STUDIES ON BIOLOGICAL CONTROL OF FALL ARMYWORM,

Spodoptera frugiperda **(J.E. Smith) ATTACKING MAIZE IN EASTERN**

CENTRAL, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE

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EXTENDED ABSTRACT

Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) was reported for the first time in Africa in 2016 from America. FAW is widely distributed in Tanzania, causing significant damage to maize. Two factor, cropping systems and biopesticides were tested in Randomized Completely Block Design arranged in a two - way factorial experiment with three replications for their efficacy against FAW and associated parasitoids on maize field at Crop Museum of Sokoine University of Agriculture (SUA). Cropping systems tested included maize sole crop, maize + cowpea, and maize + desmodium and napier grass (push pull system). Biopesticides tested included *Metarhizium anisopliae* and *Beauveria bassiana.* The insecticide flubendamide was applied as a positive control, between August 2018 - December 2018 and December 2018 - March 2019 cropping seasons. In the laboratory sampled FAW egg masses and larvae were reared, emerged parasitoids were recorded. Three species of parasitoids (*Chelonus bifoveolatus, Coccygidium luteum* and *Cotesia* sp) were recovered. Results showed that *C. bifoveolatus* was mostly dominant parasitoids. However, highest parasitism rates were in *Cotesia* sp in push pull plots treated with *M. anisapliae* in season 1 and 2 (13.7% ± 0.14 and 14.5% ± 0.17) respectively. Abundance of parasitoids was significantly affected by cropping systems ($p < 0.01$) and sampling weeks ($p < 0.001$ for season 1 and $p < 0.01$ for season 2) and percept damaged maize plants by FAW was significantly affected by cropping systems ($p < 0.001$) pesticides ($p < 0.001$) and cropping systems x pesticides application ($p < 0.01$). Furthermore, highest maize grain yields and cost benefit ratio were estimated in push pull and cowpea + maize cropping systems compared to sole maize. These results prove that, biological control are effective and involves conservation of natural enemies for sustainable control of FAW.

DECLARATION

I, **MWANJIA HASSANI NGANGAMBE**, do hereby declare to neither the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

This work is dedicated to my beloved parents Late Mr. Ngangambe H. and Mrs. Karumbe H. who laid the foundation of my education. And my lovely husband Abdullah Mohamed Mkiga and my sons Dhakiy Abdullah Mkiga and Anwar Abdullah Mkiga for their support and understanding. I will always love them.

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LIST OF ABREVIATIONS AND SYMBOLS

^0C	Degree Centigrade
ANOVA	Analysis of Variance
CABI	The Centre for Agriculture and Bioscience International
cm	Centimeter
CV	Coefficient of variance
	Database
DKC	Delkab Maize Variety from Mosanto seed Company
EPFs	Entomopathogenic fungi
FAO	Food and Agriculture Organization
FAOSTAT	The Food and Agriculture Organization Corporate Statistical
FAW	Fall armyworm
H	Hour
HSD	Honestly Significantly Difference
IITA	International Institute of Tropical Agriculture
IPM	Integrated Pest Management
Kg	Kilogram
m^2	Meter Square
mm	Millimeter
RCBD	Randomized Complete Block Design
SUA	Sokoine University of Agriculture
USA	United States of America
USAID	The United States Agency for International Development
USD	The United States dollar

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Maize (Zea *mays* L.) is one of the important cereals grown in most countries of the world (Okan *et al*., 2004). Maize is a source of food, feed and biofuel. It is also the important cereal food crop in sub - Saharan Africa (Rehman, 2006). The crop is staple food for about 1.2 billion people (Suleiman *et al*., 2015). Maize accounts for over 30 % of lower - house income and contributes to 60 % of dietary calories and 50 % of protein intake (IITA 2009). According to Seth *et al*. (2011) the crop grows well on a range of soils, but does best on deep, well drained, fertile soils that are slightly acid to neutral, pH 5.5 to 7.0. Maize crop is among the major and most preferred staple foods and cash crops in Tanzania (Suleiman *et al.,* 2015). Over two million hectares of maize are planted per year with average yields of 1.2 –1.6 tons per hectare. Maize accounts for 31% of the total food production and constitutes more than 75% of the cereal consumption in Tanzania (Seth *et al*., 2011).

Despite its economic and nutritional importance, *Z. mays* are attacked by plethora of insect pests and diseases. Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) is among the major pests of *Z. mays* (FAO, 2017). FAW was reported for the first time in African in early 2016; it has spread to southern Africa in late 2016 and by early 2017 was confirmed to be in East Africa (Kabede, 2018). The pest is highly polyphagous with a host range of almost 100 plant species in 27 families (Midega *et al*., 2018). The pest prefers to feed on gramineous plants. On maize for example the larvae feed on young leaf whorls, ears and tassels causing substantial damage which can result to total yield loss (De Almeida Sarmento *et al.,* 2002). The pest causes considerable economic losses on *Z. mays* in all growth stages (Molina - Ochoa *et al*., 2003). Depending on the degree of infestation, the

FAW can cause huge losses in maize yields and in some cases, total crop loss (Kumar, 2002). In Africa for example, maize yield losses due to *S. frugiperda* ranges from 8.3 to 20.6 m tonnes per annum, in the absence of any control methods (Kabede, 2018). Use of pesticides and hand picking are the ongoing controlling attempts. However, the efficiency of these pesticides is low resulting into high financial losses to farmers, for example – 108 375 litre insecticide (940 221 USD) used in Ethiopia, 40 000 lire (1 600 000 USD) in Kenya and 15 000 litres (450 000 USD) in Tanzania to control fall armyworm (Abrahams, 2017). Excessive use of pesticides causes pest outbreaks to occur due to insecticide resistance (Hemingway *et al.*, 2003).

1.2 Justification

Studies on determination of parasitoids species that could suppress FAW previously conducted in Ethiopia, Kenya and Eastern Central Tanzania (Sisay *et al.,* 2018). However there is still inadequate information on effects of entomopathogenic fungi (EPFs) and cropping systems on parasitoids of FAW. The information is fundamentals on developing effective control measures of FAW.

The use of biological based packages on the control of FAW has been reported (Prassana *et al.,* 2018). However, there is inadequate information on the use of intercropping systems and EPFs in the integrated methods for FAW suppression on maize. EPFs have benefits in ecofriendly pest management. EPFs can degrade, penetrate, and assimilate the insect cuticle using a combination of cuticle - degrading enzymes and mechanical pressure while overcoming any stresses encountered along the way (Ortiz and Keyhani, 2013). Upon reaching the hemocoel, the fungi quickly multiply by successfully competing for nutrients and suppressing host immunity. Furthermore, EPFs used as classical bio control agents that persist in the environment and recycle through pest populations (Hajek, McManus, and Delalibera, 2007; Hajek and Tobin, 2011). Push pull uses a combination of behaviormodifying stimuli to manipulate the distribution and abundance of insect pests and the pests are repelled away from the main crop (push) and simultaneously attracted (pull) by using highly apparent and attractive stimuli, to other areas such as trap crops where they are concentrated, hence facilitating their control (Khan *et al*., 2008). Cover crop use is based on the principle of reducing insect pests by increasing the diversity of an ecosystem which can affect the microclimate of the agro ecosystem and ultimately produce an unfavourable environment for pest (Srinivasa Rao *et al*., 2012).

However, there is limited information of efficacy of *Beauveria bassiana* (Balsamo) and *Metarhizium anisopliae* (Metsch.) on the control of FAW. Little is known on efficacy of combination of EPFs and cropping systems on the control of FAW. Also little is known on effects of EPFs and cropping systems on parasitoids of FAW on maize field especially Morogoro Tanzania. Good bio control based packages protect the crop from economic injury while minimizing negative impacts on people, animals, and the environment (FAO, 2017). Therefore, studies on finding these information gaps remained important for sustainable management of the pest.

1.3 Objectives

1.3.1 Over roll objective

To reduce maize losses due to FAW in small holder farming practices.

1.3.2 Specific objectives

i. To evaluate effects of EPFs and cropping systems on parasitoids of FAW on maize in Eastern Central, Tanzania.
ii. To test bio control based packages against FAW on maize crop in Eastern Central, Tanzania.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize Production

Maize (*Zea mays* ssp. mays) originated in Mexico and in Central America (Matsuoka *et al*., 2002). Maize cultivated as staple food and as cash crops in Tanzania, it is the most important economic activity for the majority of the population (Suleiman *et al.,* 2015) .It is the major and most preferred staple crop, more than half of cultivated land in Tanzania is allocated to cereal crops (FAO, 2017). Around 45 % or over 4.9 million hectares are used for maize production (Pauw and Thurlow, 2011). A national yield varies between 1.0 and 1 .5 metric tons per hectare, compared to the estimated potential yields of 4 - 5 metric tons per hectare (Suleiman *et al.*, 2015). Overall maize production has grown at an annual rate of 4.6 % over last 25 years.

2.2 Botany of Maize

Maize (*Zea mays* L.) is a cereal crop belonging to the Poaceae (Gramineae) family, which ranks the third place among the most important crops based on harvested area and production (Ion, 2015). It is a tall, determinate, monoecious, annual plant. Maize produces large, narrow, opposite leaves, borne alternatively along the length of stem. It has determinate growth habit and the shoot terminates into the inflorescences bearing staminate or pistillate flowers (Matsuoka *et al*., 2002). Each stalk produces ears and each maize plant contains both male and female reproductive organs. The tassels, the terminal flowers, ordinarily develop only male spikelets which grow in pairs with one being sessile, having no stalk, and the other pedicellate, and a single blossom on a leaf stalk. Each tassel contains some twenty - five million pollen grains (Ion, 2015). The lateral organ or female inflorescence is the ear. Each ear of corn contains upwards of one thousand potential kernels. The ears also bear spikelet with only one of the flowers developing. Each of these flowers has one ovary “terminated by a long style known as the silk and kernels that develop as a result of the pollination of the silk are firmly attached to the solid core of the ear, the cob (Hasanudin *et al*., 2012).

2.3 Geographical Distribution of Maize

Maize is cultivated throughout the world. From 58°N latitude to 40°S latitude, the crop spreads and is cultivated on over 139 million ha of area and around 600 million tons of maize are produced (Jones *et al*., 2003). Maize occupies the third position next to rice, *Oryza sativa* L. and wheat, *Triticum aestivum* L. in area under production. USA, China, Brazil, Mexico, India, Romania, Philippines, Indonesia are some of important countries that cultivate maize crop (Lobell *et al*., 2007).

2.3.1 Requirement of maize

According to lobell *et al*. (2007). Maize require deep, fertile soil, rich in organic matter and well drained soils, the soil should be medium textured with good water holding capacity. Also it requires 9°C to 30°C from planting to emergence, emergence to silking, leaf number increases with temperature and photoperiod, and maximum rate of maize growth is at 30°C. Longer the grain filling period, higher the grain yield provided no freezing temperature. Higher the solar radiation, higher will be the photosynthesis in maize (Jones *et al*., 2003).

2.3.2 Yield and harvest maturity indices for maize

Maize can take from 60 to 100 days to reach harvest depending on variety and the amount of heat during the growing season (Ion, 2015). At physiological maturity Sheath covering the cob will turn yellow and dry (Chung *et al*., 2010). The seeds become fairly hard and dry (Ejeta, 2007). Five tons of grain yields can be obtained per hectare (Donath, 2014).

2.3.4 Economic importance

Maize is a staple human food, a feed for livestock, and used for fermentation and many industrial uses. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Farmers consume maize in a wide variety of ways such as porridges and beer. Green maize, fresh on the cob, is eaten roasted or boiled separately or mixed with legumes (Enyisi, 2014). The oil present in corn (rich in embryo) is far and wide used for cooking and manufacture of soaps. Sticky gum from maize contains dextrin used for sealing envelopes and labels. Corn starch is well recognized for its uses in cosmetics and pharmaceutical industries as diluents. Corn seeds are used to make stem fibers for manufacture of paper (Chung *et al*., 2010).

2.3.5 Constraints to production

Despite of its importance, the average maize yields for small-holder farmers is only about 1- 2 metric tons per hectare compared to the estimated potential yield of 4 - 5 metric tons per hector (Enyisi, 2014). Poor yield is due to a range of factors. Insect pests and diseases are among the factor (Mariote, 2007). Maize is attacked by many insect pests during all stages of growth from seedling to storage (Shiferaw *et al.*, 2011). According to Suleiman *et al.*, 2015) insects are responsible for 15-100 % of the pre-harvest losses of grains in developing countries.

2.2 The Fall Armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith)

2.2.1 Description of life history and types of damage

The life cycle is completed in about 30 days during the summer, but 60 days in the spring and autumn, and 80 to 90 days during the winter (Capinera, 2001). The pests undergo complete metamorphosis consisting of four stages which are egg, larva, pupa and adult.

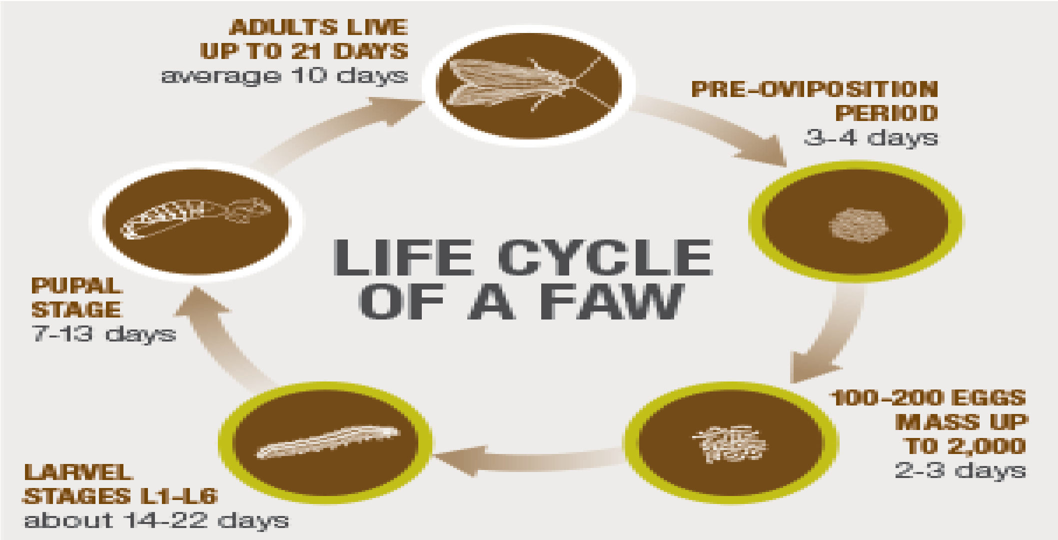

Figure 1: The life cycle of the FAW

Source: https://www.syngentaseedcare.com/news/pests/march-fall-armyworm site visited on 12/5/2018

Egg

The egg is, dome shaped: the base is flattened and curves upward to a broadly rounded point at the apex. It measures about 0.4 mm in diameter and 0.3 mm in height (Prassana *et al*., 2018). Eggs are laid in masses on leaves, mostly on the underside and on stems. Also, the egg is cream - coloured, green or brown but the whitish colour of the hair covers is easily observed on the green leaves and measures about 0.4 mm in diameter and 0.3 mm in height (Murúa and Virla, 2004).

Figure 2: Egg mass of the FAW

Source: http://entnemdept.ufl.edu/creatures/field/fall_armyworm.htm site visited on 3/4/2018

Larva

Larva usually has six instars in fall armyworm. Head capsule widths are about 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm, respectively, for instars 1– 6. Larvae attain lengths of about 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm, respectively, during these instars (Murúa, and Virla 2004). Young larvae are greenish with a black head, the head turning orangish in the second instar. In the second, but particularly the third instar, the dorsal surface of the body becomes brownish, and lateral white lines begin to form (Batista - Pereira *et al*., 2002). In the fourth to the sixth instars, the head is reddish brown, mottled with white, and the brownish body bears white sub dorsal and lateral lines. Elevated spots occur dorsally on the body; they are usually dark in color, and bear spines. The face of the mature larva is also marked with a white inverted Y. Duration of the larval stage tends to be about 14 days during the summer and 30 days during cool weather (Capinera, 2001).

 

Figure 3: Newly hatched and mature larva of the FAW

Source: http://entnemdept.ufl.edu/creatures/field/fall_armyworm.htm site visited on 3/4/2018

Figure 4: Head capsule of FAW showing light-colored inverted "Y" on front of head

Source: http://entnemdept.ufl.edu/creatures/field/fall_armyworm.htm site visited on 3/4/2018

Pupa

The pupa is reddish brown in color, and measures 14 to 18 mm in length and about 4.5 mm in width. Pupation normally takes place in the soil, at a depth 2 to 8 cm (Murúa and Virla, 2004). The larva constructs a loose cocoon, oval in shape and 20 to 30 mm in length, by tying together particles of soil with silk. If the soil is too hard, larvae may web together leaf debris and other material to form a cocoon on the soil surface. Duration of the pupal stage is about eight to nine days during the summer, but reaches 20 to 30 days during the winter (Abrahams, 2017).

Figure 5: FAW pupa (left) and FAW pupa in the soil (right).
Source: http://entnemdept.ufl.edu/creatures/field/fall_armyworm.htm site visited on 3/4/2018

Adult

The moths have a wingspan of 32 to 40 mm. In the male moth, the forewing generally is shaded gray and brown, with triangular white spots at the tip and near the center of the wing (Capinera, 2001). The forewings of females are less distinctly marked, ranging from a uniform grayish brown to a fine mottling of gray and brown. The hind wing is iridescent silver-white with a narrow dark border in both sexes. Adults are nocturnal, and are most active during warm, humid evenings (Prassana *et al.*, 2018). After a pre-oviposition period of three to four days, the female normally deposits most of her eggs during the first four to five days of life, but some oviposition occurs for up to three weeks. Duration of adult life is estimated to average about 10 days, with a range of about seven to 21 days (Murúa and Virla, 2004).

Figure 6: Adult male FAW (left) and Adult female FAW (Right)

Source: http://entnemdept.ufl.edu/creatures/field/fall_armyworm.htm site visited on 3/4/2018

2.2.2 Distribution of FAW

According to Capinera (2001) the fall armyworm is native to the tropical regions of the western hemisphere from the United States to Argentina. It normally overwinters successfully in the United States only in southern Florida and southern Texas. The fall armyworm is a strong flier, and disperses long distances annually during the summer months. It is recorded from virtually all states east of the Rocky Mountains. However, as a regular and serious pest, its range tends to be mostly the southeastern states. In 2016 it was reported for the first time in West and Central Africa (Sao Tome and Principe, Nigeria, Benin and Togo) and in late 2016 and 2017 in Angola, Botswana, Burundi, Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Namibia, Niger, Rwanda, Sierra Leone, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe, and it is expected to move further (FAO, 2017).

2.2.3 Host range of FAW

The FAW has a very wide host range, with over 80 plants recorded, but clearly prefers grasses. The most frequently consumed plants in the field are -; maize (*Zea mays*), sorghum (*Sorghum bicolor* (L.)), cotton (*Gossypium* sp), clover (*Trifolium repens* L.), oat (*Avena sativa* L.), millet (*Panicum miliaceum* L), peanut (*Arachis hypogaea* L.), rice

(*Oryza sativa* L.), sugar beet (*Beta vulgaris* L.), soybean (*Glycine max* (L.)), sugarcane (*Saccharum officinarum* L.), tobacco (*Nicotiana tabacum* L.), and wheat (*Triticum aestivum* L.). Among vegetable crops, only sweet maize is regularly damaged, but others are attacked occasionally. Other crops sometimes injured are apple (*Malus domestica* Borkh), grape (*Vitis vinifera* L.), orange (*Citrus reticulate* Blanco), papaya (*Carica papaya* L), peach (*Prunus persica* (L.), strawberry (*Fragaria ananassa*), and a number of flowers. Weeds known to serve as hosts include bent grass, (*Agrostis* spp), crabgrass (*Digitaria* spp), Johnson grass (*Sorghum halepense* L.), morning glory (*Ipomoea* spp),nutsedge (Cyperus spp), pigweed (*Amaranthus* spp) and sandspur (*Cenchrus tribuloides* L.) (Abrahams *et al*., 2017).

2.3 Management Measures Used in FAW in Area of Origin

Control has been with synthetic pesticides; however, this method is inefficient and causes chronic poisoning to growers due to incorrect use (Rios - Velasco *et al*., 2011). These were: chlorantraniliprole (Coragen 200 SC), spinetoram (Radiant 120 SC), agro - thoate 40% EC (Dimethoate 40%), spinosad (Tracer 480 SC), lambda-cyhalothrin (Karate 5 EC), Malathion 50% EC, chlorantrniliprole + lambda-cyhalothrin (Ampligo 150 SC), and Imidacloprid (Sisay, 2019).

2.4 Common Native Biological Control Agent of FAW

2.4.1 Natural enemies of FAW in native area

Almost twenty two species of natural enemies have been reported in various parts in the origin area of FAW (Rios -Velasco *et al*., 2011). Parasitoids such as -: *Pristomerus spinator* Fabricius , *Campoletis flavicincta* Ashmead, *Ophion flavidus* Brulle, *Chelonus insularis* Cresson , *Meteorus laphygmae* Viereck, *Aleiodes laphygmae* Viereck (formerly Rogas laphygmae), *Cotesia marginiventris* Cresson and *Euplectrus platyhypenae* Howard

(Ruíz - Nájera *et al*., 2007). Entomopathogenic fungi like *Nomuraea rileyi* (Farl.) *and Beuveria bassiana* together with nucleopoly - hedrovirus group (NPV) were found, with large number of parasitism in parasitoids compared to other natural enemies found (Rios - Velasco *et al*., 2011).

2.5 Biological Control of FAW

Biological control agents are organisms that feed on FAW, and can be active during all development phases of insect, reduce the FAW populations and hence the damage they caused. It is performance depends on factors, such as agronomic practices and pest management methods (Abrahams *et al*., 2017). There are many natural enemies of FAW like; Parasitoids (*Telenomus remus* Nixon, *Chelonus insularis* Cresson, *Cotesia marginiventris* Cresson, *Trichogramma* spp., *Archytas*, *Winthemia* and *Lespesia*), Predators (*Doru luteipes* (Scudder) , *Cycloneda sanguinea* (Linnaeus), *Calosoma granulatum* Perty and Zelus spp) and Entomopathogens (Viruses such as Nuclear Polyhedrosis Virus (NPVs), Fungi (*Metarhizium anisopliae Metarhizium riley* and *Beauveria bassian)* and bacteria such as the *Bacillus surigensis* , Nematodes and Protozoa (Prassana *et al*., 2018).

2.5.1 Parasitoids

Parasitoids are an important biological tool used widely in agriculture for the suppression of various pest species (Werren *et al*., 2010). It is an insect that kills (parasitises) its host usually another insect in order to complete its lifecycle (Jervis *et al*., 2016).

2.5.1.1 How insect parasitoids works

Insect parasitoids are smaller than their host and are specialized in choice of host. Only the female searches for hosts and usually destroy their hosts during development. Different parasitoid species attack at different life stages of the host (Jervis *et al*., 2016). Eggs are usually laid in, on, or near the host. The immature stages remain on or in the host and almost always kill the host (Stireman *et al.*, 2006). Adult parasitoids are free-living, mobile, and may be predaceous. With respect to population dynamics, parasitoids are similar to predatory insects (Feener and Brown, 1997). Parasitoids attack either by penetrating the body wall and laying eggs inside the host or attaching eggs to the outer body surface. The immature parasitoid develops on or within the host, consumes all or most of the host's body fluid, and pupates either within or external to the host, the adult parasitoids emerge from pupae and start the next generation afresh by actively searching for a host to oviposit (Brodeur and Boivin, 2004). Parasitism is found in at least five insect orders: Hymenoptera, Diptera, Coleoptera, Lepidoptera, and Neuroptera but the most common parasitoids that have been used in Bio control are from the insect orders Hymenoptera and, to a lesser degree, Diptera because they are the only holometabolous and haplodiploids parasitoids (Stireman *et al*., 2006).

2.5.1.2 Hymenoptera and diptera parasitoids

2.5.1.3 Hymenoptera parasitoids

Hymenopteran parasitoids account for nearly 78% of the estimated number of species and served as models of choice for nearly all recent research on insect parasitoids (Stucky, 2015). Hymenoptera are the only Holometabola that retained the primitive lepsimatid form of ovipositor and associated accessory glands (Delfín - González *et al*., 2007). Possession of this ovipositor gives female hymenopteran parasitoids direct access to concealed hosts and small hosts such as eggs or early stage larvae that are not directly accessible to parasitoids in other groups (Stucky, 2015). However, venom produced in the modified accessory glands allows hymenopteran parasitoids to subdue large active hosts and manipulate the behavior and physiology of hosts in favor of their progeny (Ruíz -Nájera *et al*., 2007). Furthermore, only hymenopteran parasitoids are haplo diploid. Such a sex-determining system gives females' control over the sex ratio of their progeny, permitting them both to match the sex of their progeny to the size of the host and to reduce the intensity of local mate competition in mixed-sex clutches (Marchiori *et al*., 2017).

2.5.1.4 Diptera parasitoids

This order includes an estimated 16 000 described species of parasitoids, or about 20% of The known species have parasitic life-style (Stucky, 2015). The structures like piercing ovipositors and respiratory funnels as well as behaviors like planidiform first instar larvae and phonotaxic host location and the distinctive host-parasitoid interactions associated with the parasitoid life-style (Marchiori *et al*., 2017). However, all species of parasitoids in Diptera and hymenoptera the egg parasitoids are considered the most important among the agents of biological control. These species prevent the pest from causing any damage to the host plant compared to larva and pupa parasitoids (Abrahams *et al*., 2017).

Table 1: Parasitoids recovered from the FAW in West, Central and East Africa

Scientific name and family	Description	Occurrence	Photograph
FAW Parasitoids Egg Parasitoids			
Trichogramma pretiosum (Riley) (Trichogrammatidae)	Trichogramma species are very small insects, with dimensions <1 mm. • T. pretiosum is used in the control of eggs of FAW and Helicoverpa spp.	West Africa	 **Source:** http://www.nbair.res.in/Biocontrol_Agents/Insects/Trichogramma%20pretiosum.htm site visited on 22/8/2018
Telenomus remus (Nixon) (Hymenoptera:Scelionidae)	Measures 0.5-0.6 mm in length and has a black, shiny body. Presents high specificity for FAW. Each female parasitizes more than 250 eggs during its lifespan. The total development period from egg placement to adult emergence is 10 days	East/West Africa	  **Source:** https://www.revolvy.com/page/Telenomus site visited on 24/9/2018
Egg-Larval Parasitoids			
Chelonus insularis Cresson (Hymenoptera:Braconidae)	Measures about 20 mm in wingspan. A very competitive parasitoid, usually predominant in maize filds. 91% of natural parasitism found in maize field samples was due to *C. insularis.*	West/CentraAfrica	  **Source:** https://www.ecured.cu/Chelonus_insularis_Cresson site visited on 24/9/2018

Larval Parasitoids			
Campoletis flavicincta (Hymenoptera: Ichneumonidae)	The insect wingspan is about 15 mm. Parasitizing initial instars larvae of the fall armyworm Spodoptera frugiperda (Smith) (Lepidoptera: Noctuidae), (Neto *et al*., 2018).	East/West Africa	 **Source**: http://beta.boldsystems.org/index.php/Taxbrowser_Taxonpage?taxid=390956 site visited on 5/11/2018
Coccygidium luteum (Brullé) (Hymenoptera:Braconidae)		East/West Africa	 **Source:** http://www.waspweb.org/Ichneumonoidea/Braconidae/Agathidinae/Coccygidium/Coccygidium_luteum.htm site visited on 5/11/2018
Cotesia icipe Fernández-Triana & Fiaboe (Hymenoptera:Braconidae)	Known to parasitize several species of Spodoptera in Africa, including FAW. Under laboratory conditions >50% parasitism has been observed on FAW.	**East Africa**	 **Source:** https://sites.google.com/site/insectsoftasmaniahymenoptera2/suborder-apocrita--terebrant/braconidae/genus-cotesia?overridemobile=true site visited on 05/11/2018

Larval - Pupal Parasitoids			
Archytas marmoratus (Townsend) (Diptera: Tachinidae)	A solitary larval-pupal parasitoid of several species of Noctuidae (Lepidoptera) including FAW. Has a complex life cycle that allows it to parasitize a wide range of host larval instars. • The female does not lay the eggs directly on the host, but rather places several of them nearby.		 **Source:** https://en.wikipedia.org/wiki/Archytas_(fly) site visited on 22/8/2018
Lespesia archippivora (Riley) (Diptera: Tachinidae)l	A generalist parasitoid capable of parasitizing at least 25 species of Lepidoptera. • A female can oviposit between 15 and 204 eggs in her life span. •The female oviposits on the back end of the caterpillar.		 **Source:** http://caterpillars.myspecies.info/taxonomy/term/56495 site visited on 6/12/2018

Source: FAO (2018)

2.6 Biopesticides

2.6.1 Entomopathogenic fungi (EPFs)

A group of fungi that kills insects by attacking and infecting its host is called entomopathogenic fungi (EPF). Use of EPFs is a promising bio control agent in the regulation of insect pest population without harming the non-target insects (Lacey and Shapiro-Ilan, 2008). Over 800 species of entomopathogenic fungi and 1000 species of protozoa pathogenic have been described and identified (Faria and Wraight, 2007). Most of the commercially produced fungi are species of *Beauveria, Metarhizium* and *Lecanicillium* (Shahid *et al.*, 2012).

2.6.2 Pathogenicity mechanism and life cycle of EPFs

EPFs penetrate their cuticle to the insect body (Lacey and Shapiro - Ilan, 2008). Physical and enzymatic mechanisms help the spores penetrate the cuticle (Shahid *et al*., 2012). Spores have degrading enzymes such as proteases, esterases, lipases and chitinases which modify the host`s cuticle surface and help the spores' attachment before penetration (Khan *et al*., 2012). Once spores meet insects' cuticle they may germinate and penetrate through the cuticle depennding on environmental conditions such as moisture (Shahid *et al*., 2012) and structure of the host cuticle (Khan *et al*., 2012). After penetration, the fungus uses the host body`s nutrients for growth before multiplying rapidly causing starvation and physiological disruption leading to death (Lacey and Shapiro - Ilan, 2008). Then, the fungus emerges throughout the cuticle through the intersegment regions (Shahid *et al*., 2012). Soon after host death, and under favourable conditions, hyphae emerge from the cadaver and they produce conidiogenous cells, sporulation occurs on the host surface and the conidia are liberated (Khan *et al*., 2012). Conidial dispersal is passive, relying principally on wind but other factors, such as rain, can play a role in dissemination and causing new infection to susceptible hosts (Shahid *et al*., 2012) while other entomopathogens such as nematodes and bacteria, insect pathogenic fungi do need to be ingested to cause death to their hosts (Elghadi, 2016).

2.6.3 EPFs for insect control

EPFs have been considered as a potential bio control agent against several insect species and as a part of integrated pest management programs for several others with limited effect on non - target. According to Elghadi (2016). *Beuveria basiana* and *Mertarhizium anisopliae* are considered as safe pathogens with low impact on the environment. *Beauveria bassiana* enter the host insect's body through food or in contact with the host cuticle and reproduce inside the insect body. It produces toxins namely beauvericin, bassianocide etc. inside the host body causes paralysis of the host insects and ultimately kills the insects within four or five days (Shahid *et al*., 2012).

2.6.4 Factors influencing fungal pathogenicity

According to Bueno *et al*. (2013), there are various factors related to the insect host, pathogen and environment which have different impacts on the pathogenicity and spread of the disease. Germination, growth, the ability of insect pathogenic fungi to induce a disease and persistence depends on environmental conditions (Elghadi, 2016). For example, soil moisture, temperature and humidity are known to be important factors influencing survival and persistence of fungal pathogens (Yeo *et al*., 2003). Temperature can influence the speed and rate of the fungal infection (Shahid *et al*., 2012). Different species of entomopathogenic fungi have different responses to environmental conditions (Elghadi, 2016).

2.7 Cultural Control

2.7.1 Intercropping for insect management

Intercropping is the agronomic practice of growing two or more crops in the same field at the same time, crops may be planted without regard to rows (mixed intercropping), in alternating rows, or with different crops alternating within the same row (Smith and McSorley, 2000). It is one of the important cultural practices in pest management and is based on the principle of reducing insect pests by increasing the diversity of an ecosystem (Srinivasa Rao *et al*., 2012). However, Intercropping systems for insect pest control includes planting of a crop that has a repellent effect, an attractant effect, or a combination of the two, on a targeted insect in close proximity to a crop that has the potential to be attacked by the insect (Brion, 2015). In balanced ecosystems, insect pests are kept in check by their natural enemies. These natural pest control organisms called beneficial insects include predators and parasitoids insects (Hassanali *et al.*, 2008). Predators kill and eat other insects while parasitoids spend their larval stage inside another insect, which then dies as the invader's larval stage ends (Abate and Ampofo, 2000). However, in conventional agricultural systems, synthetic chemical treatments that kill insect pests also typically kill the natural enemies of the insects. Conserving and encouraging beneficial organisms is a key to achieving sustainable pest management (Smith and McSorley, 2000). However Plants also have the extraordinary capacity to repel or attract insects by emitting specific volatiles and can reduce by more than 80% FAW damage (Prassana *et al.*, 2018).

2.7.2 Cowpea – maize intercropping for control FAW

Cowpea (*Vigna unguiculata* L. Walp.) is a member of the Phaseoleae tribe of the Leguminosae family. It is an important staple food for millions of relatively poor people in less developed countries (Ghanbari *et al.*, 2010). The crop is the second most important food legume in tropical Africa after common bean (*Phaseolus vulgaris* L.) which is the most widely cultivated crop in Tanzania. According to Coetzee (1995) the crop is heat - loving drought tolerant crop with high protein content (22-24%) and can thrive in lower soil fertility condition than other crops of the same family. Growth forms of cowpea vary and may be erect, trailing, climbing or bushy and usually indeterminate under suitable condition.

Cowpea has been identified as an ideal cover crop for many areas (Wang *et al.*, 2006). Intercropping system of maize with cowpea decreased major insect of maize in both seasons (Srinivasa Rao *et al.*, 2012). However intercropping can increase light interception and shading as compared to sole maize and reduce water evaporation and improve conservation of soil moisture (Ghanbari *et al*., 2010). According to Hassanali *et al*. (2008) *S. frugiperda* incidence and infestation in maize was reduced by 14% and 23% respectively in intercropping. Furthermore cowpea can both produce abundant biomass and fix substantial quantities of atmospheric nitrogen (Coetzee, 1995).

2.7.3 Push pull for control of fall armyworm FAW

Push - pull cropping is combination of repellent and attractant crops can be used in an intercropping system for insect pest control, The attractant crop draws the insect in (acts as the “pull”) and the repellent crop deters the insect (acts as the “push) (Hassanali *et al*., 2008).

According to Hailu (2018) in push pull technology maize is intercropped with Silver leaf desmodium, *Desmodium uncinatum* Jacq., to repel cereal FAW moths and Napier grass, *Pennisetum purpureum* Schum, a susceptible attractant crop, is planted surrounding the plot to attract repelled FAW moths. Observations on FAW by at least 250 farmers who had adopted the climate - smart Push - pull technology in drier areas of Kenya, Uganda and Tanzania indicated reduction of FAW larvae per plant and subsequent reduction in plant damage (FAO, 2018). Further surveys on climate - smart Push - pull and monocropped maize farms indicated 82.7 percent reduction in average number of larvae per plant and 86.7 percent reduction in plant damage per plot in climate-adapted push-pull compared to maize monocrop plots. Furthermore, in one recent study conducted across East Africa, farmers who fully implemented the Push - Pull approach reduced FAW infestation and crop damage by up to 86%, with increase in yield relative to neighboring fields that did not implement the approach (Midega *et al*., 2018). However, beyond controlling FAW and other stem borer pests, push - pull has also been reported to reduce Striga infestation, increase nitrogen and soil humidity, and most importantly, provide a suitable environment for the proliferation of predators and parasitoids of FAW (Prassana *et al*., 2018). Hence, Push - pull technology appears effective in controlling FAW, with associated maize grain yield increases under the conditions tested. This technology could be immediately deployed for management of the pest in East Africa and in areas with similar conditions (Srinivasa Rao *et al*., 2012).

2.7.4 Early planting

Planting with the first effective rains has higher chances of escaping pest infestation, compared to delay planting as FAW populations build up later in the crop season (Abrahams *et al.*, 2017).

2.7.5 Plant nutrition

Proper supply of nutrients in the plant support healthy plant growth and reduces plant damage by increasing plant health and defenses against pests (Prassana *et al*., 2018).

2.7.6 Tillage

Deep tillage of the land expose FAW pupae in the soil, reduce life cycle of the pest and hence damage caused by FAW (Abrahams *et al*., 2018).

2.8 Chemical Control

2.8.1 Synthetic pesticides for FAW control

Chemical control method is the one of the most common methods used to to slow the spread of the FAW and minimize damage to maize fields. However, it becomes much difficult since the caterpillar feeds inside the whorl of the plant, which thus hinders the insecticides to penetrate through the canopy and locate the caterpillar (Bissiwi *et al*., 2016). Furthermore, sole dependence on synthetic insecticide, results in development of insecticide resistance in FAW populations as well as other adverse effects (Yu, 1991). The use of insecticides to control the fall armyworm needs to be reconsidered and integrated with other control methods.

Contact/systemic insecticides based on pyrethroids, carbamates or organophosphates are used in Africa as an immediate management measure (Sisay, 2019). Since the greatest damage usually occurs before the reproductive phase of maize, early pest detection that allows insecticide treatment of young larval stages is crucial and spraying should target the middle portions of plants leaves (apical meristem) where the pest hides and lay its eggs (Bissiwi *et al*., 2016).

According to Prassana *et al*. (2018) a treatment is indicated when fall armyworms attack 5% of seedling plants. Also during the first month after planting, if 20% of the whorls of small plants show the presence of the pest and treatment are less indicated when the plants have initiated their reproductive phase.

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CHAPTER THREE

3.0 EFFECTS OF ENTOMOPATHOGENIC FUNGI (EPFs) AND CROPPING SYSTEMS ON PARASITOIDS OF FALL ARMYWORM (*Spodoptera frugiperda)* ON MAIZE IN EASTERN CENTRAL, TANZANIA.

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3.1 Abstract

Fall army worm (FAW), *Spodoptera frugiperda* is key pest of maize in Africa including Tanzania. Field trials were conducted to determine incidence of different species of parasitoids and their rate of parasitism on selected bio control based treatments. Experiment was conducted at crop museum of Sokoine university of Agriculture, Morogoro Tanzania for two cropping seasons and arranged in Two-way factorial in Randomized Completely Block Design with three replications. The treatment combinations were push pull without application of pesticides, push pull and *Beauveria bassiana,* push pull and *Metarhizium anisopliae*, push pull and flubendamide, cowpea + maize without application of pesticides, cowpea + maize and *Beauveria bassiana*, cowpea + maize and *Metarhizium anisopliae*, cowpea + maize and flubendamide, maize sole crop without application of pesticide, maize sole and *Beauveria bassiana*, maize sole and *Metarhizium anisopliae*, maize sole and flubendamide. Results showed that one species of egg-larva parasitoids (*Chelonus bifoveolatus*) and two species of larva parasitoids (*Coccygidium luteum* and *Cotesia* sp) were recovered from sampled fall army worm eggs and larvae. Percent parasitism of *C. bifoveolatus* and *C. luteum* differed significantly among intercropping systems (*P* < 0.05). Results also showed percent larval parasitism of *Cotesia* sp differed significantly (*p* < 0 .05 among cropping systems only. These results confirm biological control of fall army worm through conservation of natural enemies in Tanzania.

Keywords: Intercropping, *Metarhizium anisopliae*, *Beauveria bassiana*, flubendamide, *Chelonus bifoveolatus*, *Coccygidium luteum* and *Cotesia* sp.

3.2 Introduction

Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) is a highly polyphagous, migratory species that can colonize over 80 different plant species (Capinera, 2005; Goergen *et al*., 2016). The pest attacks maize (*Zea mays* L.) and other crops such as alfalfa (*Medicago sativa* L.), soya bean [*Glycine max* (L.) Merr.], Sorghum [*Sorghum bicolor* (L.) Moench] (Bohnenblust, 2016; Hailu *et al*., 2018) cotton, *(Gossypium hirsutum* L.) and other diverse pasture grasses (Virla and Murua, 2004; FAO, 2017). The pest causes considerable economic losses on *Z. mays* at all growth stages (Molina-Ochoa *et al*., 2003). Depending on the degree of infestation, FAW can cause huge losses in maize yields and in some cases, total crop loss can be recorded (Kumar, 2002). The caterpillars feeds on all stages of the maize plant by consuming foliage and mostly prefer the young plants (Bissiwu *et al*., 2016). Rows of perforations are produced in the leaves due to the feeding done in the whorls of the plant and sometimes this can lead to extensive defoliation and a reduction in the growth potential of the plant (Capinera, 2005). In heavy infestations, the caterpillars burrow into the maize ear through the husk, feed on the kernel and reduce quality of the crop (Bissiwu *et al*., 2016). The use of pesticide is an on - going controlling attempt. However, the efficiency of these pesticides is low resulting to high financial losses to farmers (Abrahams *et al*., 2017) and resistance (Hemingway *et al*., 2003). Parasitoids readily attack larval and adult stages of FAW and have the potential of reducing the FAW populations as well as the damage caused by FAW (Bianchi *et al*., 2006). Different species of hymenopteran parasitoids from the families Ichneumonidae, Braconidae and Eulophidae were recorded. Dipteran parasitoids in the family Tachinidae are also reported to be important natural enemies of FAW (Ruiz - Najera *et al*., 2007; Molina - Ochoa *et al*., 2003). In other hands, parasitoids can be highly effective at little or no cost, serve as biotic insecticides in place of chemicals, and provide long-term control without the target pest developing significant resistance to them (Stary and Pike, 1999). However, occurrence and parasitism rate of FAW larval parasitoids varies considerably between localities, regions, crop practices, plant stage, and years (Ruíz-Nájera *et al*., 2013). Push pull performed best in reducing FAW infestation over all the phonological stages of maize (Midega *et al*., 2018). Also intercropping of maize with leguminous crops provided significant reduction of FAW compared to mono-cropped maize, especially in the early growth phases of the maize up to tasseling (Hailu *et al*., 2018). Furthermore, intercrops during flowering provide ample nectar, pollen, and shelter for the resident parasitoids and protect them by providing shelter to the native parasitoids during insecticidal sprays in the main crop. This provides an added advantage of favorable microclimate for the population build - up of parasitoids (Rogers *et al.*, 2017).

FAW is also attacked by Entomopathogenic Fungi (EPFs) that cause significant mortalities (Sisay, 2018). EPFs have the potential use as biological control agents against insect pests because they are relatively safe on non - target insects, such as natural enemies (Thungrabeab and Tongma, 2007). Therefore, the use of cover crops, EPFs and push pull are based on the principle of reducing insect pests by increasing the diversity of an ecosystem which can affect the microclimate of the agro ecosystem and ultimately produce an unfavorable environment for pest (Srinivasa Rao *et al*., 2012). Several studies have been conducted assessing effect of parasitoids on FAW suppression (Molina-Ochoa *et al*., 2001; Neto *et al*., 2004; Delfín-González *et al*., 2007; Ordóñez-García *et al*., 2015). However, there is inadequate information on the use of cropping systems and EPFs for FAW suppression and their parasitoids on maize. Hence this study aimed at cataloging species of FAW parasitoids and their rate of parasitism under different maize cropping systems and EPFs applications.

3.3 Material and Methods

3.3.1 Location

Experiments were conducted in Morogoro (Central- East Tanzania) at crop Museum of Sokoine University of Agriculture (SUA). The site is located at longitude of 37^0 39' east and latitude 6^0 50' south. The place is at the altitude of about 525 m above sea level. The location experiences the sub - humid tropical type of climate and it experiences the temperature moderation effects due to the effects of the Uluguru Mountains. The site is dominated by sandy loam soil with pH of 5.16 and has bimodal rainfall pattern where short rains (Vuli) start from October to December and long rain (Masika) start from March and ends in May (Msanya *et al.,* 2003). The annual rainfall in this area ranges from 750 to 1050 mm with an average of 900 mm. The temperatures of the area vary depending on the season.

3.3.2 Experimental design and treatment application

The study was conducted in a factorial experiment (Gomez, 1972) based on randomized complete block design (RCBD) with three replications. The experiments tested the effects of two experimental factors, intercropping and biopesticides on parasitism rate of FAW predators. Two intercropping systems were tested. One system consisted of maize (Delkab variety (DKC 9089) from monsato company) intercropped with cowpea (Fahari variety from Ilonga research institute) at a spacing of 75cm by 30 cm and 75 cm x 20 cm respectively. While another was a push-pull system consisted of maize intercropped with Silverleaf desmodium, *Desmodium uncinatum* Jacq., at a spacing of 75 cm by 30 cm and 75cm by 37.5cm respectively, and surrounded by Napier grass, *Pennisetum purpureum* Schum, at a spacing of 90 cm by 60 cm . Standard agronomic practices for the crops were adopted. Maize sole crop at a spacing of 75 by 30 was used as control. Plot size was 3 m x 3 m with a space of 2 m between plots and space of 1 m between replication. Total experimental area was 780 m^2. Two commercial biopesticides were tested, Real IPM Mazao Prevail [*Beauveria bassiana* (Balsamo) Vuillemin, 1 x 10^7 cfu/ml] and Real IPM Mazao Tickoff [*Metarhizium anisopliae (*Metsch.) Sorokin, 1 x 10^7 cfu/ml] at application rates of 200ml/ha (Average 10ml in 16L sprayer) for both biopesticides. A Synthetic insecticide Belt® (flubendiamide 480 Sc, Bayer Crop Science, Germany) applied at the of 40ml/ha (Average of 4ml in 20L sprayer) was used as positive control while untreated plots were negative controls. A total of 12 treatment combinations were tested.

3.3.3 Egg masses and larval sampling

FAW eggs and larvae were sampled beginning 19 days from the date of planting and continued until the start of the reproductive stage (R1) (Murúa *et al.,* 2006) for each plot. Eggs were reared following the protocol described by Adamczyk *et al.* (1998). Sampling period lasted after six weeks. In each treatment 10 maize plants were randomly selected. Each plant was then visually checked for the presence of FAW egg masses and larvae then counted. The data from all selected plants were summed for all sampling weeks, then divided by the total number of weeks and expressed as average larva density per week in each treatment. Collected sample from each treatment were placed in a rectangular plastic ventilated container of 25 cm by 15 cm dimension, covered on top with fine screen from which the parasitoids could not go through the mesh, containing a piece of fresh maize leaf which were replaced every 48 hours until pupation (Sisay *et al.,* 2018). Egg masses and larvae were kept in the laboratory until the parasitoids had emerged. The eggs were observed twice a day while larvae were observed at daily basis for parasitoid emergence. Emerged parasitoids were identified using key presented by Prassana *et al.* (2018). Percent of parasitism was calculated by dividing number of parasitoids by total number of eggs/larvae collected multiplied by 100 (Sisay, 2018).

3.3.4 Identification of parasitoids

Recovered parasitoids were identified by Dr. Lakpo Koku B. A. Agboyi of Center for Agriculture and Biodiversity International (CABI, Ghana office) using morphological features.

3.4 Statistical Analysis

Percentage parasitized eggs were tested through two-way Analysis of Variance (ANOVA) with cropping system (3 levels: maize-push pull, maize-cowpea, maize sole) and pesticide application (4 levels: *B. bassiana*, *M. anisopliae*, flubendamide and unsprayed control) as fixed factors. In another case, percentage parasitism was tested through one-way ANOVA with cropping system as fixed factor. Arcsine transformation was applied for both egg and larval parasitism proportions after failing to satisfy the ANOVA assumptions of normality. Data normality was confirmed by performing Shapiro-Wilk tests on each variable. While temporal number of parasitoids was analysed by using logistic linear mixed model with intercept slope using ‘glmer’ function from lme4 package to test interaction effect between treatments and sampling week. All Means were separated using Tukey’s HSD test at $\alpha = 0.05$ and all statistical analyses were performed using R-version 3.2.5.

3.5 Results

3.5.1 Total number of parasitoids

Table 2 show total number parasitoids collected across all treatments. *Chelonus bifoveolatus* Szépligeti was the only egg parasitoids recovered (Table 2). Results further showed that *Coccygidium luteum* (Brullé) was the most abundant larval parasitoid followed by *Cotesia* sp in both cropping seasons.

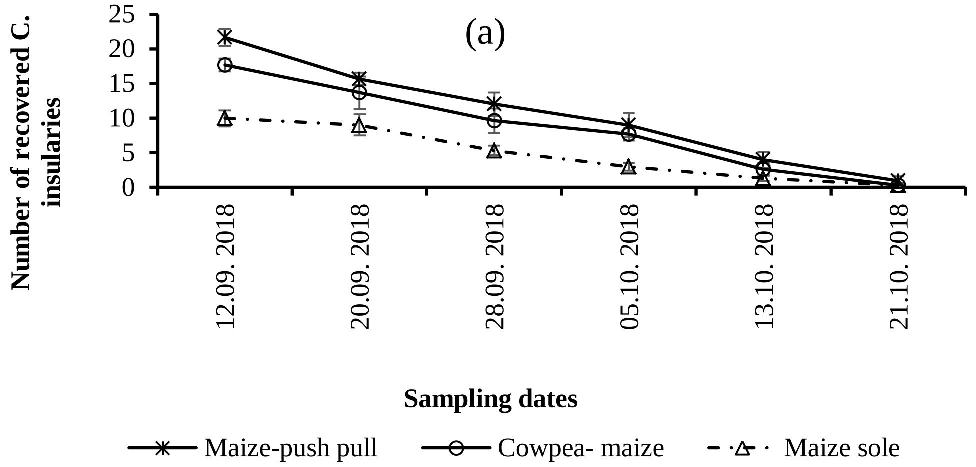
Table 2: Shows Total number of parasitoids collected across all treatments

S/n	Parasitoids	Host stage attacked	Season 1 Number of parasitoids	Season 1 Percent of total number of parasitoids	Season 2 Number of parasitoids	Season 2 Percent of total number of parasitoids
1	*C. bifoveolatus*	Egg and Larva	547	75.34	780	75.36
2	*C.luteum*	Larva	117	16.12	167	16.14
3	*Cotesia* sp	Larva	62	8.54	88	8.50
	Total		726	100	1035	100

3.5.2 Temporal variation in number of parasitoids

3.5.2.1 Temporal variation in number of *C. bifoveolatus*

Results showed, during both seasons, highest numbers of parasitoids were in the 1 and 2 week than 3, 4, 5 and 6 week in the push pull plots followed by cowpea-maize and sole maize plots (Figure 7 (a) and (b)) respectively.



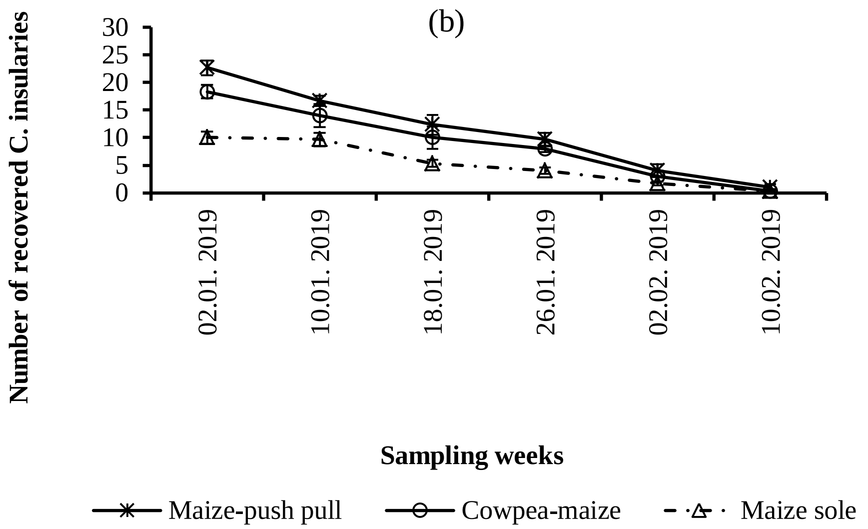


Figure 7: Temporal abundance of *C. bifoveolatus* in plots that were not treated with pesticides in the push pull, cowpea + maize and sole maize plots during the season 1 (a) and season 2 (b) growing season

3.5.2.2 Temporal variation in number of *C. luteum*

Results also showed similar trend on numbers of recovered *C. luteum* where by numbers of parasitoids decreased with time. Large numbers of parasitoids were recorded in the push pull plots followed by cowpea + maize and sole plots in growing season 1 and 2 (Figures 8 (a) and (b)) respectively.

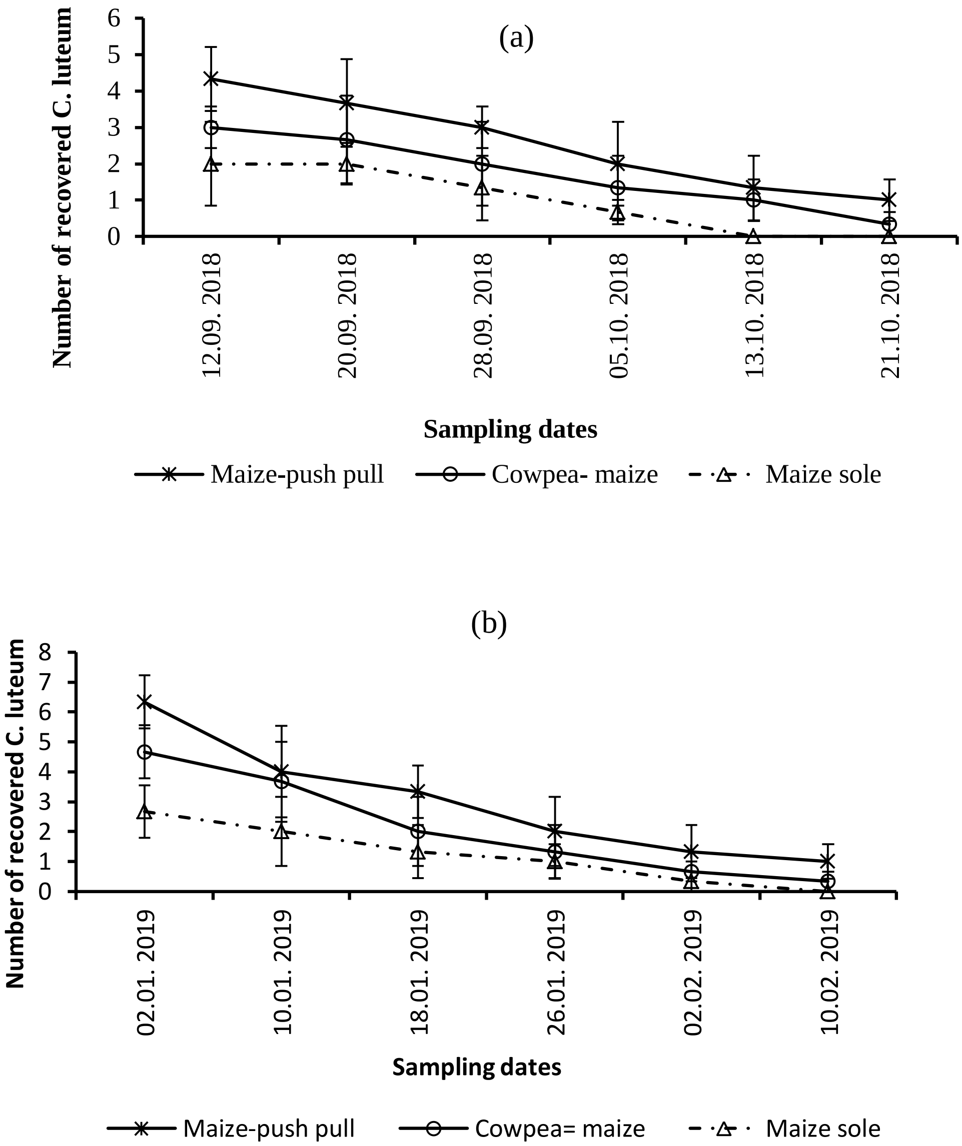


Figure 8: Temporal abundance of *C. luteum* in plots that were not treated with pesticides in the push pull, cowpea + maize and sole maize crop, during the season 1 (a) and season 2 (b) growing season.

3.5.2.3 Temporal variation in number of *Cotesia* sp

Results observed that no natural temporal abundance observed in *Cotesia* sp

in both seasons, because parasitoids occur only in plots treated with *M. anisapliae* and not in control plots.

3.5.3 Parasitism rates of eggs and larva parasitoids

3.5.3.1 Parasitism rate of egg - larva parasitoid

Results showed significant (p < 0.001) effects of intercropping system, pesticide and intercropping x pesticide on parasitism rate of C. *bifoveolatus* on S. frugiperda during both seasons (Appendix 1) respectively. The egg parasitism by the parasitoids ranged from 1.5% ± 0.07 to 12.8% ± 0.32 in season 1 and 2.24% ± 0.15 to 13.5% ± 0.11 in season 2. However, there were no emerged parasitoids from eggs sampled from plots treated with flubendamide (Figure 9).

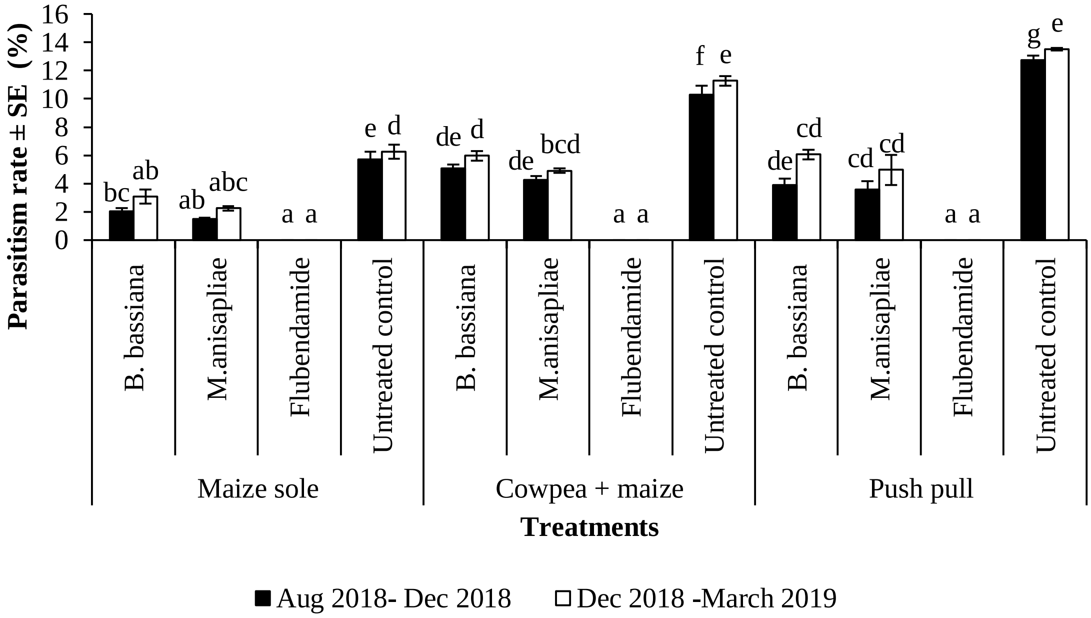


Figure 9: Parasitism rate of *C. bifoveolatus* on FAW eggs sampled in different treatment combinations. Bars caped by the same lower - case letters are not significantly different (p = 0.05, Tukey's HSD).

3.5.3.2 Parasitism rate of *C. luteum*

Significant (*p* < 0 .001 and *p* < 0 .05) effects of intercropping system observed during season 1 and season 2 respectively. Likewise the effects of pesticides were significant (*p* < 0.001) during both seasons. The effects of interaction between maize cropping system and pesticide application were also significant (*p* < 0 .001 for season 1 and p < 0 .05 for season 2) (Appendix 2). The Highest *C. luteum* parasitism rate (9.5% ± 0.22 and 12.3% ± 1.69 respectively) was recorded on the larvae sampled from plots of maize-push pull without application of pesticide while the lowest (2.3% ± 0.27 and 2.9% ± 0.30 respectively) was on maize-sole plots treated with *B. bassiana* (Figure 10). Moreover, there was also no parasitoids emerged from the larvae sampled from plots treated with flubendamide.

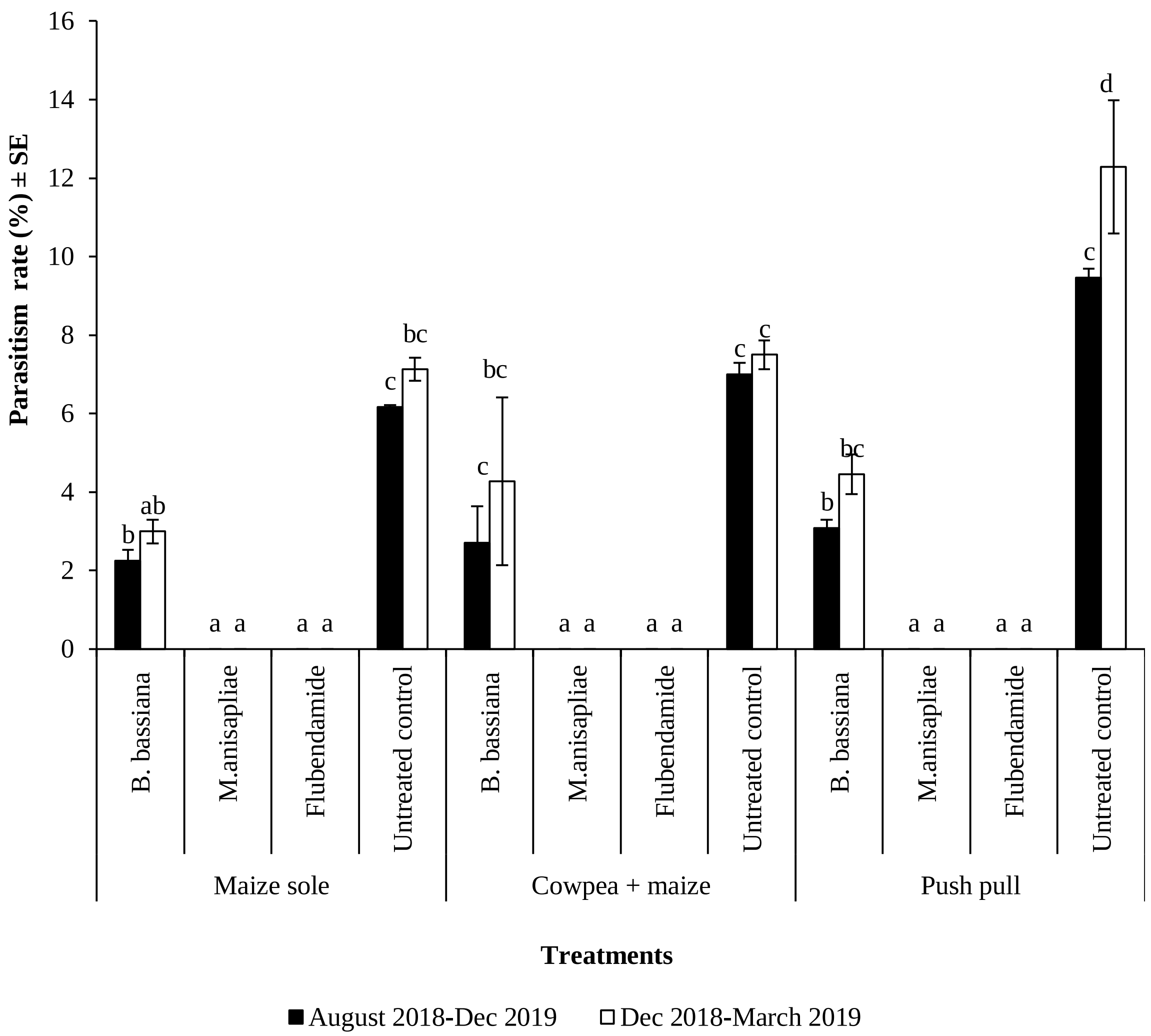


Figure 10: Parasitism rate of *C. luteum* on FAW larvae sampled in in different treatment combinations. Bars caped by the same lower - case letters are not significantly different (p = 0.05, Tukey's HSD).

3.5.3.3 Parasitism rate of *Cotesia* sp

Larval parasitism rate by *Cotesia* sp was significantly ($p < 0.001$) affected by intercropping system only in both cropping seasons (Appendix 3). The highest parasitism rate was recorded on larvae sampled from the maize - push pull followed by maize - cowpea and lastly on the maize - sole plots (Figure 11).

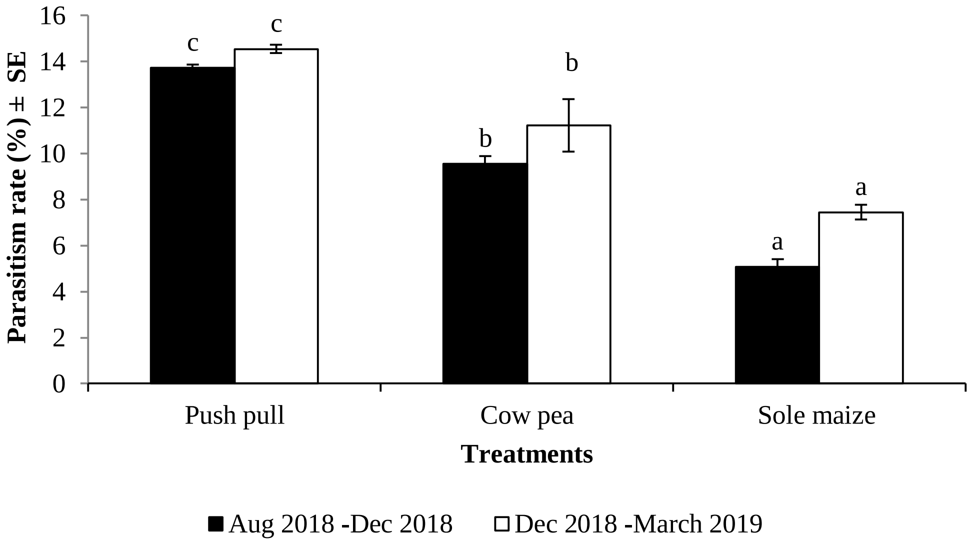


Figure 11: Parasitism rate of *Cotesia* sp on FAW larvae sampled in different cropping systems treated with *M. anisapliae*: P = push pull, C = cowpea, S = maize sole and M = *M. anisopliae*. Bars caped by the same letters are not significantly different (P = 0.05, Tukey's HSD).

3.6 Discussion

Study showed that number of parasitoids decreased with growing time of maize crop. More parasitoids were recovered in the first and second week than the rest. According to Abrahams *et al.* (2017) *S. frugiperda* feed more in tender young leaves stage than other stages. The leaf whorl is preferred in young plants, larva feels protected, chews and grows on favourite tender young maize leaves (FAO, 2018: Ruiz-Nájera *et al.*, 2013). Beserra *et al.* (2002) and Murúa *et al.* (2006) found that the distribution of FAW larvae and eggs varied according to the phenological stage of the maize. During the early plant stages when two leaves are full emerged, first and second instars were predominant, and about one to six larvae per plant were found. During the late early stages when 5 leaves are fully emerged, only one larva was usually recovered per plant.

Results showed that numbers of parasitoids varied significantly among cropping systems. High numbers of parasitoids were recorded in push pull and cowpea + maize plots compared to maize sole crop. This was attributed of increased of biodiversity in the intercropping systems (Afrin *et al*., 2017). Previous studies showed that parasitism rate varied considerably among the cropping systems (Ruíz - Nájera *et al.*, 2007; Sisay *et al.*, 2018). Molina-Ochoa *et al.* (2004) related higher parasitism of fall armyworm to more plant-diverse habitats. Murua *et al*. (2006) showed that cultural practices such as push pull and maize + cowpea intercropping developed in a plot increased the parasitoids colonization in cultivated fields through environment alterations. Meagher *et al*. (2016) reported that flowering plants could provide additional carbohydrate sources, which increase parasitoids fecundity. Percent parasitism recorded in the current study were higher than that described by Molina-Ochoa *et al*. (2001) for *C. bifoveolatus* (less than 5%) and that reported by Sisay *et al*. (2018) in Tanzania (6%) for *C. luteum*. On the other hand results of percent parasitism of the *Cotesia sp* in all intercropping system are not in agreements with those reported by Molina - Ochoa *et al.* (2004). However, these studies were not conducted in similar environment.

Also results showed significant effects of pesticides on abundance of parasitoids. Numbers of parasitoids were higher in bio pesticides treated plots compared with synthetic pesticides (Flubendamide). According to Thungrabeab and Tongma (2007) *B. bassiana* and *M. anisapliae* are relatively safe and have low virulence against non - target insects, such as natural enemies. Previous studies showed that *B. bassiana* and *M. anisopliae* had host ranges and were safer than pesticides (Mochi *et al*., 2005; Depieri *et al*., 2005). Because they are non - pathogenic toward humans, minimize pesticide residues in food and increase biodiversity in managed ecosystems (Sisay, 2018).

Results showed no parasitoids recovered from eggs and larvae sampled from the plots treated with Synthetic pesticides like flubendamide, it affects egg survival and larval mortality. This caused unsuccessfully development and recovery of parasitoids (Ndakidemi *et al*., 2016). Bernard *et al*. (2010) reported that pesticides applied in an agro-system, affected both the pests in the environment and the parasitoids. In other studies, frequent and overdose use of pesticides eliminated parasitoids and insect pests, which destroyed natural balance (Ahmad *et al*., 2011; Aydoğdu *et al*., 2017). A study by Moreau *et al.* (2010) showed species diversity decreased and new pest species, which were not considered to be harmful, previously might emerge.

In the present study, C. *bifoveolatus* was recovered from the eggs sampled from plots treated by all biopesticides. While *C. luteum* was recovered from plots sprayed with commercial *B. bassiana.* Furthermore, *Cotesia sp* was recorded from plots sprayed by commercial *M. anisopliae.*

Moreover, results showed significant interaction between cropping system and pesticide application on abundance of *C. bifoveolatus* and *C. luteum* parasitoids. Results of the current study indicate effective increase on abundance of parasitoids in cropping system x biopesticides, this caused by the use of natural product pest control agents (Intercropping and biopesticides) which have mechanism that reduce pest populations and attract parasitoids as well as increased their abundance and diversity.

Pickett *et al*. (2014) and Midega *et al*. (2018) reported that, intercropping and biopesticides application resulted in higher numbers and diversity of natural enemies, because intercropping system provided resources for natural enemies. Bio - pestcides are target - specific and inherently less toxic, and this limits their impact on non - target species (Hoballah *et al*., 2004; Uma Devi *et al*., 2008; FAO, 2018).

The present study confirmed present of different species of parasitoids with fall armyworm in Tanzania. Information on Percent parasitism is important in designing a biological control program for fall armyworm, because the use of synthetic pesticides against the FAW has a negative impact on natural enemies. We recommend, emphasize should be made to the farmer on the use cropping system and EPFs for sustainable maize production. Further investigation should be conducted to assessing interaction of the two recovered parasitoid species with the tested EPFs.

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CHAPTER FOUR

4.0 BIOCONTROL BASED PACKAGES OF FALL ARMYWORMS *Spodoptera frugiperda* ATTACKING MAIZE IN EASTERN CENTRAL, TANZANIA

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4.1 Abstract

Fall armyworm (FAW) *Spodoptera frugiperda* is among most economically important pests of maize and caused significant losses in yield of maize. The effect of cropping system and pesticides application on FAW was tested in Randomized Completely Block Design arranged in a two-way factorial experiment with three replications, for two seasons at Crop Museum of Sokoine University of Agriculture, Morogoro, Tanzania. Cropping systems tested included maize sole crop, maize + cowpea, and maize + desmodium and napier grass (push pull system). Biopesticides tested included *Metarhizium anisopliae and Beauveria bassiana.* The insecticide flubendamide was applied as a positive control. Results showed significant (p < 0.001) effects of cropping system and pesticide application on abundance of FAW larvae, percent damaged plant and grain yield of maize. Results also showed significant (p < 0.001) effects of cropping systems x pesticide on Percent damaged maize plants. On the other hand, grain yield was negatively correlated with FAW larval density as well as damaged plants by the pest. Moreover, the highest cost benefit ratio was estimated in maize push pull cropping system applied with flubendamide with cost benefit ratio of 1:3 and 1:1 in season 1 and 1:2.5 and 1:0.6 in season 2

respectively. These results confirm effectiveness of IPM on control of fall army worm in Tanzania.

Keywords: Intercroping, *Metarhizium anisopliae*, *Beauveria bassiana*, flubendamide and cost - benefit ratio.

4.2 Introduction

Maize (*Zea mays* L.) is the most important staple food crop grown predominantly by smallholder farmers in Africa (Sisay, 2018: Midega *et al*., 2017). It is production in Africa constrained by several biotic and abiotic factors (Hailu *et al*., 2018). Fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a new invasive pest in Africa, causing substantial yield losses of maize (Bissiwu *et al*., 2016; Hailu *et al*., 2018). From tropical and sub - tropical America, FAW has spread and become a serious pest of maize and other crops in many parts of the world (FAO, 2017). It was first reported in West Africa in late 2016, and early 2017, the pest invaded Eastern and Southern Africa (Goergen *et al*., 2016). The rapid spread of the pest in the African continent threatening food security of millions of people (Sisay, 2018). FAW is a well - known sporadic and long - distance migratory pest with the adult moths being able to fly over 100 km in a single night (Midega *et al*., 2017).

FAW is a polyphagous pest causing economic damage of various crops such as maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], Soya beans [*Glycine max* (L.) Merr.], and cotton cotton *(Gossypium hirsutum L.*) (Roger *et al*., 2017). Its host range however includes almost 100 recorded plant species in 27 families (Abrol *et al*., 2014). Larvae of FAW cause damage to the plant by consuming the foliage. Neonate larvae mainly feed on leaf tissue whereas the second and third instars feed on the leaf making holes in leaves, typical damage symptom of FAW (Belay *et al*., 2012; Sisay, 2018).

The extent of damage depends on factors such as planting season, geographical region, cultivar planted and cultural practices inherent in and around the field (De Almeida Sarmento *et al.*, 2002). The use of pesticide is on - going controlling attempt to reduce distribution of the pest and minimize damage in maize fields (Cook *et al.*, 2004). However, it is complicated by adverse effect due to incorrect use, shortage of information, inaccessibility of appropriate and effective products, high costs and development of resistance (Yu, 1991; Kabede, 2018). Moreover, the use of insecticides for controlling of FAW is impossible because of nocturnal behavior of the adult moths, the boring activity of the damaging larval stage, the availability of diverse alternative host plants and the resource-poor nature of many of the farmers (Kfir *et al*., 2002; Midega *et al*., 2017). It is good to develop bio - control packages that are compatible and cost - effective, for FAW because sole dependence on insecticides is not feasible. Possible ways of managing these pests is through the use of cover crops in maize fields, the push - pull technology and Entomopathogenic fungi in intergrated ways (EPFs) (Cook *et al.,* 2007).

According to Midega *et al*. (2018) push pull apart from controlling striga and cereal stem borer, a recent study proved that the technology controlled FAW in East Africa through the same mechanism as for stem borer control. However, the mechanism of stem borer control by this system includes, trap plants emit semi chemicals that are attractive to the gravid female moths while the intercrops emit semi chemicals that deter oviposition on the maize but attract the pests' natural enemies (Khan and Pickett, 2004; Midega *et al*., 2009). Also Susceptible host plants have been planted for use as trap crops to reduce the pest population build up on target crops (Khan *et al*., 2010). Furthermore crop diversification with various temporal and spatial arrangements reduces pest incidence while increasing the population of beneficial arthropods (Girma *et al*., 2000). EPFs have been used successfully for the control of the fall armyworm. They form a fungal - host relationship by adhering to the host and the germination of the conidia on the surface of the insect and a subsequent penetration of the hyphae through the cuticle. The hyphae grow through the internal organs of the insect, this kills the insect and the hypha continues to grow and emerge through the insect body and produces conidia to continue its cycle (Bissiwu *et al*., 2016). The use of bio - control based packages on the control of FAW has been reported (Prassana *et al.,* 2018). However, there is inadequate information on the use of cover crops, EPFs and push pull in the integrated methods for FAW suppression on maize. Good bio control based packages protect the crop from economic injury while minimizing negative impacts on people, animals, and the environment (FAO, 2017). Therefore, studies on finding these information gaps remain important for sustainable management of the pest.

4.3 Material and Methods

2.1 Location

Experiments were conducted in Morogoro (Central-East Tanzania) at crop Museum of Sokoine University of Agriculture (SUA). The site is located at longitude of 37^0 39' east and latitude 6^0 50' south. The place is at the altitude of about 525 m above sea level. The location experiences the sub - humid tropical type of climate and it experiences the temperature moderation effects due to the effects of the Uluguru Mountains. The site is dominated by sandy loam soil with pH of 5.16 and has bimodal rainfall pattern where short rains (Vuli) start from October to December and long rain (Masika) start from March and ends in May (Msanya *et al.,* 2003). The annual rainfall in this area ranges from 750 to

1 050 mm with an average of 900 mm. The temperatures of the area vary depending on the season.

4.3.1 Experimental design and treatment application

The study was conducted in a factorial experiment (Gomez, 1972) based on randomized complete block design (RCBD) with three replications. The experiments tested the effects of two experimental factors, intercropping and biopesticides on parasitism rate of FAW predators. Two intercropping systems were tested. One system consisted of maize (Delkab variety (DKC 9 089) from Monsanto company) was intercropped with cowpea (Fahari variety from Ilonga research institute) at a spacing 75cm by 30 cm and 75 cm x 20 cm respectively. While another was a push - pull system consisted of maize intercropped with Silverleaf desmodium, *Desmodium uncinatum* Jacq., at a spacing of 75 cm by 30 cm and 75cm by 37.5cm respectively, and surrounded by Napier grass, *Pennisetum purpureum* Schum, at a spacing of 90 cm by 60 cm. Standard agronomic practices for the crops were adopted. Maize sole crop at a spacing of 75 by 30 was used as control. Plot size was 3 m x 3 m with a space of 2 m between plots and space of 1 m between replication. Total experimental area was 780 m^2. Two commercial biopesticides were tested, Real IPM Mazao Prevail [*Beauveria bassiana* (Balsamo) Vuillemin, 1 x 10^7 cfu/ml] and Real IPM Mazao Tickoff [*Metarhizium anisopliae (*Metsch.) Sorokin, 1 x 10^7 cfu/ml] at application rates of 200 ml/ha (Average 10 ml in 16 L sprayer) for both biopesticides. A Synthetic insecticide Belt® (flubendiamide 480 Sc, Bayer Crop Science, Germany) applied at the of 40ml/ha (Average of 4ml in 20L sprayer) was used as positive control while untreated plots were negative controls. A total of 12 treatment combinations were tested.

4.3.2 Incidence levels of fall armyworm and plant damage

Incidence levels of FAW on maize plants were assessed by non - destructively methods at weekly base in both vegetative and reproductive stages of maize plants (Midega *et al.*, 2017). Using methodologies adapted from Midega *et al*. (2017). In each plot, 10 maize plants randomly selected. Each plant was visually examined and larvae on the plant counted. The larval data from the plants examined were summed for all weeks in each treatment and divided by number of sampling weeks, then expressed as average number of larvae per plot. Also, damage caused by larvae was assessed by examining the various vegetative and reproductive parts of each of the 10 plants for visible larval damage and data expressed as percentage of plants damaged per plot.

4.3.3 Maize grain yields

Maize grain yields were determined when full physiological maturity of the plant reached. All the cobs on the maize plants in each plot were harvested. The cobs were shelled and dried in the sun Then grain weights taken for each plot and calculated per plot area harvested, finally data converted into tones/hectare.

4.4 Statistical Analysis

Abundances of FAW larvae were tested through Analysis of Variance (ANOVA) with cropping system (3 levels: Maize - push pull, maize - cowpea, maize sole), pesticide application (4 levels: *B. bassiana*, *M. anisopliae*, flubendiamide, untreated control) as random factors. Shapiro normality test was used to verify the homogeneity of variances (in all cases reached after arcsine or logarithmic transformation) and Tukey's post-hoc test (P = 0.05) tests for a posteriori comparisons of means. Data on FAW temporal larvae abundances were analysed by logistic linear mixed model with intercept slope using 'glmer' function from lme4 package to test interaction effect between intercropping systems and sampling weeks. Data on percent damaged maize plants by FAW were arcsine transformed and analysed by using one - way ANOVA.

Data on maize yield in kg/ha were also analysed by using one - way ANOVA. Data normality was confirmed by Shapiro normality test. All means were separated by Tukey's post-hoc test (P = 0.05). Cost - benefit ratio was computed based on monetary gains obtained at the market price for maize grains against the total input cost following procedures described by (Karel and Ashimogo, 1991). Spearman correlation was used to analyse the association between maize grain yield, FAW larvae abundance and percent FAW damaged maize plants. All statistical analyses were performed using R - version (3.5.2) statistical software packages (R Development Core Team, 2016).

4.5 Results

4.5.1 Temporal variation in FAW larvae abundance in different maize cropping system

Figures 12 (a) and (b) shows temporal variation of FAW larvae under different cropping systems for cropping season 1 and 2. No significant peaks were observed, although the general abundance was highest in maize sole crop and lowest in maize under push pull system. Population decreased towards the last weeks of the cropping seasons. Mean population varied between 35 to 61 and 43 to 57 respectively in maize sole crop, and between 5 to 17 and 9 to 26 respectively in push pull. The mean abundance ranged between 11 to 35 and 14 to 35 respectively in maize + cowpea system.

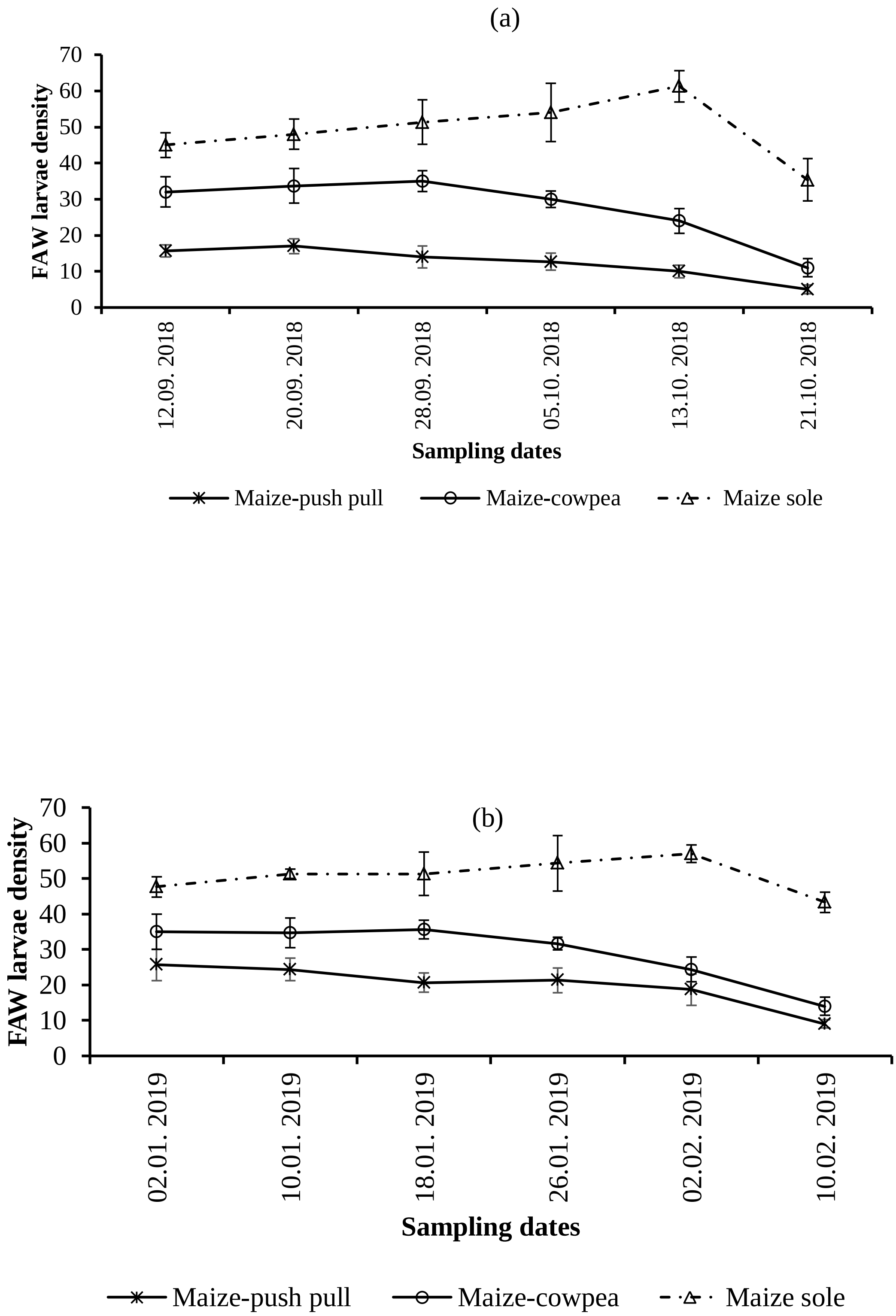

Figure 12: Temporal abundance of FAW in plots that were not treated with pesticides in the push pull, cowpea + maize and sole maize plots during season 1 (a) and season 2 (b).

4.5.2 Larval abundance

Two - way ANOVA results showed that number of larvae was significantly (p < 0 .001) affected by intercropping system and pesticides during both cropping seasons. However, interaction of intercropping and pesticides did not significantly influence larval abundance (p = 0.282 for season 1 and p = 0.082 for season 2) (Appendix 4). The larval abundance ranged from 0.72 ± 0.20 to 49.22 ± 3.80 in cropping season 1 and 1.10 ± 0.16 to 50.4 ± 3.70 in cropping season 2 (Figure 13a).

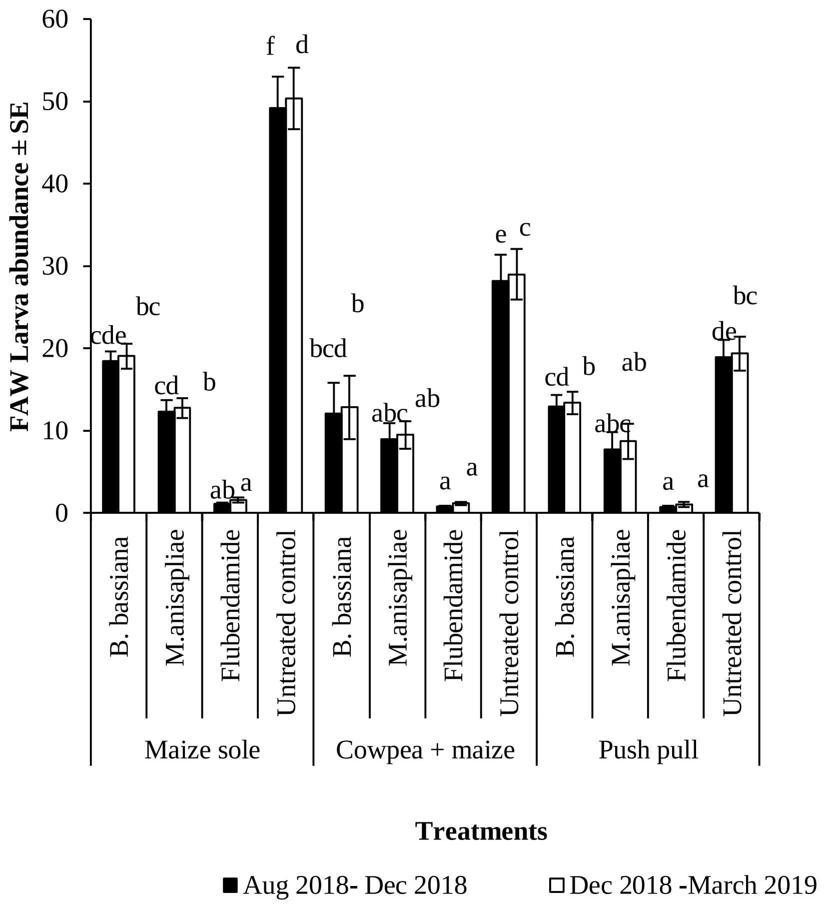

Figure 13: Larvae density of FAW larvae sampled in different treatment combinations. Bars caped by the same lower - case letters are not significantly different (p = 0.05, Tukey's HSD).

4.5.3 Percent damaged maize plant by FAW

Significant ($p < 0.001$) effects of intercropping system and pesticide application on percent damaged maize plants were observed during both seasons (Appendix 5). The effects of interaction between intercropping system and pesticide application were also significant ($p < 0.01$). The Percent damaged plants by FAW ranged from 3.8% ± 1.47 to 89.44 % ± 5.80 in season 1 and 5% ± 1.92 to 90.55% ± 5.29 in season 2 (Figure 14).

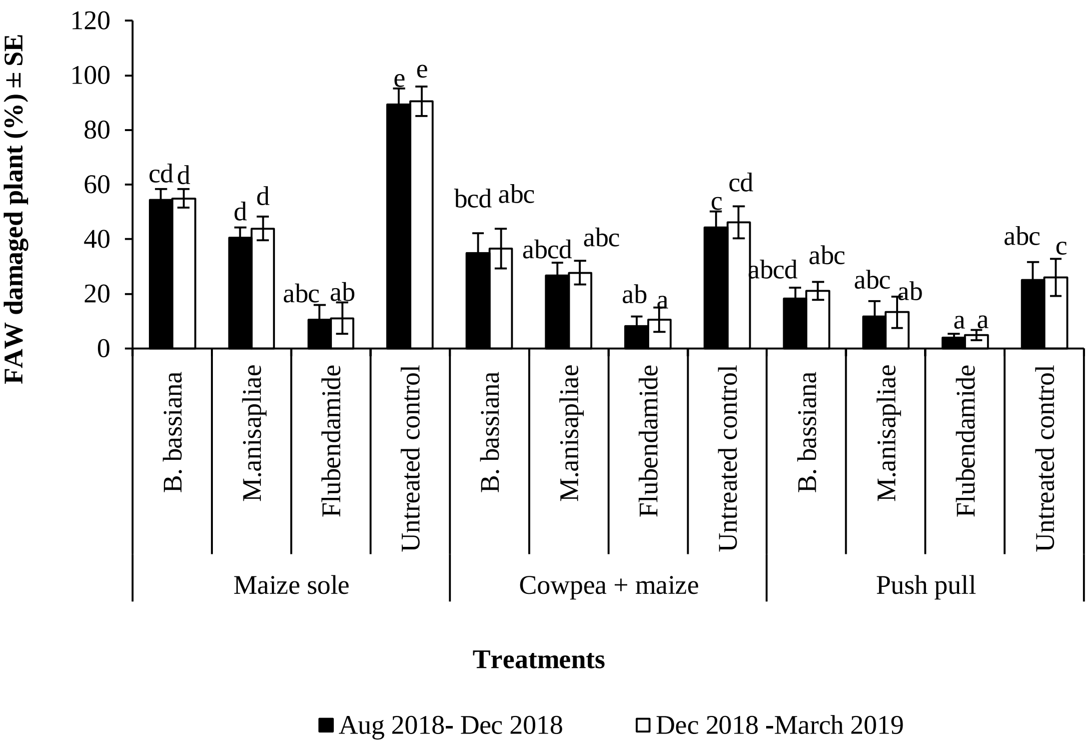

Figure 14: Percent damaged plants by FAW, sampled in different treatment combinations. Bars caped by the same lower - case letters are not significantly different (p = 0.05, Tukey's HSD).

4.5.4 Maize grain yield

Results showed significant ($p < 0.001$) variations in grain yield of maize among intercropping systems and pesticide application on maize grain yield during both season. However, there were no significant ($p > 0.05$) interaction effects on grain yield between maize cropping system and pesticide application (p = 0.38 for season 1 and p = 0.084 for season (Appendix 6). In cropping season 1 and 2, highest maize grain yield (4.7 t/ha ± 0.12 and 3.9t/h ± 0.15 respectively) were recorded on push pull plot applied with flubendamide while the lowest (0.9 t/ha ± 0.08 and 0.47 t/h ± 0.05 respectively) was on maize - sole plots without application of pesticides (Figure 15).

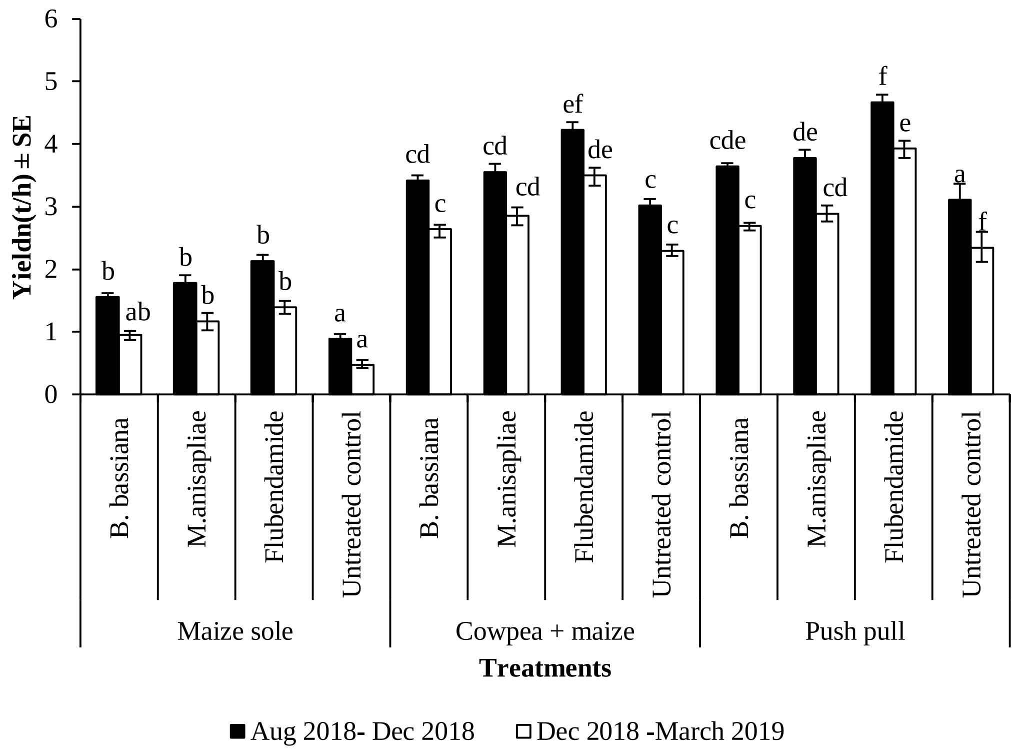

Figure 15: Maize grain yield sampled in different treatment. Bars caped by the same lower - case letters are not significantly different (p = 0.05, Tukey's HSD).

4.5.5 Cost - benefit ratio of maize production

The highest profit was estimated in maize push pull cropping system applied with flubendamide while the lowest was in maize sole crop applied with *B. bassiana* with cost benefit ratios of 1:3 and 1:1.0 in season 1 and 1: 2.5 and 1:0.6 in season 2 (Table 3).

Table 3: Cost benefit ratio of maize in different treatment combinations: P = push pull, B = *B. bassiana,* M = *M. anisopliae* F = flubendamide, C = cowpea, S = maize sole in the field experiment during the August 2018 - December 2018 and December 2018 - March 2019 growing season

	Season 1			Season 2		
Treatments	Monetary gain (US$/ha)	Total production cost (US$/ha)	Cost-Benefit ratio	Monetary gain (US$/ha)	Total production cost (US$/ha)	Cost-Benefit ratio
P+B	846	468.82	1.8	682.26	468.82	1.5
P+M	1159.84	480.92	2.4	886.94	480.92	1.8
P+F	1432.75	480.48	3	1205.33	480.48	2.5
P+U	955.17	413.82	2.3	718.65	413.82	1.7
C+B	1050.68	631.32	1.7	809.62	631.32	1.3
C+M	1091.62	545.18	2	877.84	545.18	1.6
C+F	1296.3	542.11	2.4	1073.42	542.11	2
C+U	927.88	422.63	2.2	705	422.63	1.7
S+B	477.58	494.08	1	291.01	494.08	0.6
S+M	545.81	496.71	1.01	359.32	496.71	0.7
S+F	654.97	489.96	1.3	427.55	489.96	0.9
S+U						

Means followed by the same lower-case letters are not significantly different (P = 0.05, Tukey's HSD).

4.5.6 Correlation between maize grain yield, FAW larval abundance and percent damaged maize plants by the pest

Maize yield was significantly negatively correlated with FAW larval abundance and percent damaged plants by the pest for both seasons (Table 4). Furthermore, the FAW larva abundance was significantly positive correlated with percent damaged maize plant by the pest.

Table 4: Correlation between maize yield, FAW larval density and damaged plants by the pest on Maize

	Maize yield	FAW larval abundance	Percent FAW damaged maize plants
Season 1			
Maize grain yield	-	-0.640 **< 0.001**	-0.72 **< 0.001**
FAW larval abundance		-	0.870 **< 0.001**
Percent FAW damaged maize plants			-
Season 2			
Maize grain yield	-	-0.61 **< 0.001**	-0.710 **< 0.001**
FAW larval abundance		-	0.870 **< 0.001**
Percent FAW damaged maize plants			-

Top number denotes the spearman correlation (rs) and the bottom bolded number is associated P - value.

4.6 Discussion

FAW is one of the most important maize pests that are controlled by synthetic insecticides to protect both the vegetative stages and reproductive stage the crop in different parts of the world (Malo *et al*., 2004; Belay *et al*., 2012; Capinera *et al*., 2017). Significant effects of pesticides on abundance of FAW larvae, percent damaged plant and grain yield were observed. In flubendamide plots low FAW larvae abundance and percent plant damaged with high maize grain yield were recorded. Bissiwi *et al.* (2017) reported high toxicity of flubendamide to FAW larvae. Larval mortality increased with time after insecticide application that indicated residual toxicity of the insecticides to FAW which reduced number of larva and consequently lowered percent damage and resulted in high maize grain yield (Bissiwi *et al*., 2017). Sisay *et al*. (2019) found significant reduction in leaf damage to maize when treated with synthetic pesticides, which was attributed to the reduced number of larvae in treated plants. Consequently, the highest fresh and dry weights were obtained.

In present study, synthetic pesticides showed high level of efficacy compared biopesticides. Abrol (2014) reported that, high larval mortality and grain yield of FAW occured by using chemical pesticides compared with biopestides. Bissiwi *et al*. (2017) reported that biopesticides reduced pest population to a significant level below the economic threshold and did not eradicate the pest, and that enhanced an agro ecosystem. Furthermore, we observed higher efficacy of *M.anisapliae* than *B. bassiana*. We observed less number of larvae, lower Percent damage and higher maize grain yield in plots treated with *M,anisapliae* compared to *B. bassiana*. Previous reports indicated because of high virulence of *M,anisapliae* compared to *B. bassiana* (Thungrabeab and Tongma, 2007; Mora *et al*., 2017). A study by Mochi *et al.* (2005). *Metarhizium anisopliae*, is one of the most studied fungus for the control of pest and has been used successfully for the control of the fall armyworm compared with *B.bassiana.*

Results also showed significant effect of cropping systems on percent damage plant and grain yield. Higher Percent damage and lower grain yield were in maize sole cropping system while lower Percent damage with high grain yield and cost benefit ratio was in push pull and maize - cowpea systems, this mainly because Components of intercrops are often less damaged by pest than when grown as sole crops. In intercropping certain plant species serve as trap crops, diverting pests from other crops and some crops have a repellent effect (Smith *et al*., 2000). Midega *et al.* (2018) reported reduced infestation of FAW, lowered damage and higher yield in maize grown under the push-pull system. Chamberlain *et al.* (2006) and Midega *et al.* (2009) found that, for FAW control in push pull, desmodium produces volatile chemicals, such as (E) – ß -ocimene and (E) - 4,8 – dimethyl - 1,3,7-nonatriene, which repel the FAW moths from the maize ('push') while those released by Napier grass, such as octanal, nonanal, naphthalene, 4-allylanisole, eugenol and linalool, attract female moths ('pull') to lay eggs. Recent study showed Push -

Pull, widely used in controlling the fall armyworm, providing a suitable, accessible, environmentally friendly and cost - effective strategy for management of FAW (Prasana *et al*., 2017). Khan *et al.* (2018) reported that push - pull farmers in Tanzania, Kenya and Uganda their fields were free from fall armyworm infestation associated with increases in grain yields, compared with monocrop farmers' fields.

Intercropping of maize with leguminous crops also provided better protection of maize with high yield compared to mono cropped maize (Parker *et al*., 2013). Hailu *et al.* (2017) reported that intercropping of maize with leguminous crops significantly reduced numbers of FAW and maize yield, especially in the early growth phases of the maize up to tasseling.

Study confirmed effectiveness of Integrated Pest Management (IPM) of fall armyworm in Tanzania. Information on performance of different methods on larva density and Percent damaged is important in designing a proper control program for fall armyworm, because the use of single tactics like synthetic pesticides only against the FAW has negative effect on control of FAW, We recommend, emphasize should be made to the farmer on the use of more than one methods which are compatible in integrated way for sustainable maize production

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CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

a) The study showed that one species of egg - larva parasitoids (*C. bifoveolatus*) and two species of larva parasitoids (*C. luteum* and *Cotesia sp*) were recovered from sampled FAW eggs and larvae. Although, its parasitism rates vary from one species to another.

b) *Chelonus bifoveolatus* was mostly dominant parasitoids emerged across all treatments, However, *C.luteum* was recovered in all control plots and plots applied with *B. bassiana* while *Cotesia* sp was recovered only in plots applied with *M. anisapliae.*

c) More parasitoids were recovered in the early whorl stage than in the late whorl and reproductive stage of maize in all treatments due to feeding habit of FAW.

d) Large numbers of parasitoids were recovered in intercropping systems plots compared to maize sole crop, because of increased of biodiversity in the intercropping systems.

e) Biopesticides showed influence on parasitism rates, highest parasitism rates were in plots applied with *B. bassiana* than *M. anisapliae* compared to chemical pesticides (flubendamide) because, they are relatively safe and have low virulence against non-target insects.

f) Interaction of cropping systems and pesticides application increased abundance of *C. bifoveolatus* and *C. luteum*, due to the use natural product that reduce pest populations and attract parasitoids because; biopesticides reduced pest population to a significant level below the economic threshold and did not eradicate the pest.

g) Less number of larvae, lower Percent damage and higher maize grain yield were recorded in plots treated with *M,anisapliae* compared to *B. bassiana*. Because, of high virulence of *M,anisapliae* compared to *B. bassiana*

h) Lower Percent damage with high grain yield and cost benefit ratio was in push pull and maize - cowpea systems compared to maize sole crop, this mainly because Components of intercrops are often less damaged by pest than when grown as sole crops.

i) Integration of synthetic pesticides with cropping systems showed good results in control of FAW as well as increased in grain yield than the use of it in maize sole plot

5.2 Recommendations

a) Further investigation should be conducted assessing interaction of the two recovered parasitoids species with the tested entomopathogenic fungi.

b) Entomopathogenic fungi (*B. bassiana* and *M. anisapliae*) and cropping systems were effective in control of FAW. Emphasize should be made to the farmer on the use of it for sustainable and profitable maize production.

c) Knowledge on application and storage of bio-pesticide should be given to farmers for proper use of biopesticides.

d) Knowledge on establishment and importance of push - pull system in control of FAW should be given to farmers for proper management of FAW, because such kind of intercropping reduce insect population by creating unfavourable conditions for insect pests.

e) Biopesticides based packages reduce adverse effect pesticides to human and environment because, frequently application of synthetic pesticides may results in the development of insect resistance and resurgence for sustainable management strategies.

APPENDIX

Appendix 1: Effect of intercropping system and biopesticides on percent parasitism of egg - larva parasitoids during the August 2018 - December 2018 and December 2018 - March 2019 growing season

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F*- ratio**	***p* value**	***F*- ratio**	***p* value**
Intercropping systems	$F_{(2, 24)} = 79.08$	< 0.001	$F_{(2, 24)} = 71.23$	< 0.001
Biopesticides	$F_{(3, 24)} = 715.08$	< 0.001	$F_{(3, 24)} = 324.75$	< 0.001
Intercropping systems x Biopesticides	$F_{(6,24)} = 12.81$	< 0.001	$F_{(6, 24)} = 14.40$	< 0.001

Appendix 2: Effect of intercropping system and biopesticides on percent parasitism of *C. luteum* parasitoids during the August 2018 - December 2018 and December 2018 - March 2019 growing season

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F*- ratio**	***p* value**	***F*- ratio**	***p* value**
Intercropping systems	($F_{(2, 24)} = 11.865$	< 0.001	($F_{(2, 24)} = 4.441$	< 0.05
Biopesticides	($F_{(3,24)} = 402.444$	< 0.001	($F_{(2, 24)} = 81.383$	< 0.001
Intercropping systems x Biopesticides	($F_{(6, 24)} = 7.067$	< 0.001	($F_{(2, 24)} = 2.972$	< 0.05

Appendix 3: Effect of intercropping systems on percent parasitism of *Cotesia* sp parasitoids during the August 2018 - December 2018 and December 2018 - March 2019 growing season

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F* - ratio**	***p* value**	***F* - ratio**	***p* value**
Intercropping systems	($F_{(2, 6)} = 241.4$	< 0.001	($F_{(2, 6)} = 26.07$	< 0.01

Appendix 4: Effect of intercropping system and biopesticides on FAW larval abundance during the August 2018 - December 2018 and December 2018 - March 2019 growing season

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F*-ratio**	***p* value**	***F*-ratio**	***p* value**
Intercropping systems	$F_{(2, 24)} = 13.24$	< 0.001	$F_{(2, 24)} = 12.98$	< 0.001
Biopesticides	$F_{(3, 24)} = 207.10$	< 0.001	$F_{(2, 24)} = 236.259$	< 0.001
Intercropping systems x Biopesticides	$F_{(6, 24)} = 1.33$	0.284	$F_{(2, 24)} = 2.168$	0.0822

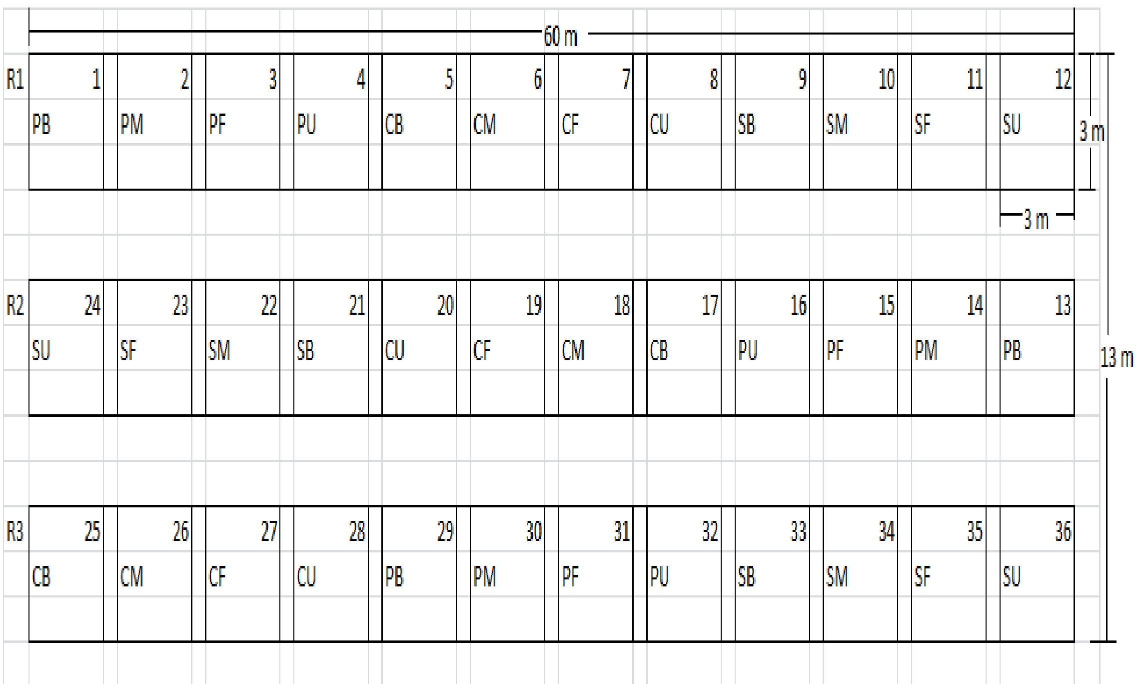
Appendix 5: Effect of intercropping system and biopesticides on percent damaged maize plant by FAW during the August 2018 - December 2018 and December 2018-March 2019 growing season.

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F*-ratio**	***p* value**	***F*-ratio**	***p* value**
Intercropping systems	$F_{(2, 24)} = 29.23$	< 0.001	$F_{(2, 24)} = 27.99$	< 0.001
Biopesticides	$F_{(3, 24)} = 29.61$	< 0.001	$F_{(2, 24)} = 30.31$	< 0.001
Intercropping systems x Biopesticides	$F_{(6, 24)} = 4.321$	< 0.01	$F_{(2, 24)} = 4.04$	< 0.01

Appendix 6: Effect of intercropping system and biopesticides on maize grain yield during the August 2018 - December 2018 and December 2018 - March 2019 growing season

Effects	August 2018 - December 2018		December 2018 - March 2019	
	***F*-ratio**	***p* value**	***F*-ratio**	***p* value**
Intercropping systems	($F_{(2, 24)} = 37.53$	< 0.001	($F_{(2, 24)} = 279.731$	< 0.001
Biopesticides	($F_{(3,24)} = 57.81$	< 0.001	($F_{(2, 24)} = 46.440$	< 0.001
Intercropping systems x Biopesticides	($F_{(6, 24)} = 1.13$	0.38	($F_{(2, 24)} = 2.153$	0.0841

Appendix 7: Treatment combination



Key: P = Push pull, M = *Mertarhizium anisapliae, B= Beuveria bassiana,* C= Cowpea, S= Sole crop, F= Flubendamide, U = Untreated control