0001$) and from flowering to boll formation ($p < 0.01$). From boll formation to boll splitting of cotton no significant effects were observed among insecticides (Table 8, 9 and 10). Overall, no significant effects were observed ($p = 0.5$) among application rates at all cotton growth stages (Table 8, 9 and 10). However, significant effects ($p < 0.0001$) were observed on insect numbers in different species across the later cotton growth stages. Significant effects ($p < 0.0001$) were also observed on the interactions among treatments and pest species before and after insecticides application (Table 8, 9 and 10).

From seedling emergence to square formation growth stage, significant effects due to chemical application was observed over the sampling days where in which all chemicals used potentially controlled the insect (Fig. 2a). However, from flowering to boll formation, only Confidor and Thunder performed better when compared to no chemical application (Fig. 2b). Between boll formation and boll splitting, chemical application there were no effects throughout the sampling period (Fig. 2c).

Across the sampling time, aphids were dominant in all cotton growth stage sampled followed by ants (Table 11, 12, 13). However, the number of insects was low between boll formation and boll splitting when beneficial species increased. These tend to eat insect pests compared with the period from seedling emergence to square formation and during flowering to boll formation of cotton growth stage.

Table 8: Effects of insecticides rates and pest insects on the abundance of insect pests and predators associated with cotton plant for phase one

		Mean squares			
Source	**Df**	**Phase one**			
		0-day	**1-day**	**3-day**	**7-day**
Location	2	216.97***	80.83	153.46	254.67
Insecticides	3	11.2	287.28***	296.61**	504.65**
Rate	2	11.87	0.17	27.27	42.94
Insecticides *Rate	6	12.34	1.6	13.34	11.84
species	7	3101.48***	570.8***	605.44***	1440.38***
Insecticides*species	21	15.21	205.52***	206.23***	374.32***
Rate*species	14	7.48	2.08	15.26	30.76
Insecticides*Rate*species	42	5.99	4.03	15.85	15.87
Experimental Error	190	19.97	19.42	41.86	80.39
Total	**287**	**287**	**287**	**287**	**287**

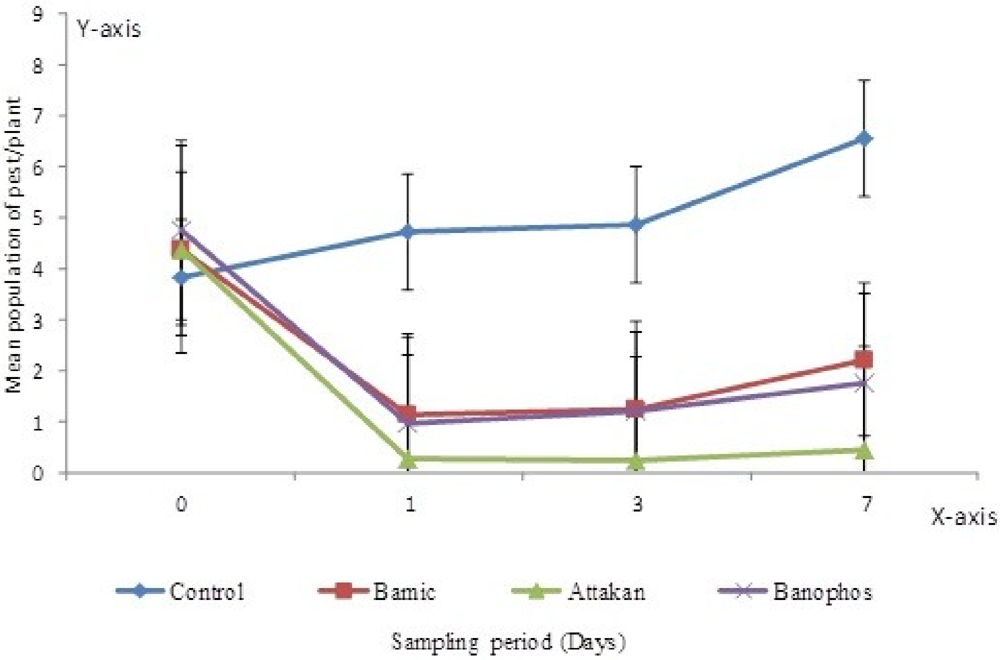
Table 9: Effects of insecticides rates and pest insects on the abundance of insect pests and predators associated with cotton plant for phase two

Source	Df	Mean squares Phase two 0-day	1-day	3-day	7-day
Location	2	472.46**	82.01	222.21	218.03
Insecticides	3	99.33	576.56***	748.82***	958.66***
Rate	2	29.20	30.55	17.68	14.83
Insecticides t*Rate	6	15.77	13.63	21.60	26.96
species	10	6835.46***	2579.05***	2511.65***	3422.70***
Insecticides *Species	30	53.05	439.13***	533.15***	687.64****
Rate* Species	20	22.39	25.74	12.68	9.15
Insecticides*Rate*Species	60	11.52	11.82	31.38	33.01
Experimental Error	262	58.73	31.65	51.73	43.53
Total	**391**		**395**	**395**	**395**

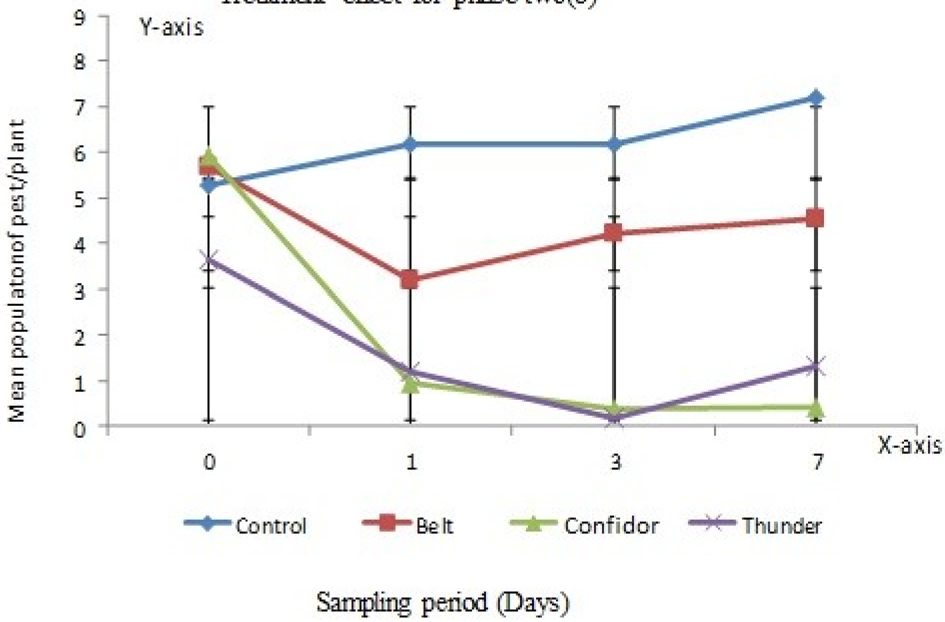
Table 10: Effects of insecticides rates and pest insects on the abundance of insect pests and predators associated with cotton plant for phase three

Source	Df	Mean squares Phase three 0-day	1-day	3-day	7-day
Location	2	370.90	100.92	100.37	138.92
Insecticides	3	95.98	32.36	23.08	43.07
Rate	2	9.95	4.72	3.67	4.96
Insecticide*Rate	6	8.77	2.17	1.06	1.75
species	12	740.58***	207.29***	203.69***	367.68***
Insecticides*Species	36	51.42	27.13**	19.43*	33.11*
Rate*Species	24	8.45	4.61	3.39	4.47
Insecticides*Rate*Species	72	8.07	1.86	1.00	1.36
Experimental Error	310	41.66	14.82	12.32	17.77
Total	**467**		**467**	**467**	**467**

Treatment effect for phase one(a)



Treatment effect for phase two(b)



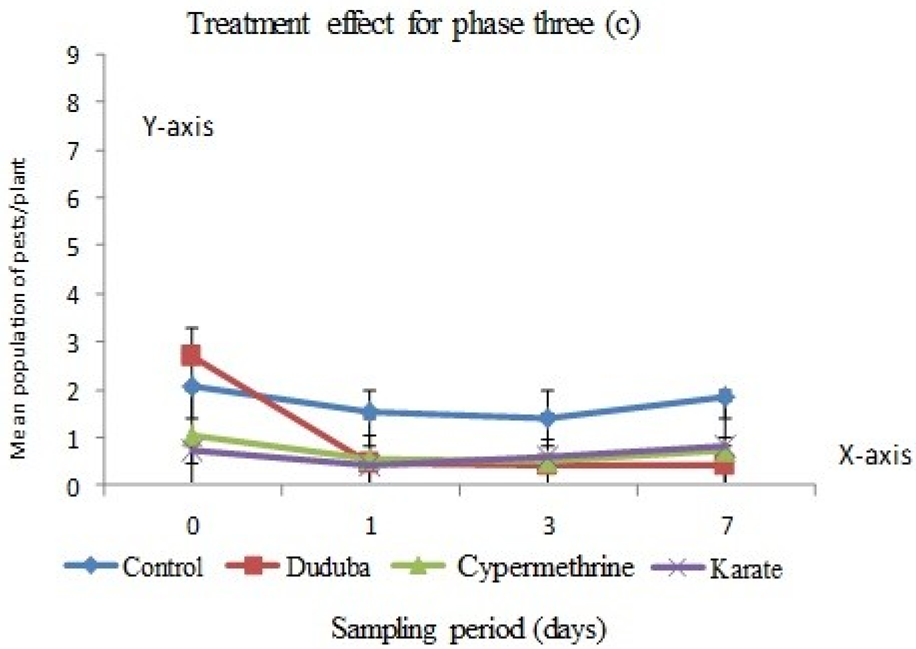


Figure 2: Effects of insecticides on mean number of insects in different application phases

4.2.2 Effect of insecticide application rates on insect pests at different cotton growth stages

Table 11: Effect of insecticides application rate on insect pests of cotton during phase one

		Day before application	Days after chemical application		
		0	**1**	**3**	**7**
B-Insecticides rate	0.8	4.75[a]	1.74[a]	2.1[a]	3.11[a]
	1	4.15[a]	1.82[a]	2.28[a]	3.13[a]
	1.2	4.12[a]	1.75[a]	1.28[a]	1.96[a]
	LSD $_{0.05}$	**1.27**	**1.25**	**1.84**	**2.55**
C- Insect species					
	Aphids	26.9[a]	11.52[a]	11.87[a]	18.29[a]
	Ants	5.23[b]	1.72[b]	2.28[b]	2.18[b]
	Jassids	1.47[c]	0.54[b]	0.36[b]	0.44[b]
	Whiteflies	0.56[c]	0.25[b]	0.04[b]	0.08[b]
	Ladybird	0.33[c]	0.06[b]	0.22[b]	0.14[b]
	Mantis	0.14[c]	0.03[b]	0.17[b]	0.19[b]
	Spider	0.08[c]	0.03[b]	0[b]	0.06[b]
	Syrphids	0[c]	0[b]	0.17[b]	0.47[b]
	LSD $_{0.05}$	**2.08**	**2.05**	**3.01**	**4.17**

* Means with the same latter(s) within columns and rows are not significantly differently

Table 12: Effect of insecticide application rate on insect pests of cotton during phase two

		Days before application	Days after chemical application		
		0	1	3	7
B Insecticides rate	0.8	5.65[a]	3.36[a]	3.1[a]	3.74[a]
	1	4.90[a]	2.88[a]	3.15[a]	3.27[a]
	1.2	4.82[a]	2.39[a]	2.5[a]	3.09[a]
	LSD $_{0.05}$	**1.36**	**1.36**	**1.74**	**1.6**
C Insect species					
	Aphids	58.25[a]	28.29[a]	27.96[a]	32.61[a]
	Ants	8.36[b]	2.6[b]	5.11[b]	3.43[b]
	Jassids	0.24[c]	0.14[b]	0.28[b]	0.32[c]
	American boll worm	0.46[c]	0.16[b]	0.23[b]	0.07[c]
	Whiteflies	0.12[c]	0.01[b]	0.03[b]	0.02[c]
	Ladybird beetle	0.34[c]	0.28[b]	0.28[b]	0.36[c]
	Praying Mantis	0.02[c]	0[b]	0.03[b]	0.01[c]
	Spider	0.07[c]	0.07[b]	0.03[b]	0.02[c]
	Syrphids	0.14[c]	0.06[b]	0.1[b]	0.17[c]
	Cotton stainer	0.02[c]	0.02[b]	0.03[b]	0[c]
	Thrips	0.05[c]	0[b]	0.05[b]	0.07[c]
	LSD $_{0.05}$	**3.41**	**2.61**	**3.34**	**3.06**

*Means with the same latter(s) within columns and rows are not significantly differently

Table 13: Effect of insecticide application rate on insect pests of cotton during phase three

		Day before application	Days after chemical application		
		0	1	3	7
B Insecticides rate	0.8	1.34[a]	0.87[a]	0.86[a]	1.07[a]
	1	1.82[a]	0.81[a]	0.74[a]	1.05[a]
	1.2	1.72[a]	0.55[a]	0.56[a]	0.75[a]
	LSD $_{0.05}$	**1.44**	**0.86**	**0.78**	**0.94**
C Insect species					
	Aphids	16.54[a]	8.72[a]	8.63[a]	1.59[a]
	Ants	2.65[b]	0.14[b]	0.05[b]	0.20[b]
	Fungal pathogen	0.54[b]	0.35[b]	0.32[b]	0.26[b]
	Syrphids	0.46[b]	0.18[b]	0.14[b]	0.19[b]
	American bollworm	0.34[b]	0.09[b]	0.05[b]	0.04[b]
	Ladybird beetle	0.21[b]	0.04[b]	0.04[b]	0.09[b]
	Cotton stainer	0.2[b]	0[b]	0[b]	0[b]
	Mealy bugs	0.17[b]	0.12[b]	0.08[b]	0.03[b]
	Jassids	0.02[b]	0.02[b]	0.03[b]	0.03[b]
	Spider	0[b]	0[b]	0[b]	0[b]
	Praying Mantis	0[b]	0[b]	0[b]	0[b]
	Green lacewing	0[b]	0[b]	0[b]	0[b]
	Damsel bug	0[b]	0[b]	0[b]	0[b]
	LSD $_{0.05}$	**2.99**	**1.79**	**1.63**	**1.96**

*Means with the same latter(s) within columns and rows are not significantly differently.

4.3 Effects of Economic Threshold of Insect Pests on Yield components of seed cotton

Across sampling times, insecticides significantly affected plant height (p=0.03) while replication, rate and insecticides interactions were not significant (Table 14). The combination of all insecticides were not statistically significantly different among yield parameters between insecticides and rates, also not statistically significant different throughout the sampling periods (Table 15). The partial correlations of plant height were highly significantly different among number of plant sympodia with yield and number of bolls per plant with yield ($p < 0.0001$). The numbers of plant sympodia with number of bolls per plant and boll weight with yield were significantly different ($p < 0 .01$). Plant height with number of bolls per plant and plant height with yield were significantly different (p=0.04). However, there were no significant correlation between plant height and number of sympondia (Table 16).

Table 14: Mean squares corresponding to various sources of variation for seed cotton yield

source	df	Plant height (cm)	No. sympodia	No. bolls per plant	Boll weight (g)	Yield (tha^{-1})
Replication	2	3200.33	167.98	889.84	3.22	80.82
Insecticides	3	578.16*	8.84	43.01	0.17	1.33
Rate	2	242.66	4.46	34.06	0.31	1.92
Insect x Rate	6	35.89	6.99	29.69	0.38	3.67
Error	22	152.85	5.59	41.55	0.3	4.45
Total	**35**					

Table 15: Mean squares corresponding to various sources of variation for seed cotton yield

FactorA-Insecticides rate	Plant height(cm)	No. Sympodia	No. Bolls Per plant	Boll weight	Yield(tha^{-1})
0.8	107.53	15.61	28.68	4.94	7.17
1	107.69	15.86	28.77	5.13	7.61
1.2	99.82	16.77	25.81	5.25	6.81
LSD$_{0.05}$	10.47	2	5.46	4.46	1.79
Factor B-Insecticides					
Control	94.86	15.43	24.96	5.08	6.67
Bamic, Belt and Duduba	102.78	15.09	27.70	5.3	7.35
Banophos, Confidor and Cypermethrin	109.22	16.59	28.0.4	5.08	7.18
Attakan, Thunder and Karate	113.20	17.21	30.3	4.97	7.58

Table 16: Partial correlation coefficients for investigated variables

	1	2	3	4	5
1. Plant height (cm)	1	0.59	0.49*	0.1	0.42*
2. Number of Plant sympodia		1	0.62**	0.46*	0.72***
3. Number of Bolls per plant			1	0.1	0.88***
4. Boll weight (g)				1	0.53**
5. Yield (tha^{-1})					1

CHAPTER FIVE

5.0 DISCUSSION

The results showed significant variations among the three different locations in the terms of insect pest abundance and its composition in the three phases. Phase one, Shanwa had higher number of aphids due to receiving more rainfall than the other location, which enabled seedlings to emerge earlier than Binza and Maswa locations. The later did not receive rainfall to allow beginning of germination (Tomar, 2010; Kabissa, 2015; Kumar *et al.*, 2017b). During this period cotton plant are in juvenile stage (leaves are juicy and succulents), which offers maximum food and good habitat for aphids and other sucking pests causing high reproduction rate (Amin *et al.*, 2008).

In later growing stages both phase two and three, Binza had higher insect pests' abundance due to agricultural practices being surrounded by trees, which create micro climate and provides shield effects and probably leads to high relative humidity. The high relative humidity allowed aphids to reproduce faster than in low humidity areas. These results are supported by the findings of Tomar (2010); Fernandes *et al. (*2013); Han *et al.* (2014); Kerns *et al.* (2015); Kumar *et al.* (2017b) they noted that aphids appeared to be positively correlated with decreasing temperature and increasing leaf moisture. In addition, a similar result has been reported by Lusana *et al. (*2019) of having high abundance of aphids.

Denholm and Devine (2013) reported that indiscriminate application of organophosphates (dicrotophos, oxydemeton-methyl and chlorpyrifos), pyrethroids (cypermethrin, lambacyhalothrin, deltemethrin and fenverelate) and other insecticides, instead of controlling cotton aphid populations, increases their reproductive potential. Pyrethroid insecticides influences cotton secondary metabolites and make the plant more attractive to aphid pests (Asrorov *et al.*, 2013; 2014).

In the current study, abundance of aphids increase in cotton after treatment with insecticides which explained with the effectiveness of insecticides to cotton beneficial species which causes lowering populations of predators and their activities (Amin *et al*., 2008; Sánchez-Bayo *et al.*, 2013; Abudulai *et al.*, 2018b), the increased level of sugars, especially monosaccharide and oligosaccharides in leaves and other vegetative and generative organs (Asrorov *et al.*, 2014). The other reason for the increased level of insects is expected to be the lower activity of Pathogenesis Related (PR) proteins having insecticidal property such as chitinase and glucanase. Chitinase and Pathogenesis Related-1, 3-glucanase, the main enzymes degrading chitin - the exoskeleton of insects and fungal and bacterial cell wall, induce in pathological conditions, which are considered a part of the multiple defense systems of plants (Bronner *et al.*, 1991; Walling, 2000; Asrorov *et al.*, 2014). Peroxidases are key enzymes in lignifications and hypersensitive responses in plants. However, lowered activity of chitinase and peroxidase, defensive PR proteins against not only insects but also microbes, may cause infection by fungi and bacteria (Asrorov *et al.*, 2014).

Female cotton aphids are able to reproduce both with and without mating. When environmental conditions are favourable females that haven't mated will give birth to live nymphs (Fernandes *et al.*, 2013; Wilson *et al.*, 2013). However, insects with high reproductive potential have higher chances of developing resistance to insecticides compared to those of low potential. As it applies to cotton aphid, their high reproductive potential complements their capacity for resurgence after application of especially for effective insecticide (Mallet and Luttrell, 1991; Kaleem *et al*., 2014).

In the current study, ants were s major insect although were also beneficial insect in a cotton cropping system. When cotton leaves were juicy and succulent, the predators' populations were low to consume aphids while number of ants was high to support aphids to reproduce fast (Leite *et al.,* 2007; Solangi *et al.,* 2008; Mrosso *et al.,* 2013; Mrosso *et al.,* 2014). Populations were more severe due to low stand density of cotton plant which was caused by late and unreliable rainfall (Rummel *et al.,* 1995). The low stand of cotton plants resulted from increasing mortality of developing American boll worm and boll weevils by direct exposure to or of enhancing the effectiveness of indigenous natural enemies. Ant are important predators of American bollworm by preying on caterpillars hence low population densities when compare to Shanwa and Maswa girl where the number of ants were low (Nyambo, 1988; Boyd *et al.,* 2004).

Also, Binza was highly populated with ants than other beneficial species compared to Shanwa and Maswa, which attracted honeydew as a predictable, renewable food resource and, consequently, accompany honeydew-producing aphids species, protecting them from predators and parasitoids (Kaplan and Eubanks, 2002; Styrsky and Eubanks, 2006; Offenberg, 2015; Singh *et al.,* 2016). For example, some aphid species alter their feeding behavior and the composition of their honeydew (e.g. by increasing the concentrations of amino acids) at the expense of their own growth and fecundity (Slosser *et al.,* 2004; Styrsky and Eubanks, 2006). Presence of tending ants and persistent honeydew removal by ants allows aphids to attain maximal feeding rates, improving nutrient uptake and assimilation, without the threat of host plant contamination. Ants can further benefit aphids by removing sticky honeydew and fungal-infected aphid cadavers, which would otherwise support fungal growth, leading to reduced aphid survival (Nielsen *et al.,* 2009; Singh *et al.,* 2016). Ants had positive impact on agricultural systems by rapidly consuming large numbers of pest insects, disturbing pests during feeding and oviposition, and increasing soil quality and nutrients (Chaote and Drummond, 2011).

The population dynamics of aphids can be affected by seasonal changes in weather conditions, physiological characteristics of the host plant, such as leaf position on plant canopy, plant age, leaf area and trichomes, natural enemies, farming methods, and management practices (Leite *et al.,* 2007; Kaleem *et al*., 2014; Offenberg, 2015; Yang *et al.,* 2017; Fernandes *et al.,* 2018). UKM-08 variety was hairy-leaf which aphids preferred and smooth-leaf varieties offer some resistance to populations of cotton aphid (Allen *et al.,* 2018). Effective suppression of aphid populations by natural enemies appears to occur despite a high incidence of predator attacks on parasitoid offspring developing within mummified aphids and the action of hyperparasites at phase two where syrphids and fungal pathogen emerged (Rosenheim *et al.,* 1997).

However, increase of rainfall from flowering stage to boll formation lead to lower population of aphids per plant probably due to splashing away aphids from cotton leaves (Tomar, 2010; Fernandes *et al.,* 2013; Han *et al.,* 2014; Kerns *et al.,* 2015**;** Kumar *et al.,* 2017b). Bhan and Kharbanda (2004) reported that as cotton is an indeterminate plant, higher rainfall and moderate temperatures during vegetative and early reproductive stages lead to excessive growth of the crop and makes the crop more succulent. The excessive growth of the crop creates a favourable microclimate for rapid multiplication of the pest and also increasing the succulence of the crop making it more susceptible to infestation.

Generally, at phase three, some of the insect pests disappeared, such as thrips and white flies while mealy bugs appeared on cotton crops. Disappearance of thrips and white flies were common due to early-season pests of cotton and its peak numbers usually occurs early in the season and during high humidity periods (Bohmfalk *et al*., 2011; Mohan *et al.,* 2014). The disappearance may be due to application of insecticides which were rotated and mixed in mode of action also buildup of various beneficial species in phase one and two, which reduced the insect pests. The heavy rainfall that occurred during March caused undesirable cool weather for the insect pests to survive (Boyd *et al.,* 2004; Luo *et al*., 2014; Mrosso *et al.,* 2013; Mrosso *et al.,* 2014; Siebert *et al.,* 2016; Amera *et al.,* 2017; Kaur *et al.,* 2017; Li *et al.,* 2018).

Mealy bugs as the secondary pests appeared after application of pyrethroid insecticide at phase three of which induced killing of most of the beneficial species (Siebert *et al.,* 2016; Amera *et al.,* 2017; Li *et al.,* 2018). The appearances of Mealy bugs comply with previous study by Gutierrez *et al.* (2015). The study found that, the use of pesticides to solve pest problems promised short-run economic benefit but instead led farmers onto path dependency that increases system complexity by inducing pest outbreaks (iatrogenic effects) that may cause crop losses (idiopathic effects) and increase costs. Heavy infestation of cotton mealy bugs may have resulted from the absence of natural enemies. The insecticides provide high efficiency against pest control but it may cause resistance in some insects. Cotton Mealy bugs due to high reproductive capacities and multiple generations (15) per year are potentially capable of becoming resistant to insecticides on consistent exposures (Noureen *et al.,* 2016). Mealy bugs are known to bribe ants with their sugary secretion (honeydew) and in return ants help in spreading mealy bugs and provide protection from predator, ladybird beetle, parasitoids and other natural enemies. Ant tending facilitates population growth of hemipterans, not only by reducing predation and parasitism from other natural enemies, but also by reducing the risk of fungal infection (Tanwar *et al.*, 2007; Zhou *et al.,* 2014).

Insecticides were applied early in the morning due to most cotton insect pest were seen easily on leaves and were not hidden to escape predator and direct sunlight also they idle due to dews which developed during night so they cannot fly and been contacted easily by insecticides. Also during morning Cotton plant stomata are opened to allow systemic insecticides to enter and translocate throughout the whole plant tissue making them toxic to any insects. All rates of insecticides used were not statistically significant different to insect pests reduction and increases of cotton seed productivity. The best efficacies of insecticides were Attakan in phase one, Confidor and Thunder in phase two and Duduba in phase three in all rates. The insecticides Attakan, Confidor and Thunder each has two active ingredients that combine systemic and contact activity. These properties give the insecticides excellent efficacy against insect pests, particularly bollworms that feed on and within cotton squares and bolls. The apparent selectivity of the insecticides to predators may be due to less contact of the predators to the insecticides or because most predators do not feed on plants (Abudulai *et al.*, 2018a).

All these Attakan, Confidor and Thunder insecticides are composed of imidacloprid which caused highest decrease of insect pests' population. Results from this study concur well with previous findings by Abudallah *et al.* (2002); Aslam *et al.* (2004); Asi *et al*. (2008); El-Wakeil *et al.* (2013); Sánchez-Bayo *et al.* (2013); Mrosso *et al.* (2013); Mrosso *et al.* (2014); Simon-Delso *et al.* (2015); Asif *et al*. (2016); El-Bassouiny (2017); Sahito *et al*. (2017) and Shah *et al*. (2017b) that Confidor is translocated throughout the plant tissues making them toxic to any insects (and potentially other organisms) that feed upon the plant regardless of manner of application and route of entry to the plant. This protects the plant from direct damage by herbivorous (mainly sap feeding) insects and indirectly from damage by plant viruses that are transmitted by insects (become distributed throughout the plant, including the apices of new vegetation growth, making them particularly effective against sucking pests, both above ground and below. Therefore, application of systemic insecticides according to threshold level might uphold appositive impact to control of sucking and chewing pests of cotton (Amin *et al.,* 2008).

Duduba gave best results for the control of both bollworm and sucking pest complex because it contained cypermethrin and chlorpyrifos. Cypermethrin is among the pyrethroids which effect ion permeability across the axon i.e. axonic poisons. Pyrethroids affect both peripheral and central nervous systems of the insect pests. They initially stimulate nerve cells to produce repetitive discharges and eventually cause paralysis while Chlorpyrifos which are organo-phosphates they attach themselves at the active site of cholkine esterase, thus preventing its function of rapid removal and destruction of acetylcholine (Mwatawala, 2010). Thus acetylcholine accumulates in the gap and blocks the transmission of impulses resulting into rapid twitching of animal's muscles, paralysis and eventually death (Mwatawala, 2010). Similar observation were reported by Alavo, (2006) who stated that a combination of a pyrethroid and an organophosphate for the control of bollworms and other members of the pest complex to enhance the effectiveness. The mixture of insecticides such as attakan, confidor, thunder and duduba, and rotation of insecticides is the best way of management of pests' abundance (Gayi *et al.,* 2016).

The plots treated with combination of Banophos, Confidor and Cypermethrin and Attakan, Thunder and Karate treatment had significantly higher plant heights than the control and those treated with combination of Bamic, Belt and Duduba. The low efficacy of Bamic and Belt applied at early stage of cotton growth to targeted insect pests leads to high population of insect pests which attacked growing tips and caused stunting and other physiology abnormalities of plant. The current results concurs the studies done by Rosenheim *et al.* (1997); Jones (2004); Kaleem *et al*. (2014); El-Bassouiny (2017). The study reported that cotton plants which were heavily infested with cotton aphids were shorter, and had fewer main stem nodes and bolls than plants with low densities of insect pests.

The number of aphids in the current study was lower from boll formation to boll splitting compared with seedling emergence to square formation growth stage and flowering to bolls formation due to buildup of various beneficial species, which attacked insect pests. This was caused by late application of pyrethroid where beneficial fauna increased (House *et al.,* 1985; Jones, 2004; Wilson *et al.,* 2013; Luo *et al*., 2014; Mrosso *et al.,* 2013; Mrosso *et al.,* 2014; Siebert *et al.,* 2016; Amera *et al.,* 2017; Li *et al.,* 2018). Predation by natural enemies can achieved the same efficacy in aphid control as pesticides used in, but that predation does not prevent outbreaks of *A. gossypii* in some years (Lu *et al.,* 2014). The reductions in abundance of insect pests and protection of natural enemies may mitigate crop yield loss and pest control expenditures in cotton production (Offenberg, 2015; Sarwar and Sattar, 2016). During boll formation there were heavy rainfalls which lead to lower aphid population per plant by splashing away.

Based on Economic threshold (ET), dominant insect pests at phase one were Aphids while in both phases two and three were Aphids and American bollworm, which was determined in order to initiate control measures which lead to increases in seed cotton production per area. ET rationalizes the use of insecticides, which result in managing attributes of yield, such as bolls per plant, number of sympodia branches and boll weight per plant, which are an indication of high potential of cotton crop for high production of seed cotton. These are considered to be the boll bearing branches as reported by Ahmed *et al.* (2002); Ganesan and Raveendran (2010); Shazia *et al.* (2010); Pires *et al.* (2014) and Kumar *et al.* (2017a)**.** It gives base of insecticides on when the first spray take place, while provides chance for natural enemies to develop and then lower the number of sprays and consequently reduce the cost of production (Nyambo, 1989; Ahmed *et al.,* 2002).

However, the current study shows that cotton yield did not differ among treatment due to higher number of aphids (i.e with 20% of effected plants) and American bollworm (with 50% infected plants). This is due to the fact that the number of cotton insect pests from randomly selected plants in natural environment can be influenced by numerous biotic and abiotic factors, including insecticide use and destruction of natural enemies, and other environmental conditions (Ahmed *et al.,* 2002; Kerns *et al.,* 2015; Da Graça *et al.,* 2016).

Protection of cotton crop from sucking insect pests at early growth stage is very important because it is a proven fact that good crop stand at initial stage results in greater production (Abudallah *et al.,* 2002). Crops with low boll numbers can have higher boll weights as there is less fruit to share around the plants resources. First position bolls are usually heavier than second position bolls and those of vegetative branches also due to the fact that some cotton plants are self-pollinating, but others need pollinators to help the process and lead to increased cotton production (Pires *et al.,* 2014; Cusser *et al.,* 2016).

Yield was not significantly different among chemical applied treatment due to weekly interval of scouting and rapid increases of insect population, which lead to failure to adhere properly to economic threshold of species composition. Similar results were reported by Basri *et al.* (1988), stated that outbreaks of bagworm and nettle caterpillar are usually sporadic and localized. Effective control methods are available, but effective control can only be achieved if one can identify the insect pests, understand the life cycle of the insect and time of the control with the vulnerable periods of the pest (Cheong and Tey, 2012).

This study, also, concurs well with the findings by Gayi *et al.* (2016) who observed that yields of unsprayed control plots within sprayed trials may be greater, or less than the yields, which would have been obtained from larger plots of unsprayed cotton. This is probably because removal of the barrier and closeness between control and treated plots after application of pesticides may drift inside the control plots thus behaving as if chemicals have been applied. The cotton plants were able to compensate the damage inflicted to it by sucking pests (Nyambo, 1985; 1988; 1989; Sahito *et al*., 2016). The high seed cotton yield was positive and significant correlated with plant height, sympodia, boll number and boll weight. Compensatory response could increase in fruit set, number of fruiting sites, setting of heavier fruits, and increased rate of late flowering hence increasing seed cotton yield per area (Rosenheim *et al.*, 1997; Barman and Parajulee, 2013).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In conclusion, the results from the present studies showed that a dominant insect pest in all growing stages of cotton was Aphids. This was followed by Ants which were beneficial insects. Spraying of insecticides were applied top and bottom of leaves during morning from 7: 30 am to 10:00 am. All the insecticides and rates of application tested decreased cotton insect pests densities and boll damage, resulting in increased seed cotton yield when compared with control. Attakan, Confidor, Thunder and Duduba were highly effective against sucking insect pests of cotton. Any contact insecticides should be applied first and last cotton growth stages (from seedlings emergence to first flare square and boll formation to boll splitting) due to most of insect pests composition were not hidden in plant parts such as; bolls, flare square and flowers. American bollworm which attack crop at flare square formation to boll formation they feed on and in the reproductive structure of cotton plant, systemic insecticides should be used. All the insecticides rates were potentially effective but to reduce cost of production and allow beneficial insects to build up, rate of 0.8 ml/ℓ (the actual recommended rate by manufacturer mined by 0.2) should be used as preventive measures of cotton insect pest.

Based on Economic threshold, dominant insect pests were Aphids (20% of infested plants) and American bollworm (0.5 flared squares per plant) which was determined in order to initiate control measures which leads to increases in seed cotton production per area. Economic threshold rationalizes the use of insecticides to overcome inappropriate choices of insecticides, wrong timing of application, poor dosages and limited knowledge on scouting pests and decision making largely contribute to ineffectiveness of insecticides.

However, indiscriminate, inadequate and improper use of pesticides can lead to severe problems such as development of pest resistance, resurgence of target species, and outbreak of secondary pests, destruction of beneficial insects, as well as health hazards and environmental pollution.

6.2 Recommendations

The current study recommends the following:

1. Rotation of insecticide groups in order to lower insect pest abundance. For example, pyrethroids should be avoided in the cotton flowering stage and broad spectrum pesticides (replaced by environmental friendly insecticides such as Attakan, confidor and Thunder so that there is minimal disruption to the beneficial parasitoids and predators also to avoid the potential upsurge of secondary pests such as Mites, Mealy bugs, Aphids and Whitefly).

2. To conduct further studies on Economic Threshold concept and simplify Integrated Pests Management technology to fit societies of Maswa district where the agricultural and socio-economic conditions represent major constraints (small-scale farmers, poor infrastructure, unstable economy, lack of financial resources, farmer’s illiteracy).

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APPENDIX

Appendix 1: Abundance and composition of cotton insect species in the Western Cotton Growing Area (WCGA) in Tanzania.