UNIVERSITY FOR DEVELOPMENT STUDIES

INFLUENCE OF ENHANCED EFFICIENCY FERTILIZATION ON FALL ARMYWORM (*Spodoptera frugiperda* J. E. SMITH) INFESTATIONS AND AGRONOMIC PERFORMANCE OF MAIZE (*Zea mays* L.)

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BY

FUSEINI ABDULAI

(B.SC. AGRICULTURE TECHNOLOGY)

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DECLARATION

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere. All other citations made from other research work have been duly cited.

Fuseini Abdulai

(Student) Signature:..................................... Date..................................

Supervisors'

Prof. Benjamin K. Badii

(Principal Supervisor) Signature:................................. Date:................................

Prof. Frederick Kankam

(Co-Supervisor) Signature:.................................. Date:.................................

ABSTRACT

Fall armyworm (FAW), still remains an important pest of many agricultural crops including corn. There is the need to use environmentally friendly to address this current menace. Field experiment was laid in randomized complete block design with three replications, using nine different fertilization regimes to evaluate the influence of enhanced efficiency fertilization on FAW infestations and agronomic performance of maize. Data were collected on FAW larval abundance, damage incidence and impact on yield. Economic viability of the treatments on maize production was also assessed. Fertilization significantly influenced maize plant growth and development. Unfertilized plot recorded significantly lower larval abundance and damage incidence compared to fertilization regimes, among the fertilization regimes, Yara NPK 15:15:15 (T15) with Croplift Bio basal (CLBb) + Amidas (AMI) with Croplift Bio topdress (CLBt) and Actyva (ACT) with CLBb + sulfan (SUL) + CLBt recorded significantly higher larval abundance and damage incidence whilst the least were recorded from CLBb + CLBt and none YARA NPK (NPK) + Sulphate of ammonia (SOA) + insecticide spray (IS). On grain yield, all the fertilization regimes obtained higher grain yield compared to no fertilization plot, among fertilization plots, CLBb + CLBt recorded significantly lower grain yield, though T15 + CLBb + URE (Urea) + CLBt and ACT + CLBb + Amidas (AMI) + CLBt yielded above all, there was no significant variation. All the fertilization regimes yielded more profit compared to no fertilization plot, among the fertilization regimes, CLBb + CLBt yielded lowest profit and cost-benefit ratio, whilst the highest profit and cost-benefit ratio obtained from T15 + CLBb + URE + CLBt. Application of T15 + CLBb + URE + CLBt or ACT + CLBb + AMI + CLBt is recommended for better management of FAW, maximized yield, as well as profit.

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DEDICATION

This thesis is dedicated to my family.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) is an economic important pest that depends on plant species, and has a muscular tendency for maize (FAO, 2017; Nboyine *et al*., 2021). Native to Americas, this polyphagous pest is an important invasive pest occurring in many countries including USA, Brazil and Argentina (Prowell *et al*., 2004: Clark *et al*., 2007). In south-west Nigeria and Ghana, the breakout of FAW was first reported in January, 2016 and sooner announced in other foreign lands in Africa; Sao Tome, Togo and Benin (Cock *et al*., 2017). This FAW has so far been advanced to not less than 21 countries (Abrahams *et al*., 2017: Stokstad, 2017). The host range of FAW is extremely broad, with more than 80 crop species documented, their favour is distinctly grasses (Huesing *et al*., 2018).

In Ghana, the pest was first reported in April, 2016 on maize field in the Eastern region of Yoilo Krobo District, it is presently found in all the 16 regions in the country (Abrahams *et al*., 2017; Asamani, 2020). FAW has a broad scale of host in Ghana, and maize is the principal host. The scope of host range of FAW is wide in Ghana, however, the main host is maize yet seriously affects sugarcane and cowpea in addition (Asamani, 2020). In 2017, a total of 249,054 hectares of corn farms were sprayed after infestation, from which 234,807 hectares recovered whilst the destroyed hectares were 14,247, with the indication of possibility for another invasions in the next cropping season (Tamakloe, 2018). Through the FAW invasion, about US$ 63.5 million have been assessed to have lost in Ghana. Research undertaken by CABI and released by the UK government estimated that the FAW invasion on maize field may cause Ghana up to $163 million in 2017 (Gakpo, 2017).

1.2 Problem statement

The utmost cited hosts of FAW include the following families: 35.5% *Poaceae*, 11.3% *Fabaceae*, 4.3% *Solanaceae* and *Asteraceae*, 3.7% *Rosaceae* and *Chenopodiaceae* while 3.2% for *Brassicaceae* and *Cyperaceae* (Casmuz *et al*. 2010). Despite the fact that FAW apparently showed a very vast host range, plant most often consumed are maize on field, sorghum and sweet corn (Capinera, 2017). As indicated by a survey, FAW has acquisitiveness and feed on over 80 species of plants, among others include maize, nuts, soybean, rice and vegetable crops (MoFA, 2017). During the outbreak season, FAW is perceived to gain from a large number of host plants, when particularly, there is relocation of the larvae from grasses that are wrecked to nearby plants. Usually, FAW feeds on sweet corn, field corn, Bermuda grass, sorghum, rice and other weed grasses. Other field crops that normally attacked by the FAW include, alfalfa, barley, cotton, millet, oat, sugar beet, sugarcane, ryegrass, tobacco and wheat (Sisay *et al*., 2018).

However, FAW main host in Ghana is maize, though it has a wide range in the country. The maize plant whorl is the hiding place for this invasive pest making their control very difficult (Ibrahim and Jimma, 2018). This FAW drives its name from its mode of feeding as the entire “army” moves to the next source of food available after they had eaten up every vegetation in an area (Ali *et al*., 1989, 1990). This pest in all plant growth stages causes damage, which normally limiting production due to serious damage to, or destroying the whorl-stage plants completely (Wiseman *et al*., 1996). In plants at whorl-stage, young larvae cater for on the outer leaves and cruel into the whorl, afterwards, injuring the emerging tassels. All stages larvae feed on the maize ear, the young maggot pass through the cob tip after feeding on the silks; generally, aged maggot pass in through the husk (Nuessly and Webb, 2001).

Across Africa, the economic impact of FAW on agricultural productivity are essential. Without proper control methods, yield losses to maize caused by the potential of the pest is estimated to have ranged from 8.3 to 20.6 metric tonnes annually from 12 sampled maize producing regions from African continent alone. Between US$2.48 billion and US$6.19 billion was estimated as the value of these losses (CAB International, 2017; Day *et al*., 2017). Maize and sorghum grain yield losses caused by FAW attack can reach 80% (Lima *et al*., 2010) and 34% (Andrews, 1988), respectively. Farmers reported of the minimum maize grain yield loss to be 26.6% in Ghana. This is much lower than reported in 2017. In Ghana, the nationwide annual maize grain yield lost value was estimated to be US$177m (Rwomushana, *et al*., 2018).

1.3 Justification

A number of challenges has been faced by Africa in the development and accomplishment of a collaborated, evidence-informed efforts to manage FAW. To regulate FAW outbreak in Ghana, Ministry of Food and Agriculture (MoFA) secured 72,774 litters of liquid pesticides along with powdered pesticides of 4,320 grams to be used in the infested fields (MoFA, 2017). Currently, there is a little knowledge of proper tactics to prevent and avoid FAW, and attempts to limit the pest population mostly depended on the synthetic pesticides use, sometimes in an improper way with ability to bring about danger to human, animals and the environment (Prasanna *et al*., 2018). Aside the cost involved in the control of this pest using insecticides, the penetration of this pesticides in to the whorl of the maize is another problem, as the pest (larvae) hide inside the whorl of the maize plant and need regular application (Yu *et al*. 2003). It has been reported of FAW building resistance to a number of individual classes of insecticides including carbamates, organophosphates, benzoylureas and pyrethroids (Diez-Rodrigues and Omoto, 2001; Yu *et al*., 2003). However, there is a limited knowledge on the use of enhanced plant nutrition in the management of FAW.

Mineral nutrients are important for plant growth and development. In disparity to fungal and bacterial pathogens, visual factor like leaf colour is essential factor in pests susceptibility. Discolour of the leaf surfaces by nutritional deficiencies increases its susceptibility to pests (Schumann *et al*., 2010). These nutrients usually served as food for plants essentially for better growth and yield yet, mineral nutrition also impacts growth and yield by influencing resistance and susceptibility of plants to insects and pathogens (Schumann *et al*., 2010). Plant development depends on nutrients availability, while that of insect-pests fall on the availability of host plants food quality (Gogi *et al*., 2012). Plants with nutrients deficiency are weak and unsafe to incidences of plant diseases and insect-pests attack (Huber and Thompson, 2007). Plant health is improved by nutrient management, which warrants the plant to tolerate the incidence of herbivores – insect (Gogi *et al*., 2012). According to Schumann *et al*. (2010), supply of a balanced nutrients ensures optimal plant growth. As well, plants with an optimum nutritional status have a maximum resistance (tolerance) to pests and diseases compare to nutrient deficient plants. Mineral nutrition can impact two primary mechanisms of resistance: The mechanical barriers formation (in essence through the development of thicker cell walls) and the combination of natural defense compounds, (for instance phytoalexins, flavonoids, and antioxidants) which issue defense against pathogens.

Deficiency of boron reduced the resistance to pests attack as well as fungal infection (Schumann *et al*., 2010). According to Altieri and Nicholls (2003), the vital plant physiological features for hold out against pests and diseases is healthy plants and vigorous plant growth. However, despite higher pest pressure in a field that received inorganic fertilizer, there was a yield improvement as a result of improved plant growth. Also, as a consequence of inadequate plant nutrition among majority of smallholder farms, a substantial yield gap exists (Vanlauwe *et al*., 2014). As there is a likelihood of FAW staying, medium and longstanding responses are essential, along with actions to address the instantaneous crises that farmers are facing (CABI, 2017a).

In Ghana, YARA is the largest importer of bulk fertilizer (estimated to account for around 70,000-80,000 tones in 2008) (Arthur, 2014). Also, YARA Vita (Croplift Biofertilizer) being a newly formulated foliar fertilizer with both the macro (NPK+B small quantity) and micro nutrients such as Copper (Cu), Manganese (Mn), Molybdenum (Mo), and Zinc (Zn) can improve nourishment to the plants to boost it immunity to be able to withstand (tolerance/resistance) insect-pests infestation especially FAW. However, there is a little research findings available on the influence of fertilization on FAW infestation and yield of maize in Ghana. Hence, there is the need to use YARA formulated fertilizers with the Croplift Bio to improve the health and vigorous growth of plants to be able to withstand the fall armyworm infestation.

1.4 Objectives

This study sought to evaluate the influence of enhanced efficiency fertilizer formulations on FAW infestation, and impact on the agronomic performance of maize in the Guinea Savanna ecology of Ghana.

The specific objectives were to evaluate the effect of the fertilizer formulations on;

i. growth and development of maize.
ii. FAW abundance and damage incidence on maize
iii. grain yield of maize, and
iv. the economic viability of investing in FAW control using the formulated fertilizers.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Taxonomy and description of fall armyworm (FAW)

FAW belongs to domain: Eukaryota, Kingdom: Metazoa, Phylum: Arthropoda and Subphylum: Uniramia. The Class: Insecta, the Order: Lepidoptera, family: Noctuidae, Genus: *Spodoptera* and in Species: *frugiperda* (CABI, 2020). Two races of fall armyworm occurred: ‘rice strain’ (R strain) and ‘corn strain’ (C strain); the first one preferred feeding on rice and numerous pasture grasses and the later preferred feeding on maize, sorghum and cotton. Morphologically, the strains are identical, by the molecular techniques they can be differentiated (Rwomushana *et al*., 2018). Recent proof shows that the various FAW in Africa are more than what has been thought previously, as well as haplotype that has not so far been perceived in the Western Hemisphere (Nagoshi *et al*., 2018).

In Uganda, the populations of FAW were set up to comprise what the authors called two sympatric sister family of rice and maize favoured strains (Otim *et al*., 2018). These outcome specified that the two strains appeared to be almost escalating together in Africa. There has been some efforts to prove the origin of these strains, and prove from Ghana (Cock *et al*., 2017) and Togo (Nagoshi *et al*., 2018), recommended that the populations are more alike to that established in the Caribbean region and eastern coast of the United States (Rwomushana *et al*., 2018).

2.2 Origin of FAW

FAW is an insatiable pest of agriculture indigenous to North and South America, but was unmasked in African continent for the first time in 2016. It is the main noctuid pest of corn and has endured restricted there in spite of asymmetric interceptions by European quarantine services in the past few years (Goergen *et al*., 2016). FAW in African continent has currently been introduced (Stokstad, 2017). Thirty one species comprising the genus *Spodoptera* with seven species recorded earlier from the Afro-tropical zone, six species are known to occur in Central and West Africa (Pogue, 2002). The transient behavior with high distribution limit of FAW permit it to disperse at once along with the range of its hosts (Kondidie, 2011). The moths emerge out of the hibernating pupae in the late winter, and relocate significant distances to territories where the conditions are favorable for their survival; from spring to fall and this can happen for successive generations (Westbrook *et al*., 2016).

According to Kondidie (2011), immediately, no evidence of FAW resettlement exists, nonetheless, its incapacity to hibernate in northern America and it annually emergence in those states signified FAW movement. In addition, molecular works ongoing state that the genetic variableness of the moth in the Western Hemisphere, covering southern and northern states of United States, exhibiting the slightest existence of movement of this species (Clark *et al*., 2007; Kondidie, 2011).

2.3 Geographical distribution of FAW

FAW was reported first in January, 2016 as present in the African continent (Goergen *et al*., 2016). Further studies disclosed that the pest is almost in all sub-Saharan Africa (SSA), in which sizeable damage caused, particularly to corn farms and to a small extent sorghum and other crops. Presently, countries such as Cape Verde, Madagascar, Sao Tome and Principe, and the Seychelles are among more than 30 countries that recorded this devastating pest within their borders (Huesing *et al*., 2018). Because, the leading proof suggested that the FAW category instituted into Africa is the haplotype derived along with the Caribbean and south Florida (USA). Unlike other *Spodopteran* moths, the FAW moths have both habits of migratory and localized distribution and can easily scatter around a large geographical area. Moths on migration can travel more than 300 miles (500 km) prior to oviposition. With the aid of wind, migratory distances of the moths can far much longer (Huesing *et al*., 2018).

2.4 Host range of FAW

The host range of FAW is extremely broad, with more than 80 crop species documented, their favour is distinctly grasses. Sweet corn, maize plants sorghum, and grass weeds comparatively crabgrass (*Digitaria* spp.) are the largest often consumed crops. They defoliate the favoured crops once the larvae is extremely numbered, obtain the classic “armyworm” behavior, and scatter in maximum numbers, consuming almost every vegetation in their way. Crops in the field are usually injured, such as Bermuda grass, barley, alfalfa, buckwheat, peanut, rice, millet, maize, cotton, cloves, oats, Sorghum, ryegrass, sugar beet, sugarcane, soybean, wheat, timothy, Sudan grass and tobacco (Huesing *et al*., 2018).

However, only sweet corn is normally damaged among vegetable crops, yet others are attacked sometimes. Occasional injured crops include apple, orange, grape, strawberry, peach, papaya and a innumerable flowers. Known weeds to set out as host are *Agrostis* spp., bent grass, crabgrass, Johnsongrass, *Sorghum halepenese*, *Digitaria* spp., *Ipomoea* spp., morning glory, nutsedges, *Amarantus* spp., *Cyperus* spp., pigweed and sandspur (Huesing *et al*., 2018). Casmuz *et al*. (2010) reported that, the utmost recognized hosts of FAW include families such as: 35.5% *Poaceae*, 11.3% *Fabaceae*, 4.3% *Solanaceae* and *Asteraceae*, 3.7% *Rosaceae* and *Chenopodiaceae* while 3.2% for *Brassicaceae* and *Cyperaceae*. Despite the fact that FAW apparently show a very vast host range, the plants utmost often eating are field corn, sorghum and sweet corn (Capinera, 2017).

2.5 Life cycle of FAW

The life cycle of FAW is between 35-61 days. The moth lives as an adult for 1-14 days, it eggs usually laid on an immature plants that hatches in 3-5 days while the larvae emerges in 14-28 days which may tunnel directly into the ear of the maize, following development, the larvae then crawls in to the soil for 7-14 days pupation, the pupation ends and cycle repeated in the warmer climate (Badii, 2020). According to Huesing *et al*. (2018), at a day to day temperature of ~ 2 ºC the alternation of generation of FAW can be ended in some where 30 days throughout the months of warm summer, however in cooler temperatures may be increase up to 60-90 days. Figure 1.1 shows the generalized life cycle of FAW.

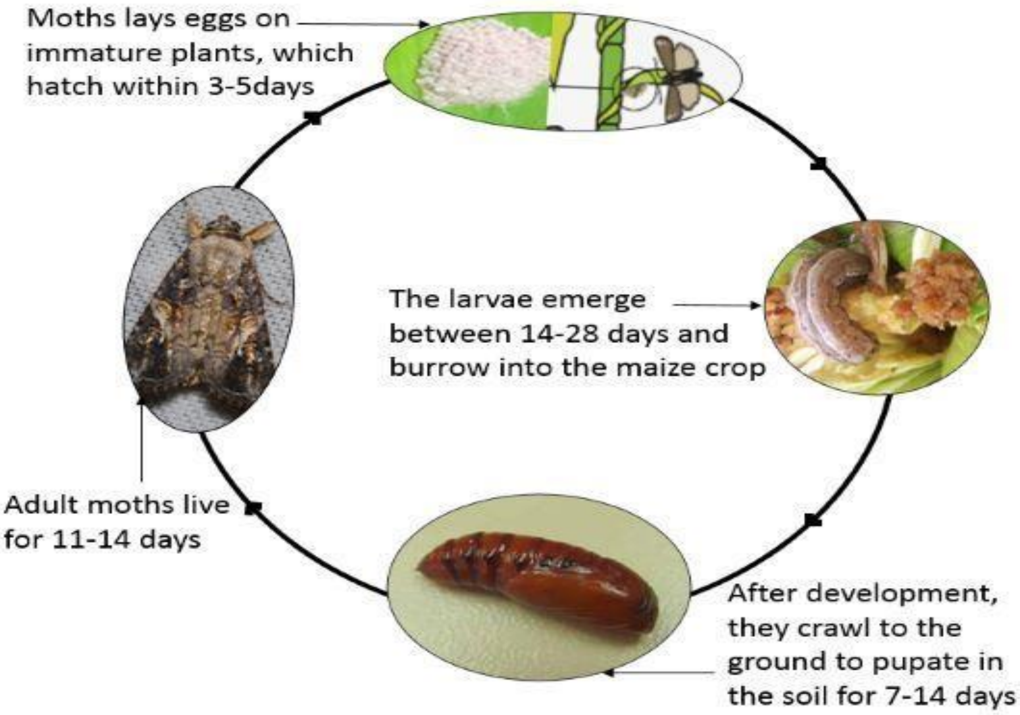


Plate 2.1: Generalized life cycle of *Spodoptera frugiperda*.

Source: IMMIC and CABI, modified by Mawuko, 2020

FAW moth may lay cluster of 10-500 eggs all around canopy of the plant, but usually prefer to oviposit in the bottom two-triplets of the cotton plants or in the whorls of maize or sorghum. First instars can be noticed in an aggregate closer to the egg mass area, nonetheless late instars militantly scatter around and across adjacent plants (Ali *et al.*, 1989, 1990).

The typical FAW has larval instars of six and the young larvae colour being greenish with head being black, the second instar head is changing to a further orange colour. The widths of the head capsule fall from about 0.3 mm first instar to 2.6 mm sixth instar, about 1 mm in length can be obtained by the 1st instar to around 45 mm of the

6th instar. The body of the dorsal surface of the 2nd instar, especially the 3rd instar turns brownish and the sideways white marks start to form. The head is reddish brown when it is at the fourth to sixth instar stage with white mottled while the brownish body contains white at the sub-dorsal and sideways (Pitre and Hogg, 1983).

Normally, the pupation of FAW fall from the depth of 2 to 8 cm in the soil. A loose cocoon usually constructs by the larvae through binding soil particles and silk together. The shape of the cocoon is oval and in length 20 to 30 cm. leaf debris and if the soil is harder other materials may web together by the larvae to form cocoon on the exterior of the soil. Reddish brown is the colour of the pupa, the measurement of the length fall from 14 to 18 mm and width about 4.5 mm. About 8 to 9 days is the duration of the pupa during summer, while during cooler weather it reaches 20 to 30 days. FAW cannot resist prolonged times of chilly weather when at the pupa stage (Pitre and Hogg, 1983; Igyuve *et al*., 2018).

The wingspan of adult moths FAW is between 32 mm to 40 mm. generally, the male moth of FAW forewing has a gray and brown shading, with white spots in a triangular form at the end and close to the wing middle. The forewings of female FAW are apparently marked, the range of colour fall between a uniform grayish brown to a fine mottling of gray and brown. In both sexes is the sparkling silver-white with narrowing dark border at the hind wing. Adults are nocturnal, and are utmost energetic throughout warm, humid evenings. Following a 3 to 4 days of pre-oviposition period, the female usually laid largest of her eggs throughout the first 4 to 5 days of life, nonetheless, some oviposition come about for up to 3 weeks. About 10 days averagely is the estimated duration of adult life, with about 7 to 21 days range (Huesing *et al*., 2018).

2.6 Damage caused by FAW

FAW infestation occur all over the year in areas where this pest is endemic, since the pest does not have the potential to diapause. Migration of FAW arrives in non-infectious areas when conditions of the environment is favourable and may at least have one life cycle before they become vanished (Huesing *et al*., 2018). The insatiable feeding and far-distance flight conducts of FAW show a notable threat to agriculture in African with the capacity for fast spread all over the continent (Nagoshi *et al*., 2017). The larvae of the FAW depend on leaves, stem and reproductive parts of more than 80 species of different crops. While FAW has maize as preference, they also attack numerous other vital cultivated crops, like cabbage, sorghum, rice, sugarcane, onion, groundnuts, beet, cotton, soybean, tomato, millet, potato and pasture grasses (Huesing *et al*., 2018).

The young leaf whorls, ears and tassels are where the FAW larvae feed causing important damage to the crops resulting in the estimated yield loss of 20%. An entirely sectioning of the base of the stem of maize seedlings can be done by larger larvae as they can act as cutworm (Midega *et al*., 2018). Per Casmuz *et al*., (2010), FAW is announced to be feeding on 186 host plants and has become an essential pests in economically essential crops like sorghum, corn and rice; in cotton it is a sporadic pest, where it can give rise to remarkable damage, the reproductive parts of the plants are where they favour feeding on rather than the foliage, forth rightly affecting crop production (Barros *et al*., 2010). Infestations of the FAW larval can be detected on the maize leaves and ears, later instars can be spotted feeding on the maize whorl (Capinera, 2000; Murua *et al*., 2009). FAW is present throughout vegetative development of maize (V2-V12), y*et al*so, it can infest maize at “silking” and “blister” stages in some areas (Blanco *et al*., 2014).

FAW attack on maize was first time reported in Africa in 2016 (Goergen *et al*., 2016), causing remarkable damage on maize crops. In early 2017, a huge swathes of corn were reportedly destroyed in South Africa (Igyuve *et al*., 2018). Because of the very little food requirement of the first stage of FAW caterpillar’s life and about 50 times more requirement by the later stages, destruction can occur about overnight. Because of this fast switch in food consumption, larval presence will not be realized till everything is nearly destroyed in an overnight (Spark, 1979).

According to Igyuye *et al*. (2018), Larval feeding behavior was studied by Pannuti *et al*., (2015), and described that despite the fact that vegetative stage (young leaf tissue) is favourable for growth and survival, the leaf tissue is unpalatable on more older plants, and the ear zone is where the larvae tend to settle and feed on, especially the silk tissues. Nonetheless, the silk is unsuitable for growth. The larval reaching the kennels of the corn exhibit the quickest rate of development.

Plate 2.2: Damage caused by *S. frugiperda* larvae to the whorl and ear of maize

2.7 Economic impact of FAW

The capacity to travel and feed on a broad host range, existence of manifold generations makes FAW an extreme economic pest in the Americas. FAW is a perpetual pest of maize and sorghum in the United States (Gutierrez-Moreno, 2017). In 2003 in the United States, FAW was placed at the eighth highest remarkable cotton pest at the national level and in Arkansas, the third highest notable principal pest to cotton for that same year (Williams, 2003). As reported by Spark (1986), FAW placed second among agricultural pests in sequence of total losses, ranking from $39 to $297 million annually. As per Martinelli *et al*. (2006), FAW is the utmost devastating and economically principal pest of corn in Brazil whilst the existence of the pest in both cotton and maize farms have compounded the implementation of IPM tactics in these two crops.

Losses caused by FAW to maize in United State, were estimated to average $300 million annually (Knipling, 1980). CABI, (2017a) released new report that exhibits that inappropriate control of the armyworm could fetch ten corn producing countries in Africa an economic value between $2.2 billion and $5.5 billion annually due to a decrease in maize production. Kiprop, (2017) reported that, FAW is currently a lasting provocation to the continent which mainly feeds on maize, disseminating to 28 African countries absolutely a year following its first report. The country that will be most affected by the FAW is Malawi with prophesying that the invasion could black out between 12.5% and 30% of the country's agricultural economy. Tanzania is anticipated to be the highest pretentious by the disastrous pest in East Africa, with yield loss estimated to be up to 3,238,980 metric tonnes over Ethiopia and Uganda , with yield loss estimated to be up to 3,054,727 tonnes and 1,391,109 tonnes, respectively. According to a documents as written in the report by the Uganda's Ministry of Agriculture, the FAW black out 450,000 tonnes of corn pegged at $192.8 million in the last cropping season, per their countries Ministry of Agriculture's latest statistical reports.

Across Africa, the economic impact of FAW on agricultural productivity are essential. Without proper control methods, yield losses to maize caused by the potential of the FAW as estimated from 8.3 to 20.6 metric tonnes annually from 12 sampled maize producing regions from African continent alone (CAB International, 2017: Day *et al*., 2017). FAW has the ability to bring about 45% yield reduction in maize (Hruska and Gladstone, 1988), yet it could reach 100% if left uncontrolled in some tropical areas (personal communication with Henry Teran-Santofimio) (Igyuve *et al*., 2018). As reported by their findings, the densities of FAW at lowest level of 0.2 to 0.8 larvae in a plant at the later whorl stage may be enough to lower yields by 5 to 20% (Igyuve *et al*., 2018). As reported by Williams and Davis (1990), overspread with 30 larvae of FAW in a single plant of a hybrid maize arose in heavy leaf feeding damage with yield reduction of 13%. According to Cruz and Turpin (1983), when 20% of field corn in the mid-whorl phase of growth were overspread with FAW egg masses, 17% yield was reduced.

The utmost broadly cultivated and a primary food crop for about half of the continental populace in Africa is maize. Maize is farmed throughout distinct agro-ecological zones (AEZs) where over 200 million people depends upon it for sustenance security (Day *et al*., 2017). Preliminary evaluation on the economic impression of this pest on the yield losses of maize in 12 paramount corn producing countries in Africa has been valued for its economic losses to fall from US$ 2,480 million and US$ 6,188 million yearly of complete anticipated evaluation of US$ 11,590 million yearly (CAB International, 2017; Kebede, 2018). More than $13 billion has caused to Africa by these FAW as expert warn awareness that, the pest is likely to remain in African continent (Banson *et al*., 2019). Also reported by Gakpo, (2017) that, Africa will loss US$ 13 billion which will cause the continent's Gross Domestic Product (GDP) a decrease of 9%. In Africa, ongoing evaluation of 20 to 50% yield loss of maize suggest greatest harm to livelihoods (Gonzalez-Moreno and Murphy, 2018).

The existence of FAW in Ghana was unveiled for the first time in the Yilo Krobo District of the Eastern region in 2016. From a basal amount of 1,400 hectares of infested cropping area as at May 2017, the FAW infested an extra 112,000 hectares of corn fields. Last season a sum of infested and sprayed maize fields were 249,054 hectares, 234,807 hectares out of it were retrieved and 14,247 hectares were knock down, proofing the possibility for another destructions in the 2018 cropping season (Tamakloe, 2018). Through FAW distortion, Ghana is evaluated to have off-track lost around US$ 63.5 million.

2.8 FAW invasion in Ghana

In 2016, the FAW as invasive pest was attest as being exist in Ghana. To regulate their breakout, the MoFA secure 72,774 litters of liquid pesticides along with 4,320 grams of powdered pesticides to be used in the takeover fields (MoFA, 2017). In Ghana, through a collective endeavor in the company of the Plant Protection and Regulatory Service Directorate (PPRSD) of the MoFA in reaction to the outbreak of this FAW, CABI in collaboration with further stakeholders in Ghana through its measures on Invasive programme to assist a number of FAW-specified works. A plan was developed on FAW management that centered on four priority areas: monitoring and surveillance; research and management; co-ordination and collaboration; and awareness-raising. The most principally, the national management plan point at securing correlated endeavor between private, public and civil society organization in the FAW management. A nationwide multi-stakeholder taskforce were designed and asked to be counseling the MoFA and correlating the reaction to FAW. As reported by Williams *et al*., (2020), the outcome attained and as announced by the FAW reaction in Ghana on the four priority areas are indicated below:

Research and Management of FAW were the key components of FAW reaction in Ghana. Research supplied new awareness and successful ways of controlling the FAW and the taskforce ease cooperative research amidst the government, research institutions, the private sector and other partners, where formerly they had worked independently. A sub-committee of the taskforce in 2017, made up of researchers, Environmental Protection Agency (EPA) and PPRSD examined insecticides and make recommendations to EPA for their approval and approval were made to those that met the criteria. The three examples of effective and successful products included Uphold (Methoxyfenozide + Spinetoram), Chemomectin (Emamectin-benzoate) and NOVA BTK (Bt) were effectively examined and launched, after booking by EPA for FAW management (Williams *et al*., 2020). However, correspondingly, in 2018, the efforts of the government were concentrated on the marketing of biorational products for the control of FAW (Kansiime *et al*., 2020; Williams *et al*., 2020).

Monitoring and surveillance; the important constituent in answering to the FAW epidemic in Ghana. Orderly monitoring and surveillance ventures were guided by extension officers and set in motion in all 216 districts, through the initiation of monitoring and early warning mechanisms. A mobile phones, laptops, and pheromone traps were supplied by Food and Agricultural Organization (FAO) for monitoring and surveillance of the FAW populations. More than 2,811 technical officers were trained in FAW identification, quick evaluation of extent of infestations, management, and early warning attempts to allow them to keep truck of FAW levels, in addition, teach the farmers on the identification and management of the pest. There was an establishment of call lines for farmers to give technical advice and additionally warrant the weekly maps development, established on farmer report, that exhibit present-day FAW infestations (Williams *et al*., 2020).

In order to successfully react to FAW infestation, awareness of the pest at all the national, regional and local levels were critical in answering to the infestation of FAW in Ghana, the government set up a master plan for awareness raising for the decision-makers, farmers and advisors. Symposiums and seminars were organized throughout the country to intensify awareness of FAW by the staff of MoFA. Also, increases commitment and coaching of the media on FAW, public sensitization was accomplished across radio stations, worship places, in schools and through extension officers/plant doctors. Also part of the tools used in the awareness creation include the use of print materials and over 227,000 posters and flyers were developed and issued at the side of host of articles issued in the print and online media (Williams *et al*., 2020). All these information's manifest increased steadiness, precision and sureness of information, due to the participation of the media in the FAW taskforce, specifically its communication sub-committee, additionally build up working partnership between National Plant Protection Organization and the media (Kansiime *et al*., 2020; Williams *et al*., 2020).

Policy change/shift through the FAW response may lead to viability of the FAW response and preparedness for future pest infestations (Williams *et al*., 2020). The consequence receiving disclosed the public policy related results and shifts as a consequence of FAW response as indicated in Kansiime *et al*. (2020). The outcome from the taskforce evaluation activities and the prove notes of FAW, supply data that aided to shape policy discussions, specifically on the use of low-risk options for FAW management, succeeding the extensive use of chemical pesticides throughout the country, and their related health and environmental risks (Williams *et al*., 2020).

The FAW response in Ghana facilitated cooperative research amid partners. Through the taskforce MoFA were collaborated, aided to correlate the activities being carried on by stakeholders, comprising enhanced research cooperation, increased interactivity between communities and extension officers, and increase collaboration between the ministries of agriculture, information/communication and finance (Williams *et al*., 2020).

2.9 Management strategies for FAW

The economic damage caused by FAW on maize fields recently was significantly high, especially in SSA countries. This call for structured partnership hence that can aid control the enervated pest in the continent. An IPM tactics is one which supplies a functional framework to control such pest (FAO, 2017). Some of the essential management techniques adopted and practiced in part of African countries including Ghana so far are presented below;

2.9.1 Monitoring

For an effective IPM programme to be successful, a critical activities such as monitoring, surveillance and scouting have to be implemented. These allow for forecasting what time the pest will be in attendance and then evaluating stage of seriousness of an infestation, permit timely alleviation of the difficulty utilizing the minimum and quickest interference to successfully and economically safeguard opposed to loss of yield whereas conserving the needed ecological community services and reducing danger to the environment (McGraph *et al*., 2018).

According to McGraph *et al*. (2018), monitoring indicates an attempt to assiduously truck the presence, and the pest movement in a specified geographical area. Monitoring activities may be assembled and executed at varying stages utmost representative by governments, through trained practical personnel who orderly collect data to enlightened policymakers and professionals about the existence and seriousness of the pest throughout a geographical area. Nonetheless, more restricted measurements, like data obtain via farmers trained to scout fields of theirs, can additionally be accumulated and integrated in to wider, legal monitoring schemes. Lastly, monitoring has a particular significance in the circumstances of Insect Resistance Management (IRM), which mention to in progress, continuous computation of the susceptibility of an insect- pest to a specific toxin (example, a traditional pesticides or insecticidal protein conveyed in a genetically engineered crop).

As reported by McGraph *et al*. (2018), surveillance indicates the natural, passive observation of pest matters as they emerge. On the other side, this approach does not search diligently for a specific pest but rather just account when economic damage exist. Surveillance is classically carried out in the field and farm level via farmers, and presumes no specific teaching or approach. Surveillance principal should not be underrated. Field farmers are usually include the paramount to recognized surfacing problems, when mechanism live to receive and truck surveillance reports as there come to light, the collaborative response of thousands of farmers can supply strong details about the pest infestation dynamics. In accordance with McGraph *et al*. (2018), scouting refers to an activity managed in accordance with science-based customs by instructed individuals-classically by a farmer, instructed at the farmer field school or extension level or noticing his or her personal farms for the pest. Scouting permit the farmer to exactly evaluate pest pressurize (for instance, the strength of FAW infestation) and crop production in the farm. Scouting is classically done in other to assess both the economic menace of the infestation of the pest and the potentiality efficiency of pest management measures inside the closest field context, with the aim of enlightening technical crop management resolutions at every person's farm and farm level. Nonetheless, restricted scouting data can be collected also and absorb on-to monitoring schemes at wider geographical scales.

For the timing of management tactics, observation of a pest and evaluation of its population density is important (Trematerra, 2013). The notable apparatus for monitoring the population thickness of the pest in studies and IPM programme is insect traps. Traps can aid determine strikes by novel pest species, the starting of consistent pest action, suggest the scope and ability of the pest distortions and truck swaps in pest densities, for pest management, altogether aid enlightened in decision making. Observation of FAW should be practicable by capturing the flying moths using pheromone traps and dark light (Rojas *et al*., 2004). Pheromone traps are systematically productive be contrary with backlight traps; they need to be hang at the height of the canopy at the whorl stage in crops such as maize (Sisay *et al*., 2018). The capturing of the traps can suggest the existence or nonexistence of the pest, in any case, they are really not admissible measure of population thickness (Asamani, 2020).

Monitoring FAW locally is suggested to efficiently stick to the existence, population and the pest movement inside a predetermined topography. Usually, this led across prepared professional personnel at locations throughout the nation or District, yet can otherwise be limited at the farmer's stage for all smallholder farmers and town-level energetic farmers. Among the two cases, monitoring usually depends on pheromone traps placed near the fields for the catching of male adult moths. The entire numeral of adult moths inside the trap is documented, and used to throw light on appropriate activity (frequently reporting the details to suitable professionals to help in their management decisions) (Prasanna *et al*., 2018). Monitoring and surveillance depends over trap choice, its location and positioning and the inspection of the trap (CABI, 2017b).

2.9.2 Natural control

Maize is the preferred host plant for a female adult FAW to lay eggs on. Plant diversity has been by FAO recommended to maize farmers to implement (FAO, 2018). This will help natural enemies to control the pests and lower their infestation. Consequently, the use of varying varieties and intercropping system practices, can lower the level of oviposition, thereby lowering the rate of infestation (FAO, 2018). Therefore, farmers should be discouraged by practicing maize monoculture. Farmers in Central America have observed that when corn is intercropped with either beans or squash, they usually experience lower FAW infestation (FAO, 2018). According to FAO, (2018), the policy of poly-cropping have been endorsed by the agronomist to manage FAW epidemic for four major reasons:

i. In a field of plant diversity, the FAW confuses with difficulties in finding its favoured maize host plant, consuming unsatisfactorily or laying small number of eggs.

ii. The releasing of chemicals by some plants avert strike by female moth of FAW. Certain plants are attracted to them. The efficacy of "push and pull" in the maize field is an essential step in averting FAW infestation. It has announced evaluation of this recommendation in recent study, where in excess of 80% lower FAW population in treatments where this "push and pull" phenomenon was noticed with related increases in yield comparative to mono-crop treatments (Midega *et al*., 2018).

iii. The use of poly-culture may allow beneficial insects (predators and parasitoids) to for FAW control.

iv. The organic matter of the soil increases with inter-cropping, for instance leguminous crops such as groundnuts increases the content of N therefore improving or increasing the health of plants to compensate for damage caused by the FAW.

Deterring or scarring pests using natural method is a habitual custom amid African farmers. Hand picking and killing of caterpilars (larvae), maize intercropping, wood ashes application and soil to leaf whorls are one of the usual practice (Day *et al*., 2017).

2.9.3 Host plant resistance

Evaluating and placing successive host plant resistance (HPR) is among the essential of an efficacious IPM tactics in opposition to FAW. In African context, HPR is specially required where smallholder farmers carry the majority with lean access to guard and inexpensive FAW management possibilities (Prasanna *et al*., 2018). Resistance by the host plant to pest attack is a heritable trait owned by a plant that permits the host to tolerate, avoid or retrieve from the insect-pest attack under situations that should cause sufficient damage to other plants that belong to the same species (Kumar, 1984). In conjunction with the desiring behavior of the ability to be effective when alone or as a constituent of an overall pest management tactics, the farmer's most beneficial is considered to be host plant resistance. The use of insect resistant varieties has been shown to be the inexpensive, and the safety way of pest control means under poor management situation and with low farm inputs (Pathak, 1985). Besides, close reports have been made for FAW on contrasting maize varieties with different level of resistance being reported (Rojas *et al*., 2018). Varying cases of transgenic-based FAW resistance varieties in maize for example, have been reported by Horikoshi *et al*. (2016)).

2.9.4 Cultural control

Cultural method of control is a remarkable constituent of management master plans including FAW. If the crops were kept weed free, FAW damage to the crops could be virtually avoided as reported by many studies (Stewart and McClure, 2013). Better soil management and crop nutrition for example, lead to increasing the health of plant which can warrant that crops to grow a long period prior to pest damage effects yield-assuming component (for instance, leaf zone) (Savary *et al*., 2012). More resistance can otherwise be put in by plants that are healthy, therefore improving the likelihood of running away from significant damage (such as planting early). Damage could be restraint, if clean culture approaches were used steadfastly by the farmers at the close of the day (Andrews, 1988). A study done in Kenya and Etopia shows that, around 14% to 40% of the farmers practice cultural tactics, (like handpicking) for management of FAW (Teshome *et al*., 2018).

The upper hand of cultural approaches frequently appeared out of the interactivity of natural components above a scope of dimensional scales through experimental unit to field to farm to landscape- that interrupt and manage the pest at many stages of its life cycle (Martin *et al*., 2016). Example include, cultural practices like companion cropping, intercropping, conservative agriculture and agroforestry may at normal time better the health of crop, supply food with possible food sources for beneficial insects, and reduce the ability of FAW larvae to travel among host plants (Ratnadass *et al*., 2012). In addition, Van Huis, (1981) reported that, FAW invasion of maize in Nicaragua was 20 to 30% lesser when inter-planted with beans compare with maize poly-cropping. The poly-cropping system are likely going to aid additional predators, disturb egg laying by female moths of FAW and further interrupt the movement from plant to plant by the FAW larvae. Allowing less strips of weeds in the middle of the lines of maize also can help with declining maize distortion by filling in as undesirable host for the larvae that travel between maize plants.

Crop rotations or intercropping in the company of FAW none-host crops plants can aid repel *Spodoptera frugiperda*. Some intercrops, such as those that of course manufacture insecticidal substances (such as Tephrosia) or repulsive semiochemicals such as (Desmodium), repulse the female adult moths, limiting the amount of eggs laid on harboring plants. Contrastingly, development of practicable ecosystem that apprehend and conserve inherent enemies of FAW, including predators and parasitoids, can donate to intensify predation and parasitism that control FAW inhabitants. Particularly, enlarging habitat assortment at the landscape plate (example, rigorously safeguarding or development of blotches of ordinary vegetation, hedgerows or three spread) can put up the reward of predacious bats and birds. The influence of these insatiable and great mobile pest predators fall on the availability of acceptable living apace within the farm (for instance, proper roosts or perch landing spaces) and over more substantive landscape (CABI, 2017b).

Farmers who entirely applied the Push and Pull tactics reduced the infestation of FAW and damage caused to crops up to 86%, with a 2.7- fold yield increase compare with nearby farms that did not execute the technique (Midega *et al*., 2018). On account of the materiality that attainment of Push and Pull need capital associated cost to establish the associate plants, cost moderately reduced in ensuing farming or cropping seasons.

Apart from, far off controlling FAW, Push and Pull has otherwise been accounted or to reduce Striga infestation, improve soil humidity and increase N content of the soil, and most importantly, give a suitable domain to the FAW natural enemies multiplication (Khan *et al.*, 2010). In southern states, the utmost essential societal practice, utilized broadly is early maturing varieties and/or early planting. Numerous maize ears break out the high armyworm infestations that come about sooner in the season by harvesting early (Mitchell, 1978).

2.9.5 Biological control

Biological method is one the principal and alternative methods of controlling FAW population. This method involve using another organisms to control the population of the FAW. It provide defensible plant protection and safety (Samia *et al.*, 2016; Burtet *et al.*, 2017). Numerous biological organisms, vertebrates and invertebrates can aid manage this FAW. Whilst some are of course occurring in the form of parasitoids (wasps and flies), predators and entomophagens, require to be instituted. The predators often used comprise birds, bats, beetles, earwigs, and other insects. These natural enemies can be active in the Americas, and probable in Africa during all developmental stages of FAW, such as egg, larval, pupal and adult stage (FAO, 2018). These beneficial insects have the ability of reducing the FAW population significantly and as a result reduced the damage caused by this FAW (FAO, 2018).

The population of the FAW has been shown to reduce significantly through direct predation which lead to maize yield increment (Burtet *et al.*, 2017). Their conduct of relocating aside from over-seasoning and breeding sites led to the low efficient of the natural antagonist (Corcos *et al*., 2018; Leach and Isaac, 2018). Works reported of FAW larvae recovery from distinct hymenopteran parasitoids and dipterans parasitoids species. These work finalized that FAW populations can considerably be controlled by the natural antagonist (Quispe *et al*., 2017; Corcos *et al*., 2018). The populated and the most ordinary larval and pupal parasitoids species belong to the ingress-and-sting guild (Ndemah *et al*., 2001). This FAW is susceptible to many of entomopathogens comprising virus, protozoa, fungi, nematodes and bacteria (Hoffmann *et al*., 2014; Zothansanga *et al*., 2016). Biological control measures of FAW has been friendly. The important alternatives for managing FAW are B. *thuringiensis* (Bt) and Bt engineered corn is used in numerous countries for the management of FAW (Burtet *et al*., 2017). There are numerous actions that the farmers can be lay hold of to protect and improve natural enemy's populations in the field of theirs (conservation biological control method). Actions to be taken include, keeping away from misuse of chemical pesticides that can have a negative consequences on these natural enemies; securing various boundaries around farms comprising shrubs and open flowers as a practice or sustenance for these natural enemies; bird perches or trees inside and around the farms. If insecticides are regarded essential, choosing products that are comparative to that of biological control like Bt and botanicals based formulations are necessary (FAO, 2018; Harrison *et al*., 2019).

2.9.6 Chemical control

In numerous species of insect-pests, pesticides are principal management alternative in crop pests control. FAW resistance to pyrethroids in Florida and USA was reported to fall from 2 to 216 folds, 12 to 271 folds for the organophosphorate and 14 to 1,192 folds for carbamate based insecticides (Yu *et al*., 2003). The FAW population in China is mostly managed by the use of synthetic insecticides. This led to their resistance to numerous pesticides used comprising Emamectin benzoate. The mortality of fall armyworm on treated diets with Emamectin benzoate was noticed to be 90.6 to 100% (Zuo *et al*., 2018). A considerable volume of the pesticide is required to penetrate and kill the feeding larvae far down in the corn plant whorl. In irrigation conditions where overhead sprinklers are used, pesticides can be put in the irrigation water and it must be well monitored (CABI, 2017a). The recently invasion of FAW has distress various African countries presidents to employ enormous pesticides spray programme as emergency response in FAW infested areas particularly in maize farms to safeguard damage to crop and avert additional infestation of the pest (CABI, 2017a). There has been observed of resistance to some organophosphorus pesticides which fall from 12 to 271-fold; and the lead resistance level perceived was with methyl parathion (Carvalho *et al*., 2013). In a survey run in Kenya and Ethiopia recently was observed that different types of unregistered insecticides were applying by the farmers. Due to the invasive character of the pest that need a fast response might have led to this response by the farmers (CABI, 2017a; FAO, 2018). The improper use of pesticides led to the development of resistance (CABI, 2017a). There has been FAW resistance to carbamates with the towering level of resistance noticed with carbaryl (Carvalho *et al*., 2013; FAO, 2018).

Most varieties of maize grown in East Africa was susceptible to FAW infestations which usually led to the yield loss increases (Hruska and Gould, 1997). A variety of insect-pests in maize fields was most frequently controlled by the synthetic pesticides

(Azerefegne and GebreAmlak, 1994). The popular method used for the control of various insect pests in maize fields is mostly Synthetic pesticides (Azerefegne and GebreAmlak 1994). The combinations of chemicals such as pyrethroids and chlorpyrifos with even at lower rates than recommended arises in successful control of FAW infestation in the fields of maize. Nonetheless, to some of the frequently used insecticides some FAW strains confer some resistance (Yu *et al*., 2003).

2.9.7 Use of pheromones traps

Pheromone trap is an insect entrap that utilizes pheromones to captivate (normally) male insects. A secrete chemical by (normally) a female insect to capture males for mating is termed Pheromone. Through air pheromones can move far distance and consequently are extremely functional for observing the existence of insect. Mostly, the popular kinds of pheromones in use include sex pheromones and aggregation pheromones (McGraph *et al*., 2018). The basic device for identifying and managing pest density is pheromone lures (Spears *et al*., 2016). Employment of sex pheromone entraps can otherwise lessen the male moths and their multiplication. The females-manufactured sex pheromone of FAW is accessible commercially in the bulk regions in the world. Pheromones obsolete an instruments that are helpful for observing male populations (Malo *et al*., 2004). Many trap manufacturing companies have indicated that, for the utilization at a consistency of one trap each in a field of five hectares, the trap need to be set in the center of the field setting (Schauff, 2001). The traps and the trapping procedure for FAW observation are reliant on the captivator and the essence of the zone. The traps need to be hung free from any branch or leaf at around 1.5 m from the soil surface. A trap must be intended for 0.5 to 2 hectares each. The traps should be at least inspect twice each week and totaling the quantity of FAW moths trapped in the trap. Generally, to attain ideal output the pheromone lure should be replaced three to six weeks (FAO, 2017). Usually the best for sticky traps when placed at 1 m over the ground in and around host plants (Asamani, 2020).

2.9.8 Use of biopesticides

According to FAO (2018), bioppesticides can be helpful as a component of an IPM proposal against FAW. The word biopesticide emanates from a Greek root word "bio", which implies "life" while "pesticide" comprise all materials or mixture of materials that are intentioned to subdue pests and avert the danger or loss that they bring about. A collective word normally applied to a material obtained from out of nature is termed biopesticide, comparatively a microorganism, semiochemical or botanical, that may be put together and applied in a way closer to the ordinary synthetic insecticide and that is usually applied for temporal pest management. So, biopesticides are "living formulations" that are extracted out of natural materials derived out of organisms (normally cultured to multiply the number so as to utilized their characteristics of managing pests), plants, and animals (including predators and parasitoids). Biopesticides in general may belong to numerous classes:

- Pheromones and another semiochemicals; these chemicals bring about by animals and plants (and artificial analoques of such materials) that effect the individuals conduct of the same or another species.
- Microbial pesticides or microorganisms – comprising algae, viruses, bacterial, protozoa or fungi.

- Botanicals and plant extracts
- Nonvertebrate biological control agents, or microbial – comprising mites, nematodes and insects that are natural enemies, correlate or contestants of a pest. This category is sometimes not regarded as a "biopesticide" per se.

As indicated by FAO (2018), biopesticides are normally utmost target-determined and inherently low toxic compared to wide spectrum ordinary pesticides, and this restrict their influence on untargeted species, like mammals, birds and other insects. They are normally biodegradable in the native habitat, as a consequence lessening exposure and environmental pollution in addition lessening chances of pests developing resistance to them. For the management of FAW, microbial pesticides are specifically relevant. The active ingredients of this class of biopesticide is naturally the microorganisms themselves or the spores that they make that are pathogens against the earmarked pest. They may be fungi, viruses, protozoans, bacteria or algae that subdue the earmarked pests, either by causing toxic metabolites that are moderately determined to the specific insect-pest or jointly associated species, giving rise to disease and are consequently entomopathogenic. Like those based on fungi (*Beauveria bassiana*), bacteria (*Bacillus thuringiensis)* and *Baculoviruses*, biopesticides have demonstrated to be successful in the FAW control (FAO, 2018).

2.9.9 Use of botanicals

Plant-extract pesticides are popularly known as botanicals pesticides. A huge numeral of crops are studied to have insecticidal qualities while in America part of them have been used for the FAW management. Pesticides with botanical properties are degradable, environmental friendly and less toxic to producers and consumers, and frequently less toxic to natural enemies and consequently manageable for usage in biocontrol-based master plan of IPM. Also, based on accessibility the pesticidal plants in the ecosystem, smallholder farmers can easily prepare botanical pesticides (Cruz *et al*., 2018; FAO, 2018). As reported by FAO (2018), the use of pesticides that derived from plants (popularly known as “botanicals”) in the management of FAW is a cultural procedure of many farmers in African. It could provide possible arsenal against the FAW in Africa. The botanical pesticides mode of action is wide and fall along with: knock-down, repellency, larvicidal to anti-feedant, moulting inhibitors and growth regulation. They have a wide scope pursuit with overall small or no harmful to mammalian; nonetheless, the toxicity of part of the botanical insecticides are high and therefore nontoxic to pests only yet additionally for natural enemies and for mammals as well as humans, specifically tobacco extract. Generally, farmers grind plant materials using water, after which they extract bioactive compounds as a concoction. Important oils and powdered forms from bioactive rich plants to some extend are also used.

Numerous plant extracts that have insecticidal properties comprise Acacia (*Acacia* spp.), Neem (*Azadirachta indica*), Pyrethrum (*Tanacetum cinerariifolium*), Persian lilac (*Melia azedarach*), Fish poison bean (*Tephrosia vogelii*), Wild marigold (*Tagetes minuta*), wild sage (*Lantana camara*), Chillies (*Capsicum* spp.), West African pepper (*Piper guineense*), Jatropha (*Jatropha curcas*), Onion (*Allium sativa, Allium cepa*), Lemon grass (*Cymbopogon citratus*), Tobacco (*Nicotiana* spp.), Wild sunflower (*Tithonia diversifolia*) and Chrysanthemum (*Chrysanthemum* spp.) (Ogendo *et al*., 2013; Mugisha-Kamatenesi *et al*., 2008; Stevenson *et al*., 2017). In Africa, insecticidal properties of leaf and seed extract of Melia, Neem and Pyrethrum to FAW control have been proof effective preliminarily, which requires to be further researched on (Cruz *et al*., 2018).

2.9.10 Integrated pest control

Integrated Pests Management (IPM) is a system that utilizes all the available and suitable tactics and methods in a compatible way at many possible extend to reduce the populations of the pest and maintain them below economic injury level (Kumar, 1984). The system integrates control elements like host plant resistance, cultural practices, chemicals and biological (Akinsola, 1990). In maize-based production system, an IPM program can consequently be employed to subdue FAW population in maize-based production systems (Van den Berg, 1997: Prasanna *et al*., 2018).

2.10 Influence of fertilization on maize growth and resistance to insect pests

Majority of insects get their food and shelter from the plants (Mello and Filho, 2002). Insects using plants as their food source are herbivores (Fraser and Grime 1997; Carson and Root, 2000). However, mineral nutrients are important for plant growth and development and microorganisms and are essential factor in plant-disease interactions. Visual factor like leaf colour were essential factor in pests susceptibility. Discolour of the leaf surfaces by nutritional deficiencies increases its susceptibility to pests (Schumann *et al*., 2010). These nutrients usually seen simply as food for plants essentially for better growth and yield, yet, mineral nutrition also impacts growth and yield by influencing resistance and susceptibility of plants to pests and pathogens (Schumann *et al*., 2010). Plant development depends on nutrients availability while that of insect-pests depends on the availability of quality food from its host plants (Gogi *et al*., 2012). The interrelationship of insect-plant may be high-flown by macro/micro-nutrients application to crop crops (Abro *et al*., 2004). Crops with nutrients deficiency are not strong and unsafe to incidences of plant disease and insect-pest attack (Huber and Thompson, 2007). Plant health are improves by nutrients management, which warrants the crops to permit the incidence of chewing and sucking pests (Gogi *et al*., 2012).

Herbivores population size and/or development may be affected by nutrients availability changes. Past research have proof that potassium (K) is an essential constituent in the fabricated and issuance of prime metabolites in plants, and such physiological traits impact hormonal, metabolic and signaling pathways in plants. These swaps can have powerful influence on crop susceptibility and captivation to pest and diseases (Amtmann *et al*., 2008). Over 2000 works have been assessed by International Potash Institute (Perrenoud, 1990) to list the influence of K nutrition on incidence pest of, with 63% indicate that use of K fertilizer lower mites and insects in plants (Amtmann *et al*., 2008). Yet, it is a fact that, K fertilizer at times has no result on insect-pest development (Chen, 2014).

According to Schumann *et al*. (2010), plants with an optimum nutritional status have a maximum resistance (tolerance) to pests and diseases to nutrient deficient plants. Mineral nutrition can impact two primary mechanisms of resistance: The mechanical barriers formation, (in essence through the development of thicker cell walls) and the combination of natural defense compounds, (for instance phytoalexins, flavonoids, and antioxidants) which issue defense against pathogens. The interdependence of soil fertility and plant resistance to insect/pest is of a crucial role in their management (Tingey, 1981). As indicated by many studies, different fertilizers impact development, sustainability and fecundity of insects/pests (Singh 1970; Tingey and Singh 1980). According to Vaithillingan and Baskaran (1983) more phenols are accumulated with increasing K level which probable put up to rise insect resistance in some rice cultivars. Deficiency of boron reduces the resistance to pests attack as well as fungal infection (Schumann *et al*., 2010). According to Altieri and Nicholls (2003) the principal plant physiological features for resisting pests and diseases is healthy plant and vigorous plant growth.

However, despite higher pest pressure in a field that received inorganic fertilizer, there was a yield improvement as a consequence of improved plant growth. The nourishing of many host plants of this pests can impact the expression of crop resistance (Chang *et al*., 1985). Leuck *et al*. (1974), proved that foliage of ‘Coastal’ Bermuda grass, ((L.) person), corn, or sorghum, (*Sorghum bicolor* (L.) Moench), sprayed with 14 chemical fertilizer could scare off FAW larval feeding. Further, according to Leuck and Hammons (1974), fertilizer can instigate significant differences in the resistance of peanut (*Arachis hypogaea* L.) cultivars to FAW feeding.

2.11 Enhanced efficiency fertilizer products for YARA Ghana limited.

In Ghana, YARA is the largest importer of bulk fertilizer (estimated to account for around 70,000-80,000 tones in 2008) (Arthur, 2014). Some of the YARA fertilizer formulations include:

Amidas (Yara Vera) consist of nitrogen (N) and sulphate sulphur (S) that is completely available to crops in an ideal N:S ratio of 7:1. The N is available mostly in the form of urea while that of S improves N efficiency from urea by limiting N volatilization losses up to 35% on low PH soils. Sulfan (Yara Bela) contained nitrate and ammonium, this nitrate is immediately available to the plants compared to ammonium-N contained in SA, supports other nutrients uptake such as K, Mg and Ca, and also reduces soil acidification compared to Urea and SA. YARA Mila (Actyva) contains NPK 23-10-5+2MgO+3S+0.3Zn. However, part of its N is in the form of nitrate that is absorbed by the crops directly. The nitrophosphate production procedure makes Actyva a distinctive blend of polyphosphates and orthophosphates. The polyphosphate component of the product assist crops availability of micronutrients such as manganese.

Urea contain 46% N (high N concentration) while T15 (Unique15) contains the right proportion of NPK 15-15-15. Also, YARA Vita (Croplift Bio) being a newly formulated foliar fertilizer with both the macro (NPK+B small quantity) and micronutrients (Cu, Mn, Mo and Zn). This YARA Vita ensures precise application of the right micronutrients at the right time and can be particularly targeted to the leaf or fruit to meet immediate needs of the crop. This foliar fertilizer provide nutrients for immediate uptake by the leaves and consequently, the farmer is not reliant on the right soil only, PH or the condition of the media and can keep the crop on course. However, these micro nutrients are more important in plant growth and development, metabolism, resistance and susceptibility to insects and disease as well as yield. Per Tripathi (2015), Boron (B) for instance play an essential role in betterment of the optimal growth of plant cell. Also reported by Beato *et al*. (2010) and Tripathi (2015) that, apart from playing optimum role in the biosynthesis of cell wall and lignifications, B additionally takes part remarkably in different physiological and biological procedures like tissue differentiation, vegetative growth, membrane integrity, phenolic metabolism, etc.

Copper (Cu) play a magnificent role in numerous metabolic and physiological processes regulations of the plants (Rehm and Schmitt, 2002; Tripathi, 2015). It also play a role as cofactor of enzymes and significantly acts in photosynthesis, respiration, lignification, phenol metabolism, protein synthesis and regulation of auxins etc. (Tripathi, 2015). Manganese (Mn) takes part in the phenolic compounds production and the production of other plant mechanisms (Fernando *et al*., 2009; Tripathi, 2015). Mn play a revolved role in biosynthesis of ATP acyllipids, fattyacids and proteins. (Tripathi, 2015). Zink (Zn) is a structural protein cofactor and a catalytic (Hambidge *et al*., 2000). Zn controls biological membrane, controls transcription directly through effects on DNA/RNA binding and synchronization of chromatin structure RNA metabolism and protein- protein interactions and anti-oxidative defense enzymes (Tripathi, 2015). Molybdenum (Mo) for instance can lower disease resistance when one small ounce of it is lacking per acre by hindering the production of nitrate reductase. Two molecules of Mo contains in this enzyme, and this enzyme is required in conversion of nitrates to proteins (Tripathi, 2015). Magnesium takes part actively in photosynthesis as it is an essential constituent of the chlorophyll molecule, it is a co-factor in numerous enzymatic reactions that leads to the processes of phosphorylation. (Silva and Uchida, 2000). Sulfur is important in plant proteins formation as it is a constituent of certain amino acid, actively, it takes part in B vitamins metabolism. S also involves in seed production, chlorophyll formation and protein structure stabilization (Silva and Uchida, 2000).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The experiment was conducted at the University for Development Studies Research Field, Nyankpala. The experimental site was located about 16 km west of Tamale and lies in the interior Guinea Savanna agro-ecological zone of Ghana. The area has a unimodal rainfall pattern which has a mean annual rainfall ranging from 800 mm to 1200 mm (Kombiok *et al*., 2012). The area has a warm climate of mean minimum temperature of 25°C and a maximum temperature of 35°C, which falls between April and early November each year, followed by a pronounced dry season from the latter part of November to March (Savanna Agricultural Research Institution (SARI), 2001). The soil is largely developed from voltaian shale and sandstone with texture being sandy loam to loamy sandy (Yidana *et al*., 2011). Kumah (2016), described the area as a gentle undulating to flat terrain. According to Yidana *et al*. (2011), the area is a low-lying grassland with few spread perennial woody species.

3.2 Experimental design and treatments

The experiment was a single factor experiment with ten treatments, arranged in a randomized complete block design with three replications. The variety of maize used was Obatanpa. Plot size of 4 m × 4 m were used (16 m²). Buffer zones of 2.0 m were created between blocks and 1.0 m within plots on the same block. The experiment covers a land area of 16 m × 49 m (784 m²).

The experiment consist of ten (10) treatments replicated three times. Eight treatments were based on YARA Ghana limited protocol provided, one

The experiment consist of ten (10) treatments replicated three times. Eight treatments were based on YARA Ghana limited protocol provided, one treatment from commercial fertilizers and a control. Table I shows the treatments and their descriptions.

Table 3.1: Fertilizer treatment protocols used for the trial

Treatments	Description	
	2 weeks after planting	**4 weeks after planting**
ACT+CLBb + AMI+CLBt	Actyva @ 250kg/ha with CropLift Bio @2.5 l/ha	Amidas @ 125kg/ha with CropLift Bio @2.5 l/ha
ACT+CLBb+ SUL+CLBt	Actyva @ 250kg/ha with CropLift Bio @2.5 l/ha	Sulfan @ 125kg/ha with CropLift Bio @2.5 l/ha
ACT+CLBb + URE+CLBt	Actyva @ 250kg/ha with CropLift Bio @2.5 l/ha	Urea (46%N) @ 125kg/ha with CropLift Bio @2.5 l/ha
T15+CLBb + AMI+CLBt	NPK 15-15-15 @ 250kg/ha with CropLift Bio @ 2.5 l/ha	Amidas @ 125kg/ha with CropLift Bio @2.5 l/ha
T15+CLBb + SUL+CLBt	NPK 15-15-15 @ 250kg/ha with CropLift Bio @ 2.5 l/ha	Sulfan @ 125kg/ha with CropLift Bio @2.5 l/ha
T15+CLBb + URE+CLBt	NPK 15-15-15 @ 250kg/ha with CropLift Bio @ 2.5 l/ha	Urea (46%N) @ 125kg/ha with CropLift Bio @2.5 l/ha
ACT+CLBb + ACT+CLBt	Actyva @ 250kg/ha with CropLift Bio @2.5 l/ha	Actyva @ 125kg/ha with CropLift Bio @2.5 l/ha
NPK+SOA+IS	(none YARA) N-P-K (15-15-15) @ 250kg/ha with insecticide spray	Sulphate of Ammonia 125kg/ha with insecticide spray
CLBb+CLBt	CropLift Bio @2.5 l/ha	CropLift Biofertilizer @2.5 l/ha
CONTROL	No fertilization	No fertilization

CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

3.3 Application of fertilizer treatments

The fertilizer treatments application was strictly done in accordance with the protocol indicated in Table 3.1 above. Application of the treatments was done using deep placement method. A dibbler was used to puncture a hole about 2 cm from the plant, after which the fertilizer was then put in to the hole and covered with soil to prevent it from carrying away by rain water.

3.4 Crop husbandry

Previously, the experimental field was cultivated with maize. During the third week of May, the field was disc-ploughed and leveled with a hand weeding hoe. The Obatanpa (late maturity maize variety) obtained from Ganorma agrochemicals in Tamale was used for planting. The field was planted on the fourth week of June 2021, while refilling was done a week after planting. Three seeds were planted per hill and later thin to two. They was a sowing spacing of 40 cm between plants and 75 cm between rows. There was a construction of bunds around each plot before application of the treatments to prevent drift of the fertilizer into adjacent plots.

The control of the weeds was undertaking at three weeks and six weeks after planting. At three weeks after planting, a hand weeding hoe was used to control the weeds whiles at six weeks a selective post-emergency herbicides (Nikoking) with an active ingredients of Nicosulfuron 40g/l OD was used to control the weeds. However, a RidOut (glyphosate IPA Salt 480g/l SL) was used to control weeds immediately after planting.

For optimizing the growth and yield of crops, it is important to control pests in maize field. K-optima (insecticide) was used to control pest in NPK + SOA +IS plots and that of No fertilization plots to control pests. The insecticide was applied two weeks, four weeks and six weeks after emergency and after the application of the treatments.

3.5 Measurement of plant growth parameters

Five plants were selected at random per plot and tagged for the measurement of plant height and leaf area. Measurement was made at four weeks, six weeks and eight weeks after planting. A measuring tape was used for the measurement of plant height from the base of the plants to the tip of the flag leaf.

Leaf area was obtained from measuring the width and length of three leafs randomly from each of the five plants and find average. The leaf area was determined using linear regression analysis equation below.

Leaf Area

W = leaf w= k$(L \times W)$

Where,

K = 0.75 which is constant for all cereals

L = leaf length idth.

3.6 Assessment of FAW abundance

FAW larval abundance was assessed using 2×3 m (6 m^2) at the middle of each plot. This was done to avoid the border effect. In the course of each data collection, the maize plants that fall within the 6 m² were rigorously hunted for the existence of the larvae and the number existed were then counted and recorded. However, they were assessed three times, that is four weeks after planting (4 WAP), 6 WAP and 8 WAP.

3.7 Assessment of FAW damage incidence

Leaf and Whorl defoliation was assessed using 2×3 m (6 m²) at the middle of each plot. Each maize plants that fall within the 6 m² were rigorously searched for the damage incidence using the Davis rating scale from 0 to 9 (Table 2) to score FAW damage incidence on plants (Davis and Williams, 1992).

Table 3.2: Leaf damage rating scale used to access plant damage due to FAW

Scale (1-9)	Description	Resistance reaction
1	No visible leaf feeding damage	Highly resistant
2	Few pin holes on older leaves.	Resistant
3	Several shot-holes injury on a few leaves.	Resistant
4	Several shot-hole injuries common on several leaves or small lesions.	Moderately resistant
5	Elongated lesions (> 2 cm long) on a few leaves.	Moderately resistant
6	Elongated lesions on several leaves.	Susceptible
7	Several leaves with elongated lesions or tattering.	Susceptible
8	Most leaves with elongated lesions or severe tattering.	Highly susceptible
9	Plant dying as a result of foliar damage.	Highly susceptible

Source: Davis and Williams (1992).

3.8 Estimation of maize yield

The harvesting was done in plot bases manually while each harvested plot were put into the various experimental sacks. Six meters square (6 m^2) in the middle of each plot was harvested, de-husked and de-grained. The grains were allowed to further dry to 12% moisture content before aerial winnowing to take out the chaffs from the grains. The resulting grains were then weighed on a Camry digital weighing scale and later converted to kilogram per hectare for each treatment using the formula (Asante *et al*., 2001; Badii, 2005) below. The yield analysis was done by comparing the obtained yield weight from the control plots to that of fertilization regimes. Hundred (100) seeds were also counted and weighed.

$$\text{Grain yield/ha} = \frac{10{,}000}{Area\ harvested} \times \text{Grain yield /plot}$$

3.9 Resistance/tolerance level of *S. frugiperda*

Foliar damage caused by FAW infestation was evaluated by scoring each infested crops on 1-9 scale (Davis and Williams, 1992) modified by Prasanna *et al*., (2018). This scale assessment was based on degree of foliar damage, where highly resistant plants were graded with 1 (no visible damage) whilst 9 rated as highly susceptibility crops (completely damaged).

3.10 Statistical analysis

The data collected were transformed using $\sqrt{y}+0.5$ where y is the response variable, before subjected to repeated measures analysis of variance (ANOVA) in GenStat Statistical Programme (12th edition). Treatments means were separated at the probability level of 5% using least significant difference (LSD) test.

3.11 Partial budget analysis

Partial budget analysis was employed to evaluate the net benefit as a result of fertilization and net returns to FAW control. This were to assess the economic view of investment in FAW management compared to no fertilization. Both chemicals, maize and the fertilizer market prices were employed in landing at the value of production and cost of production respectively. The assumption was that, all other cost were constant whilst the cost that differ were therefore applied to calculate the input cost. The value of yields increment due to fertilization were calculated using mean grain yield of maize with the following formula:

$$Value\ of\ increased\ yield\ due\ to\ fertilizer$$

$$= Price\ \times\ Increased\ yield\ over\ control$$

$$V_{yield} = P_{makt}\ \times (Q_{treatment} - Q_{control})$$

Where $P_{market}$the market is price of maize (GHS) and $Q_{treatment}$ is the output of treated plot (kg/ha) and $Q_{control}$ is the output of control plot (kg/ha).

The total variable cost of fertilizer application was calculated as:

$$TVC_{faw} = \left(P_{mf} \times Vol_f\right)$$

Where $TVC_{faw}$is the total variable cost (GHS), P_{mf} is the market price of fertilizer used, Vol_f is the volume of fertilizer used (lha^{-1}).

The net benefit is calculated using the following:

$$Net\ benefit\ due\ to\ fertilization = V_{yield} - TVC_{faw}$$

Where V_{yield} is the value of increased yield due to fertilization and TVC_{faw} is total variable cost of fertilizer.

The returns to fertilization were then calculated using the following:

$$Returns\ to\ fertilizer\ use = \frac{Value\ of\ increased\ yield\ over\ control(GHS/ha)}{Total\ variable\ of\ fertilizer\ application(GHS/ha)}$$

CHAPTER FOUR

4.0 RESULTS

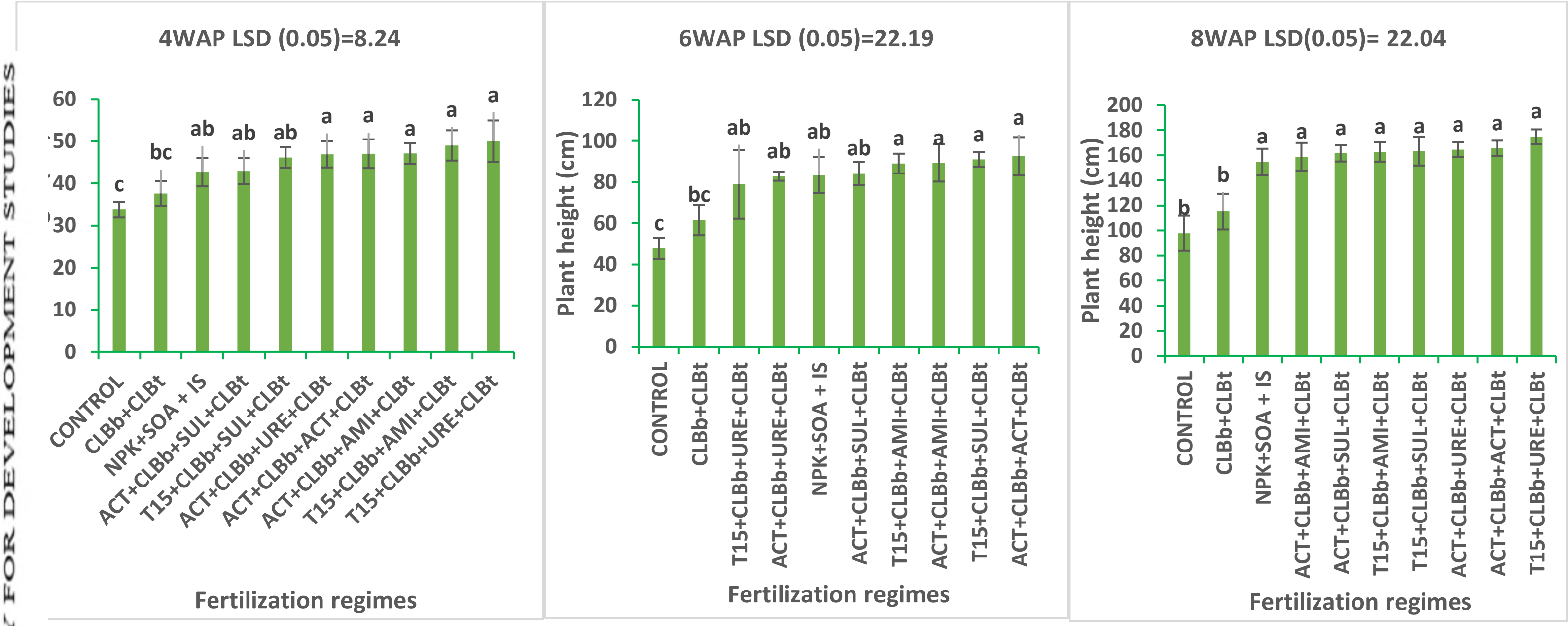
4.1 Maize growth parameters

4.1.1 Plant height

At 4 weeks after planting (4 WAP), maize plant height was significantly affected ($P < 0.05$) by the fertilization regimes (Figure 4.1; Appendix 1). Maize plant height was found to range from 33.76 cm to 50.04 cm in the control and T15 + CLBb + URE + CLBt treatments respectively. Plant height in the control plot was found to be significantly lower than all the fertilization regimes except CLBb + CLBt. Among the fertilization regimes, there was no significant variation except CLBb + CLBt which recorded significantly lower.

At 6 WAP, maize plant height was affected significantly ($P < 0.05$) by the fertilization regimes (Figure 4.1; Appendix 2). Plant height was found to range from 47.8 cm in the control to 92.6 cm in the ACT + CLBb + ACT + CLBt. Plant height in the control was significantly lower than the fertilization regimes apart from CLBb + CLBt. With the exception of CLBb + CLBt there was no significant variation among the fertilization regimes.

At 8 WAP, there was a significant variation in maize plant height ($P < 0.05$) as affected by the fertilization regimes (Figure 4.1; Appendix 3). There was a range of plant height from 97.8 cm to 174.8 cm in the control and T15+CLBb+URE+CLBt treatments respectively. Control recorded significantly lower than all the fertilization regimes except CLBb + CLBt. Among the fertilization regimes CLBb + CLBt recorded significantly lower.



rs (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, WAP= weeks after nting. CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, ›ptimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

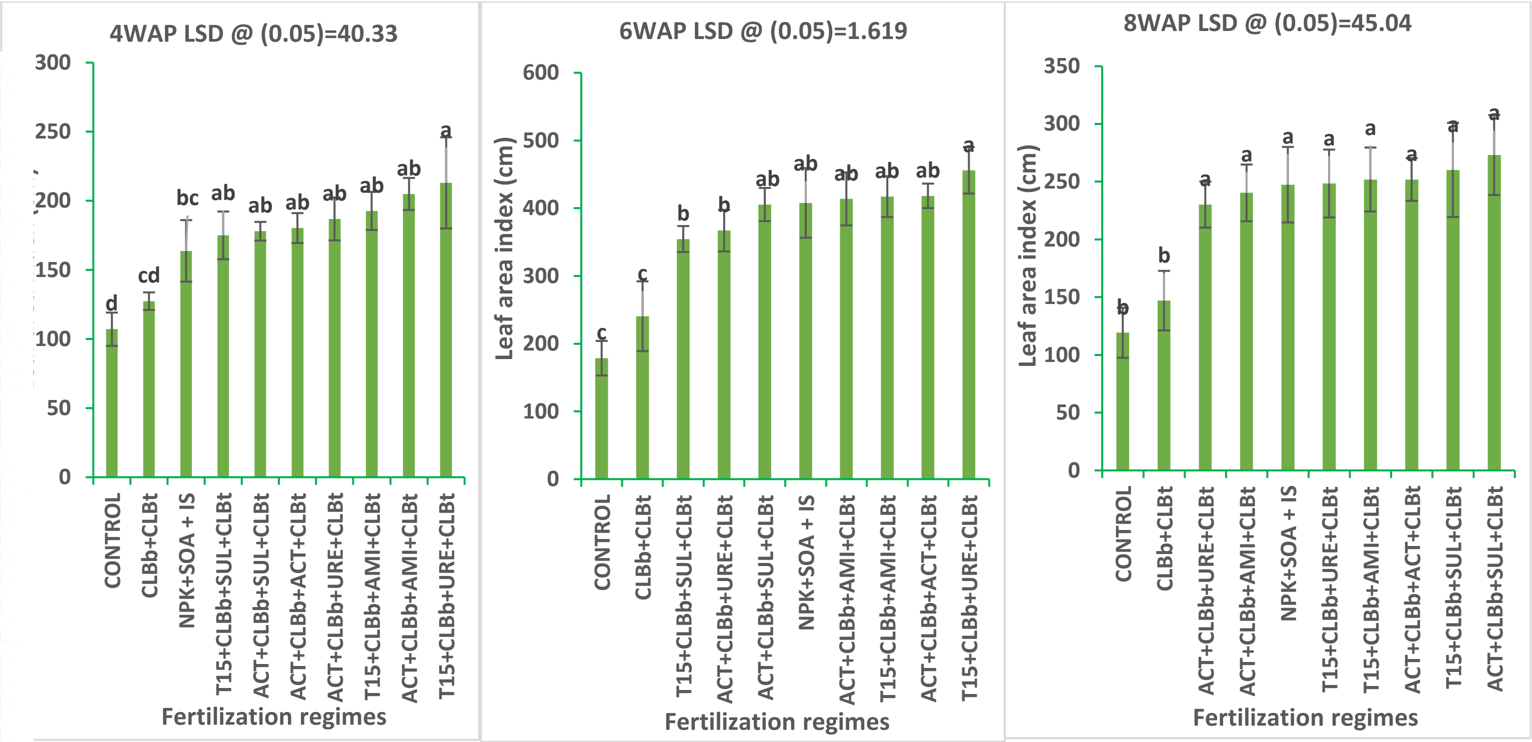
gure 4.1: Effect of fertilization regimes on plant height of maize

4.1.2 Leaf area index (LAI)

At 4 WAP, LAI was significantly affected ($P < 0.05$) by fertilization regimes as shown in figure 4.2; Appendix 4. Control recorded significantly lower LAI compared to the fertilization regimes except CLBb + CLBt. Among the fertilization regimes T15 + CLBb + URE + CLBt recorded significantly higher LAI (213 cm^2) than NPK+SOA + IS and CLBb + CLBt, though no significant difference recorded between T15 + CLBb + URE + CLBt and the rest of the fertilization regimes.

At 6 WAP, fertilization regimes affected leaf area index significantly ($P < 0.05$). Control recorded significantly lower (178.6 cm^2) LAI compared to fertilization regimes except CLBb + CLBt (240.5 cm^2). T15 + CLBb + URE + CLBt recorded significantly higher LAI (456 cm^2) than ACT + CLBb + URE + CLBt, T15 + CLBb + SUL + CLBt and CLBb + CLBt respectively, while CLBb + CLBt performed significantly lower LAI among the fertilization regimes when compared (Figure 4.2; Appendix 5).

At 8 WAP, LAI was significantly affected ($P < 0.05$) by the fertilization regimes as shown in figure 4.2; Appendix 6. Though, there was no significant variation between control (119.2 cm^2) and CLBb + CLBt (147 cm^2), but however, both performed significantly lower than the rest of fertilization regimes.

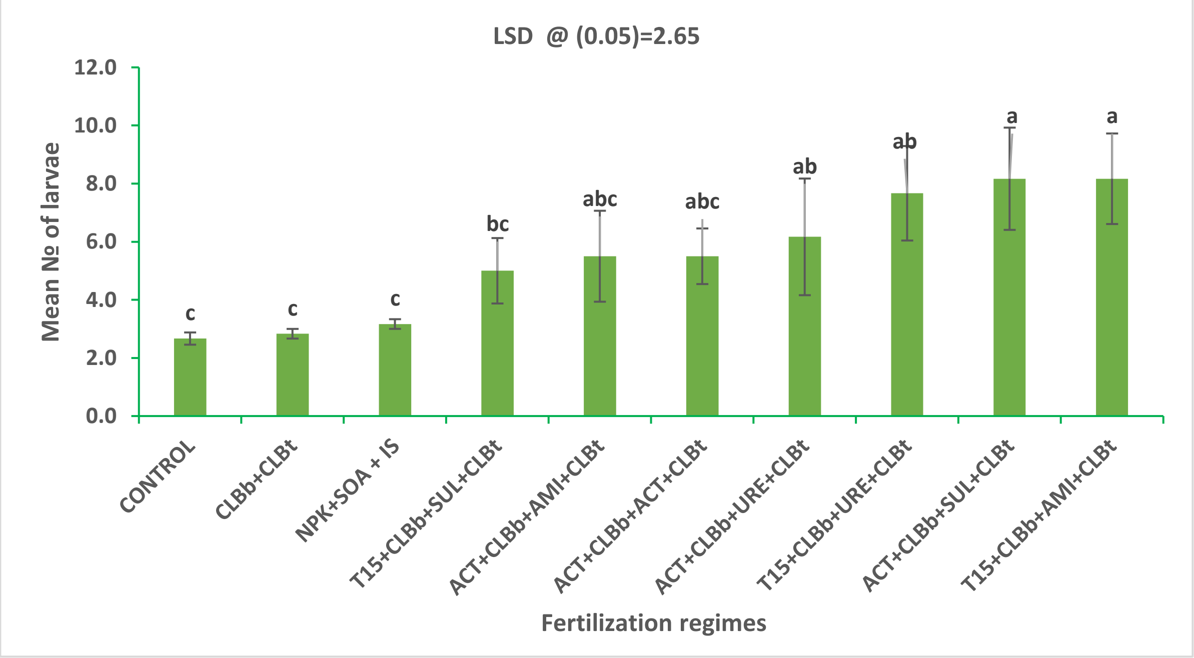


rs (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, WAP= weeks after nting. CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, ptimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

gure 4.2: Effect of fertilization regimes on leaf area index of maize

4.2 FAW larval abundance

FAW larval abundance was significantly affected ($P < 0.05$) by the fertilization regimes as shown in figure 4.3; Appendix 7. Control recorded significantly lower larval abundance than ACT + CLBb + SUL + CLBt, T15 + CLBb + AMI + CLBt, T15 + CLBb + URE + CLBt and ACT + CLBb + URE + CLBt. Comparing the fertilization regimes, ACT + CLBb + SUL + CLBt and T15 + CLBb + AMI + CLBt recorded significantly higher larval abundance. Also, T15 + CLBb + URE + CLBt and ACT + CLBb + URE + CLBt recorded significantly higher larval abundance than NPK + SOA + IS and CLBb + CLBt when compared.



Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal); CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

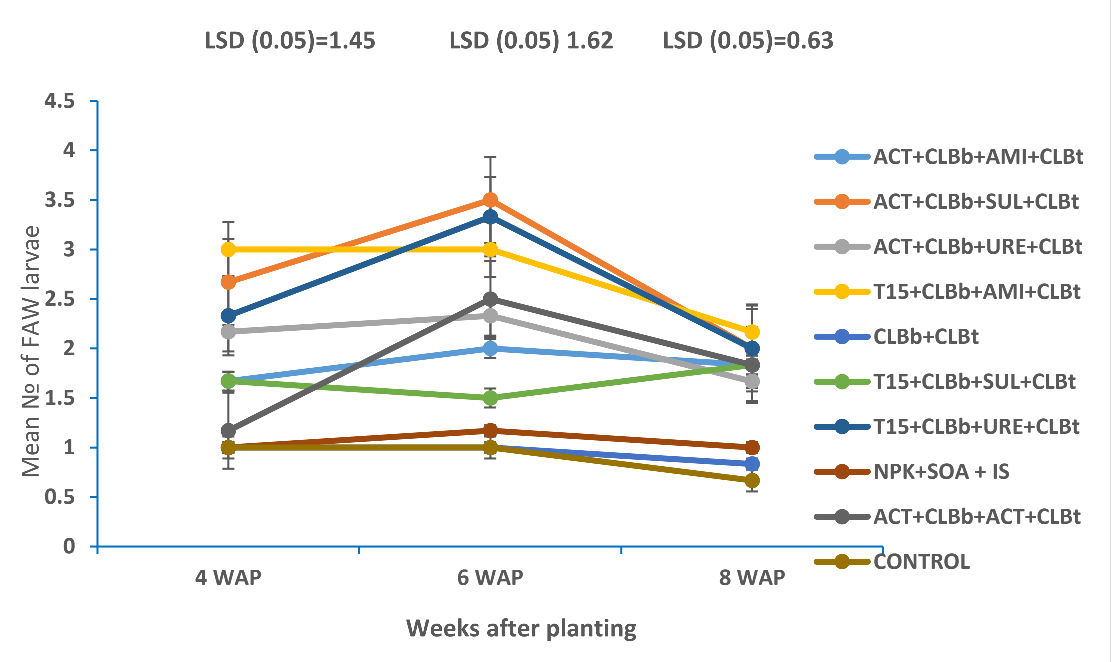
Figure 4.3: Effect of fertilization regimes on FAW larval abundance.

4.3 FAW population dynamics

The population dynamics of *S. frugiperda* was affected significantly by the fertilization regimes as presented in figure 4.4. At 4 WAP, T15 + CLBb + AMI + CLBt recorded the highest larval mean number (Appendix 8) while ACT + CLBb + SUL + CLBt recorded the second highest followed by T15 + CLBb + URE + CLBt. However, CLBb + CLBt, control and NPK + SOA + IS recorded the least larval mean number.

At 6 WAP, ACT + CLBb + SUL + CLBt and T15 + CLBb + URE + CLBt recorded the first and second highest mean number of larval population followed by T15 + CLBb + AMI + CLBt, while the least number recorded from CLBb + CLBt and control (Appendix 9).

There was a similar trend of 8 WAP to that of 4WAP (Appendix 10) where T15 + CLBb + AMI + CLBt recorded the highest, followed by ACT + CLBb + SUL + CLBt and T15 + CLBb + URE + CLBt. However, control recorded the lowest mean larval number followed by CLBb + CLBt and NPK + SOA + IS.

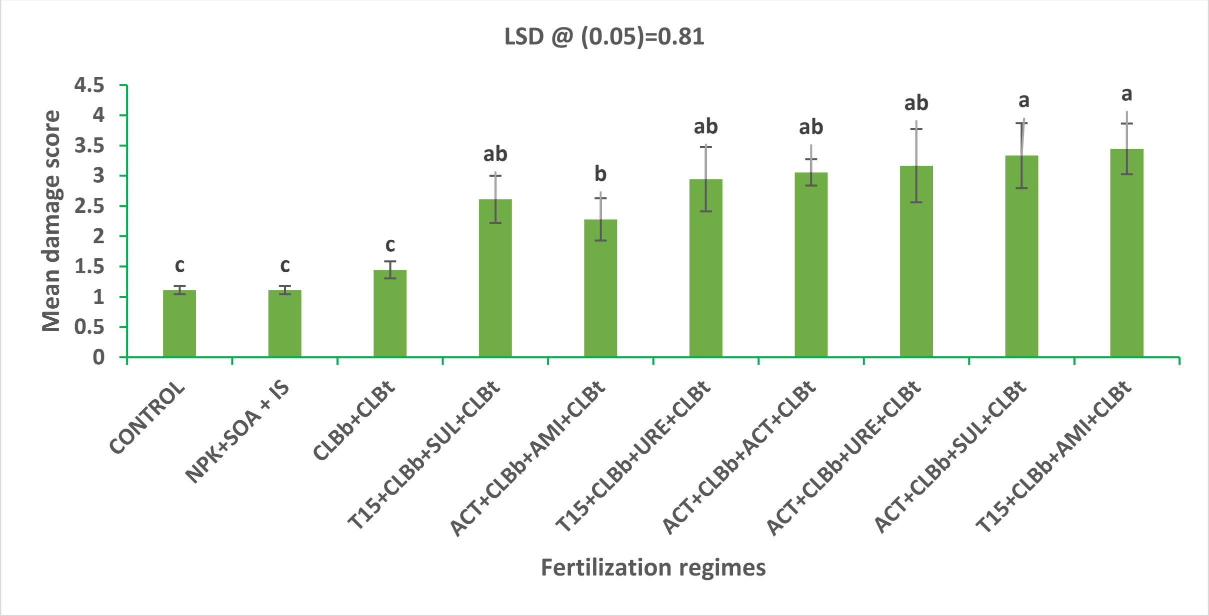


Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

Figure 4.4: Effect of fertilization regimes on FAW population dynamics.

4.4 FAW damage incidence

There was a significant variation ($P < 0.05$) in FAW damage incidence among the fertilization regime (Figure 4.5; Appendix 11). Apart from NPK + SOA + IS and CLBb + CLBt, control recorded significantly lower damage incidence than the rest of the fertilization regimes. Among the fertilization regimes, T15 + CLBb + AMI + CLBt and ACT + CLBb + SUL + CLBt recorded significantly higher damage incidence than ACT + CLBb + AMI + CLBt, CLBb + CLBt and NPK + SOA + IS. Significantly, CLBb + CLBt and NPK + SOA + IS recorded the lowest damage incidence.



Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

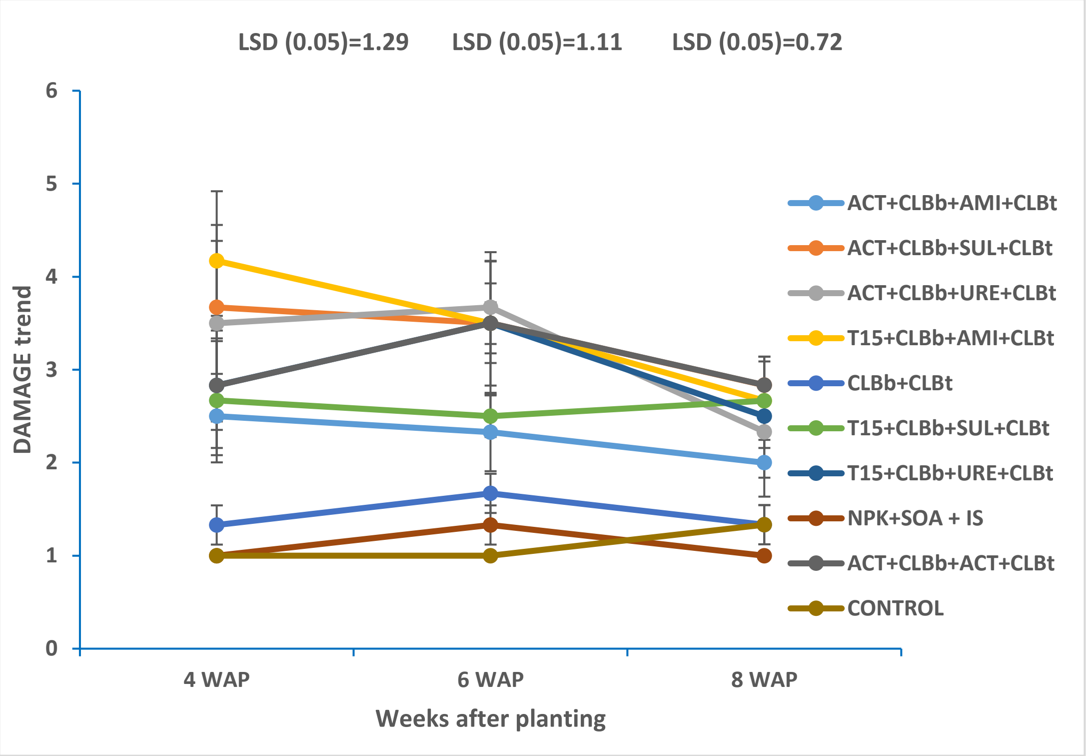
Figure 4.5: Effect of fertilization regimes on damage incidence of FAW to maize.

4.5 Trend of FAW damage incidence on maize.

The trend of damage was affected significantly by the influence of fertilization regimes (figure 4.6). At 4 WAP, with the exception of NPK + SOA + IS, control recorded the least trend of damage than the rest of the fertilization regimes. The highest damage incidence recorded in T15 + CLBb + AMI + CLBt followed by ACT + CLBb + SUL + CLBt while NPK + SOA + IS recorded the least damage incidence among the fertilization regimes (Appendix 12).

At 6 WAP, control recorded the lowest damage incidence compared to the fertilization regimes. Among the fertilization regimes ACT + CLBb + URE + CLBt (3.67) placed at the highest damage incidence level whilst ACT + CLBb + SUL + CLBt, ACT + CLBb + ACT + CLBt, T15 + CLBb + AMI + CLBt and T15 + CLBb + URE + CLBt recorded (3.5 each) the second highest. However, the least damage incidence was recorded from NPK + SOA + IS (1.33) (Appendix 13).

At 8 WAP, with the exception of CLBb + CLBt and NPK + SOA + IS, control recorded the least damage incidence compared to the fertilization regimes. Among the fertilization regimes, NPK + SOA + IS recorded the lowest damage incidence while ACT + CLBb + SUL + CLBt (2.83) and ACT + CLBb + ACT + CLBt (2.83) recorded the highest damage score (Appendix 14).



Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

Figure 4.6: Trend of FAW damage incidence on maize as affected by the fertilization regimes across the sampling weeks.

4.6 Resistant/tolerance level of maize to FAW infestation

There was an influence of the resistant levels of maize by the fertilization regimes as presented in Table 4.1. The fertilization regimes were able to tolerate /resist the FAW infestation by obtaining a varying damage scores below four (4) and confirming by obtaining the expected output.

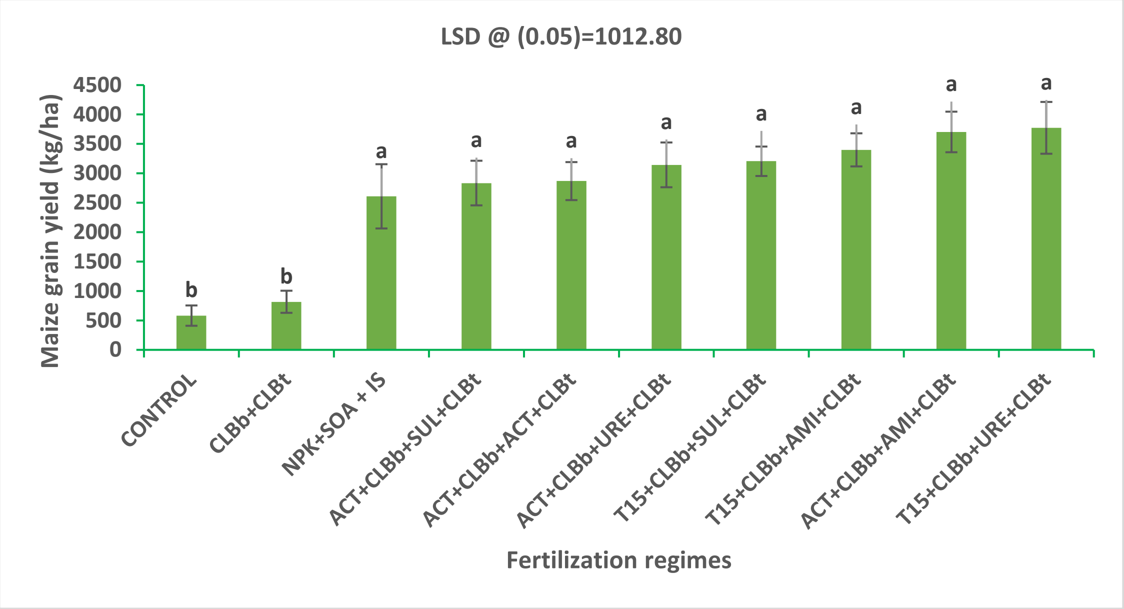
Table 4.1: Resistance status of maize to FAW infestation as influenced by YARA fertilizer formulations.

Fertilization regimes	Damage score	Description	Resistance status
CLBb+CLBt	1.44	No visible leaf feeding damage	Highly resistant
ACT+CLBb+AMI+CLBt	2.29	Few pin holes on older leaves.	Resistant
ACT+CLBb+URE+CLBt	3.17	Several shot-holes injury on a few leaves	Resistant
T15+CLBb+AMI+CLBt	3.44	Several shot-holes injury on a few leaves	Resistant
ACT+CLBb+SUL+CLBt	3.33	Several shot-holes injury on a few leaves	Resistant
T15+CLBb+SUL+CLBt	2.61	Several shot-holes injury on a few leaves	Resistant
T15+CLBb+URE+CLBt	2.94	Several shot-holes injury on a few leaves	Resistant
ACT+CLBb+ACT+CLBt	3.06	Several shot-holes injury on a few leaves	Resistant

CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

4.7 Grain yield

The grain yield of maize was significantly affected ($P < 0.05$) by the fertilization regimes (figure 4.7; Appendix 15). Maize grain yield ranged from 582 kg/ha in the control to 3,773 kg/ha in T15 + CLBb + URE + CLBt respectively. All the maize plots treated with fertilizer, recorded significantly higher grain yield compared to control except CLBb + CLBt. Among the fertilization regimes, grain yield was in the order, T15 + CLBb + URE + CLBt, ACT + CLBb + AMI + CLBt, T15 + CLBb + AMI + CLBt, T15 + CLBb + SUL + CLBt, ACT + CLBb + URE + CLBt, ACT + CLBb + ACT + CLBt, ACT + CLBb + SUL + CLBt, NPK + SOA + IS and CLBb + CLBt. However, apart from CLBb + CLBt which recorded significantly lower maize grain yield, there was no significant variation among the rest of the plots treated with fertilizer.

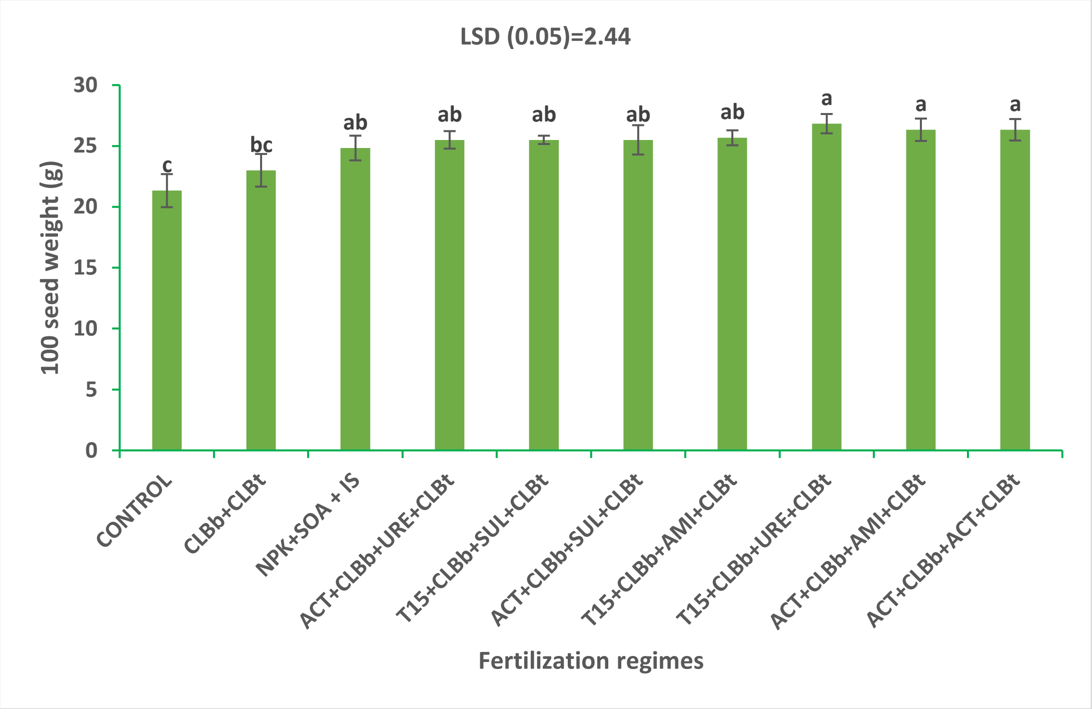


Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

Figure 4.7: Effect of the fertilization regimes on grain yield (kg/ha) of maize.

4.8 100 seed weight

Hundred (100) seed weight of maize was found to be significantly affected (*P < 0.05*) by the fertilization regimes (Figure 4.8; Appendix 16). Mean seed weight obtained from all the fertilizer treated plots was found to be significantly higher than control except CLBb + CLBt. Among the plots treated with fertilizer, T15 + CLBb + URE + CLBt (26.8) ACT + CLBb + ACT + CLBt and ACT + CLBb + AMI + CLBt (26.3) obtained significantly higher maize grain weight than CLBb + CLBt (23.0).



Bars (mean ± standard of error of means) with the same letters are not significantly different, LSD= least significant difference, CLBb (CropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); ACT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas).

Figure 4.8: Effect of fertilization regimes on 100 seed weight of maize.

4.9 Partial budget analysis from maize grain yield

The results of partial budget analysis showed a positive value of grain yield increment for all the fertilization regimes compared to no fertilization plot (control). The net benefit of using YARA formulated fertilizers for FAW management were positive and these net returns on investing in YARA formulated fertilizers were higher than unity. Among the fertilizer treatments used, T15 + CLBb + URE + CLBt had the highest net benefit and net returns compared to other treatments as presented in Table 4.2.

Among the fertilization regimes, T15 + CLBb + URE + CLBt recorded the highest profit (GH¢ 10,986/ha) closely followed by ACT + CLBb + AMI + CLBt with a profit of (GH¢10,488/ha). T15 + CLBb + AMI + CLBt (GH¢ 9,614/ha), T15 + CLBb + SUL + CLBt (GH¢ 9,143/ha) and ACT + CLBb + URE + CLBt (GH¢ 8,873) yielded third, fourth and fifth highest profit. However, with the exception of CLBb + CLBt (GH¢ 640/ha), NPK + SOA + IS (GH¢ 6758/ha) gave the lowest profit compared to YARA formulated fertilizers.

The cost-benefit analysis shows that T15 + CLBb + URE + CLBt provided the highest cost-benefit ratio (GH¢ 10.1) while T15 + CLBb + SUL + CLBt provided the second highest cost-benefit ratio (GH¢ 7.9). The third highest was obtained from ACT + CLBb + AMI + CLBt with cost-benefit ratio of GH¢ 7.8, which was closely followed by T15 + CLBb + AMI + CLBt (GH¢ 7.5). ACT + CLBb + URE + CLBt was lower with cost-benefit ratio (GH¢ 7.2) than T15 + CLBb + AMI + CLBt (GH¢ 7.5) but higher than ACT + CLBb + SUL + CLBt (GH¢ 6.1). ACT + CLBb + ACT + CLBt and NPK + SOA + IS obtained GH¢ 5.2 and GH¢ 5.0 respectively, while CLBb + CLBt (2.1) recorded the least.

Table 4.2: The profit and cost-benefit ratio accrued from the maize grain yield obtained from the fertilization regimes FAW management.

ilization regimes	Outputs			Inputs		
	Yield kg/ha	Increased yield due to fertilization over control kg/ha	Value of increased GH¢/ha	Cost of fertilizer GH¢/ha	Net benefit due to fertilization GH¢/ha	Net returns due to fertilization
CONTROL	582	–	–	–	–	–
T+CLBb+AMI+CLBt	3,703	3,121	12,484	1,423	11061.5	7.8
T+CLBb+SUL+CLBt	2,835	2,253	9,012	1,273	7739.5	6.1
T+CLBb+URE+CLBt	3,144	2,562	10,248	1,249	8999.5	7.2
5+CLBb+AMI+CLBt	3,399	2,817	11,268	1,324	9944.5	7.5
CLBb+CLBt	817	235	940	300	640.0	2.1
5+CLBb+SUL+CLBt	3,205	2,623	10,492	1,174	9318.5	7.9
5+CLBb+URE+CLBt	3,773	3,191	12,764	1,149	11615.5	10.1
NPK+SOA + IS	2,609	2,027	8,108	1,350	6758.0	5.0
T+CLBb+ACT+CLBt	2,868	2,286	9,144	1,474	7670.5	5.2

Optima (250ml) = GH¢50, T15 (50kg) = GH¢175, Actyva (50kg) = GH¢195, Amidas (50kg) = GH¢155, Urea (50kg) = GH¢85, Sulfan (50kg) = GH¢95, NPK 15-15 (50kg) = GH¢190, SOA (50kg) = GH¢160, Croplift Bio (1L) = GH¢30, maize (1kg) = GH¢3.20. These prices was for 2022 cropping season. CLBb ropLift Bio basal), CLBt (CropLift Bio topdress); NPK (NPK none Yara); SOA (Sulphate of Ammonia); IS (Insecticide sprayed, K-optimal); CT (Actyva), SUL (Sulfan); URE (Urea); T15 (NPK 15:15:15); AMI (Amidas)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of the fertilization on growth and infestation of FAW on maize

This research revealed that maize growth and development was significantly affected by the fertilization regimes. At 4 weeks, 6 weeks and 8 weeks after planting, control recorded significantly shorter plant height compared to the fertilization regimes except CLBb + CLBt (Figure 4.1). The leaf area index (LAI) followed the same trend as the plant height (Figure 4.2). The low performance of control may be due to nutrients deficiency whilst that of CLBb + CLBt may be due to low concentration of the NPK (8.5-3.4-6) in its formulation. This is in conformity with Arthur (2014), who stated that, plants in a plot with NPK 250 kg/ha fertilizer application were taller significantly compared to that of no fertilization plots. Also, since both fertilization regimes received the required nutrients, there was no significant variation among them. This is in conformity with Schumann *et al*. (2010), who stated that, mineral nutrients are important for plant growth and development and that, supply of a balanced nutrient ensures optimal plant growth.

The abundance of *S. frugiperda* was significantly affected by various fertilization regimes (Figure 4.3). However, the abundance of *S. frugiperda* on T15 + CLBb + AMI + CLBt, ACT + CLBb + SUL + CLBt and T15 + CLBt + URE + CLBt could be due to the balance of nitrate and ammonium nitrogen in ACTYVA, in combination with SULFAN that has a combination of nitrate and ammonium of which the N is immediately available to the plants compared to SA, the unique combination of T15 that give a well and true proportion of NPK 15-15-15 in combination with high efficiency of the sulfur that improves N efficiency by reducing N volatilization losses in AMIDAS, in combination with the high quality urea that promote green leafy growth and make the plant look lush. This is in line with Shah (2017) who reported that, nutrients application to the soil help crops to produce more succulent, broad and fresh leaves which serves a surface suitable for egg-laying by the varying pests. Also, per Schumann *et al*. (2010) revealed that, nutrients usually seen simply as food for plants essentially for better growth and yield, yet, mineral nutrition also impacts growth and yield by influencing resistance and susceptibility of plants to pests and pathogens.

The low abundance of *S. frugiperda* on control, CLBb + CLBt and NPK + SOA + IS could be attributed to plants starved by nutrients and also, the insecticide treated in the control plots. According to Gogi *et al*., (2012), plants development depends on nutrients availability while that of insect-pests depends on the availability of quality food from its host plants. The low abundance of *S. frugiperda* on CLBb + CLBt (8.5N, 3.4P, 6K+B+Cu+Mn+Mo+Zn) treatment could be the effect of the foliar fertilizer that scared off the FAW larval feeding. Leuck *et al*. (1974) proved that foliage of 'Coastal' Bermuda grass, (*Cynodon dactylon* (L.) person), corn, or sorghum, (S*orghum bicolor* (L.) Moench), sprayed with 14 chemical fertilizers could scare off FAW larval feeding. Nonetheless, the low abundance of FAW in the NPK + SOA + IS plots is due to the pesticides (K-optima) sprayed on those plots that scared off the FAW larvae. Research proofed that, the larval of FAW inflict excessive leaf feeding damage in unsprayed maize than those treated with pesticides (Babendreier *et al*., 2020; Nboyine *et al*., 2021).

Generally, the results from population dynamics of FAW shown that, population increases from the 4 WAP to 6 WAP and finally dropped at the 8 WAP (Figure 4.4). Normally FAW moths lay their eggs at the early stages of maize growth, therefore damage is limited. The succulent growth stage is the time that the infestation becomes great and the damage duplicated, while during and after tasselling leaf become unpalatable for feeding, that is when the leaf became old. This is in corroboration with Igyuye *et al*. (2018) that, larval feeding behavior was studied by Pannuti *et al*. (2015), and described that despite the fact that vegetative stage (young leaf tissue) is favourable for growth and survival, the leaf tissue is unpalatable on more older plants. Consequently, the leaves of maize are unsuitable for the development of early instars after the VT and reproductive growth stages (Nboyine *et al*., 2021).

The analysis of variance indicated that there was a significant variation on the damage incidence among the fertilization regimes (Figure 4.5). The high damage incidence on T15 + CLBb + AMI + CLBt and ACT + CLBb + SUL + CLBt may be due to their combinations (T15 with Amidas or Actyva with Sulfan) that turned to give the high concentrated nutrients especially N that invites the pests (FAW). As reported by Martin *et al*. (1980) that, Coastal Bermuda grass in particular was susceptible to FAW when pastures are heavily fertilized. More so, as reported by Wiseman *et al*., (1973), that maize plants applied with N fertilizer was the most susceptible to this pest. Further, adding more N to any NPK combination increases the susceptibility of ‘Antigua’ corn (*Zea mays* L.) foliage to FAW larval feeding greatly. Further reported by Chang *et al*., (1985), that both the larval number and the leaf damage related with FC (fertilized every two weeks) was significantly greater than the larval number and leaf damage of NC (non-fertilized) during all the three observational periods of centipedegrass**.** However, the low damage incidence recorded from NPK + SOA + IS treatment was due to the insecticides treatment. This is in conformity with Babendreier *et al*., (2020) who stated that, leaf feeding damage incident caused by FAW larvae was higher in corn that was not protected compared to those with insecticides protection.

The weekly trend of FAW damage incidence generally moves from high to low, though some treatments move from low to high and back to low (Figure 4.6). This incidence could be attributed to the fact that, at the early stages the plants are succulent and palatable for their consumption but at the latter stages leaf becomes tough and unpalatable for consumption. This corroborates with Nboyine *et al*. (2021) that, FAW larvae/neonate feeding on leaf depends on the age and quality of the leaf because these factors have effect on their establishment, growth and survival. Also, maize leaf age impacts quality parameters like availability of water, nitrogen and toughness; these may give on to high mortality of the neonate even if the same leaves are consumable for older instars (Pannuti *et al*., 2015; Nboyine *et al*., 2021).

5.2 Resistance/tolerance level of maize to FAW damage as influenced by the fertilizations.

The fertilization regimes without insecticides were able to withstand FAW infestation (Table 4.1). The resistance level of the fertilization regimes might be influenced by the high quality nutrients that gives a smooth and continuous flow at the righteous proportion and at the righteous hour to the plants when required, the ability to resist the pest damage through thicker cell wall development and or natural defense compounds. This corroborate with Singh *et al*. (2011) who stated that, mineral nutrition safeguard the crops from varying hurdles and greatly execute a unique aspect during the plants whole life cycle. Also reported by Schumann *et al*. (2010) that, plants with an optimum nutritional status have a maximum resistance (tolerance) to pests and diseases to nutrient deficient plants. Another report by Schumann *et al*. (2010) that, Mineral nutrition can impact two primary mechanisms of resistance: The mechanical barriers formation, (in essence through the development of thicker cell walls) and the combination of natural protection compounds, (for instance phytoalexins, flavonoids, and antioxidants) which issue defense against pathogens. However, fertilization regimes in combination with the CLBb + CLBt that made up of 8 chemical fertilizers can also influence plant ability to tolerate the damage incidence of FAW. As reported by Leuck *et al*., (1974) that foliage of 'Coastal' Bermuda grass, (*Cynodon dactylon* (L.) person), corn, or sorghum, (*Sorghum bicolor* (L.) Moench), sprayed with 14 chemical fertilizer could scared off FAW larval feeding. Further, some of the nutrients such as S, Mn, Cu and Zn can aid in plants ability to defend itself from the FAW infestation. This corroborates with Fernando *et al*. (2009) that, manganese contributes in the manufacturing of phenolic compounds and some crop protection mechanisms. Also reported by Graham and Webb (1991) and Dordas (2008), that there is a predominantly documentation of the role of micronutrients (such as Mn, Fe, Zn and Cu) in plant defense.

5.3 Impact of the fertilization on maize grain yield

This result indicated that, fertilization has a significant effect on maize grain yield (Figure 4.7). The low maize grain yield received out of control could be accredited to inadequate nutrition to the plants as there was no fertilizer applied to the control plots. This correspond with Arthur (2014) that, grain yield among plants in the fertilizer treated plots were significantly higher than those in the no fertilizer treated plots. Among the fertilization regimes, CLBb + CLBt treated plots obtained significantly low grain yield. This low grain yield might be caused by insufficient macro-nutrients applied to the crops as the NKP concentration in CLBb + CLBt is not adequate for the plant to give good yield. This corroboration with Adu *et al*. (2014), who reported that, nutrients requirements of corn is high particularly NPK. Further, observation by Memon *et al*. (2012) reported that, the yields of grain were affected by a variety of fertilizer treatments.

Among the fertilization regimes, there was no significant variation though, the highest grain yield recorded from T15 + CLBb + URE + CLBt (3,773 kg/ha) followed by ACT + CLBb + AMI + CLBt (3,703 kg/ha) and T15 + CLBb + AMI + CLBt (3,399 kg/ha) demonstrated that, the maize grain yield increased in the company of increasing of N concentration. The increment of the grain yield might be influenced by the concentration of N content in the fertilizer formulations applied as a top-dressing after applying NPK as basal. Urea (46% N content) applied as top-dressing recorded highest grain yield followed by YaraVera (Amidas) (40% N content with 5.6% S). This correspond with Bua *et al*., (2020) that, high yield response were observed in high rate of N applied with moderate or little rates of P and K. further, Adu *et al*., (2014) reported that, among the primary nutrients that most often limits yield is N, the quantity of leaves the plant produces and the seed quantity per cobs is determined by the N and thereby determines the potential of the yield. Further, as reported by

Harrison *et al*., (2019), that inorganic fertilizer can lead in increased yield in spite of higher pressure of the pest, as a result of better plant growth.

5.4 Partial budget analysis from maize grain yield

As shown from the partial budget analysis, it will be most profitable managing FAW in maize field for grains using YARA formulated fertilizers compared to unfertilized field (Table 4.2). All the YARA formulated fertilizers yielded more profit than the non-YARA formulated fertilizer with insecticide spray (NPK + SOA + IS) except CLBb + CLBt. The highest profit and cost-benefit ratio obtained from T15 + CLBb + URE + CLBt (GH¢11615.5) among the fertilizer treatments may be due to its high yielding and low input cost associated with the production. Though ACT + CLBb + AMI + CLBt (GH¢11,061.5) and T15 + CLBb + AMI + CLBt (GH¢9,944.5) yielded second and third highest profit per hectare, the cost-benefit ratio (7.8 and 7.5 respectively) obtained from its use was lower than that of T15 + CLBb + SUL + CLBt (GH¢ 9,318.5) cost benefit ratio (7.9). This high cost-benefit ratio of T15 + CLBb + SUL + CLBt could be associated with the low cost of sulfan to that of amidas. However, CLBb + CLBt (GH¢641.0) lowest profit and cost-benefit ratio (2.1) obtained could be attributed to the inadequate nutrients supply. This correspond to Teetes, (1980) and Listinger, (1993), who stated that plants that get adequate nutrients are healthier, stronger and generally capable to pay back for the pest damage better compared to those under nutritional deficiency.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the results and findings obtained from the study, the following conclusions were made;

On plant height and leaf area index, control performed poorly when compared to fertilization regimes. Among the fertilization regimes CLBb + CLBt recorded the lowest while that of T15 + CLBb + URE + CLBt recorded high. The low performance of control was due to nutrients deficiency whilst that of CLBb + CLBt was due to low concentration of the NPK (8.5-3.4-6) in its formulation.

Generally, there was significant variation in FAW larval abundance in various fertilization regimes. Apart from CLBb + CLBt control recorded significantly lower larval abundance compared to fertilization regimes. Among the fertilization regimes, T15 + CLBb + AMI + CLBt and ACT + CLBb + SUL + CLBt obtained statistically higher larval abundance whilst CLBb + CLBt recorded the least. The balance of nitrate and ammonium nitrate in Actyva, high efficiency of the sulfur in Sulfan, nitrogen and sulphate sulphur that is totally available to plants in an ideal N:S ratio of 7:1 in Amidas and the unique combination of NPK in T15 promote the plants succulent growth that lead to the high abundance of the FAW larvae. However, the population dynamics showed that, the population increases from 4th week to 6th week and dropped at the 8th week.

There was some level of tolerance offered to maize plants against FAW infestations by the fertilization regimes. Control obtained significantly lower damage incidence compared to fertilization regimes except NPK + SOA + IS and CLBb + CLBt. The low damage incidence recorded from NPK + SOA + IS and control was influenced by the insecticide sprayed. Among the fertilization regimes, T15 + CLBb + AMI + CLBt and ACT + CLBb + SUL + CLBt obtained statistically higher damage incidence when compared. This could be due to their combinations (T15 with Amidas or Actyva with Sulfan) that turned to released adequate nutrients especially N that invites the pests (FAW) by given the plants succulent growth that attract the pest.

Maize grain yield were affected by the fertilization regimes, all the fertilization regimes yielded significantly higher compared to control. Among the fertilization regimes, CLBb + CLBt recorded significantly lower maize grain yield, though there was no significant variations among the rest of the treatments, T15 + CLBb + URE + CLBt, ACT + CLBb + AMI + CLBt and T15 + CLBb + AMI + CLBt was in the order of high to low. This has demonstrated that the grain yield of maize increased with the increasing of N concentration.

The partial budget analysis demonstrated a positive value of profit increment for all the fertilization regimes compared to control. Among the fertilization regimes, CLBb + CLBt yielded less profit and cost-benefit ratio, whilst the highest profit and cost-benefit ratio was obtained from T15 + CLBb + URE + CLBt. The second and third profit was recorded from ACT + CLBb + AMI + CLBt and T15 + CLBb + AMI + CLBt respectively. Though T15 + CLBb + SUL + CLBt recorded fourth in terms of profit yet, it cost-benefit ratio was higher compared to ACT + CLBb + AMI + CLBt and T15 + CLBb + AMI + CLBt respectively. The reason could be associated with the low cost of sulfan to that of amidas.

6.2 Recommendations

The following recommendations were made based on the conclusions raised above;

- It is recommended that, farmers should apply T15 (NPK 15-15-15) with Croplit Bio at basal and urea with Croplit Bio as top dressing, in the absent of urea farmers can apply amidas as topdressing with Croplit Bio for management of fall armyworm, better yield as well as high profitability per hectare.
- It is recommended that, in the absent of T15 (NPK 15-15-15) and urea, farmers can substitute it with actyva with Croplit Bio as basal and top dress it with amidas and Croplit Bio for management of fall armyworm, better yield as well as high profitability per hectare.
- However, with sole application of Croplift Bio as basal and top dressing is not recommended for maximum grain yield and profit.
- For further research work, this research needs to be repeated with artificially infestation of FAW larvae in the field for further evaluation.
- Evaluation of the soil nutrients and pH levels before, during and after the field trial is recommended.

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APPENDICES

Appendix 1: ANOVA for plant height of maize at 4weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	41.27	20.64	0.56	
REPS.*Units* stratum					
TREATMENT	9	912.24	101.36	2.75	0.033
Residual	18	664.13	36.90		
Total	29	1617.65			

Appendix 2: ANOVA for plant height of maize at 6weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1056.3	528.2	2.76	
REPS.*Units* stratum					
TREATMENT	9	5588.1	620.9	3.24	0.016
Residual	18	3448.3	191.6		
Total	29	10092.8			

Appendix 3: ANOVA for plant height of maize at 8weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1087.4	543.7	1.80	
REPS.*Units* stratum					
TREATMENT	9	12339.4	1371.0	4.53	0.003
Residual	18	5450.5	302.8		
Total	29	18877.3			

Appendix 4: ANOVA for LAI of maize at 4weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2451.6	1225.8	2.74	
REPS.*Units* stratum					
TREATMENT	9	18791.9	2088.0	4.67	0.003
Residual	18	8045.6	447.0		
Total	9	29289.0			

Appendix 5: ANOVA for LAI of maize at 6weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	15271.	7635.	1.52	
REPS.*Units* stratum					
TREATMENT	9	220616.	24513.	4.89	0.002
Residual	18	90235.	5013.		
Total	29	326121.			

Appendix 6: ANOVA for LAI of maize at 8weeks after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	19364.	9682.	5.70	
REPS.*Units* stratum					
TREATMENT	9	88515.	9835.	5.79	<.001
Residual	18	30600.	1700.		
Total	29	138479.			

Appendix 7: ANOVA for effect of fertilization regimes on FAW larval abundance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	12.200	6.100	0.74	
REPS.*Units* stratum					
TREATMENT	9	312.300	34.700	4.23	0.005
Residual	18	147.800	8.211		
Total	29	472.300			

Appendix 8: ANOVA for effect of fertilization regimes on FAW population dynamics at 4WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.200	0.100	0.06	
REPS.*Units* stratum					
TREATMENT	9	53.867	5.985	3.46	0.012
Residual	18	31.133	1.730		
Total	29	85.200			

Appendix 9: ANOVA for effect of fertilization regimes on FAW population dynamics at 6WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	3.800	1.900	0.58	
REPS.*Units* stratum					
TREATMENT	9	73.333	8.148	2.49	0.047
Residual	18	58.867	3.270		
Total	29	136.000			

Appendix 10: ANOVA for effect of fertilization regimes on FAW population dynamics at 8WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.6000	0.3000	0.80	
REPS.*Units* stratum					
TREATMENT	9	16.6667	1.8519	4.95	0.002
Residual	18	6.7333	0.3741		
Total	29	24.0000			

Appendix 11: ANOVA for effects of fertilization regimes on damage caused to maize by FAW

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	0.6222	0.3111	0.83	
REPS.*Units* stratum					
TREATMENT	9	42.5222	4.7247	12.67	<.001
Residual	18	6.7111	0.3728		
Total	29	49.8556			

Appendix 12: ANOVA for effects of fertilization regimes on damage trend caused to maize by FAW at 4WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.067	0.533	0.43	
REPS.*Units* stratum					
TREATMENT	9	75.333	8.370	6.77	<.001
Residual	18	22.267	1.237		
Total	29	98.667			

Appendix 13: ANOVA for effects of fertilization regimes on damage trend caused to maize by FAW at 6WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.4000	0.7000	1.00	
REPS.*Units* stratum					
TREATMENT	9	50.0000	5.5556	7.94	<.001
Residual	18	12.6000	0.7000		
Total 29 64.0000					

Appendix 14: ANOVA for effects of fertilization regimes on damage trend caused to maize by FAW at 8WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.2667	0.6333	1.88	
REPS.*Units* stratum					
TREATMENT	9	18.0333	2.0037	5.95	<.001
Residual	18	6.0667	0.3370		
Total 29 25.3667					

Appendix 15: ANOVA Effect of the fertilization regimes on grain yield (kg/ha) of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	2005892.	1002946.	1.32	
REPS.*Units* stratum					
TREATMENT	9	32960718.	3662302.	4.83	0.002
Residual	18	13639160.	757731.		
Total	29	48605770.			

Appendix 16: ANOVA Effect of fertilization regimes on 100 seed weight of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	2	1.867	0.933	0.24	
REPS.*Units* stratum					
TREATMENT	9	22.300	2.478	0.65	0.743
Residual	18	68.800	3.822		
Total	29	92.967			