POTENTIAL OF PUSH-PULL TECHNOLOGY OPTIONS FOR MANAGING FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*) IN MAIZE

BY

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REG NO: 17/U/14494/GMCS/PE

A RESEARCH DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN CROP SCIENCE OF KYAMBOGO UNIVERSITY

OCTOBER, 2022

DECLARATION

I, **Natukunda Charles,** solemnly declare and affirm that this dissertation is my original work and has never been submitted to any university or higher institution of learning for award of degree, diploma or certificate except where due reference has been indicated to such published work.

Signed.. Date..04/10/2022

APPROVAL

This is to certify that this work was conducted under our supervision as University supervisors and is now ready for supervision for examination

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DEDICATION

I dedicate this work to my uncle, Hon. Shem Bageine.

ACKNOWLEDGEMENT

I am grateful to God for the far he has brought me. Special thanks go to my supervisors Dr. Tumuhaise Venansio and Dr. Tinzaara William for the guidance, advice and suggestions which led to the successful completion of this study. I also extend my sincere appreciation to the staff of National Crops Resources Research Institute (NaCRRI) Namulonge for all the assistance rendered to me during the time I was carrying out this research.

In a special way, I would like to appreciate my beloved wife, Natukunda Sylvia and my sister, Tumuheki Allen, for the love and financial support rendered towards my education. Lastly, I would like acknowledge with sincere gratitude Ms. Proscovia Namazzi and Mr. Akasairi Ocwa for the assistance in data collection and analysis, and all those who supported me in different ways especially Hon. Shem Bageine.

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LIST OF ACRONYMS

ANOVA:	Analysis of variance
Bt:	*Bacillus thuringiensis*
CABI:	Centre for Agriculture and Bioscience International
RCBD:	Randomized Complete Block Design
FAOSTAT:	FAO Statistics
FAO:	Food and Agricultural Organization
FAW:	Fall Armyworm
ICIPE:	International Centre of Insect Physiology and Ecology
IPM:	Integrated Pest Management
LSD:	Least Significant Differences
MAAIF:	Ministry of Agriculture, Animal Industry and Fisheries
MLN:	Maize Lethal Necrosis
NaCRRI:	National Crops Resources Research Institute
NARO:	National Agriculture Research Organization
OPVS:	Open pollinated varieties
SSA:	Sub- Saharan Africa
UK:	United Kingdom
WAE:	Weeks after emergence

ABSTRACT

Fall armyworm is a key insect pest of maize. Without proper management, the pest can cause maize yield losses in the range of 8-21 million tones. It has been through application of synthetic pesticides, use of natural enemies, intercropping, use of resistant varieties, and pheromones, among others. Push – pull technology is generally considered as a cost-effective option for pest management with minimum negative effects on human health and the environment. This study aimed at assessing the potential of different push - pull plant combinations, in managing FAW in maize. Treatments included three plant combination namely, Desmodium + Brachiaria, Molasses grass + Brachiaria, Garlic + Brachiaria, and also Sole maize as a control. Molasses grass + Brachiaria recorded the highest plant height (228.9 ± 0.49cm) while sole maize + had the lowest plant height (191.4 ± 1.00cm). For stem girth, molasses grass + Brachiaria still outperformed the rest (7.3 ± 0.42cm) while garlic + Brachiaria recorded the lowest (5.6 ± 0.34cm). Similarly, desmodium + Brachiaria recorded the lowest number of maize plants infested by FAW (5.3 ± 1.2) while sole maize recorded the highest (31.3 ± 4.2). Desmodium + Brachiaria recorded the highest maize grain weight (12.6 ± 0.8kg) whereas sole maize had the lowest (5.6 ± 0.2kg). The highest Benefit: Cost (B: C) ratio of (14.1) was recorded in plots of Greenleaf desmodium + Brachiaria while the lowest (1.1) was recorded in plots of garlic + Brachiaria. Generally, all push pull plant combinations recorded an increase in maize growth, reduced fall armyworm damage and increased maize grain yield in comparison with control. The push-pull plant combination of Desmodium + Brachiaria outperformed the rest with the highest B: C ratio, and

is therefore recommended as the best for consideration in further development of FAW IPM packages.

CHAPTER ONE: INTRODUCTION

1.1 Background

Maize (*Zea mays*) (Ian Khan) is the most important food crop grown predominantly in Africa (Byerlee *et al*. 1997). East African countries produce 3.07m tons of maize annually on 17, 26688 ha of land (FAOSTAT, 2017). In the past three decades, maize has been grown on an average of 384,000 ha of land, with an average production of 522,000 tons annually and maize grain yield of 1.3 tons per ha (Kasenge *et al*., 2001). The production pattern, area, and yield throughout this period reveal that the maize yield has decreased, and that the increase in maize yield has been due to area expansion (Kasenge *et al*., 2001; Pender *et al*., 2001).

In Ethiopia, a combination of several constraints, like disease, pest infestation, moisture deficiency, soil infertility, and poor traditional practices, contribute to low yield of maize (Xing *et al.*, 2001). The factors that lead to low yield of maize are arthropod pests. Arthropod pests continue to cause major agricultural losses despite the use of insecticides, especially in underdeveloped countries (Azerefegne *et al.*, 2001). In the field, maize has been infested by more than 40 species of insect pests, including termite species (*Macrotermes spp*), maize stem borer (*Buseola fusca*) and fall armyworm larvae (*Spodoptera frugiperda*) which is one of the significant insect pests. Goergen *et al*. (2016) reported that fall armyworm originated from the tropical regions of America. Fall armyworm was discovered on the African continent over the last 16 months, and it has spread to at least 21 nations (Abrahams *et al*., 2017). There are 31 species in the genus Spodoptera, seven of which have been registered in Afro - tropical region and six occur in West and Central Africa (Pogue, 2002). Fall armyworm in West Africa was appeared for the first time in 2016 and 2017 and it spread to Eastern and Southern Africa. The appearance of fall armyworm was confirmed in 28 African nations (Abrahams *et al*., 2017); showing its quick spread across African and posing a threat to food security (FAO, 2018).

This pest in Uganda was first detected in three districts which are Kayunga, Kasese, and Bukedea Between May and July 2016 which was later confirmed to cause maize yield losses between 15 and 75 percent (FAO, 2018). Many plant species including maize is attacked by fall armyworm larvae (Abrahams *et al*., 2017). Fall armyworm is a maize pest which can reduce yields by up to 53% (Day *et al*., 2017).

The fall armyworm larvae affect young stages of maize plants and this is when most of the damage occurs (Ayala *et al*., 2013). The fall armyworm comes in two genetically distinct but physically identical strains. The cotton strains affect corn, sorghum, and cotton, whereas the rice strains affect the rice and Bermuda grass (Abrahams *et al*., 2017). There have been reports about dissimilarities between these strains, including variations in pesticide resistance (Adamczyk, 1999).

Fall armyworm larvae attack maize from seedling to ear development. Fall armyworm larvae kill young plants for example; damage of whorl leaves can reduce maize yields, while ear damage can lower grain quality and reduce yields, respectively (Sisay *et al*., 2019). The report by Centre for Agriculture and Bioscience International (CABI) indicates that fall armyworm may lead to maize yield losses ranging from 8 - 21m tons leading to losses of 6.1 billion USA dollars and affect over three hundred million people in Africa who depend on maize for food (Abrahams *et al*., 2017; Midega *et a.l.*, 2018).

The plants suffer damage as a result of fall armyworm larvae infesting maize leaves. The 2nd and 3rd instars of fall armyworm feed on leaves, causing holes in leaves which are a typical damage symptom of fall armyworm. Neonate larvae mostly consume leaf tissue (Belay *et al*., 2012). Spraying insecticides has been the typical control technique for the fall armyworm in Eastern Africa and America and it is common with other major agricultural pests. However, the fall armyworm has become resistant to a number of pesticides (Day *et al*., 2017).

The life cycle of the fall armyworm is season's dependant, taking one month during the summer period, two months during spring and autumn, two months and twenty days during winter period, and one month worm summer months (Kondidie, 2011). The eggs of this maize pest are normally deposited on the upper surfaces of leaves of the host plant, and each mass contain between 100 and 200 eggs. In its life time, a single female adult fall armyworm moth can lay up to a thousand eggs (Prasanna *et al*. 2018).

Fall armyworm development pass through 6 larval phases; the 1st and 2nd larval phase make holes in the leaves of host plants. Mature larvae leads to serious defoliation, and often leaves the ribs and stalks of corn plants, or a ragged appearance, while frequent attack of the whorl leaf of maize results in a distinctive perforations in the leaves (Marenco *et al*., 1992). Depending on the weather conditions, larval stage takes between 14 and 30 days (Capinera, 2017).

Fall armyworm recommended management tactics include the use of natural enemies, intercropping, resistant cultivars, pheromones, and biopesticides and these measures, however, this technique has not been successful, and the pest has continued to severely and extensively harm the region's corn harvest (Niassy, 2018). Push-pull technology, a strategy for managing agricultural pests by employing plants that serve as both traps and repellents, has been effective in managing fall armyworm in Kenya (Midega *et al*., 2018). This technology involves companion cropping of maize with Greenleaf desmodium and surrounding it with *Brachiaria cv. mulato* II as border plants.

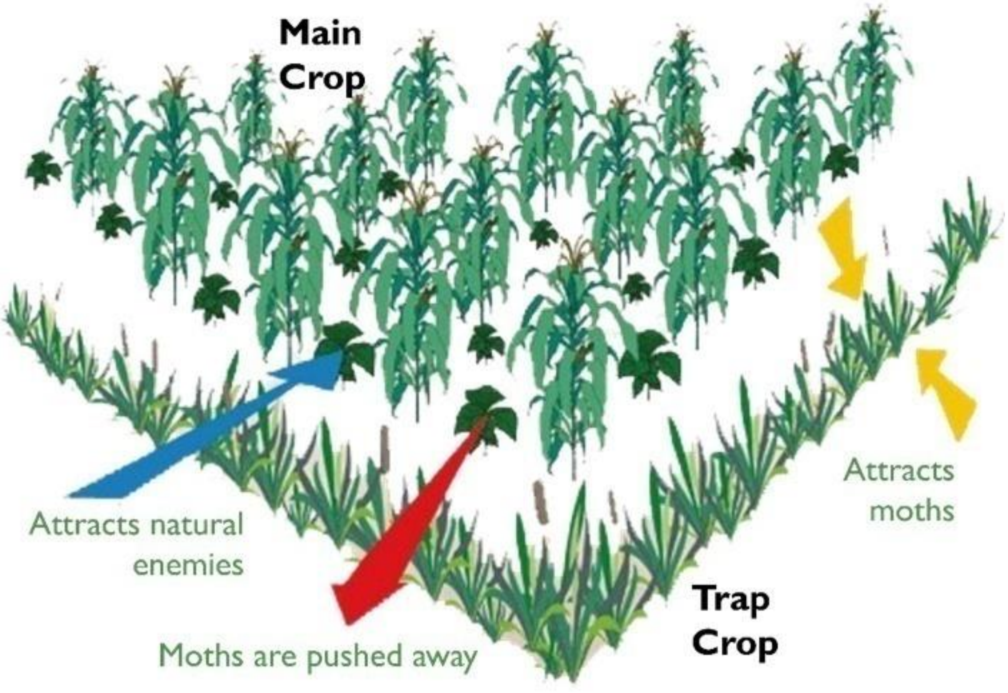

Figure 1: push - pull technology for management of fall armyworm (Source: Hassanali, 2008)

The field study was conducted to determine the effect of different push-pull plant combinations on the growth and yield of maize, the damage caused by fall armyworms, as well as the economic benefit of employing different push-pull plant combinations to manage fall armyworm in maize.

1.2. Statement of the problem

Fall armyworm larvae have ability to cause maize yield losses of 21–53% (Abrahams *et al.*, 2017). Control measure of fall armyworm larvae has been use of synthetic insecticides (Hardke & Leonard, 2011). Although the chemicals have been able to attain up to 40% level of control, are considered to be damaging to the environment and are also harmful to humans and other non - targets. The fall armyworm has also been reported to develop resistance against most synthetic pesticides, thus calling for adoption of alternative control options. One of the different management strategies that have been used to control fall armyworm is biological control. However, these have not been effective due to their inherent short falls. For instance, biocontrol agents especially predators normally take long to attain sufficient population to check the pest population and thus reduce the damage in good time. Push-pull technology, an eco-friendly method that has previously been recommended for managing striga weed and stem borers in cereals, has recently been discovered to be successful in controlling the fall armyworm in Kenya (Midega *et al.*, 2018). However, this new application of push-pull technology against fall armyworm has not been tested in Uganda; in Kenya, different plant combinations have been used in push-pull technology depending on the agro-ecology. In the Ugandan context, push-pull plant combinations that increase maize growth, minimize fall armyworm damage, provide the highest possible yield of maize, and improve farmer returns are required.

1.3. Objectives of the study

1.3.1. General objective

To evaluate the effect of push – pull plant combinations in managing fall armyworm in maize.

1.3.2. Specific objectives

The specific objectives of this study were:

i) To assess the effect of push – pull plant combinations on growth and yield of maize.

ii) To determine the effect of push – push plant combinations on fall armyworm damage.

iii) To evaluate economic benefit of using different push – pull plant combinations in management of fall armyworm in maize.

1.4. Hypotheses

The following are research hypotheses that guided this study:

i) Different Push pull plant combinations affect maize growth and yield.

ii) Different Push pull plant combination has an effect on fall armyworm damage.

iii) Economic benefit of using different push pull plant combination in management of fall armyworm in maize is higher compared to that of sole maize.

1.5. Justification of the study

In Uganda, the most important food crop is maize. The crop plays a significant role in food security and poverty eradication through income generation. Over the past years maize yields declined due to fall armyworm infestation. The main worry is that, because of the pest's devastating effect, present cereal supply cannot keep up with the rising demand for them. In order to address the issues associated to food in the nation and the world at large, it is crucial to design an environmentally friendly technology that has the ability to solve this issue. One such technology that has the ability to address this issue effectively and efficiently is push-pull technology.

1.6. Significance of the study

The study gives information to small holder maize growers on effectiveness of different push- pull plant combination on the management of fall armyworm larvae damage, and consequent impact on maize growth and yield. The study identifies the push - pull plant combination with the highest economic return that farmers may consider for adoption. Furthermore the farmer will also benefit from this study since it provides a cheap alternative fall armyworm management options which would reduce the need for synthetic pesticides use and their associated harmful effects.

1.7. Scope of the study

The study aimed at determining the effect of push-pull plant combinations on maize growth and fall armyworm damage, effect of different push-pull plant combinations on maize yield in fall armyworm infested fields, and economic benefits of employing different push-pull plant combinations in two seasons from October 2018 to February 2019 and April to August 2019. The field study was carried out at National Crops Resources and Research Institute (NaCRRI) Namulonge Wakiso district.

CHAPTER TWO: LITERATURE REVIEW

2.1 Taxonomy of fall armyworm (*Spodoptera frugiperda* (Lepidoptera: Noctuidae)

Fall armyworm is of Noctuidae family, Order Lepidoptera, and class insecta. The largest insect order in the world is Lepidoptera which includes butterflies and moths. The characteristics of Butter flies and moths are scaly wings. Many pests of the order lepidoptera are the major pests that feed on field plants, stored grains and textiles. The smooth, dull-colored larvae of the noctuid family posses' 5 pairs of prologs, and many of them feed on plant foliage while a small number feed on fruits (Kondidie, 2011).

Several species of the genus *Spodoptera*, such as the cotton leaf worm (*Spodoptera littoralis*), African armyworm (*Spodoptera exempta*) the tobacco cutworm (*Spodoptera litura)*, beet armyworm (*Spodoptera exigua*), yellow striped armyworm (*Spodoptera ornithogalli*) and fall armyworm (*Spodoptera frugiperda*) are significant crop pests (Guerrero *et al.,* 2014).

2.2. Distribution of fall armyworm

The major insect pest in Americas is fall armyworm (Sisay *et al*., 2019). Fall armyworm in West Africa was reported in 2016 and quickly covered the whole of Sub-Saharan Africa (SSA), and confirmed later in 44 African nations (Sisay *et al*., 2019). Fall armyworm which is a native of America entered Africa by airplanes, cargo containers and then spread through wind (Day *et al*., 2017).

Numerous Asian nations have reported seeing fall armyworm. The fall armyworm was first spotted on the Indian subcontinent in Karnataka in 2018. Later, it expanded to several locations including Bihar, Chhattisgarh, Gujrat, Maharashtra, Odisha, and West Bengal, among others (CABI, 2020). Asiatic nations like China, Thailand, Indonesia, Korea, Japan, Bangladesh, Cambodia, , Myanmar, , , Sri Lanka, and Vietnam have experienced the insect infestation (FAO, 2019). Although the fall armyworm has not yet been identified in other continents, its spread is quik. It was reported first in Nepal's Nawalparasi district on May 9, 2019 (Bhusal and Bhattarai, 2019). Fall armyworm has been observed in fifteen districts of Nepal (Bajracharya and Bhatt, 2019).

Goergen *et al*, (2016) showed that in Africa, the first confirmed reports of fall armyworm were in west Africa in 2016, namely Nigeria, Sao Tome, in Benin and Togo, which caused damage to maize, and it was confirmed later in Ghana (Erik, 2017) and Zimbabwe (FAO, 2018). In the case of Uganda, fall armyworm was first identified in the districts of Kayunga, Kasese, and Bukedea in 2016 and 2017 (FAO, 2018).

2.3. Biology and behavior of the fall armyworm

The life cycle of fall armyworm takes one month during the summer season, two months during the spring and autumn seasons and three months during the winter season (Capinera, 2017). On maize, upper part of leaves and other parts is where fall armyworm lays its eggs (Prasanna *et al*., 2018). The fall armyworm eggs are dome-shaped and flattened on the bottom and also curves upward to an apex that is broadly rounded. The fall armyworm eggs are around 0.3mm length and

0.4mm in diameter. The eggs are laid in large groups between 100 and 200 eggs each group (Figure 2). A single female fall armyworm can lay 1500 - 2000 eggs in its life time. Sometimes, eggs are deposited in layers, but some are distributed in a single layer attached to vegetation. The female fall armyworm moths put a coat of grayish scales between and on top of eggs giving them a mouldy appearance (Moses *et al.*, 2018). In the summer, eggs hatch within 2 -3 days (Capinera, 2017).

Fall armyworm has 6 larval stages. The head of young larvae is black and greenish; it becomes more orange in the 2nd stage. The surface of fall armyworm larvae turns brownish in the 2nd and 3rd stages, and white lines begin to develop. The head of fall armyworm larvae appear reddish – brown in color and marked with white both in 4th – 6th larval stages, while the body bears white sub dorsal and lateral lines (Figure 2). Dorsally, patches appear on the body of fall armyworm larvae and are often dark in color and include spines (Capinera, 2017). Larvae that have just emerged from the egg live together and feed on maize leaves, and as they grow large, they attack other plants (Capinera, 2017). The 1st and 2nd larval stages of fall armyworm eat sides of the maize leaves and as they grow, they feed and develop holes in the leaves. The average length of the larval stage of fall armyworm is fourteen days in the summer and one moth in winter (Capinera, 2017). Each larval stage has active and inactive feeding periods before emerge. Much as temperature can affect the larval stage of fall armyworm, low temperatures lengthen the inactive period, but during active time; food is important (Oh & Lee, 2020). Pitre (1983) reported that the development time of fall armyworm was found to be 3.3, 1.7, 1.5, 2.0, and 3.7 days when fall armyworm larva is reared on maize at 25^{o}C.

According to Pitre and Hogg (1983), pupation of fall armyworm larvae occurs in soil at 2 to 8 cm deep. Larvae construct loose cocoons by tying soil particles together with silk threads they produce. The pupa stage of fall armyworm is not tolerant to prolonged cold temperatures. The study by Pitre and Hogg (1983) in Florida found out that winter survival of fall armyworm pupa is 51% in southern Florida, 27.5% in central Florida, and 11.6% in northern Florida. At pupa stage, fall armyworm measures fourteen to eighteen millimeters long and four millimeters wide, with a reddish brown hue (Figure 2). Pupa stage of fall armyworm takes 8 - 9 days during summer season and reaches 20 - 30 days during winter season.

The color of fall armyworm moths varies, and they have wingspans that range from 32 - 40 mm. For males, the fore wings are dark and gray with white marks towards the end and in the middle (Figure 2). For the female moths, fore wings are marked grayish to a fine mottling of gray and brown. The hind wing has a thin, dark border and is iridescent silver-white. Male and female fall armyworm moths have silver - white hind wing with thin dark edges. Fall armyworm moths are active at night (Abrahams *et al*., 2017). Following a three to four day pre - oviposition stage, the female fall armyworm moth normally lays its eggs within 4 - 5 days, while some oviposition takes three weeks. The life span of fall armyworm moth ranges from 7 to 21 days. Because of length of life cycle, each cropping cycle can produce 2 to 10 generations, depending on the weather or climate (Assefa *et al*., 2019)

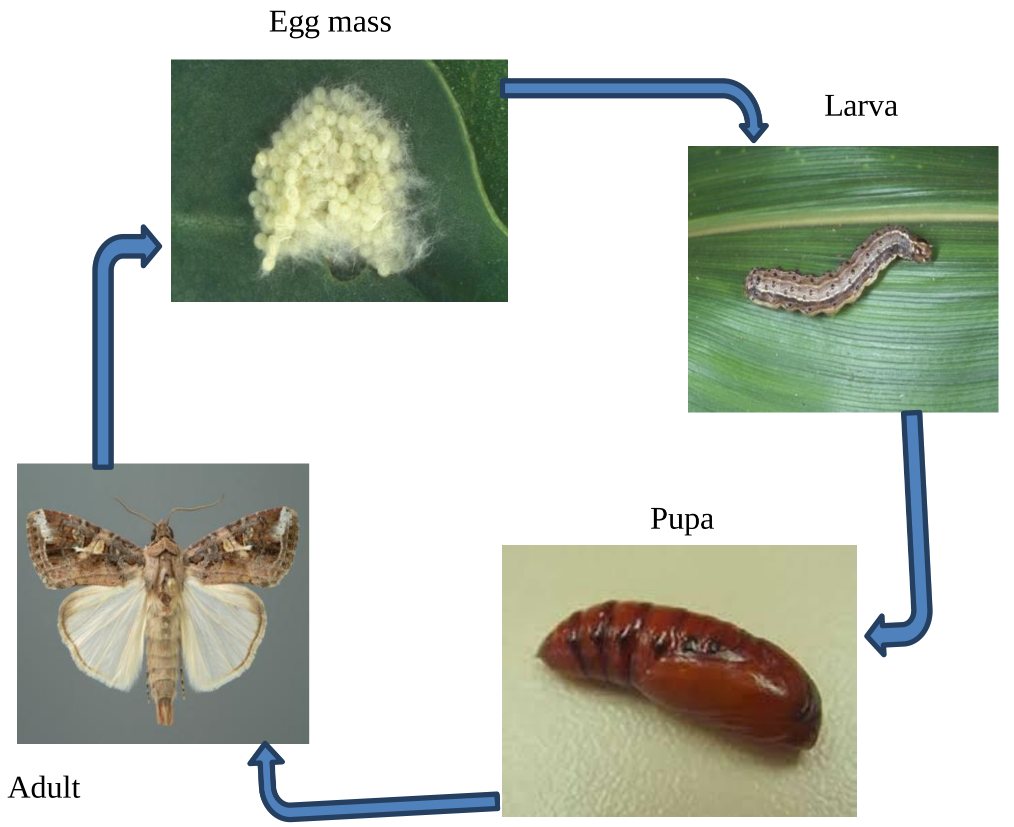

Figure 2: The life cycle of the fall armyworm (Source: James, 2017)

2.4. Host range of fall armyworm

Fall armyworm larvae are polyphagous pests that attack over 80 plant species causing 70% yield loss (Kumela *et al.*, 2018). The fall armyworm larvae feed on plants like field corn, sorghum, rice, Bermuda grass, and weed grasses like crab grass. Other field crops attacked by fall armyworm are alfalfa, barley, buckwheat, cotton, clover; oat, millet, ryegrass, sugar beet, Sudan grass, sugarcane, tobacco, and wheat (Abrahams *et al*., 2017).

2.5. Fall armyworm spread

In North America, interest in insect movement has greatly increases during the past ten years (Mackenzie *et al*., 1986). Many noctuid species are very migratory and seriously harm important food and forage crops over a large area and the migration of these pests has attracted a lot of attention (Johnson and Mason, 1986).

2. 6.Nature of fall armyworm damage

Leaf tissue is initially eaten by young larvae by feeding on one side leaving the opposite side complete. However, for the 2^{nd} and 3^{rd} larval stages, larvae attack both sides of maize leaves creating perfolations. Attack of the corn whorl leaves by fall armyworm, causes perforations in the leaves. However, defoliation caused by mature larvae gives the maize a ragged with torn appearance (Capinera, 2017).

According to Marenco *et al*. (1992), fall armyworm infestation on maize causes damage at the late whorl stage than at the early whorl stages. Fall armyworm larvae burrow into the maize growing point like buds and whorls thus destroy the plant’s growing ability. However, in maize fall armyworm burrow in ears of corn and feeds on the kernels of maize ear. Fall armyworm larvae however, feed by tunneling through the husk on the side of the ear. It's also confusing how fall armyworm and stem borer damage affects leaves. In close examination, it is easy to discover which of the two is responsible for the damage because holes that are made by fall armyworm larvae have smooth edges while holes that are made by larvae of stem borer show ragged edges (Goergen *et al*., 2016).

2.7. Influence of plant combinations on the behavior of fall armyworm

The traditional methods include companion cropping of maize with a repellant plant like desmodium (*Desmodium incinatum*) and bordering the intercropped field with attractive plant like Napier grass (*Pennisetum purpureum*). The repellant plants repel fall armyworm moths away from their host crops and are attracted to the trap plant (Khan *et al*., 2010). It is difficult for fall armyworm moths to identify their host especially when plants are intercropped in the same plot and this arrangement favors natural enemies of the fall armyworm larvae (Hilje *et al*., 2001). Additionally, hiding of the host and encouragement of natural enemies slows down growth of fall armyworm populations and lower the need to use pesticides and increase crop yield (Parker *et al*., 2013). According to Schuster (2004), when a tomato plot was bordered with marrows, the population of tobacco white flies (*Bemisia tabaci*) decreased. According to Medeiros *et al*. (2009), Companion cropping of tomatoes with coriander favors predatory arthropods, coinciding with peak of tomato leaf miner, *Tuta absoluta*, populations.

According to Auger (2005), repellant plants possess volatile that can affect pest development and favors growth of host plant. Alternating of wheat with alfalfa (*Medicago sativa*) as a biological control method for the cereal aphid

(*Macrosiphum avenea*) by the mite (*Allothrombium ovatum*) was studied by (Zhang *et al.,* 2007). Wheat - garlic intercropping can lower the population of wheat aphids (*Sitobion avenae*) by increasing their predators (Wang *et al*., 2008). The effects of companion cropping to control aphids and increasing their predators was studied in wheat, oilseed rape (*Brassica napus*), cowpea (*Vigna unguiculata*), and pea (*Pisum sativa*) (Wang *et al*., 2009). However, numerous reports about repellant volatiles' failures on reducing insect pests in the field have been reported (Moreau & Hoyle, 2006).

It is a well-known fact that many botanical species frequently coexist in nature; it appears that plants have certain preferences in terms of their companionships. Some of these relationships are also very effective in controlling pests, keeping them away from their host plants and provide habitat for predators and parasitoids (Parker *et al*., 2015). For instance, onion has been discovered to be a helpful companion plant for several veggies. Lettuce (*Lactuca sativa*), broccoli (*Brassica oleracea*), carrots (*Daucus carota*), beet root (*Beta vulgaris*), and lettuce (*Lactuca sativa*) because it repels the green peach aphid (*Myzuspersicae*), one of the most pervasive and destructive phytophagous insects and also other insect pests (Lakmali *et al*., 2007). Intercropping can protect the crop because the non-host crop can operate as a physical barrier to insect pests, release compounds that repel insect pests or chemicals compounds that attract their predators (Parker *et al*., 2015), release repellent chemicals to insect pests or chemicals that attract their predators (Letourneau *et al.*,2011).

2.8. Management of fall armyworm

The ability to detect infestation of fall armyworm is essential for its management before it causes economic damage (Ferreira, 2015). Black light pheromone traps can be used to catch the flying moths for the purpose of monitoring fall armyworm populations. The traps need to be suspended at canopy height after the maize crops have reached the whorl stage. The black light trap catches can be used to determine whether the pests exist or not, but they do not always represent a good population density. Cultural practices, biological, botanical, and synthetic pesticides are additional management practices for the fall armyworm (Viana, 2003).

2.8.1. Detection and monitoring

Applying an efficient fall armyworm management measure in maize crops is recommended when 20% of the whorl leaves of young maize plants are damaged by fall armyworm within the first month in order to stop further damage (Fernandez, 2000). Currently, a synthetic mixture of sex pheromone compounds is used as a lure to monitor adult fall armyworm male populations (Mitchel *et al*., 1989). Chemicals other than sex pheromones have been tested as fall armyworm moth attractants (pests).

2.8.2. Cultural control

Local control measures are important pest management strategies for a number of pests of which fall armyworm is inclusive (FAO, 2018). As a result, the most farmers employ a variety of cultural pest control techniques that either scare away pests or kill them, like intercropping, collecting and kill caterpillars, applying wood ash and put soil to leaf whorls (Kamanula *et al*., 2011). The study carried out by Kumela *et al*. (2018).in Ethiopia and Kenya revealed that 39% of farmers used traditional measures like handpicking for managing fall armyworm

2.8.3. Biological control

The fall armyworm migration from breeding sites makes its natural predators less efficient. However, it has been discovered that certain biocontrol agents have been found effective in managing the fall armyworm. According to FAO (2018), FAW has been successfully controlled by the use of biopesticides, particularly from the bacterium *Bacillus thuringiensis* (Bt), fungi (*Beauveria bassiana*), and *Baculo viruses*. Additionally, these biotic agents help minimize maize leaf defoliation (Molina-Ochoa *et al*., 2003). According to Pilkington *et al.* (2010), the fall armyworm has been successfully controlled by a number of microbial pathogens and arthropod bio-control agents.

2.8.3.1 Parasitoids

Many insect pests have been reported feeding on fall armyworm eggs and larvae. According to Sisay (2018), FAW larvae were found in eleven districts of Ethiopia containing three parasitoid species like *Palexorista zonata* (Diptera: Tachinidae), *Cotesia icipe* (Hymenoptera: Braconidae) and *Charopsater* (Hymenoptera: Braconidae). The *Cotesia icipe* parasitoid emerged in fall armyworm larvae in Hawassa, Jimma (South west Ethiopia), and Awash Melkassa. The parasitoids ranged from 33.8 - 45.3% in Jimma and Awash Melkassa. *Charopsater* and Tachinid flies *Palexorista zonata* was at only 6.4%.

2.8.3.2. Predators

Natural enemies of fall armyworm are generally those that attack the larvae of other lepidopteran species. Ground beetles (*Calleida decora*), tiger beetles (*Cicindela*), striped ear wing (*Labidurariparia*), spined soldier (*Podisusma culiventris*), and lady birds (*coleopteran coccinellidae*) are the main predators of fall armyworm (Capinera, 2017). The adults and larvae stage of lady birds attack a variety of phytophagous insects, including mites, aphids, scales, and mealy bugs, as well as eggs and young larvae of fall armyworm (FAO, 2018).

2.8.3.3. Entomopathogens

Fall armyworm larvae are susceptible to 16 different entomopathogen species, like viruses, fungi, protozoa, and nematodes (Molina-Ochoa *et al*., 1996). According to Lezama-Gutierrez *et al*. (2001), the pathogens *Bacillus thuringiensis*, *Metarrhizium anisopliae*, and *Beauveria bassiana* significantly reduce fall armyworm population and leaf defoliation in maize crops. According to Lezama-Gutiérrez *et al*. (2001), fungal pathogens including the White muscadine fungus (*Beauveria bassiana*) and the Green muscadine fungus (*Metarrhizium anisopliae*), affect fall armyworm larvae. Many of them naturally occur in the population of fall armyworms, and some of them induce natural epizootics (Gardner & Fuxa, 1980). According to Molina-Ochoa *et al*. (2003), naturally occurring parasitic nematodes and entomopathogenic nematodes caused 3.5% of the fall armyworm larval mortality in Mexico. From fall armyworm larvae, the scientists isolated three entomopathogenic fungus species, representing two different classes: Zygomycetes (*Entomophthora sp*), Metarhizium rileyi (*Nomuraearileyi),* Hirsutella (*Ophiocordycipitaceae: Hypocreales*), Hyphomycetes (*Nomuraearileyi*), Geen muscardine fungus (*Metarhizium anisopliae*), and White muscardine fungus (*Beauveria bassiana*) from soil samples.

2.8.3.4. Use of botanical insecticides

Research to identify environmental friendly methods for pest management has been the top agenda due to the impacts resulting from use of synthetic insecticides. In less developed countries, farmers have applied botanical insecticides to manage insect pests in field crops and stored produce for centuries due to their cost and availability (Schmutterer, 2009). Neem (*Azadirachta indica*), Broad-leaved Croton (*Croton macrostachyus*), African soapberry (*Phytolacca dodecandra*), Purging Nut (*Jatrophacurcas*), Tobacco (*Nicotiana tabacum*), and Pyrethrum (*Chrysanthemum cinerariifolium*) are just a few of the botanicals that were successfully used to control insect pests (Schmutterer, 2009). Some of these plants have one or more beneficial properties, like ability to lower insect resistance, oviposition, deterrent, growth disrupters, biodegradability and repellency (Mochiah *et al*., 2011).

One of the plants studied against many insect pests and vectors is Chinaberry tree (*Melia azadirachta* (Charleston, 2004). Lepidopteran pests' growth is inhibited by the substance cisdehydrocroton which was isolated from the bark of broad-leafed croton (*Croton macrostachyus*) (Viegas, 2003). Neem seed cake's aqueous extract is much toxic than the leaf extract that farmers usually use to control fall armyworm larvae (Silva *et al*., 2015).

2.8.4. Use of synthetic insecticides

Insecticides are important management tools for the management of fall armyworms, (Capinera, 2017). However, high dosage of insecticide is needed to kill fall armyworm larvae that feed in the whorl leaves of maize plants. It may be applied in irrigation water where sprinkler irrigation is used, control of fall armyworm larvae in maize during vegetative period helps to lowerthe number of sprays required during the silking stage (Marenco *et al*., 1989). Although chemical pesticides can control fall armyworm, fall armyworm larvae develop resistance to majority of pesticides. (Yu *et al*., 2003) reported that fall armyworm strains got from corn in Citra and Florida, showed high resistance to carbaryl by 562-fold and methyl parathion 354-fold. Similarly, in Argentina, applying insecticides on corn to control fall armyworm did not reduce the population of the pest but rather diminish parasitoids establishment that can assist to reduce fall armyworm larvae population (Virla *et al*., 2008).

2.8.5. Use of pheromone traps

Tools for investigating pest population growth in surveys and integrated pest management (IPM) strategies are pheromone traps. These pheromone traps help to identify pest invasion, pest emergence, severity of pest damage and changes in pest populations that assist in making decision for pest management. Insect pests are often attracted to traps by attractive chemical or visual cues or stimuli (Wyatt, 1997). Pheromone traps are the essential strategy for controlling insect pest populations (Spears, 2016). Pheromones for lepidopteran pests have been successful in monitoring of many insect pests, pest trapping, mating interrupt, and for diverse of insect pests (Wyatt, 1997).

Pheromone traps for monitoring fall armyworm moths shows demand of managing fall armyworm months in maize particularly when placed in field soon after planting (Cruz *et al*., 2010). The use of fall armyworm sex pheromones have been in America and showed to be an essential strategy for fall armyworm male moths monitoring (Adams *et al*., 1989). A multi component sex pheromone is used as a trap to monitor the population of adult male fall armyworm moths in agricultural system

2.8.6. Host plant resistance

Crop varieties with improved fall armyworms resistance have been developed through breeding programs for example maize (Mihm *et al*., 1988). An example of resistance mechanism of maize crops is leaf toughness and thicker epidermis (Davis *et al*., 1995). In order to resist fall armyworm infestation, transgenic maize containing delta-endotoxins gene from *Bacillus thuringiensis* has been commercialized in America and Brazil. During the vegetative growth, vegetative insecticidal proteins (vip) from *Bacillus thuringiensis* (Bt) have been isolated, and they exhibit a broad range of spectrum against lepidopteran pests, including fall armyworm (Estruch *et al*., 1996). These toxins control fall armyworm but development of resistance against such toxins is a great concern (Moar *et al*., 1995). Field-evolved resistance to Bt maize that expresses the Cry 1Ab protein is reducing its efficiency in Brazil (Omoto *et al*., 2016). Most of Bt maize hybrids lost their potential to manage fall armyworm in three years of being introduced to Brazil (Fatoretto *et al*., 2017).

2.8.7. Integrated pest management for fall armyworm

The integrated management of fall armyworm as the maize pest is comprised of cultural practices, biological control, botanical extracts, monitoring insect populations, crop management practices and judicious use of chemicals among others. According to Bista *et al*. (2020), managing fall armyworm infestation with a single strategy is un sustainable. As a result, various methods are applied in an integrated way to manage fall armyworm infestation. However; these must be used in a way that ensures sustainability and economic return while also being less harmful to man and the environment (Bateman *et al*. 2018).

Detection of fall armyworm infestation before it reaches economic damage is important. According to Fernandez (2002), use of control measures in maize is recommended only when 20% of the whorl leaves of small plants are infested with fall armyworm (within the first 30 days). According to Assefa and Ayalew (2019), the fall armyworm larval stage is the most effective time to manage the fall armyworm with timing morning, afternoon or evening when they are active.

2.8.8 Use of Push- Pull Technology in fall armyworm management

Push-pull is a strategy in which companion plants are planted around and between the main crops. The companion plants emits volatiles that repel fall armyworm moths from the main crop in which it is used as an intercrop and attract fall armyworm moths away from the main crop where it is used as a trap crop (Cook *et al*., 2007).

Plant diversity, like intercropping system and growing of many crop varieties, reduce oviposition by confusing female fall armyworm moth and helps to lower the level of fall armyworm damage. According to FAO (2018), a climate-adapted version of push-pull has been effective in management of fall armyworm damage, offering an environmental friendly strategy for managing this pest. This technology is comprised of companion cropping of maize with a repellant plant, like desmodium and surrounding this intercrop with *Brachiaria cv. Mulato* II. Maize protection is provided by volatiles generated by the border crop that attract (pull) stem borer moths whereas those released by the intercrop repel (push) them. When Greenleaf desmodium was used in a push-pull system, maize stem borer population and damage were significantly reduced compared to maize mono crop (Khan *et al*., 1997). The stem borer moths are repelled by the volatile compounds that Greenleaf desmodium releases. Hexanal, (E)-2-hexenal, (Z)-3-hexen-1-ol, and (Z)-3-hexen-1-yl acetate are the primary volatiles in this mixture (Chamberlain *et al*., 2006).

Intercropping of wheat with garlic can lower the population of wheat aphid by increasing their predators, (*Sitobion avenae*) (Wang *et al*., 2008). In a test for fumigation, diallyl disulfide from garlic (Edris and Fadel, 2002), possess insecticidal action against larvae of the Japanese termite (*Reticulitermes speratus*) and mushroom fly (*Lycoriella ingénue*) (Park *et al*., 2006).

Research conducted in western Kenya showed that companion cropping of maize with molasses grass (*Melinis minutiflora*) reduced spotted stem borer (*Chilopartellus*) damage in maize crop fields, and also promotes Braconid wasp (*Cotesia sesamiae*) as its parasitism (Khan *et al*., 1997). Molasses grass (*Melinis minutiflora*) released volatile compounds that attract female Braconid wasps (*Cotesia sesamiae*) and repelled female stem-borers (Khan *et al*., 1997). Molasses grass (*Melinis minutiflora*) contains the active substances (E)-ocimene, (E)-4, 8-dimethyl-1, 3, 7-nonatriene, b-caryophyllene, humulene, and a-terpinolene (Pickett *et al*., 2006). Stem borer moths also prefer Brachiaria species for oviposition over maize and sorghum (Midega *et al*., 2011). Moths lay eggs on preferred crop because it emits attractive chemical compounds than the mean cereal crop. The foliar tissue of Congo signal grass (*Brachiaria brinzatha*) when fed by stem borer larvae, produces a sticky sap that traps and kill roughly 80% of the stem borer larvae (Khan *et al*., 2006). Garlic, molasses grass, and green leaf desmodium have been reported to release volatiles that repel different insect pests (Midega *et al*., 2009; Khan *et al*., 2001; Tamiru *et al*., 2015; Cook *et al*., 2007). The time of planting determines the growth of garlic because a combination of a short photoperiod and low temperature encourage vegetative growth while a prolonged photoperiod with high temperature promotes bulb production. The growth and developmental of garlic bulbs are influenced by sowing date and plant age (Bayan *et al*., 2014). Up until bulbing is initiated, plant growth increases until bulbing is initiated (Kamenetsky, 2004). The formation of bulbs, vegetative growth, and reduced production are all affected by extremely high or heavy humidity and rainfall. During its growing period, garlic is stressed by insufficient moisture and water logging (Rubatzky and Yamaguchi, 1997).

Greenleaf desmodium is a summer growing perennial. The favorable temperature ranges between 25–30°C. In the tropics, it performs better at an altitude of 500 and 2500 meters above sea level. It can be grown in regions with annual rainfall of above 900mm up to 3000mm. It is more susceptible to drought throughout the growing season than silver leaf desmodium, and it can withstand flooding and water logging better. Greenleaf Desmodium is resistant to shade and may thrive on a variety of soil types with a pH range of (4.5-5) and without saline conditions (Hacker, 1992).

Being a grass that is commonly used as cattle fodder and can survive in poor soils, molasses grass is also very invasive (Hoffmann *et al*., 2004). Molasses grass survives better at a temperature range of 14°C - 27°C. This plant grows between 300 and 2400 meters above sea level in tropical and subtropical regions. It naturally grows where annual rainfall ranges from 750 to 2500m, but mostly between 1000 and 2000m. The plant is tolerant to dry season of up to five months. Additionally molasses grass can withstand moderate fire, and if burned, it quickly regenerates from the remaining portions. Plants are resistant to animal trampling after they have established (Cook *et al.*, 2005). The intension of including garlic was to use garlic as a repellent plant as its volatiles are reported to be effective in insect pest management.

2.9. Effect of fall armyworm on maize yield, growth and economic benefit

Day *et al*. (2017) study showed that fall armyworm larvae cause maize yield losses between 45 – 67 percent annually in countries affected by fall armyworm in addition to other cereal crops that cost more than $6.2 billion annually. The most destructive stage of fall armyworm is larva which feeds on leaf whorls, ears, and tassels and as a result, maize crops suffer significant damage and results in large grain yield losses (De Almeida *et al*., 2022). Late larval instars can cut young maize seedlings base and kill the entire plant (Harrison *et al*., l 2019).

When fall armyworm larvae feed on leaf whorls, photosynthesis is interrupted due to destruction of the photosynthesis mechanism, and when maize tassels and silk are cut, it affects pollination, lower fertility, kernel failure and reduced maize yield (Darby and Lauer, 2000). Fall armyworm larvae have the ability to cut maize seedlings up to ground level, while mature plant leaves are defoliated and this affect growth. If large number of fall armyworms is present, young seedlings may suffer severe loss (Heinrichs *et al*., 2017).

Fall armyworm being a maize pest boost diversity of Lepidopteran pests of cereal crops and increases negative effects on agricultural production and food security in Africa. Fall armyworm increases costs through labor required and the skills required to deal with the pest, high yield losses and financial costs incurred in its control (Shylesha *et al*., 2018).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study location

Field experiments were done at National Crops Resources and Research Institute (NaCRRI) Namulonge Wakiso District between April and August 2019. Namulonge is found in Central Region of Uganda in the North Kyaddondo Constituency, Kyaddondo County, and Wakiso District. Namulonge is located in latitude 00 31 30 and longitude 32 36 54. (Latitude: 0.5250; longitude: 32.6150). The climate around Namulonge is categorized as tropical by the Koppen-Geiger system with an average temperature of 21.7°C annually (https://en.climate-data.org.>). Uganda 2012 (accessed on 18. June. 2020). The central region experiences average rainfall of 1242 mm annually and the rain fall is significant in most moths of the year and the short dry season has little impact on crop production climate-data.org (https://en. Uganda 2012 (accessed on 18. June. 2020). The pH of the soil at the test site was 4.9 (https://en.climate-data.org > Uganda 2012). The soil type was sandy, clay, and loam (accessed on18. June. 2020).

3.2. Experimental design and treatments

Experimental plots measuring 8 x 7m were planted with Bazooka maize variety spaced at the recommended spacing 0.75x 0.60m which was considered to accommodate sufficient population of maize plants for sampling during data collection. Bazooka maize variety was released by National Agriculture Research Organization (NARO) in 2002 and its maturity period is 125 days. Its positive attributes are resistance to lodging, drought and maize lethal necrosis

(MLN) tolerant. The recommended planting density of this is 0.75 x 0.60m, with one seed per hill, and its expected yield is 3200-3600 kg/ha. This variety was chosen because it is most susceptible to fall armyworm larvae infestation in comparison with other maize varieties in the region (Dr. Otim Michael, pers. comm.). The Bazooka maize seeds were obtained from Nalweyo Seed Company (NASECO) in Kampala, Uganda.

Inter-plot spaces measuring 1m were, maintained. Each plot was surrounded by two lines of Brachiaria spaced at 0.75x 0.75m. For the case of control experiment, no border crop was planted around the plot. The intercrop in each experimental plot, i.e.desmodium, molasses, or garlic, was planted at the same time with maize, and no fertilizers were applied

The treatments consisted of:

(i) Desmodium + Brachiaria = Maize intercropped with green leaf desmodium and bordered with *Brachiaria brinzatha* (Figure 3-A).

(ii) Molasses grass + Brachiaria = Maize intercropped with molasses grass and bordered with *Brachiaria brinzatha* (Figure 3-B).

(iii) Garlic + Brachiaria = Maize intercropped with garlic bordered with *Brachiaria brinzatha* (Figure 3-C).

(iv) Control (sole maize) = Sole maize, with no intercrop and border plant (Figure 3-D)

These treatments were laid in a randomized complete block design (RCBD) replicated three times. All experimental plots were weeded as and when necessary.

Figure 3: Experimental treatments: A = Desmodium + Brachiaria; B = Molasses grass + Brachiaria*;* C = Garlic + Brachiaria*;* D = Control (Sole maize)

3.3. Data collection

3.3.1. Effect of different push pull plant combination on maize growth and fall armyworm damage

Data collection started two weeks after emergence. Data recorded include number of maize plants infested by fall armyworm larvae, plant height, and also stem girth as described below:

(a) ***Fall armyworm infestation*****:** Infestation levels of fall armyworm in each plot were assessed by counting number of maize plants affected by fall armyworm at every two 2-week interval using the methodology adapted from (Midega *et al*., 2015).

The number of plants infested by fall armyworm in each experimental plot were summed up and then divided by the total number of plants in each experimental plot and expressed as the fall armyworm infestation in each plot.

(b) Plant height (cm): The height of 10 plants randomly selected at each sampling occasion were measured using a carpenter's tape measure at two-week interval starting from week 2 until week 16 after plant emergence. The zero-end of the tape measure was placed at the ground level and height recorded to the tip of the terminal leaf. Mean height for the ten plants was then computed and recorded for each plot.

(c) ***Stem girth***: Stem girth was measured using a thin cotton thread which was placed around the stem, 8cm above the ground level to obtain the circumference. The thread was then laid onto a ruler to read off the measurement.

3.3.2. Effect of different push – pull plant combinations on maize yield component

a) Maize grain yield**:** At physiological maturity, all the maize cobs in each experimental plot were harvested and then sun dried separately. Then the maize cobs were shelled manually and the maize grain sun dried to 12 percent moisture content confirmed by use of moisture meter (multi grain tester), and the grain weight (kg) for each individual plot were individually recorded. The grain weight was computed per plot area harvested and the yield data converted to kg/hectare, to determine the total maize yield of individual experimental plot.

(b) Cob length: The cob length was assessed by randomly selecting 10 de-husked cobs from the bulk harvested from each plot. The length of each cob was then carefully measured using thin cotton thread which was put from end to end of the cob then the thread was transferred to a ruler to read off the measurements in centimeters. The mean length of the ten cobs was then computed and recorded.

(c) Cob girth: Cob girth was obtained by randomly selecting 10 dehusked cobs from each harvested maize plot by using a thread which was put at the middle region of the cob and then transferred to a ruler to read off the measurements in centimeters. The mean girth of ten cobs was then computed and recorded.

(d) Weight of 100 seeds**:** A hundred grains from each plot were weighed by the use of electronic balance at moisture content of 12% and then the mean was computed.

(e)Number of grain lines: Number of grain lines was obtained by selecting 10 cobs at random from each plot. The number of grain lines was then counted and the mean number of grain lines per cob then determined.

3.3.3. Economic benefit of different push pull plant combinations in management of fall armyworm in maize

Benefit: Cost ratio was done according to procedures described by Shabozoi *et al*. (2004), with slight modification. As per recommended spacing of 0.75 x 0.6m, the benefit per acre was computed by subtracting total revenue per acre of sole maize from the treatments' total revenue per acre and the product was divided by the total treatment costs per acre. The total revenue per acre was calculated by multiplying the total yield from each treatment with the price. Finally, the Benefit: Cost ratio (B: C ratio) was computed by subtracting the revenue of control plot from the total revenue. The products were divided by per acre expenses

3.4. Data analysis

The data on number of plants infested by fall armyworm, plant height (cm), plant girth (cm), cob length (cm), cob girth (cm), weight of 100 seeds (g), number of lines on the cob of maize, and maize yield (kg) were subjected to analysis of variance (ANOVA) to determine whether there were significant differences in the effect of treatments to derive comparison between different treatments. This allowed for comparisons between the various treatments. The Significance level was set at $\alpha = 0.05$. All data analyses were conducted using Genstat 15th Version. Differences in means were separated using Ryan multiple comparison. Before data analysis, data were tested for its normal distribution and it was transformed prior to analysis.

CHAPTER FOUR: RESULTS

4.1. Effect of different push – pull plant combinations on maize growth and fall armyworm damage

4.1.1. Effect of different push pull plant combination on maize growth

(i) ***Plant height:*** Plant height generally increased steadily from week 2 up to week 14 after emergence and later becomes constant during both seasons the first season (Figures 4a and b). Overall, there was no significant difference ($P > 0.05$) in the final plant height at week 16 for both seasons (Table 1). The highest and the lowest plant height were obtained from the treatment molasses grass + Brachiaria and sole maize, respectively.

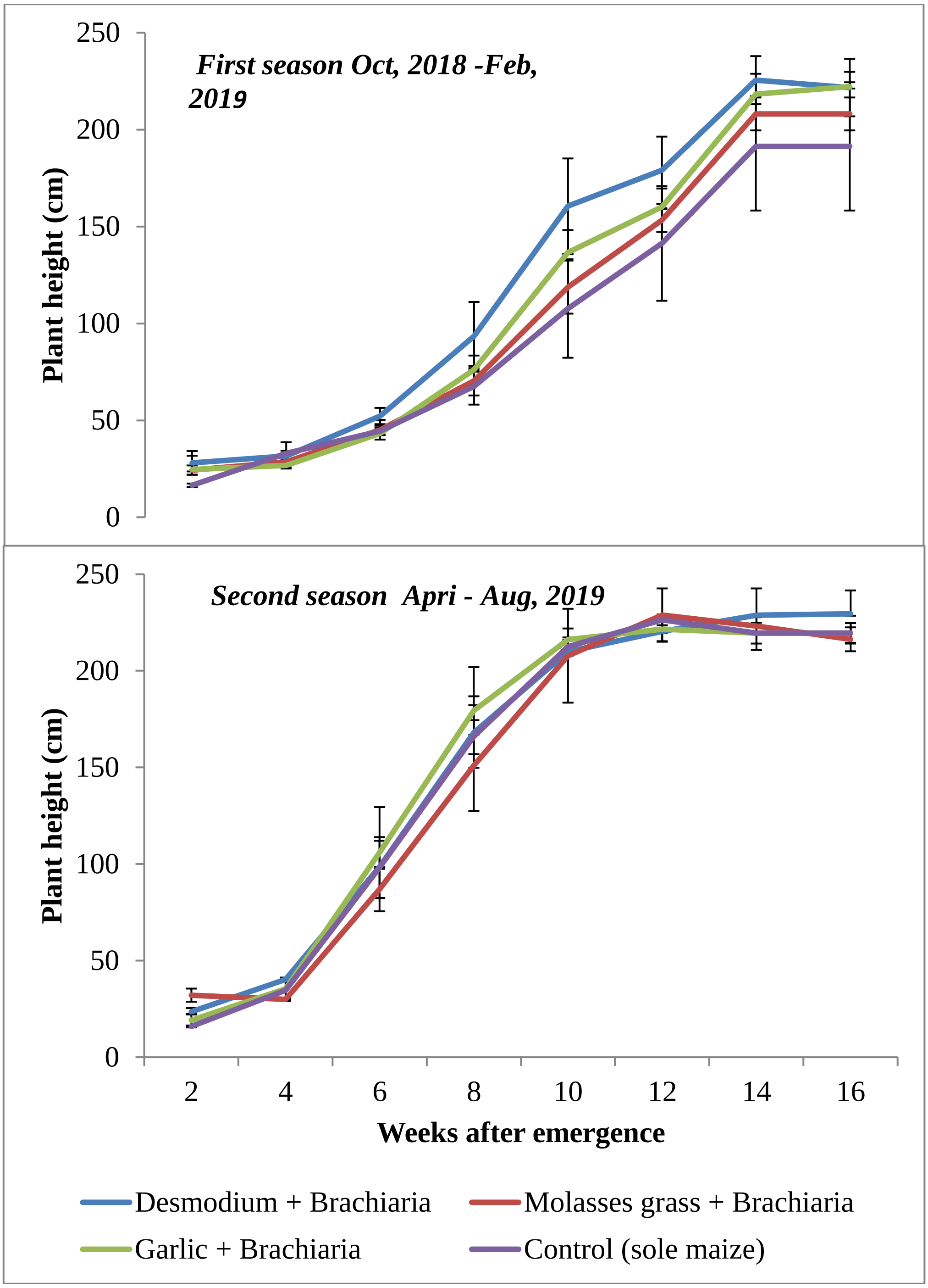

Figure 3a: Maize plant height over time under different push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

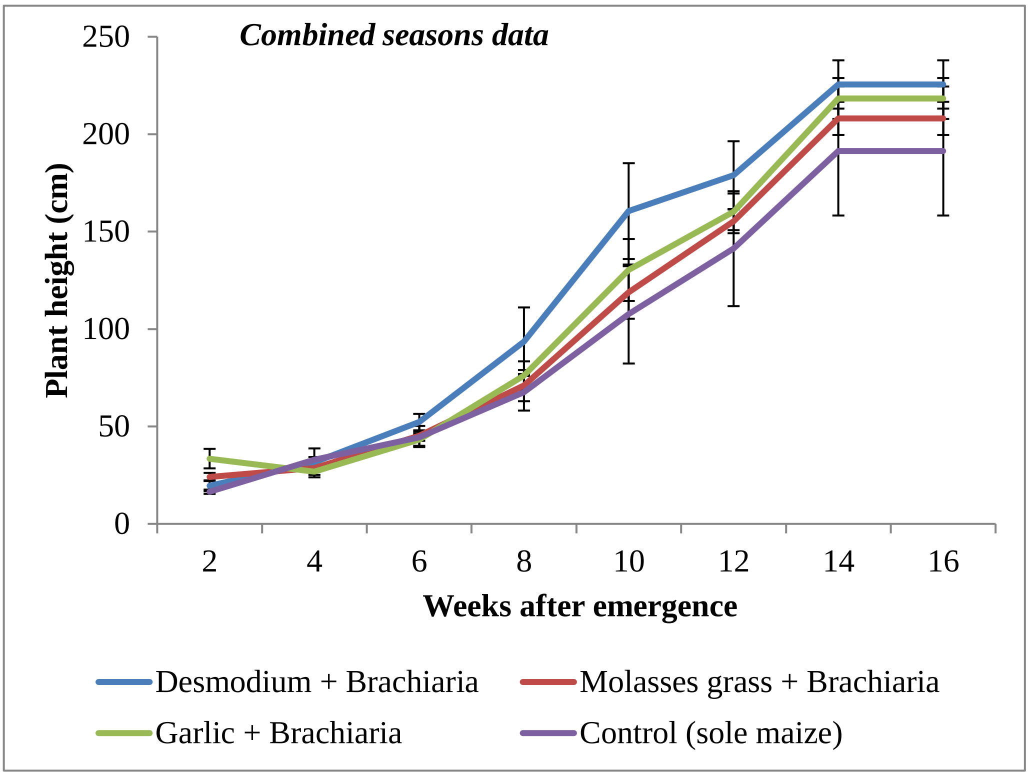

Figure 4b: Maize plant height over time under different push - pull plant combination for two seasons average

Table 1: Maximum maize plant height (cm) grown under different push - pull plant combination at WAEfor two seasons at NaCRRI, October, 2018- February, 2019 and April- August, 2019

	Plant height (cm)		
Treatment	**First season (Oct 2018 – Feb, 2019)**	**Second season (Apr – Aug, 2019)**	**Two – seasons average**
Desmodium + Brachiaria	218.3±0.69	223.2±0.30	228.0±0.28
Molasses grass + Brachiaria	208.1±0.46	228.9±0.49	219.2±0.44
Garlic +Brachiaria	225.5±0.59	219.5±0.35	214.3±0.33
Control (sole maize)	191.4±1.00	219.6±0.97	223.0±0.51
P.value	**0.45**	**0.46**	**0.43**
Df	**3**	**3**	**3**
LSD	**50.52**	**0.9**	**50.01**

(ii) **Stem girth**: Stem girth increased steadily from week 2 up to week 10 and started declining up to week 14and thereafter became constant in both seasons (Figure 5a and b). Overall, there was significant difference P < 0.05) in stem girth among the treatments from week 2 up to week 16 in both seasons (Table 2). The highest and the lowest stem girth were recorded from plant combination of molasses grass + Brachiaria and Garlic + Brachiaria, respectively.

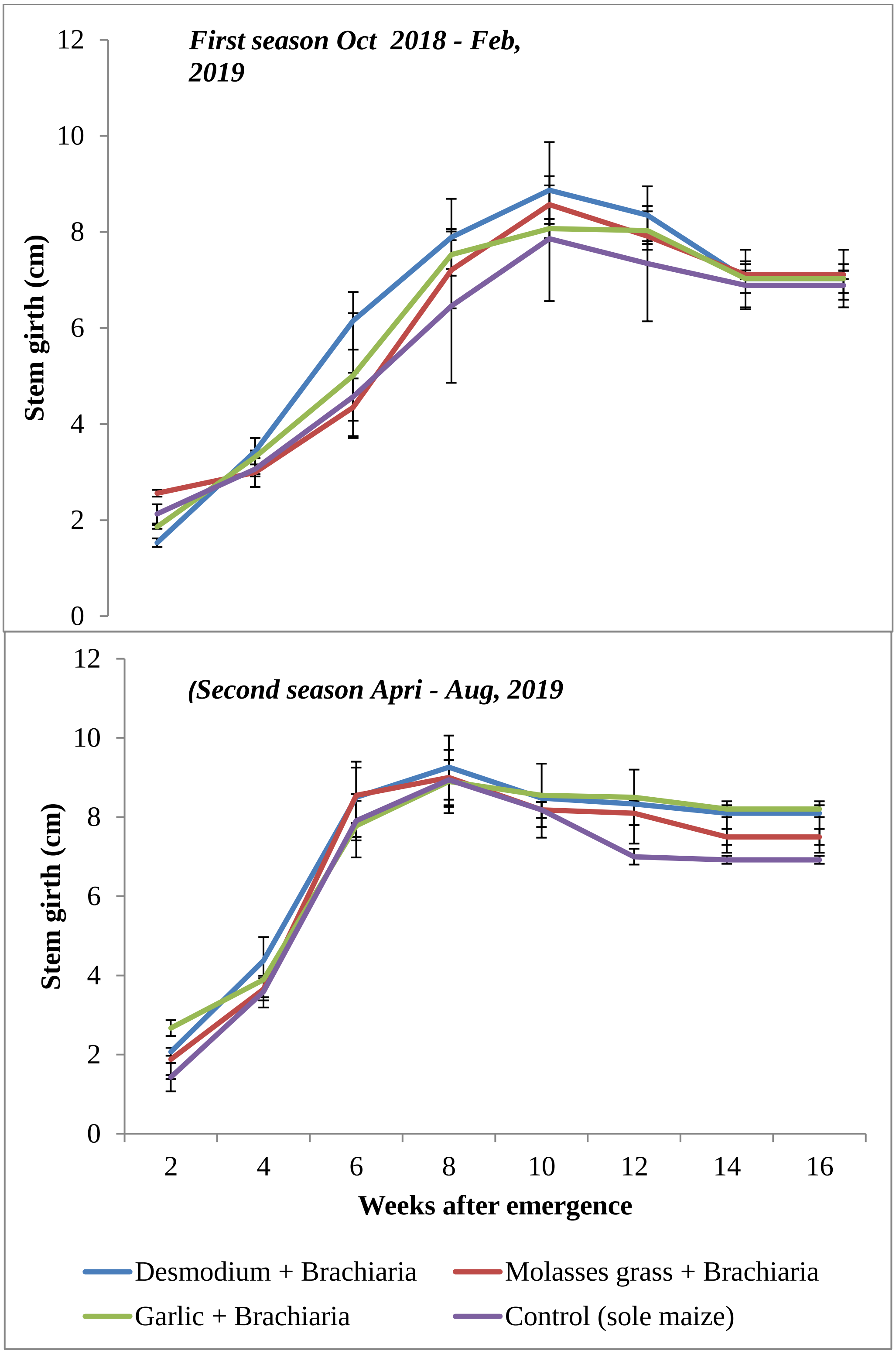

Figure 5a: Maize stem girth under different push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

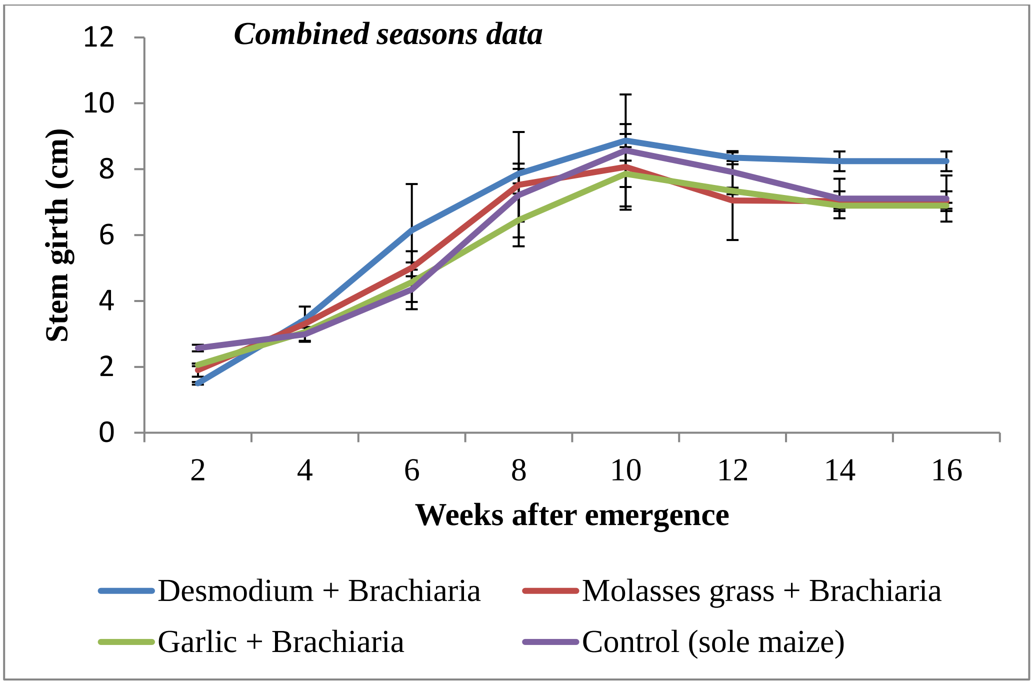

Figure 5b: Mean stem girth (cm) under different push - pull plant combination for management of fall armyworm for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Table 2: Mean maize stem girth (cm) under push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Treatment	Stem girth (cm)		
	First season (Oct, 2018 – Feb, 2019)	**Second season Apr – Aug, 2019**	**Two – seasons average**
Desmodium + Brachiaria	6.0±0.54ab	7.1±0.46	6.6±0.24b
Molasses grass + Brachiaria	5.7±0.38a	7.3±0.42	6.5±0.12b
Garlic + Brachiaria	6.6±0.69b	6.9±0.26	5.6±0.34a
Control (sole maize)	6.5±0.28b	6.9±0.18	6.1±0.48ab
P.value	**0.02**	**0.33**	**0.02**
Df	**3**	**3**	**3**
LSD	**0.64**	**0.47**	**0.64**

Means with the same letter (s) within a column are not significantly different at P = 0.05 .

4.1.2 The effect of different push – pull plant combination on the incidence of fall armyworm

The incidence of fall armyworm from the different push – pull plant combinations as presented in Figures 6a and b. The highest fall armyworm infestation was recorded in sole maize and the lowest was in plots of maize intercropped with desmodium during second season of April – August, 2019. Fall armyworm infestation was observed 4 WAE during first and second season. Fall armyworm infestation was consistently higher in sole maize plots throughout the two seasons of 2018 and 2019. Infestation steadily increased from week 4 up to week 12 and then became constant throughout the two seasons.

There was significant difference in fall armyworm incidence among treatments at 16 WAE during the second season of April - August 2019(P = 0.01), and when seasons were combined (P = 0.05) (Table 3). The highest and the lowest incidence of fall armyworm were recorded from the sole maize and Desmodium + Brachiaria, respectively.

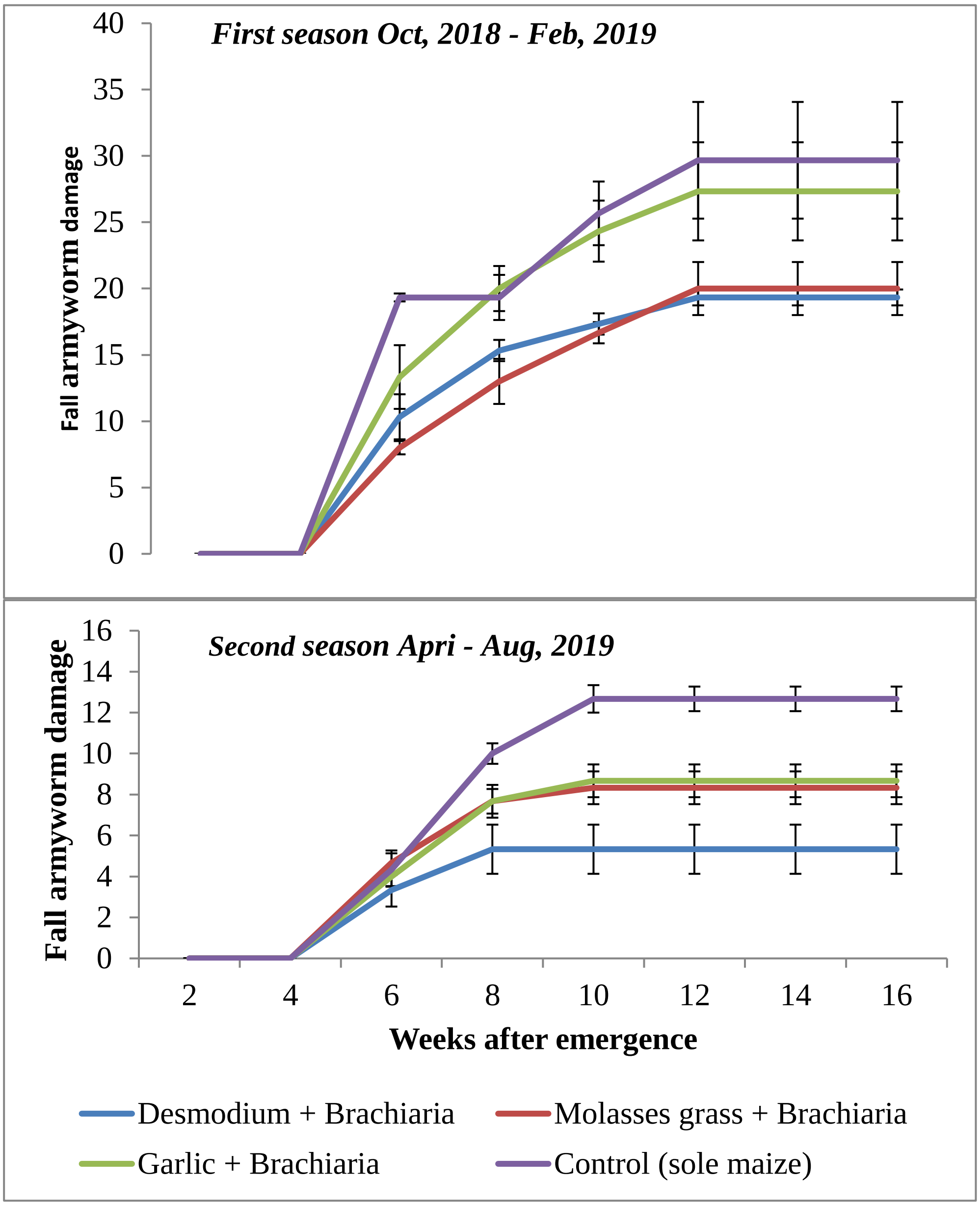

Figure 6a: Incidence of fall armyworm on maize grown under different push - pull combination at NaCRRI, for two seasons, October, 2018 - February, 2019 and April - August, 2019

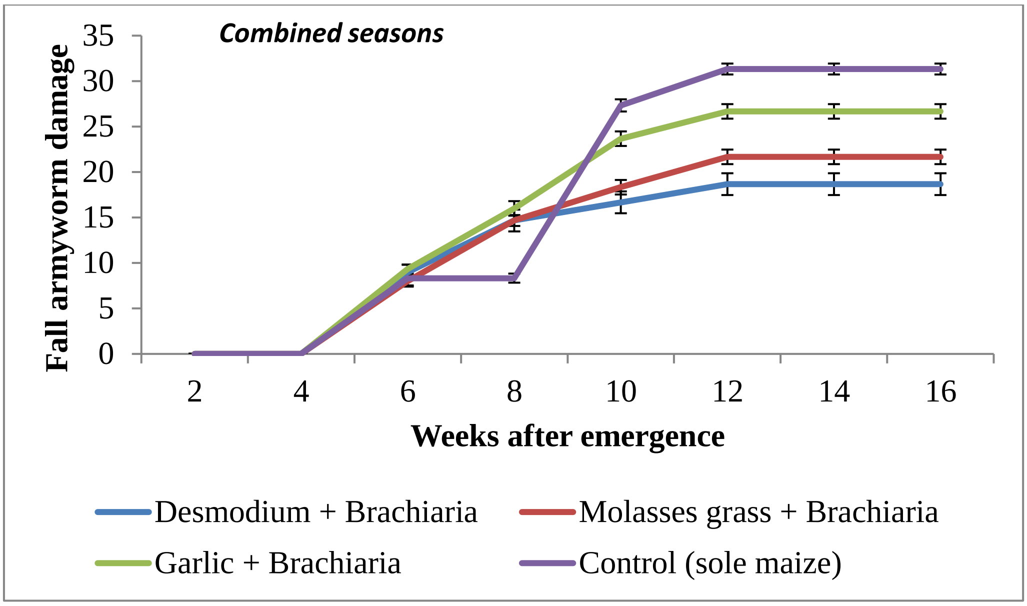

Figure 6b: Incidence of fall armyworm on maize grown under different push pull plant combination for two seasons average at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

.

Table 3: Mean infestation of fall armyworm on maize under different push - pull plant combination for two seasons at NaCRRI, October 2018 - February, 2019 and April - August, 2019

Treatment	**Mean number of FAW-infested plants**		
	First season (Oct, 2018 – Feb, 2019)	**Second season (Apr – Aug, 2019)**	**Two – seasons average**
Desmodium + Brachiaria	19.3±0.6	5.3±1.2a	18.6±0.6a
Molasses +Brachiaria	20.0 ± 2.0	8.3±0.8ab	21.6 ±1.7ab
Garlic +Brachiaria	27.3± 3.7	8.6±0.8b	30.0 ±3.5b
Control (sole maize	29.6± 4.4	12.6±0.6b	31.3±4.2b
P.value	**0.05**	**0.01**	**0.02**
Df	**3**	**3**	**3**
LSD	**8.27**	**3.66**	**7.96**

Mean with the same letters within a column are not significantly different at P = 0.05.

4.2. Effect of different push - pull plant combinations on yield of maize

(i) Cob length: There was significant difference in cob length among treatments during the first season of October 2018 – February 2019 (P = 0.009), during the second rainy season of April – August 2019, (P < 0.001) and in two – seasons average (P < 0.001) (Table 4). Desmodium + Brachiaria recorded the highest cob length (31.3 ± 1.0cm) while sole maize recorded the lowest cob length (8.6 ± 7.9cm).

Table 4: Mean cob length (cm) of maize under different push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Treatment	**Cob length (cm)**		
	First season (Oct, 2018 – Feb, 20119	**Second season Apr – Aug, 2019**	**Two - seasons average**
Desmodium + Brachiaria	31.3±1.0b	16.6±1.1c	24.6±1.1c
Molasses grass + Brachiaria	29.4±1.8a	12.9±7.5b	22.1±0.9b
Garlic Brachiaria	29.4±2.1a	10.1±0.4a	19.9±0.5a
Control (sole maize	29.4±2.1a	8.6±7.9a	18.7±1.3a
P.value	**0.009**	**<0.001**	**<0.001**
Df	**3**	**3**	**3**
LSD	**1.42**	**1.36**	**1.14**

Mean with the same letter (s) within a column are not significantly different at P = 0.05

(ii)Cob girth: There was significant difference P< 0.05) in cob girth among treatment for both seasons (Table 5). The highest cob girth (16.7 ± 6.5cm) was recorded from the plant combinations of Greenleaf desmodium + Brachiaria and the lowest cob girth (8.6 ± 1.7cm) was sole maize respectively.

Table 5: Mean cob girth (cm) under different push - pull combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

	Cob girth (cm)		
Treatment	**season 1 (Oct,2018 – Feb, 2019**	**Season 2 Apr – Aug, 2019**	**Two - seasons average**
Desmodium + Brachiaria	16.7±6.5b	16.6±1.1c	16.6±1.8c
Molasses grass + Brachiaria	12.9±9.9c	12.9±7.5b	12.9±1.6b
Garlic +Brachiaria	9.5±2.6a	10.1±0.4a	9.6±2.7a
Control (sole maize)	8.6±1.7a	8.6±7.9a	8.7±2.6a
P.value	**<0.001**	**<0.001**	**<0.001**
Df	**3**	**3**	**3**
LSD	**1.46**	**1.33**	**1.41**

Mean with the same letter (s) within a column are not significantly different at P = 0.05

(iii) Number of grain lines per cob

The differences between treatments on number of grain lines per cob was significant P< 0.05) among treatments during the first seasons (Table 6). The highest number of grain lines per cob was recorded in Greenleaf desmodium + Brachiaria and sole maize respectively.

Table 6: Mean number of grain lines per cob under different push - pull plant combination for two seasons at NaCRRI,October, 2018 - February, 2019 and April - August, 2019

	Number of grain lines per cob		
Treatment	**First season (Oct,2018 - Feb, 2019)**	**Second season Apr - Aug, 2019)**	**Two - seasons average**
Desmodium + Brachiaria	14.0±0.4b	12.5±5.5	13.2±0.35
Molasses grass +Brachiaria	13.1±0.4a	13.01±0.4	13.1±0.35
Garlic + Brachiaria	13.0±0.2a	13.3±0.1	13.0±0.2
Control (sole maize)	12.2±0.4a	13.3±0.3	12.8±0.4
P.value	**0.008**	**0.47**	**0.64**
Df	**3**	**3**	**3**
LSD	**0.75**	**1.31**	**0.86**

Means with the same letter (s) within a column are not significantly different at P = 0.05

(iv)Weight of 100 grains

There was significant difference (P< 0.05) in weight of 100 grains of maize among treatments during both the first and second season. The highest and the lowest weight were recorded from the plots of Greenleaf desmodium + Brachiaria combination and sole maize respectively (Table 7).

Table 7: Mean weight of 100 grains (g) under different push - pull plant combination for two seasons at NaCRRI, October, 2018 -February, 2019 and April - August, 2019

Treatment	**Weight of 100 grains (g)**		
	First season (Oct, 2018 – Feb, 2019)	**Second season (Apr – Aug, 2019)**	**Two – seasons average**
Desmodium + Brachiaria	13.8±0.35b	13.4±0.46c	12.7±0.7
Molassesgrass +Brachiaria	12.6±0.13a	12.6±0.18b	12.7±0.15
Garlic + Brachiaria	12.7±0.43a	12.1±0.48a	12.8.1±0.45
Control (sole maize)	11.7±0.43a	12.0±0.42a	11.9±0.57
P.value	**0.006**	**<0.001**	**0.45**
Df	**3**	**3**	**3**
LSD	**0.83**	**0.29**	**300.7**

Means with the same letter (s) within a column are not significantly different at P = 0.05

(v).Grain yield: There was significant difference (P< 0.05) in grain yield of maize among treatments during both two seasons and two – seasons average. The highest and the lowest maize grain yield were recorded from the Greenleaf desmodium+ Brachiaria and sole maize respectively (Table 8).

Table 8: Mean grain yield (kg) under different push - pull plant combination at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Treatment	**Maize grain yield (kg)**		
	First season (Oct, 2018 – Feb, 2019)	**Second season (Apr – Aug, 2019)**	**Two - seasons average**
Desmodium + Brachiaria	11.5±0.2b	12.6±0.8b	12.1±0.8c
Molasses grass + Brachiaria	6.6±0.5a	7.6±0.7ab	7.1±0.3ab
Garlic + Brachiaria	9.6±0.8b	11.3±0.8ab	10.5±0.2bc
Control (sole maize)	5.6±0.2a	6.3±0.2a	6.0±0.3a
P.value	**0.004**	**0.03**	**0.01**
Df	**3**	**3**	**3**
LSD	**2.46**	**4.21**	**3.22**

Means with the same letter (s) within a column are not significantly different at P = 0.05

4.3. Economic benefit of using different push–pull plant combinations for the management of fall armyworm in maize

(i) Production cost of maize

The production cost for maize was higher during the first season on plots with garlic + Brachiaria compared with cost of molasses grass + Brachiaria. However, during the second season, the production cost of maize was higher under garlic + Brachiaria as compared to those of molasses grass + Brachiaria. Overall, the production cost of maize was the same for other seasons although higher production cost was incurred during the first season than second season (Table 9).

Table 9: Production cost of maize under different push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Treatment	**Inputs (per acre)**		**Cost UGX (per acre)**		
	Season 1	**Season 2**	**Season 1**	**Season 2**	**Two-seasons average**
Garlic + Brachiaria	144.53 kg of garlic (@UGX 20,000)	144.53 kg of garlic (@UGX 20,000)	2,890,600	2,890,600	2,890,600
	216.8 bags of Brachiaria (@UGX 5,000)	**	1,084,000	**	542,000
	10 kg of maize seed (@UGX8,000)	10 kg of maize seed (@UGX8,000)	80,000	80,000	80,000
	Labor for planting garlic and Brachiaria (24 man days @UGX 5000)	Labor for planting garlic and Brachiaria (24 man days @UGX 5000)	120,000	120,000	120,000
	Labor for weeding garlic and Brachiaria (24 man days @UGX 5000)	Labor for weeding (24 man days @UGX 5000)	120,000	120,000	120,000
	Labor for harvesting Garlic and Brachiaria (12 man days @UGX 5000)	Labor for harvesting Garlic and Brachiaria (12 man days @UGX 5000)	60,000	60,000	60,000
	Treatment Total		**4,354,600**	**3,270,600**	**3,812,600**

Treatment	Inputs (per acre)		Cost UGX (per acre)		
	Season 1	Season 2	Season 1	Season 2	Two-seasons average
Desmodium +brachiaria	144.53 kg of desmodium (@UGX 15,000)	**	2,167,950	**	1,083,975
	216.8 bags of Brachiaria (@UGX 5,000)	**	1,084,000	**	542,000
	10 kg of maize seed (@UGX8,000)	10 kg of maize seed (@UGX8,000)	80,000	80,000	80,000
	Labor for planting Desmodium and brachiaria (24 man days @UGX 5000)	Labor for planting Desmodium and brachiaria (24 man days @UGX 5000)	120,000	120,000	120,000
	Labor for weeding Desmodium an db rachiaria (12 man days (@UGX5,000)	Labor for weeding Desmodium and brachiaria (12 man days (@UGX5,000)	120,000	120,000	120,000
	Labor for harvesting Desmodium and Brachiaria (12 man days @UGX 5000)	Labor for harvesting Desmodium and Brachiaria (12 man days @UGX 5000)	60,000	60,000	60,000
	Treatment Total		**3,631,950**	**380,000**	**2,005,975**
Molasses grass + Brachiaria	289 bags of molasses grass (@UGX 5,000)	**	1,445,000	**	722,500

Treatment	Inputs (per acre)		Cost UGX (per acre)		
	Season 1	Season 2	Season 1	Season 2	Two-seasons average
	216.80 bags of Brachiaria (@UGX 5,000)	**	1,084,000	**	542,000
	10 kg of maize seed (@UGX8,000)	10 kg of maize seed (@UGX8,000)	80,000	80,000	80,000
	Labor for planting Molasses grass and Brachiaria (24 man days @UGX 5000)	Labor for planting Molasses grass and Brachiaria (24 man days @UGX 5000)	120,000	120,000	120,000
	Labor for weeding Molasses grass and Brachiaria (24 man days (@UGX5,000)	Labor for weeding Molasses grass and Brachiaria (24 man days (@UGX5,000)	120,000	120,000	120,000
	Labor for harvesting Molasses grass and Brachiaria (12 man days @UGX 5000)	Labor for harvesting Molasses grass and Brachiaria (12 man days @UGX 5000)	60,000	60,000	60,000
	Treatment Total		**2,909,000**	**380,000**	**1,644,500**

**During second season, there was no buying and planting of Desmodium, Molasses grass, and Brachiaria since those planted in the first season were fully established, and therefore in the second season, there were no costs relating to those particular items.

(ii) Revenue from the treated

The revenue from the different push – pull plant combinations is presented in Table 10. Higher revenue was obtained from the Greenleaf desmodium + Brachiaria combination during first season and the lowest revenue was registered plots of molasses grass + Brachiaria during second season.

Table 10: Income from maize grown under different push pull plant combination for two seasons at, NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Treatment	**Products harvested (per acre)**		**Income (UGX) per acre**		
	Season 1	**Season 2**	**Season 1**	**Season 2**	**Two-seasons average**
Garlic + Brachiaria	192.7 kg of garlic	192.7 kg of garlic	3,854,000.0	3,854,000.0	3,854,000
	618 kg of maize grains	795 kg of maize grins	1,236,000	1,590,000.0	1,413,000
	289bags of Brachiaria	192.7 bags of Brachiaria	1,445,000	963,500.0	1,204,250
	Total		**6,535,000**	**6,407,500**	**6,471,250**
Desmodium + Brachiaria	457.6 bags of desmodium	433.5 bags of desmodium	2,288,000	2,167,500	2,227,750
	1148 kg of maize grains	1325 kg of maize grains	2,296,000	2,650,000	2,473,000
	481.7 bags of Brachiaria	433.5 8bags of Brachiaria	2,408,500	2,167,500	2,288,000
	Total		**6,992,500**	**6,985,000**	**6,988,750**
Molasses grass + Brachiaria	433.5 bags of molassess grass	337.2 bags of molasses grass	2,167,500	1,686,000	1,926,750
	972 kg of maize grains	1060 kg of maize grains	1,944,000	2,120,000	2,032,000
	289 bags of Brachiaria	192.7 bags of Brachiaria	1,445,000	963,500	1,204,250
	Total		**5,556,500**	**4,769,500**	**5,163,000**
Sole maize	771 kg of maize grains	819kg of maize grains	1,542,000	1,638,000	1,590,000
	Total		**1,542,000**	**1,638,000**	**1,590,000**

Table 11: Benefit: Cost ratio of maize grown under different push - pull plant combination for two seasons at NaCRRI, October, 2018 - February, 2019 and April - August, 2019

Season	Treatment	Total income (Per acre)	Total cost (Per acre)	Benefit (Per acre)	Benefit : Cost ratio
Season 1 (Oct - Feb, 2018)	Garlic+ Brachiaria	6,535,000	4,354,600	4,993,000	1.1
	Desmodium+ Brachiaria	6,992,500	3,631,950	5,450,500	1.5
	Molasses grass + Brachiaria	5,556,500	2,909,000	4,014,500	1.4
	Sole maize	1,542,000			
Season 2 (Apri-Aug, 2019)	Garlic + Brachiaria	6,407,500	3,270,600	4,769,500	1.5
	Desmodium+ Brachiaria	6,985,000	380,000	5,347,000	14.1
	Molasses grass + Brachiaria	4,769,500	380,000	3,131,500	8.2
	Sole maize	1,638,000			
Two - seasons average	Garlic + Brachiaria	6,471,250	3,812,600	4,881,250	1.3
	Desmodium+ Brachiaria	6,988,750	2,005,975	5,398,750	2.7
	Molasses grass + Brachiaria	5,163,000	1,644,500	3,573,000	2.2
	Sole maize	1,590,000			

CHAPTER FIVE: DISCUSSION, CONCLUSSIONS AND RECOMMENDATIONS

5.1. Discussion

The push-pull strategy that is regarded as an environmentally viable approach for IPM is based on an understanding of the mechanisms that govern the ecology of plants and insects and makes use of carefully selected repellent intercrops and attractive trap plants. This study aimed at assessing the potential of different push - pull plant combinations, namely, Greenleaf desmodium + Brachiaria, Molasses grass + Brachiaria, garlic + Brachiaria in managing FAW in maize. Generally, different plant combinations influenced fall armyworm infestation and maize crop growth and yield. The “push” plants used in this study namely, green leaf desmodium, molasses grass, and garlic have been shown to influence insect pest behavior (Midega *et al..,* 2009; Khan *et al.,* 2001; Tamiru *et al*., 2015; Cook *et al*., 2007).

According to a study by Tamiru *et al*. (2015), maize land race exposed to molasses, *Melinis minutiflora* volatile organic compounds in bioassays attracted the spotted stem borer wasp, *Cotesia sesamiae* (Hymenoptera: Braconidae) and deters *Chilopartellus* from egg laying on the exposed plants. According to earlier field study by Khan *et al*. (2001) showed a significant decrease in damage to sugarcane by the sugar cane stalk borer, *Eldana saccharina*, and an improvement in sugarcane growth when molasses grass was intercropped within sugarcane,. Additionally, the number of *Eldana saccharina* larvae in sugarcane was found to be lower in molasses grass treatment plots compared with the control plots.

Garlic too has been reported to influence insect behavior (Mtambo and Zeledon, 2000; Cook *et al*., 2007). Mtambo and Zeledon (2000) showed that companion cropping of garlic between strawberries reduced two-spotted spider mites in the field. A study conducted by Cook *et al*. (2007) revealed that garlic performed well than other treatment in management of English grain aphid, *Sitobion avenae,* when wheat was intercropped with garlic. However, in this study, garlic performed poorly as fall armyworm being a different pest might not be affected by the repellant volatile chemicals from molasses grass in the same way English grain aphid was affected.

The superior performance of green leaf desmodium + Brachiaria could also be attributed to the ability of desmodium, as a legume, to fix atmospheric nitrogen in the soil. This concurs with Khan *et al*. (2006) who noted that green desmodium improves soil fertility through nitrogen fixation, natural mulching, improves biomass, and control erosion.

Results of the current study showed lower numbers of plants infested by fall armyworm larvae in push-pull plots in comparison to the control. This could be due to the volatiles emitted by the "push" plants, namely green leaf desmodium, Molasses grass, and Garlic that repel female fall armyworm moths and also attract parasitoids (Khan *et al*., 2010). On the other hand, Brachiaria, the "pull" plant serves as a trap plant, and as such emits semiochemicals which are attractive to the female fall armyworm moth (Midega *et al*., 2009).

The observed better yield parameters exhibited by the push-pull plants relative to the control, could be a resultant of several interactions including FAW repellency from the maize plants by the “push” plants, attraction of the FAW from the maize plants to the “pull” plant, Brachiaria, and also the positive modification of the microclimate around the maize plants by these plants including nitrogen fixation, in the case of desmodium.

The results of Benefit: Cost B: C ratios indicate that Greenleaf desmodium + Brachiaria registered the highest ratio (14.1) while the lowest B: C ratio (1.1) was obtained from garlic + Brachiaria. This was due to less cost incurred in plots of green leaf desmodium + brachiaria and high revenue obtained from green leaf desmodium forage, more bags of maize grains harvested and more revenue obtained from Brachiaria in push pull plots with Greenleaf desmodium + Brachiaria as compared with other treatments.

5.2. Conclusions

The current study aimed at determining the effect of different push-pull plant combinations on maize growth, fall armyworm infestation, maize grain yield, and economic benefit. Different push-pull plant combinations recorded an increase in maize growth, reduced fall armyworm infestation, and increased maize grain yield in comparison with the control. Overall, green leaf desmodium + Brachiaria outperform the rest of the treatments in terms of cob length, cob girth, maize grain yield, fall armyworm infestation reduction and Benefit Cost ratio while Molasses grass + Brachiaria outperformed the rest of treatments in terms of maize plant growth.

5.3. Recommendations

- Green leaf desmodium + Brachiaria is recommended as the best push-pull plant combination for inclusion into fall armyworm IPM as it outperformed the rest of treatments in terms of reducing fall armyworm damage, increased maize grain yield and Benefit : Cost ratio.

- More studies should be done to further validate findings from the present study and more so under diverse agro-ecological conditions, as well as using different maize cultivars.

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