

UNIVERSITY FOR DEVELOPMENT STUDIES

**INCIDENCE OF MAIZE LEAF HOPPER (*CICADULINA MBILA*, NAUDE) AND
ITS MANAGEMENT USING ENHANCED EFFICIENCY FERTILIZATION**

BY

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OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY
DEGREE IN CROP SCIENCE**

MAY, 2024



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 literature sources used from other research works have been duly cited.

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ABSTRACT

Maize leaf hopper (*Cicadulina mbila*, Naude) still remains a yield declining major pest of maize in Ghana and other parts of the world. Field experiment was laid in randomized complete block design with three replications, using nine different fertilization regimes to evaluate the effect of enhanced fertilization application on the incidence of *C. mbila* and its impact on grain yield of maize. Data were collected on *C. mbila* abundance, damage incidence and impact on yield. Economic viability of the treatments on maize production was also assessed. Fertilization significantly influenced *C. mbila* abundance and incidence on maize. Unfertilized plot recorded significantly higher *C. mbila* abundance and damage incidence compared to fertilization regimes. Among the fertilization regimes, T15-SUL and ACT-SOA recorded significantly higher *C. mbila* abundance and damage incidence respectively whilst the least were recorded from CLB-CLB and T15-URE. On grain yield, all the fertilization regimes obtained higher grain yield compared to unfertilized plot. Among the fertilized plots, CLB-CLB recorded significantly lower grain yield. Though ACT-URE, ACT-NIT, T15-URE, ACT-SOA and T15-NIT yielded above all, there was no significant variation. All the fertilization regimes yielded more profit compared to no fertilization plot, among the fertilization regimes, CLB-CLB yielded lowest profit and benefit-cost ratio whilst the highest profit and benefit-cost ratio was obtained from ACT-URE. Application of ACT-URE or ACT-NIT is recommended for better management of *C. mbila*, maximized yield, as well as high profitability.



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DEDICATION

This thesis is dedicated to my late first wife, Mrs. Abdallah Salmu.



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LIST OF ABBREVIATIONS

ABSF	African Biotechnology Stakeholders Forum
ACT	YaraMila Actyva
B	Boron
BCR	Benefit Cost Ratio
CaO	Calcium oxide
CIMMYT	International Maize and Wheat Improvement Center
CuB	CropLift Biofertilizer
CSIR	Centre for Scientific and Industrial Research
Cu	Copper
DNA	Deoxyribonucleic Acid
FAOStat	Statistical Database of Food and Agriculture Organization
GDP	Gross Domestic Product
GM	Genetically Modified
IITA	International Institute of Tropical Agriculture
IPM	Integrated pest Management
ISSER	Institute of Statistical and Economic Research



LSD	Least Significance Difference
MGO	Magnesium oxide
MO	Molybdenum
MSD	Maize Streak Disease
MSV	Maize Streak Virus
N	Nitrogen
NH_4NO_3	Ammonium Nitrate
NIT	YaraLiva Nitrorbor
$\text{NO}_3\text{-N}$	Nitrate Nitrogen
NPK	Nitrogen Phosphorus Potassium
QTL	Quantitative Trait Loci
RCBD	Randomized Complete Block Design
S	Sulphur
SOA	Sulphate of Ammonia
SRID	Statistics Research and Information Directorate
SUL	YaraBela Sulfan
T15	YaraMila triple super phosphate



URE	Urea
WAP	Weeks After Planting
WHO	World Health Organization
ZN	Zinc



CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is the most significant food crop in the world after rice and wheat (Bamire & Akinola, 2017). In Africa, maize is a staple food for many millions of people and an essential source of carbohydrates. It is also a component of animal feed (Time *et al.*, 2020). In Ghana, it makes up between 50 and 60 percent of the cereal production (MiDA, 2010; Agyare *et al.*, 2013). As one of the first crops to be collected for sustenance during a time of famine, maize is, in fact, quickly emerging as the most favored grain. It is the most efficient cereal in the world in converting solar energy into usable food energy, yielding higher grain than any other cereal (Yonli *et al.*, 2010). In Ghana, maize is cultivated in every agroecological zone, usually in combination with other crops. Between 2015 and 2020, the average yearly planted area for maize in the country was 936,800 hectares, while the average yearly production during same time was 1,622,900 metric tons. These figures indicate growth rates of 18.5% and 36.5%, respectfully (Pauw, 2021)

A decrease in maize yields throughout sub-Saharan Africa, including Ghana, is caused by a number of environmental variables, including diseases and pests, erratic rainfall, and poor soil fertility (Karavina, 2014) ; Obeng- Bio, 2010; MOFA, 2013). One of the most detrimental diseases to maize in Africa in terms of growth and production loss is called "maize streak disease." (Karavina, 2014)The virus that causes the illness is spread by a number of leafhopper species, with *Cicadulina mbila* serving as the primary vector (Karavina, 2014). With an estimated production loss of roughly 20%, maize streak disease is recognized as a factor reducing maize yield in Ghana (Oppong, 2013).



According to reports from other sources, yield losses from the maize streak disease range from trace to over 100% (Gichuru, 2013)

1.2 Problem statement

One of the most common vectors that can spread the maize streak disease is *Cicadulina mbila*, which feeds on the host plant for the majority of its life. A week after infection, the earliest signs of the disease appear as tiny, rounded, dispersed dots on the youngest leaves. With the growth of the plant, the number of spots rises and their size enlarges parallel to the veins in the leaves. Spots appear at the bases of leaves shortly after and are especially noticeable on the youngest leaves (Ambayeba *et al.*, 2018). Chlorotic bands may merge in severely damaged plants, giving the plant a distant appearance of pale green, yellow, or white. Stunted plants may also produce little cobs with open husks and may die early or become barren (Murithi *et al.*, 2013)

Africa's most important food crop, maize, continues to be plagued by the most serious viral disease (Salaudeen *et al.*, 2015) based on a conservative estimate of only 6–10% average yearly yield losses, costing between US\$120M and US\$480M every year (Awata *et al.*, 2019). According to reports, the disease is also a contributing factor to Ghana's diminishing maize crop, with an approximate 20% yield loss (Oppong, 2013). This substantial yield loss directly impacts food security, farmer livelihoods, and economic stability, necessitating urgent intervention. Furthermore, the feeding activity of *Cicadulina mbila* not only facilitates the transmission of maize streak virus but also directly damages maize plants (Oppong, 2013). Leafhopper feeding leaf curling, chlorotic streaks, and necrosis, leading to reduced photosynthetic efficiency and stunted plant growth (Blankson *et al.*, 2018). These effects significantly decrease maize yield and quality, compounding the economic burden on farmers. Reports indicate that heavy infestations can cause yield reductions of up to 30 -40% in severely affected fields



(Oppong, 2013). The random and unexpected nature of the disease poses a significant barrier in determining the best course of action for any control approach (Blankson *et al.*, 2018). Despite these challenges, management of *Cicadulina mbila* has not been prioritized in many maize production systems. Farmers often lack access to effective pest control strategies, and current interventions primarily focus on managing the disease rather than addressing the vector itself. Without integrated pest management strategies that include vector control, the persistence of *Cicadulina mbila* will continue to threaten maize productivity (Wiredu *et al.*, 2010). African savannas are noted for relatively low Nitrogen and Phosphorus availability, and more importantly low phosphorus in soils in the savanna ecology. The use of organic fertilizers and manure on maize crop is reported to improve plant nutrition which can subsequently lead to higher yield (Wiredu *et al.*, 2010). Moreover, there is limited research information regarding the effect of fertilizers on insect pest incidence in maize ecosystems. Understanding the relationship between soil fertility management and *Cicadulina mbila* infestation levels could provide valuable insights into developing holistic control measures for maize streak diseases.

1.3 Justification

The incidence of the maize leafhopper (*Cicadulina mbila*) can be managed in a number of ways, such as by using resistant varieties, managing soil nutrients, altering the soil environment through tillage practices, providing adequate plant nutrition and fertilization, and using insecticides to kill the leafhoppers (Blankson *et al.*, 2018)

According to (Awata *et al.*, 2019) managing soil nutrients offers a viable substitute strategy for expanding the reach of managing maize streak disease. According to (Altieri *et al.*, 2012), ideal physical, chemical, and mostly biological qualities of soils as well as soil management are linked to a crop plant's capacity to withstand or tolerate insect pests and diseases (Altieri *et al.*, 2012).

According to reports, nutrients in the soil can influence the pathogen, plant physiology, or both during the course of a disease infestation (Altieri *et al.*, 2012). A plant's ability to resist harm from pests and diseases depends largely on its health (Walker *et al.*, 2019). Plants develop a natural defensive system against pest damage as a result of the vascular tissues becoming harder with growth. Leafhopper infestation in maize might be greatly decreased and yields could rise as a result of proper soil nutrition and fertilizer management (Ochilo, 2013). This highlights the critical role of enhanced fertilization strategies in reducing the vulnerability of maize plants to *Cicadulina mbila* infestations (Ochilo, 2013).

The YARA fertilizer formulation, which is extensively utilized for agricultural production in Ghana and other countries, contains the necessary plant nutrients at the right grades. Unlike conventional fertilizers, YARA formulations are designed to optimize nutrient uptake and improve plant resilience, thereby enhancing the plant's natural defense mechanisms against insect's pests and diseases. In the Ghanaian fertilizer market, YARA is also a prominent importer of bulk fertilizer (Arthur, 2014). However, for effective pest management, it is crucial to assess the specific impact of YARA fertilizer on maize plant immunity and its ability to reduce *Cicadulina mbila* incidence (Arthur, 2014). YARA formulations such as YARA Vita (Croplift Bio) is a recently developed foliar fertilizer that contains micronutrients (Cu, Mn, Mo, and Zn) in addition to macronutrients (NPK+B in tiny quantities), which are essential for improving plant immune responses. These nutrients strengthen maize plants against pest attacks by promoting healthier growth and reinforcing structural defenses. In order to address the crop's urgent demands, this YARA Vita provides accurate delivery of the necessary micronutrients at the right moment, with the ability to specifically target the leaf or fruit.



Whereas T15 (Unique15) has the proper ratio of NPK 15-15-15, urea has a high nitrogen concentration of 46% (Arthur, 2014).

It is important to evaluate the effect of enhanced efficiency fertilization (YARA formulation) on *C.mbila* incidence and maize grain yield. The study seeks to boost the immune system of maize plant to find out if by so doing it could help fight against certain insect pests and diseases especially the maize leafhopper (*Cicadulina mbila*) through enhanced efficiency fertilization.

1.4 Objectives

The study sought to evaluate the effect of enhanced fertilization on the incidence of *Cicadulina mbila* and its impact on grain yield and profitability for maize production.

The specific objectives were to determine the effect of fertilization on:

1. Abundance of *C. mbila*
2. Damage incidence of *C. mbila*
3. Maize yield and economic efficiency of *C. mbila* management using the fertilizer formulations.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of maize

After rice was domesticated in the Yangtze Valley of China and wheat was domesticated in the Fertile Crescent of the Near East some 10,000 years ago, maize (*Zea mays* L.), also known as corn, was domesticated more than 9,000 years ago in southern Mexico and America (Awika, 2011; Kennett *et al.*, 2020). Since its domestication, maize has rapidly spread over the world, and according to Garcia-Lara and Serna-Saldivar (2019), it is now the world's most produced staple grain, with an annual output of over one billion metric tons. The Americas produce more than half of the world's maize (53%), followed by Asia (28%), and Europe (15%). Important corn-growing regions are the US corn belt, Northeastern China, and Eastern Europe. In 2012, the US (with over 270 million tons), China (with over 200 million tons), and Brazil (with 71 million tons) were the top producers. India, Mexico, Argentina, Ukraine, Indonesia, France, and Canada were next in line. The developing world accounts for over 70% of all maize-growing land (FAOStat, 2021).

2.2 Botanical description of maize

The word "Arawak mahiz," which literally translates to "that which sustains life," is where maize (*Zea mays* L) gets its name. Maize stalks can reach heights of two to twenty feet, with eight to forty-eight leaves and several ears. Every stalk yields ears with multiple rows of kernels that emerge from the ear cob and are encased in a leafy husk. *Zea mays* is an annual grass belonging to the family Maydeae within the Graineae genus (Pradhan *et al.*, 2022). This family of grasses also includes rice, sorghum, sugarcane, wheat, and barley. The biggest feature that sets maize apart from other cereals is the size of its seed heads, or ears, which are greater than those of any other grass. In addition, maize yields



more per unit area than any other crop. One of the key reasons maize is so appealing to farmers is its productivity (Illiasu, 2015).

There are reproductive organs on both the male and female maize plants. The terminal blooms, known as tassels, typically produce only male spikelets that grow in pairs, one of which is sessile and lacks a stalk, and the other is pedicellate and has a single blossom on a slender stalk. There are around 25 million pollen grains in each tassel. The ear is the lateral organ or female inflorescence. A maize ear might have up to a thousand potential kernels in it (Pradhan *et al.*, 2022). The ears have spikelets, just like the male tassels, but only one flower opens. One ovary, known as the silk, ends in a long style in each of these flowers. To collect pollen that is being blown by the wind, fine hairs cover the end of the silks. The kernel will not emerge if the silk that will eventually become one is not fertilized (Pradhan *et al.*, 2022). The substantial core of the ear or cob is securely linked to the kernels that emerge from the pollination of the silk. The pericarp, or thin shell, the endosperm, or food storage organ, and the embryo, or germ, make up a mature kernel (Illiasu, 2015). The entire seed is surrounded by a thin covering of maternal tissues called the pericarp. Starch makes up the majority of the endosperm, or food storage organ, and is broken down into sugar during germination and growth. The aleurone, a very thin layer of the endosperm that is most helpful in maize genetic research, is one of the most important characteristics for science. Lastly, the majority of the fat, vitamins, and minerals are found in the embryo or germ (Illiasu, 2015) ; (Pradhan *et al.*, 2022)

2.3 Economic importance of maize

Maize ranks second to rice in the utilization of agricultural resources which is usually use not only for human consumption but also for animal feeds and also industrial uses (Darfour & Rosentrater, 2016) According to (Bello *et al.*, 2018) , maize is an excellent and significant source of minerals, vitamin B, proteins, carbs, and fiber. As per the report



of Statistics Research and Information Directorate (SRID) (2007), the estimated amount of maize consumed nationally in 2006 was 943,000 Mt. In Ghana, the estimated per capita consumption of maize in 2000 was 42.5 kg (Darfour & Rosentrater, 2016)

In the dry and semi-arid tropics, maize is the most significant grain crop and source of cereal feed. It is farmed in both rain-fed and irrigated agricultural systems (Murtaza *et al.*, 2020) (Wongnaa *et al.*, 2018) observed that there are several ways in which maize is consumed in Ghana. It is usually consumed as a thick gruel in the north and is often used to make porridges and hearty meals like akpele in the south. Fresh green corn on the cob is delicious grilled, baked, parched, or boiled. It is crucial for bridging the food gap that occurs after the dry season. Given that they include 72% carbohydrate, 10% protein, 8.5% fiber, 4.8% oil, 3.0% sugar, and 1.7% ash, maize grains have a good nutritional value (Ali *et al.*, 2014) In western and central Africa, millions of subsistence farmers rely on maize production for their livelihood. It makes up over 45% of agricultural production, which is still the majority of Ghanaians' primary source of income, employing over 60% of the workforce and adding roughly 30% to the country's GDP (ISSER, 2011). Half of the fundamental calories in sub-Saharan Africa come from maize, which is a staple diet for an estimated 50% of the population. The crop can be utilized to make both food and non-food products in all parts (Ekaette, 2017) While maize flour and meal are the two most common products, the ways in which maize is processed and consumed vary greatly throughout nations (Robert & Alieu, 2010) Just 5% of maize is consumed by humans in the developed world; the majority, 70%, is utilized as feed for cattle and poultry (ABSF, 2010). By 2050, the demand for maize in developing nations will have doubled (Gazal *et al.*, 2017)



2.4 Production estimates of maize

The world's largest producer of maize is the United States of America. In 2020, the United States of America produced 360,252 thousand tons of maize, or 34.28% of the total amount produced worldwide. 74.86% of the world's maize production is produced in the top 5 countries: the United States of America, China, Brazil, Argentina, and Ukraine. According to FAOStat (2021) estimates, 1.05 million tons of maize were produced worldwide in 2020. Approximately 75 million tons of maize were produced in Africa in 2018, accounting for 7.5% of the global total. In Africa, maize accounts for around 24% of all farmland, and its average production hovers around 2 tons per hectare annually. Nigeria is the continent's biggest producer, with over 33 million tons, followed by South Africa, Egypt, and Ethiopia. Because the majority of maize cultivation in Africa is done under rain-fed circumstances, the continent imports 28% of its required amount of maize grain (FAOStat,2021). The past few decades have seen a dramatic growth in the production of maize worldwide, driven by growing demand as well as a confluence of yield increases, area expansion, and technical advancements. In terms of production volume, maize is now the most popular grain and is expected to overtake all other crops as the most frequently grown and traded commodity in the decades to follow (FAOSTAT, 2012).

2.5 Agronomic requirements of maize

The ideal summertime air temperatures for maize are between 21 and 27°C. It is grown in the latitude range of 45oS to 55oN. Warm enough soils allow for good, vigorous emergence with minimal growth inhibition (IITA, 2020). At a soil temperature of 16–18°C, maize typically emerges one week after planting, with a minimum temperature of 10°C required for germination. Plant seeds that have been certified by local, licensed agro-input shops, seed firms, and registered seed producers (IITA, 2020). A seed is a



living organism; handle it carefully to preserve its embryo, which will give rise to a new plant. Before planting, keep it somewhere dry and cool after purchase. Do not discard seed bags since, once planted, cracked and damaged seed is more susceptible to microbial and fungal infections (IITA, 2020). Execute a germination test. Ten days prior to planting to avoid a weak stand caused by damaged or subpar seeds. Use the procedures listed below to perform a germination test: Pick 100 healthy seeds at random, then plant them in a field that has been prepared or in a container at home that has been exposed to the sun at a depth of 5 cm. Count the number of seedlings that emerges after 8 days (IITA, 2020). Table 2.1 shows the number of seeds to plant based on the results of the germination test.

Table 2.1: Recommended seedling rate after germination test.

Number of plants counted	Number of seeds to be planted
85 or higher.	each hole with two seeds
70 to 84	each hole with three seeds
50 to 70	Obtain superior seeds.
Not more than 50	Get better seed and do not try planting.

Source: Maize improvement programmes of CSIR-SARI, Tamale.

Time of planting

Higher yields are linked to early planting when rainfall is normal. Maize needs to be planted early in order to take advantage of the full growing season and optimize production. Planting is always safe once the rains have stopped. Maize seeds require warm, moist, well-ventilated soil that is fine enough to allow for good seed-to-soil contact



in order to germinate well. For the seed to take up moisture from the soil, there must be good seed to soil contact (Kamara *et al.*, 2020). Uniformity of seedling emergence, given enough soil moisture at the start of the growing season, is dependent on several factors, including seed quality (viability, purity), seed treatment against soil-borne diseases, appropriate planting techniques (depth and spacing), and the right number of seed (Kamara *et al.*, 2020). In the first three to four weeks of growth, maize can withstand dry spells better than later in the season, despite the unreliability of rainfall at this time. Even with a smaller plant height, good ear development is still possible. The tasselling and silking stages of the crop require the highest amount of moisture (Kamara *et al.*, 2020).

Site selection

With a pH range of 5.0 to 7.0, maize adapts well to many soil types. Maize grown in deep, fine-textured, well-aerated, well-drained loamy soils with high organic matter content gives high yields (IITA, 2020). Avoiding shallow sandy or clayey soils is advised since they are more susceptible to dryness and have a decreased ability to absorb fertilizer. All locations that are prone to water-logging should be avoided because maize does not perform well in wet soils. If it is not possible to avoid such fields, excavate channels to divert water away from any locations that may have water ponds. Better weed control, early cultivation, and a decreased risk of nutrient loss are all made possible by proper drainage (IITA, 2020). Typically, low-lying locations have inadequate drainage, and water logging will lower production (IITA, 2020). For effective photosynthesis, maize must be cultivated in full sun. Maize should not be planted in shaded places. If the amount of sunshine reaching the plant is reduced, the yield will also drop. Before planting maize, try to find out if the chosen location is fertile. Visual evaluation could be deceptive; to ascertain pH and fertility, always conduct a representative soil test (IITA, 2020).



Seed quality

Every production location has a different set of production constraints (pest and disease pressure, yearly rainfall, water retention capacity, etc.). Similar to this, different kinds of maize have different traits from one another and each has a unique potential for productivity and adaptability (Baijukya *et al.*, 2020). Plant enhanced cultivars with the appropriate agronomic strengths for your region to get high, consistent yields. An early maturing variety that is tolerant of dryness, for instance, might produce good yields in regions with minimal rainfall, like the Sudan savannah zone (Baijukya *et al.*, 2020). Some recommended maize varieties and their characteristics are presented in table 2.2 below.

Table 2.2: Some recommended maize varieties widely cultivated in Ghana.

Variety	Grain colour/texture	Maturity days	Average yield Tonnes/hactare	Average yield Bags/acre
Wang-Dataa	White/flintdent	90	4.7	19
Obatanpa	White/dent	105	4.6	19
Bihilifa	Yellow/flintdent	90	4.6	19
Sanzal-sima	White/flintdent	110	5.4	22
Tigli	Yellow/flintdent	120	5.2	21
Omankwa	White/flintdent	95	4.5	18
Abontem	Yellow/flint	80	4.0	15



Dorke-SR	White/dent	95	3.8	15
Dodzi	White/dent	75	3.4	14
Mamaba	White/flint	110	6.0	24

Source: Maize improvement programmes of CSIR-SARI,Tamale.

Nutrient requirement

Nitrogen (N) is the primary nutrient that frequently restricts output among the others. It establishes the yield potential by counting the amount of leaves and seeds the plant generates each cob. The use of organic manure improves the physical properties of the soil and increases maize's ability to retain water (Baijukya *et al.*, 2020). Mineral fertilizers will facilitate rapid vegetative growth and meet nutrient requirements for active plant growth. The production of maize is mostly dependent on mineral fertilizer, which is occasionally enhanced by manure or by rotating the crop with legumes. The soil's phosphorus (P) and potassium (K) contents, moisture content, and variety maturity period all affect how much mineral fertilizer should be applied (Baijukya *et al.*, 2020).

Fertilizer application

The ideal amount of fertilizer needed for maize relies on the variety's potential for productivity, past cropping history, adopted cultural practices, and the overall fertility of the field. The optimal utilization of these fertilizers also depends on the timing and technique of fertilizer application. Since nitrogen readily permeates the soil, the entire amount of nitrogen fertilizer needed should be applied twice to the crop to ensure nitrogen availability during the crop's crucial growth stages and increase yields (IITA, 2020). Typically, two-thirds of the N and all of the P and K are applied basally, with the



remaining N being top-dressed thereafter. Instead of dispersing the fertilizer, especially if urea is being used, place it roughly in a hole that is 4-5 cm deep and 5-7 cm distant from the plants on moist soil, then cover it with earth to reduce losses. When urea is left exposed, there is a significant loss of nitrogen due to volatilization (IITA, 2020). Avoid growing maize continually on the same plot of land for longer than two growing seasons as this may cause the soil to lose important plant nutrients, lowering yields. Soil fertility can be preserved by using crop rotation techniques and intercropping legumes with maize. Prior to maize, groundnuts, soy beans, and cowpeas will add residual nitrogen to the soil, which maize can subsequently use (IITA, 2020).

Weed control

In the fight for space, light, nutrients, and soil moisture, weeds supplant maize, reducing yields, lowering grain quality, and raising production costs. Additionally, weeds harbor diseases and insects. Weeds must thus always be kept under control before they surpass maize plants in size (IITA, 2020). Removing weeds in the crucial 2-4 weeks post-planting significantly increases grain yield. This encourages the existing maize plants to develop rapidly and become extremely competitive. Planting immediately after land preparation helps to reduce weed competition. Furthermore, planting in rows makes weed control easier. For manual weed management, undertake two hand weeding's at 3- and 6-weeks following planting. Before harvesting, weeding may need to be done again (IITA, 2020). Herbicides could be used sparingly to achieve far better weed control. It is less time-consuming, tiresome, and laborious. Generally speaking, the kind of weeds present—that is, grassy or broadleaved weeds—determine the type of herbicide that is used (Goldman, 2019). Herbicides that are frequently used are paraquat and glyphosate. Round-up,





Sunphosate, and Sarosate are examples of glyphosate that should be administered strictly 1-2 weeks prior to planting, but paraquat, such as Gramozone, can be mixed with pendimethalin at the appropriate rate and sprayed right away following planting. Pendimethalin kills pre-emerging weeds in the field, while paraquat kills any live weeds present (Goldman, 2019). Additionally, two to three days after planting, specific pre-emergence herbicides, such as atrazine, can be sprayed at the indicated amount. It is always recommended to apply pre-emergence herbicides before to the emergence of maize and weed seedlings. Use integrated weed management tactics that include mechanical, chemical, biological, and cultural treatments for optimal weed control and maximum grain yields (Goldman, 2019)

Precautions for the safe use of agrochemicals:

Always remember to:

- Use substances that come from reputable sources.
- Before using, read the package label.
- Comply with the directions and suggestions provided by the manufacturer on the label.
- Make the appropriate kind. strategies for dose and application, as well as the necessary safety measures.
- Establish a calibration rate and stick to it.
- If unsure, get technical advice.
- Never utilize chemicals that have expired.
- After handling agrochemicals, properly wash your hands with soap and water.
- Avoid eating treated seeds.

Control of striga in maize

The parasitic weed *Striga hermonthica*, also referred to as witch weed, is a major issue in many areas of Ghana's Guinea and Sudan savannah zones. The presence of a maize crop encourages the germination of striga seeds, and the young plant attaches to maize roots to obtain the moisture and nutrients it needs, stunting the growth of maize plants, lowering yields, and in extreme cases, killing the plants (IITA, 2020). When striga is an issue, it is advised to use the following integrated control methods:

- Remove striga plant before it sets seed and blossoms.
- Rotate maize with crops that are resistant to it, such as sunflower, cotton, soy beans, or groundnuts.
- Plant maize types resistant to striga, such as Wang-dataa and Bihilifa
- Use other cultural practices and fertilizer rates as advised

Pests and diseases control

In Ghana, termites, cutworms, grasshoppers, weevils, stem borer, and bigger grain borer are the main pests of maize. Grain losses following harvest are caused by storage insects. Smuts, rust, bacterium blight, and maize streak are the main diseases that affect maize. Here are some helpful pointers for controlling pests and diseases in maize:

- Recognize the prevalent pests and illnesses in the crop's growing region and choose plant kinds that are resistant to or tolerant of them.
- As soon as the seeds appear, begin scanning the field for pest infestation. Regularly check on the amount of infestation to assess if the pests are causing enough economic harm to justify control measures.
- Plant early to prevent late plantings, which result in increased insect pressure.
- Rotating maize with legumes can increase soil fertility, boost yields, and lessen the burden of weeds, insects, and diseases.



- Use insecticide sparingly when there is a severe infestation of pests.
- For effective control, integrating all of the aforementioned techniques is essential.

Harvesting and storage

When the grain has sufficiently dried, maize is harvested. In certain situations, especially in temperate areas, harvested grain must be dried to 15% moisture content or less before being stored. This will preserve grain quality and prevent the accumulation of mycotoxin, such as aflatoxin (IITA, 2020). Postponed harvesting results in bird nesting, pests and diseases during storage, and damage. To guarantee even drying, the grains should be swept across the drying surface on a frequent basis. Cribs outside can be used to store ears (IITA, 2020). Additionally, maize can be shelled and kept inside in sacks or other containers. Before storing, thoroughly shell and dehusk the dry grains. If maize is stored for an extended period of time (more than three months), the moisture content of the grain must stay below 11% to prevent the development of aflatoxin, which could have harmful side effects for grain consumers. Before shelling, take off any rotting cobs from the crop (IITA, 2020). After shelling, clean the grains, discard any dirt or insects, and store them in jute bags. Place bagged corn in a well-ventilated area and stack it on a pallet off the ground. Use pesticides to keep grains safe from storage pests throughout extended storage times (IITA, 2020).

2.6 Field insect pests of maize

Arthropods, or animals with joint limbs, include insects. They have been extremely effective from a revolutionary standpoint and are now found in the most varied ecologies on the planet. There are more than a million species identified, and many more are yet unidentified. An insect's ability to reproduce, spread, and withstand harsh surroundings are crucial factors in determining its success (Salaudeen *et al.*, 2015)



2.6.1 Stem borers

In Africa, lepidopterous stem borers are one of the most significant insect pests of maize. Four types of borers significantly reduce production:

- The *Busseola fusca* Fuller (Lepidoptera: Noctuidae) maize stalk borer.
- *Sesamia calamistis* Hampson, the pink stalk borer (Lepidoptera: Noctuidae).
- *Eldana saccharina* Walker, an African sugarcane borer (Lepidoptera: Pyralidae).
- *Chilo partellus* Swinhoe, the spotted stalk borer (Lepidoptera: Pyralidae).

While *C. partellus* is Asian and was just recently brought to eastern Africa, the first three are African and found in most sub-Saharan African countries (Salaudeen *et al.*, 2015)

2.6.2 White grubs.

Africa is home to several kinds of scarab beetles. Their diet is diverse, and they go through every stage of development in the soil. White grubs are more prevalent in soil that has a lot of organic matter. While adults can live up to a year and gnaw roots, larvae only exist for several months and consume decaying plant material (Kankonda *et al.*, 2017). When the rains start, the adults come out and lay their eggs on the ground. When adult beetles attack maize fields, the damage can be significant, causing the seedlings to wilt and collapse. The adult is lustrous black or brown, about 15–20 mm in length. The larva is a grub that is yellowish white, soft, and curled, with brown legs and a head (Kankonda *et al.*, 2017)

2.6.3 Cutworms.

When their eggs hatch, female moths deposit them near the base of weeds or crop plants, where the young larvae consume leaves. Older larval stages live underground and feed at night at the plant's base, frequently severing the plant's neck at the ground (Moeng, 2017)



2.6.4 Termites

Maize is attacked by several termite species belonging to the genera *Macrotermes*, *Microtermes*, and *Odontotermes*. Although they are found throughout the tropics, termites pose a greater threat in arid areas. There is a chance that lodging will occur if the roots and lower portion of the stem are damaged. Vascular tissues could sustain damage, and withering would happen, particularly in situations where there is water stress. Not only can young, strong plants get infected, but senescent or drought-stressed plants are frequently targeted. In severe situations, termites infiltrate the ears (Koffi, 2019)

2.6.5 Armyworm

Maize is rarely attacked by armyworms. Although 1988 saw significant outbreaks across West Africa, this pest is more prevalent in East Africa. Larvae are gregarious and quick moving through vegetation, frequently in great numbers, under particular conditions. On the underside of leaves, eggs are placed. Larval phases endure ten to twenty days. Pupation takes place in the earth. The wet season is connected to outbreaks (Han *et al.*, 2016)

2.6.6 Grain weevils

The worldwide presence of the maize grain weevil (*Sitophilus zeamais*) can cause infestations in stored grain or maize ears prior to harvest. When they are feeding or laying eggs, they penetrate kernels irregularly (Han *et al.*, 2016)

2.6.7 Grain borers

Insects such as the lesser grain borer (*Rhyzopertha dominica*) and larger grain borer (*Postephanus truncatus*) infest mature maize ears in the field as well as stored grain. The adults burrow into the grains and feed on them, producing vast amounts of floury dust in a relatively short period. Grains that are damaged are easily recognized since this dust typically covers them. The compact, almost cylindrical beetles have a head that is bent



down and looks to be shrouded in a hood (Koffi, 2019). They range in color from reddish brown to dark brown. The larger grain borer has a smoother surface and is 1 to 2 mm longer than the lesser grain borer. They can both fly. In the floury dust or on the grain, the beetles lay their eggs. Although they can survive in temperate climates in warm grain stockpiles, these insects are mainly found in the tropics and subtropics (Koffi, 2019)

2.6.8 Leafhoppers

A significant carrier of the maize streak virus (MSV) and disease is *Cicadulina mbila*. The mature leafhopper is transparent, 2-4 mm long, and has a longitudinal stripe. Their dorsum has dark patterns, and their body is yellowish in color. Often, adults are observed dozing on the upper surface of immature maize leaves (Muiru *et al.*, 2015)



Plate 2.1: Picture of *Cicadulina mbila* infesting a maize plant



2.7 Taxonomy and description of *C. mbila*

Nymphs in their early instars are small, up to half the size of an adult, and have a pale green-yellow color. With the appearance of deeper coloring, later instars resemble adult insects more (Mylonas *et al.*, 2014). Mature maize leafhoppers are typically 3 mm long and have a pale yellow-green color. On the front edge of the head's crown, between the eyes, are two little brown or black dots. Brown markings that stretch around the body behind the eyes and two tiny black spots are characteristics of *Cicadulina mbila*. Its wings are lined with brown pigment (Mylonas *et al.*, 2014). The dorsal surface of the abdomen bears lateral dark banding, and the pronotum, or pale-like coating of the front segment of the thorax, also has dark markings. The organ used to deposit eggs, the black-tipped ovipositor, is a characteristic unique to females. The oval, slender, smooth, creamy-white eggs of *C. mbila* measure between 0.3 and 0.5 mm in length and 0.1 mm in diameter (Mylonas *et al.*, 2014)

2.8 Origin and distribution of *C. mbila*

There are currently reports of *Cicadulina mbila* from Yemen and Tadjikistan, as well as from areas of India and Sub-Saharan Africa (Kılıç & Sertkaya, 2019) Nevertheless, the Yemen report refers to an interception in Hodeida port and does not, therefore, show that *Cicadulina mbila* remained there. Most central and southern sub-Saharan African nations, such as Angola, Botswana, Congo, Ethiopia, Kenya, Mauritius, Mozambique, Namibia, Nigeria, South Africa, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe, plus the nearby islands of Cape Verde and Reunion, are home to *C. mbila* (Juroszek & Tiedemann, 2013) Since the maize streak virus severely limits maize output in Rwanda *C. mbila* is also present there and most likely elsewhere. Rainfall and the presence of host plants are thought to have a significant impact on its abundance When its



hosts get ugly, *Cicadulina mbila*'s capacity to travel great distances becomes apparent (Madzokere, 2015).

2.9 Biology of *C. mbila*

The three developmental phases of the *Cicadulina mbila* life cycle are the egg, nymph, and adult. There are five instars in the nymphal stage (Mylonas *et al.*, 2014) Depending on the environment, amount of rain, and host availability, *Cicadulina mbila* will complete 5-8 generations (Adilson, 2015) It does not appear to undergo diapause or exhibit any other type of dormancy. It evolves all year round, with extended growth intervals (Adilson, 2015) Usually close to the main vein, females deposit their eggs in the leaf tissue. Eggs are slender, elliptical, creamy-white, and range in size from 0.3 to 0.5 mm in length and 0.1 mm in diameter. Depending on the temperature, eggs hatch in 7 to 35 days, and young nymphs need 14 to 20 days to mature into adults at 25°C (Mylonas *et al.*, 2014) Depending on temperature and population conditions, adults have a comparatively extended preoviposition period that can last anywhere from two to twenty days (Mylonas *et al.*, 2014) The host plant and the origin of the population have an impact on adult lifespan and fecundity. On millet, females typically live for 33 days, whereas on sorghum, they only live for 18 days. At 28°C, female fecundity averages 129 eggs per female (Saquee *et al.*, 2023)



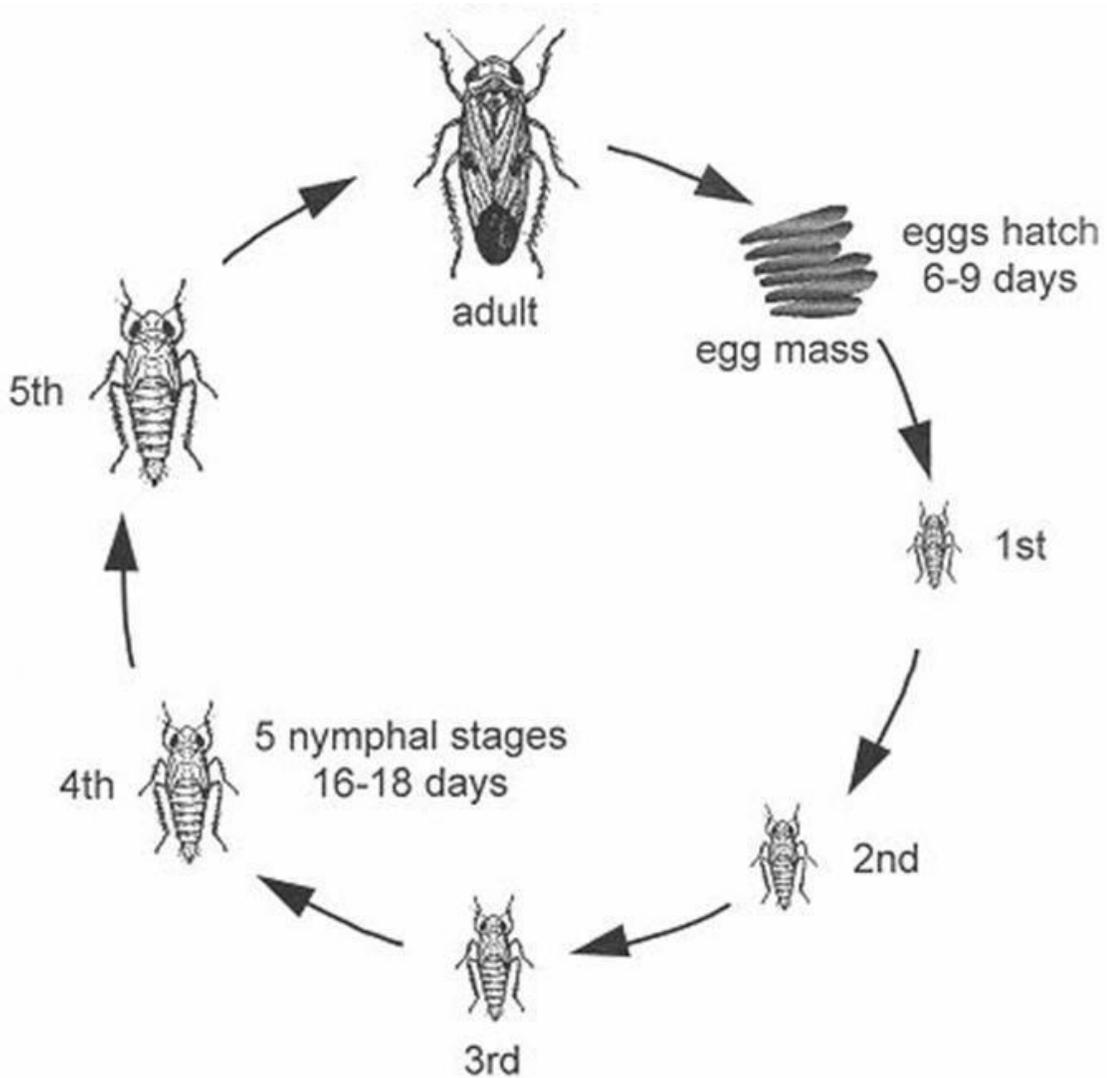


Figure 2.1: Life cycle of *C. mbila*

2.9.1 The adult

The majority of adult maize leafhoppers are tiny, pale yellow-green in color. Between the eyes on the front edge of the head's crown are two little brown or black dots. These leafhoppers have brown markings across the length of their bodies behind the eyes and two tiny black spots (Salaudeen *et al.*, 2015). Their wings are lined with brown pigment. With a mean length of 3.04 mm for men and 3.15 mm for females from the apex of the crown to the tip of the tegmina, males are noticeably smaller than females. For males, the average breadth of the head across the eyes is 0.72 mm, whereas for females it is 0.75 mm. Adults have a preoviposition period that can last anywhere from two to twenty days,

depending on the population's features and the temperature (Salaudeen *et al.*, 2015). The host plant and the origin of the population have an impact on adult lifespan and fecundity. After the last nymphal moult, adults can mate anywhere from two to six days later, however there is usually a slightly longer wait before producing eggs. Male and female average adult lifespans at 26 °C range from 8 to 28 days and 14 to 33 days, respectively, depending on the host plant. Adults have the ability to fly away. They pierce into the tissues of plants to feed (Salaudeen *et al.*, 2015)

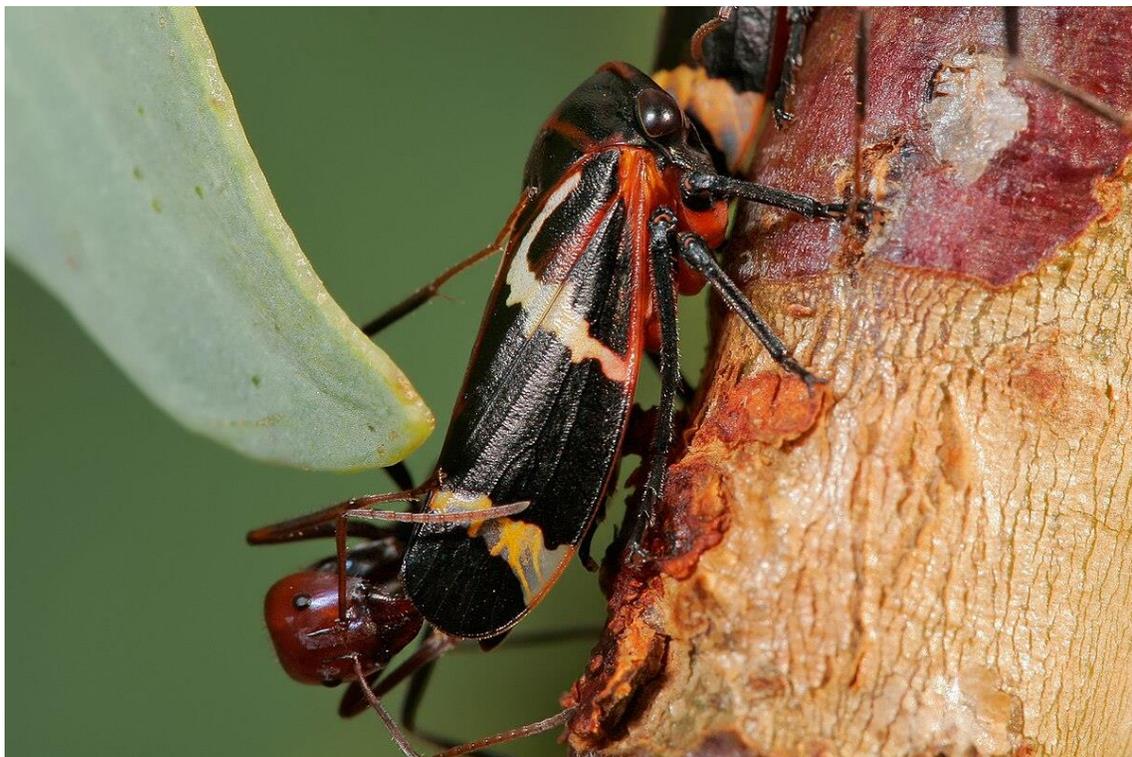


Figure 2.2: The adult *C. mbila*

2.9.2 The egg

The female of the *C. mbila* plant places the ivory-white eggs between the two epidermal layers of the leaf blades or leaf sheaths in the host plant's tissues. At about 28°C, a female can produce 100 eggs on average over her lifetime. Eggs can either mature and hatch in a few weeks or stay dormant for a duration ranging from a month to more than a year (Mylonas *et al.*, 2014). Eggs are visible from both sides of the leaf unless they are laid in the midrib. They are often laid individually, seldom in pairs or clusters. The eggs have a



mean length of 0.77 mm and a length range of 0.75 to 0.81 mm. The eggs have an average width of 0.172 mm with a range of 0.15 to 0.19 mm. It takes an egg 7 to 35 days to hatch, depending on the temperature. Eggs hatch in 7–10 days in laboratory conditions at about 25°C, and nymphal development takes an additional 14–20 days to complete (Mylonas *et al.*, 2014)



Figure 2.3: Egg mass of *C. mbila*

2.9.3 The nymphs

The eyes of the first-instar nymphs are black, and their skin is creamy white. Following the initial or any subsequent moult, a characteristic purple mark may develop on the dorsum of the thorax and abdomen. However, some nymphs did not get this purple mark until they reached the adult stage (Salaudeen *et al.*, 2015). Before maturing, the nymph undergoes five moults. After turning significantly darker in the second instar, nymphs gradually change color until they are pale yellow in the fifth instar. After the third moult, the wing pads differentiate themselves. It takes nymphs around three weeks to mature into adults. They pierce into the tissues of plants to feed (Salaudeen *et al.*, 2015)





Figure 2.4: Nymphs of *C. mbila*

2.10 Damage caused by *C. mbila*

There is hardly much direct harm caused by the maize leafhopper's feeding activity. It spreads maize streak disease, which is one way it negatively affects people. This results in the leaf developing yellow streaks, which may induce dieback, dwarfism, or even death of the plant. The plants under six weeks old sustain the most damage. When plants are severely damaged, they are stunted and yield little cobs with open husks. From a distance, the plants seem pale green, yellow, or white. The timing of the infestation and plant development is highly connected with the extent of the harm. Infested plants lose all of their output during the first three weeks following seedling emergence. Plants affected eight weeks after seedling emergence yield their full yield; later infections result in tiny



and poor ear formation. Only leaves developed after infection show symptoms. According to reports, Nigeria's virus infection incidence can fluctuate from 5% to 100% in a single year and between the country's first and second growth seasons (Oluwafemi & Jackai, 2013)





Plate 2.2: Damage caused by *C.mbila* on maize plant.

2.11 The maize streak disease

Early in the 20th century, South Africa saw the discovery of the maize streak virus (MSV), which causes streak disease. Since then, outbreaks of the disease have been reported in other nations with varying occurrences. The prevalence and severity of maize streak disease have been documented in a number of African nations, including South Africa, Burundi, Ghana, Nigeria, Zimbabwe, Uganda, Kenya, and Reunion, as well as in nearby Indian Ocean islands (Madagascar, Madagascar, and Principe) (Brunel *et al.*, 2014). More than 80 species of the Poaceae family, including barley, wheat, sorghum, millet, and sugarcane, were impacted by the major outbreaks of maize streak disease that occurred in some parts of West Africa in 1983 and 1984. In sub-Saharan Africa, maize streak disease causes production losses ranging from 30% to 100%, with yearly expenses of up to \$480 million (Asare- Bediako *et al.*, 2017).

A member of the Geminiviridae family, maize streak virus is a single-stranded circular DNA virus with viral particles containing roughly 2,685 nucleotides (Karavina *et al.*,





2012). The only means of sustained, non-propagative MSV transmission between plants is by biting, sucking Hemiptera leafhoppers (Shepherd *et al.*, 2010) As leafhoppers are necessary for MSV transmission, the effectiveness of these vectors determines the virus's spread and outbreak (Shepherd *et al.*, 2010) Symptoms of maize streak disease differ according on the MSV isolate. Chlorotic stripes that range from fragmented to nearly continuous and are located on the tertiary leaf veins are the hallmark of the symptoms (Pande *et al.*, 2017) Initially, they appear as tiny, pale circular dots on the leaf's lowest exposed portion. According to (Pande *et al.*, 2017), leaves below the spot of infection remain healthy, while only newly emerging leaves exhibit the signs of a virus infection. Primary veins are less damaged than secondary and tertiary veins when the spots grow into discontinuous pale-yellow streaks that stretch up to several millimeters down the blades, parallel to the veins, or broken chlorotic streaks on secondary or tertiary veins. Consequent to the longitudinal chlorotic streaking, the plant's photosynthetic area, growth, and yield are all reduced. The streaks frequently unite laterally to form slender, broken chlorotic stripes that might run the whole length of leaves that are completely impacted (Pande *et al.*, 2017).

Chlorotic streaks have a tendency to combine to generate a nearly uniform chlorosis in genotypes that are very vulnerable to it. The inability of chloroplasts to form in the tissue surrounding the vascular bundles is what causes chlorosis, which lowers photosynthesis and increases respiration, which in turn lowers leaf length and plant height. Therefore, within the first three weeks of emergence, infected maize plants become severely stunted, either producing significantly aberrant cobs or yielding no yield at all. Usually, if an

infection happens more than eight weeks after the plant emerges, there won't be much of



an economic loss (Lukuyu *et al.*, 2013)

Plate 2.3: Picture of maize plant infected with maize streak disease (MSD)

2.12 Economic impact of *C. mbila* infestation

The potential of *Cicadulina mbila* to spread the virus that causes maize streak disease has a significant economic impact. According to Shepherd *et al.* (2010), this is most likely the most significant insect-vectored plant disease in Sub-Saharan Africa. Early infection can cause plants to die and lose all of their yield (Daudu *et al.*, 2013) However, as plants age, the severity of infection decreases, and infections that happen more than eight weeks after emergence have little to no impact on yield (Bhanu *et al.*, 2016) In Sub-Saharan Africa, the illness is one of the biggest biological hazards to food security. It significantly jeopardizes the already vulnerable social and economic well-being of subsistence farmers across the continent by lowering yields of Africa's most important food crop. The problem persists even with the availability of disease control measures (Shepherd *et al.*, 2010). This is primarily because epidemics of maize stripe disease are inherently unpredictable,



making it challenging for farmers to determine when and where to implement effective management measures. Furthermore, without more accurate assessments of the disease's financial effects, there is unlikely to (Shepherd *et al.*, 2010)

2.13 Management strategies for *Cicadulina mbila*

2.13.1 Cultural control

Currently, *Cicadulina mbila* is managed using a variety of cultural customs. Crop rotation, cultivar selection, early planting, and field hygiene are a few of these. Broadleaved crops, such as cowpea, peanut, and bean, should be rotated because maize streak disease does not affect them at all ((Shahzad *et al.*, 2010) ; Shepherd *et al.*, 2010). Farmers often give priority to cultivating staple crops over managing maize streak disease on their tiny acreages. Intercropping is a superior crop rotation substitute. Cereal food crops can be interplanted with legumes and cucurbits by farmers. Intercropping, however, lowers the primary cereal crop's production (Lukuyu *et al.*, 2013) To control maize streak disease (MSD), common field hygiene practices include roguing and eliminating weeds, volunteer crops, and ratoon crops. When crops are discovered to be infected during the growing season, they should be rogued and buried right away. It's also important to eradicate volunteer crops of cereal and grassy weeds. Smallholder farmers typically lack the funds to buy certified seed every season, which makes them inclined to continue growing volunteer and ratoon crops. These serve as MSV inoculum sources if they are contaminated (Karavin *et al.*, 2014). In order to minimize leafhopper migration and the subsequent spread of viruses, farmers in the commercial agricultural sector keep a buffer zone of five to ten meters surrounding the field. According to (Saquee *et al.*, 2023), this area needs to be sprayed with pesticides on a regular basis, or the buffer's grass needs to be mowed short. It is possible to keep an identical zone between crops planted early and late. Due to their smallholding's restricted acreage, smallholder farmers are unable to



maintain such a buffer zone. The farmer is likewise unable to buy insecticides to apply to the buffer. In order to maximize land usage, they can cultivate MSD non-host crops such groundnuts, beans, and cucurbits in this buffer zone, should they want to create one (Awata *et al.*, 2019) According to Shepherd *et al.* (2010), early planting is also advised for the management of MSDs. An early planted crop outgrows the vulnerable stages before the population of leafhoppers reaches a critical mass to disseminate the virus. In addition, the crop grows quickly since it has access to high heat units in the early summer. However, the start of the rainy season plays a major role in determining planting dates, particularly in the smallholder sector where irrigation facilities are lacking. Due to the fact that smallholder farmers are typically compelled to plant after the first meaningful rains, it is challenging to advocate for this alternative in light of climate change. Because short season varieties are susceptible to the disease for a shorter period of time than long season varieties, it is preferable to grow them in places where MSD pressure is high. Corn shouldn't be planted next to older grain crops by farmers. It will be simple for leafhoppers to go downwind and infect the fresh crop (Awata *et al.*, 2019).

2.13.2 Biological control

Leafhopper control in Asian countries has been shown to be possible with the use of entomopathogenic bacteria and natural enemies (predators and parasitoids) (Widyaningrum, 2015) Numerous entomopathogens, parasitoids, and predators of significant cicadellid pests, such as *Cicadulina* spp. found in India, have been identified (Sahito *et al.*, 2018) But no thorough effort has been made to find and apply biological control agents for leafhoppers in Africa. In Burkina Faso, (Sahito *et al.*, 2018) reported rearing a species of dryinid parasitoid (*Anteon traorei*) from the eggs and larvae of *C. mbila*. Investigating and identifying Africa's native natural enemies of *C. mbila* is crucial.

Similarly, the application of transgenes and genetic engineering in maize breeding programs will be conceivable as our understanding of the adaptive reasons of plant defense against insects grows. There's little doubt that this technology will bring up new issues and hazards. To compare GM crops with other alternative pest management options, it is imperative to weigh the hazards and advantages of GM crops (C. Liu *et al.*, 2014).

Host plant resistance

The necessity of an interdisciplinary approach to cultivar creation has been highlighted by the majority of recent host plant resistance studies. Few investigations on the breeding of maize cultivars resistant to MSD vectors have been published in the literature. (Drechsler *et al.*, 2014) used four maize genotypes—100 MSR, HASR, Reunion, and H512—to examine the settling, probing, and oviposition behaviors of *C. mbila*. They came to the conclusion that, in general, *C. mbila* settled in higher numbers on this genotype, and that only H512 was fully vulnerable to MSV. The findings revealed the possibility of helpful resistance mechanisms to the vector.

(Badu-Apraku *et al.*, 2017) examined the feeding habits of leafhoppers using inbred lines of maize that were resistant to streaking, obtained from several resistance breeding initiatives. Inbred lines E739 and CML206 exhibited strong antixenosis against *C. mbila*, whilst P606, P590, P612, and CML206 shown moderate antixenosis. J2705tv and VH188w, on the other hand, exhibited very little antixenosis. Utilizing the detected antixenosis in national breeding programs has the potential to lower the level of primary infection in plants with an antiviral resistance component, since the severity of the disease is somewhat dependent on the amount of the virus that was acquired (Badu-Apraku *et al.*, 2017).



The creation of maize germplasm resistant to MSV has been the aim of various initiatives in Africa (Mafu *et al.*, 2014) The International Institute of Tropical Agriculture (IITA) in Nigeria, Reunion, and South Africa were the first places where resistance in maize germplasm was observed in 1931 (Oluwafemi & Jackai, 2013)). At IITA and the International Maize and Wheat Improvement Center (CIMMYT) station in Harare, maize cultivars possessing resistance characteristics to MSV were created (Murithi *et al.*, 2013) Actually, a lot of African breeding programs include MSV-resistant germplasm sources created at IITA into their variety development processes.

Many of the IITA open-pollinated varieties and hybrids exhibit reduced symptom severity together with low field virus incidence, which is indicative of MSV resistance (Oluwafemi & Jackai, 2013) (Karavina, 2014) have observed that the resistance of the IITA maize germplasm to MSV is governed by two or three major gene pairs, with the potential participation of minor genes. Although (Srinivasan & Janick, 2016) went one step further and showed the existence of a single main gene (identified as *msv 1*) that governs MSV tolerance, (Illiasu, 2015) mapped out the quantitative trait loci (QTL) for resistance to MSV. The majority of African countries have seen occasional MSV outbreaks with considerable yield losses despite efforts to breed types resistant to the disease. Indeed, it has been seen on the island of Reunion that certain types of maize that are resistant to MSV in one ecological zone may become susceptible to the illness in another (Salaudeen *et al.*, 2015) Therefore, it is imperative to comprehend how more virulent MSV isolates can spread quickly throughout agro-ecological zones and seasons as well as the local distribution of MSV strains. The various ongoing maize breeding initiatives throughout Africa would benefit greatly from this information (Salaudeen *et al.*, 2015).



2.13.3 Use of biopesticides

Using botanicals to control insects is a sustainable and successful method of pest management. Using plant extracts lowers the risk of maize streak disease considerably. The reason for the considerable decrease in the occurrence of maize stripe disease after neem oil was applied topically is probably that it stopped leafhoppers from feeding on maize leaves. It has been determined that azadirachtin, nimbodinine, solanine, deacetylazadirachtinol, and melantriol—among the compounds isolated from neem seed oil—are biologically active against insects. The primary active component of neem, azadirachtin, interferes with insects' development (Silva *et al.*, 2007).

These outcomes concur with those of Aziz (2013), who found that neem extracts considerably reduce the number of aphids that attack wheat. The incidence and severity of maize streak disease, as well as insect populations, are significantly reduced by treatment with *Chenopodium ambrosioides* extract. Because flavonoids and terpenoid chemicals are harmful to insects, *C. ambrosioides* may have insecticidal effects (Abiodun *et al.*, 2016). According to Guzzo *et al.* (2014), *C. ambrosioides* aqueous extract dramatically increased *Sitophilus Zea mais* mortality up to 50%.

2.13.4 Chemical control

The goal of using pesticides is to manage the vectors. There are insecticides that can be used to control leafhoppers, including imidacloprid, aldicarb, carbofuran, carbosulfan, dimethoate, and endosulphan. Imidacloprid and carbofuran are the pesticides that are most frequently utilized. Carbofuran can be sprayed conventionally, used as a seed treatment, or used in planting furrows (Awata *et al.*, 2019) Research on the chemical management of *Cicadulina mbila* revealed that 0.2 g a.i./m of carbofuran granules sown in the planting furrow significantly reduced the number of leafhoppers (Moeng, 2017)



The Cicadulina populations were decreased by carbofuran used as a seed dressing at 0.80 and 1.04 g a.i. /kg seed (Moeng, 2017)

Additionally, it was revealed that carbofuran insecticide was superior to traditional spray treatments that used aldicarb in granule form at 0.3 g/m or endosulfan at 31 and 45 days following the emergence of maize plants in terms of suppressing MSD vectors (Moeng, 2017) According to (Van Antwerpen *et al.*, 2011) using carbofuran effectively lowered the rate of MSD in treated fields by a factor of 10. This may be because the most susceptible immature maize plants are protected by the systemic carbofuran. In a review, (Sahito *et al.*, 2018) noted that leafhopper populations seemed to be under the control of pesticides belonging to the carbamate class. However, the incidence of viral illnesses was not mentioned in these investigations, making it impossible to determine whether the decrease in yield loss was caused by a low incidence of viruses or by less direct feeding damage. Although these experiments demonstrate that the application of persistent systemic insecticides can accomplish partial control of leafhoppers, the crop's protection is deemed inadequate due to the recurrent influx of migrant leafhopper populations that re-infect the crop following each application.

Furthermore, the World Health Organization (WHO) and the Food and Agricultural Organization (FAO) (WHO, 1986; FAO, 1998) have recorded numerous cases of health problems linked to pesticide users in maize-based systems in Africa. In Africa, a million individuals are affected by pesticide poisoning every year, and 20,000 of those instances end in death (WHO, 1986). A large portion of the pesticide issue stems from the application of pesticides by numerous small-scale farmers who don't wear the proper protective gear and don't know enough about them (Goldman, 2019) In the same way, most farmers with little resources are unable to pay for the expenses associated with using pesticides. Use of the proper insecticides will remain crucial for controlling the maize



virus or its vector. However, for tropical farmers with limited resources, non-chemical alternatives continue to be the most economical, secure, and ecologically friendly methods (Goldman, 2019)

2.13.5 Integrated control

Integrated pest management, or IPM, is a knowledge-intensive, environmentally friendly method of managing pests by combining cultural, biological, physical, and chemical tactics and techniques in a way that minimizes threats to the environment, economy, society, and health (Abudulai, 2018). In integrated pest management (IPM), choosing the optimal blend of locally accessible pest control techniques is crucial and is mostly determined by understanding the interactions between pests and crops. Unlike pesticides, which are made to be stored, integrated pest management is not a single product or technique (Yang *et al.*, 2016). Programs for sustainable management have shown great success when several approaches are used simultaneously as part of an integrated strategy (Heinrichs and Muniappan, 2018). In the meantime, pests can quickly adapt to single management measures through co-evolution brought about by natural selection (Badii, 2005).

2.14 Effect of fertilization on *C.mbila* infestation

For tropical soils to be managed sustainably, soil fertility control is crucial. Nonetheless, controlling soil fertility can have an impact on how susceptible plants are to illnesses and pests. According to (Awata *et al.*, 2019) the kinds and amounts of nutritional components in host plant tissues have an indirect impact on leafhopper population dynamics, which may have an impact on maize streak virus transmission. Despite no decrease in the incidence of maize streak disease, the administration of NPK had a substantial impact on its severity. When appropriate nutrients are used, all wheat diseases are decreased. This indicates that while fertilizer treatment may not directly impact the occurrence of maize



streak disease, it can have a major effect on the plant's capacity to prevent the invasive virus from penetrating and developing (Huber *et al.*, 2007). Furthermore, the plants that were fertilized received enough nutrients to grow stronger and better, offsetting any potential virus damage. This suggests that applying fertilizer helps reduce the severity of maize streak disease. According to Wang *et al.* (2013), applying K fertilizer dramatically lowered the incidence of aggregate sheath spot and stem rot disease in rice. (Awata *et al.*, 2019) also found a substantial inverse relationship between the amount of K in the soil and the quantity of *Cicadulina mbila*, noting that the largest concentrations of *C. mbila* were found in fields with low K contents.

2.15 Fertilizer and types of fertilizer

Fertilizer is a material that is applied to the soil or sprayed on crops aboveground directly or indirectly in order to supply nutrients, increase crop yields and improve product quality (Olaniyi *et al.*, 2011). Direct fertilizer supplies essential nutrients to crops, including NPK fertilizer, compound fertilizer and micro-element fertilizer, etc. Indirect fertilizer is used for improving soil physical and chemical properties, thereby making growth condition of crops better, such as lime, gypsum and bacterial fertilizers (Olaniyi *et al.*, 2011).

Fertilizer application is a crucial aspect of crop production, irrespective of the nutrient content of the land to be cultivated, it is advisable to supplement with fertilizer as the plant grows. This approach increases the fertility of the land during cultivation and conserves the fertility of the soil after cultivation (Karagöz, 2014).

2.15.1 Types of fertilizers

Organic fertilizers

Organic fertilizers derived from animal or plant material that has been decomposed by bacteria. They tend to be slow release. meaning they provide nutrients over a long period



of time (Mi *et al.*, 2019). They also tend to be less expensive than inorganic fertilizers, but they are easy to use because they do not require special handling or equipment (Karagöz, 2014). Organic fertilizers include manure, compost, wood, chips, and other organic materials that can be spread on the soil as they are being prepared for planting (Mi *et al.*, 2019).

Inorganic fertilizers

Inorganic fertilizers contain chemical substances like ammonium nitrate or urea specially formulated to supply a single or combination of nutrients into the soil quickly when applied at planting time (Liu *et al.*, 2019). These products have many advantages over organic fertilizers because they work faster and better than organic fertilizer, however, there are drawbacks as well. They are expensive and since these products do not contain carbon from decomposition processes like organic sources do (which helps add structure), their nutrients may leach out more quickly than those from organic sources after application (Mi *et al.*, 2019).

2.16. Fertilizer application techniques or methods

2.16.1 Broadcasting

The broadcasting method of fertilizer application is a technique that involves spreading fertilizer evenly over the soil surfaces. This method can be used with almost any type of fertilizer, including liquid, granular and pelletized forms (Liu *et al.*, 2019). The broadcasting method can be used for large-scale applications, such as farms or for lawns. This technique is simple and suitable for large-scale farming. It's important to use the right equipment to achieve even distribution. Calibration of spreaders is essential to prevent over- or under-application (Hazra, 2016).



2.16.2 Placement

Placement is a tactical method of applying fertilizers. It is the application of fertilizer to a fixed portion of the soil where the plant can easily take up for usage. It is used when the fertilizer is in small quantities, hence, it must meticulously utilize, the soil has a low level of fertility, hence, it must be used efficiently by the crops, and when the development of the root system is poor, hence, used to stimulate rooting. Basal placement is the application of the fertilizer to the base or around the root zone of the plant (Olaniyi *et al.*, 2011). Fertilizers are placed at the root zone of the plant. In a plow sole placement, fertilizers are applied during plowing. The fertilizers are buried in the furrow(space)made by the plow during operation (Hazra, 2016). Deep placement is another method of placement commonly used in paddy fields. It involves placing the fertilizers near the root zone of the plant. It is used in the applications of nitrogenous fertilizers for optimum distribution and usage of the fertilizer in the root (Olaniyi *et al.*, 2011). Localized placement is another method of fertilizer application that involves the application of fertilizer into the soil close to the seed or plant with the ai, of making the nutrient readily available for the plant (Olaniyi *et al.*, 2011).

2.16.3 Foliar fertilizer application

Foliar application is the process of applying fertilizer or nutrients directly to the leaves of a plant.it is also called foliar feeding, or foliar fertilization. The type of fertilizer used in the foliar application is usually liquid fertilizers, but powders can be used as well (Mischke & Zimba, 2010). Foliar application can be used to supplement deficiencies in soils and fertilizers, as well as to increase nutrient availability for plants during periods of rapid growth or stress. Foliar application, is most often used on plants that are growing



well and have enough nutrients in the soil, but still need more help getting their growth going (Mischke & Zimba, 2010).

2.16.4 Fertigation

Fertigation is the process of applying fertilizer to plants roots zone by using an irrigation system. This practice improves the efficiency of water and fertilizer use, while protecting the environment from runoff and waste (Hasler *et al.*, 2015). It is commonly used in hydroponic or greenhouse environments, where plants are grown in soil-free grow media such as rock wool or coconut. A typical fertigation system consists of a pump, controller, valves, and tubing (Wang *et al.*, 2017). The pump delivers water from a tank or pond through the valves and tubing to either sprinklers for broadcast application or drip emitters for localized application. The controller regulates the flow rate, timing, and frequency of each cycle. Fertigation allows for precise delivery of nutrients in a controlled manner, which helps prevent waste and over-application (Wei *et al.*, 2018).



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study is an on-station trial at the UDS Experimental Farms in Nyanpkala during the 2023 cropping season. The area has a gentle undulating to flat terrain (Kumah, 2016) and also largely characterized by low-lying areas of grassland with few spread perennial woody species. Maize, rice, cowpea, soybean and groundnuts are some of the crops cultivated in this ecological zone. Soils in this area are largely developed from Voltarian sandstone and shale with texture being loamy sand and sandy loam (Yidana *et al.*, 2011) which is classified as Ferric Luvisol.

3.2 Experimental period

The experimental site was located in the University for Development Studies experimental field in the Nyankpala Campus during the 2023 cropping season. It is situated in the Tolon District of the Northern region and lies in the interior Guinea Savannah agro-ecological zone of Ghana. Geographically, the district lies between latitude 90 15' North and longitude 00 53' West. It shares borders North Gonja District to the west, Kumbungu to the North, Central Gonja District to the South and to the East with Tamale Metropolis (Ghana Statistical Service, 2014). 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 (SARI, 2001). The area has a unimodal rainfall pattern which has a mean annual rainfall ranging from 800mm 1200mm (Kombiok *et al.*, 2012). The relative humidity in the study area is at its maximum during the rainy season with mean monthly value of 80 % and a sharp decrease to a minimum of 53 % during the dry season (SARI and Yudhistira, 2021)

3.3 Experimental details

The experiment was a single factor with nine treatments arrange in a randomized complete block design with three replications. The variety of maize used was Obatanpa and plot size of 4 m by 4 m were used (16 m²).

3.4 Land preparation, experimental design and treatments

The field was disc-ploughed and harrowed with a hoe during first week of July. A 544 m² of land area was marked out for the experimental layout. The trial was laid out in a Randomized Complete Block Design (RCBD) with ten treatments and three replicates. A field size of 34 m x 16 m with plot size of 4 m x 4 m was used. A 1 m and 2m alleys were allowed between treatments in each block and between blocks respectively. The treatments included nine (9) different fertilization regimes each replicated three (3) times in the study. The treatment layout as follows (Table 3.1):



Table 3.1: Fertilization treatments

TREATMENTS	DESCRIPTION
ACT-SUL	YaraMila Actyva @ 125kg/ha and top dressed with YaraBela Sulfan @ 125kg/ha
ACT-NIT	YaraMila Actyva @ 125kg/ha and top dressed with YaraLiva Nitabor @ 125kg/ha
ACT-SOA	YaraMila Actyva @ 125kg/ha and top dressed with Sulphate of Ammonia @ 125kg/ha
T15-SOA	YaraMila triple super phosphate (15-15-15) @ 125kg/ha and top dressed with Sulphate of Ammonia @ 125kg/ha
ACT-URE	YaraMila Actyva @ 125kg/ha and top dressed with Urea (46%N) @ 125kg/ha
T15-URE	YaraMila triple super phosphate (15-15-15) @ 125kg/ha and top dressed with Urea(46%N) @ 125kg/ha
T15-NIT	YaraMila triple super phosphate (15-15-15) @



	125kg/ha and top dressed with YaraLiva Nitrobor @ 125kg/ha
T15–SUL	YaraMila triple super phosphate (15-15-15) @ 125kg/ha and top dressed with YaraBela Sulfan @ 125kg/ha
CLB–CLB	YaraVita CropLift biofertilizer @ 2.5l/ha and top dressed with YaraVita CropLift biofertilizer @ 2.5l/ha
CONTROL	No fertilizer application

3.5 Planting and application of treatments

Four to three seeds of Obatanpa were sown per hole at a spacing of 80cm between rows and 40cm within rows up to a depth of 5cm on 2nd July, 2023. After emergence, the seedlings were thinned to two per hole.. All the plots received a base application of fertilizer except the control. The application of the fertilizer treatments was done strictly in accordance with the protocol indicated in Table 3.1 above using the deep placement method. The basal fertilizer was applied two weeks after emergence while the second application was done six weeks after emergence. An insecticide (Lamda K Optimal) was also used to control fall armyworm infestation in the field.



3.6 Crop husbandry

Thinning was done fourteen days after sowing by retaining two healthy seedlings per hill. Weeding was carried out manually using hoe on 2nd, 5th and 12th weeks after sowing that was on 16th July, 2023, 6th August, 2023 and 1st October, 2023 respectively. Basal application of compound fertilizer, NPK (15:15:15) kg/ha was applied for twenty-seven plots with the exception of the three (3) control plots on 16th July, 2023 at 2 weeks after planting (WAP).

On August 9, 2023, five weeks after planting (WAP), top dressing was applied as the second application to twenty-seven (27) experimental plots. On November 6, 2023, the corn was harvested as a sign of cob maturity and leaf senescence because the leaves had fallen off and gone yellow (Ijoyah and Jimba, 2009). Before being shelled, the entire plant on each plot was manually harvested, sun-dried, and packed separately in bags.

3.7 Assessment of *C. mbila* abundance

Assessment of *C. mbila* abundance was done using a 2×3 m (6 m²) at the middle of each plot, this was done to avoid the border effect. W method was used in the course of the data collection. This was done by walking to draw a W (Kpemoua *et al.*, 2021) and all maize plants that fall within the W were assessed by visual observation and recording the number of *Cicadulina mbila* abundance that is their physical presence. The data was taken for six times that is, 3WAP (week after planting), 4WAP, 5WAP, 6WAP, 7WAP and 8WAP.

3.8 Assessment of *C. mbila* damage and disease incidence

Cicadulina mbila damage incidence and the disease incidence were assessed using a 2×3 m (6 m²) at the middle of each plot. The W method was used for the assessment of all plants in each plot by visual observation and recording the number of *C. mbila* damage



incidence or feeding symptoms and the disease incidence (Kpemoua *et al.*, 2021). Assessment was done for six times that is, 3WAP (week after planting), 4WAP, 5WAP, 6WAP, 7WAP and 8WAP.

Table 3.2: Visual rating scale for maize streak disease (MSD) severity

Rating scale	Description	Expression in terms of severity
1	No symptoms	Absence of infection
2	Very little leaf streaking, with minor striping on older leaves that gradually disappears on younger leaves.	Mild infection
3	mild stunting, moderate striping on both young and elderly leaves	Moderate infection
4	severe streaking across 60–75% of the leaf surface, resulting in stunted plants	Severe infection
5	extreme streaking covering over 75% of the leaf surface, severely stunted or dead plants.	Very severe infection

Source: Bosque-Perez *et al.* (1992) and Oppong *et al.* (2014a, b).



3.9 Estimation of maize grain yield and quality

Each 4 m x 4 m net plot area had its maize harvested when it reached physiological maturity. Following drying, shelling, and winnowing, the grains were weighed. The following formula was used to calculate the grain yield of maize per hectare:

$$\text{Grain yield (Kg/ha)} = \text{Weight of grains} \times 10,000\text{m}^2 / \text{Net area.}$$

After shelling and sun-drying the seeds from each plot, the hundred seed weight were recorded by counting the seeds and mean seed weight determined.

3.10 Data analysis

Prior to analysis, all data were transformed using the square root transformation. Data were repeatedly analyzed using the ANOVA method in the statistical program GenStat (12th version). The least significance difference (LSD) was used to distinguish means with significance at the 5% probability level.

3.11 Benefit-cost analysis

To assess the net benefit of fertilization and net returns to *C. mbila* management, partial budget analysis was used. The purpose of this was to evaluate the financial impact of managing *C. mbila* as opposed to not fertilizing. The market prices for chemicals, maize, and fertilizer were used to calculate the production value and cost, accordingly. The underlying premise was that all other costs would remain constant, and the costs that varied would be applied to determine the input costs. The following formula was used to compute the value of the yield increments due to fertilization using the mean grain yield of maize:

$$\begin{aligned} & \text{Value of increased yield due to fertilizer} \\ & = \text{Price} \times \text{Increased yield over control} \end{aligned}$$

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



Where P_{market} is the market 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:

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

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:

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

The benefit cost ratio was then calculated using the following:

$$B.C.R = \frac{gross\ monetary\ returns}{total\ cost\ of\ production}$$



CHAPTER FOUR

4.0 RESULTS

4.1 Effect of fertilizer treatments on the abundance of *C. mbila*

Highly significant differences ($P < 0.001$) were observed in the total number of *C. mbila* due to the application of fertilizer treatments during the period of study. In table 4.1, it can be observed that the highest number of *C. mbila* was found in maize plants in control plots (126) which was statistically similar to T15-SUL . The least number of *C. mbila* was found in CLB-CLB treated plots (77). Control produced 1.64 times more *C. mbila* than CLB-CLB. CLB-CLB was followed by T15-NIT with a total of 92 *C. mbila* observed. T15-SOA, ACT-SUL and ACT-URE produced similar total number of *C. mbila* as T15-NIT.

Table 4.1: Mean Abundance of *C. mbila* under the fertilization regimes

WEEKS AFTER PLANTING	TREATMENTS	Control	ACT-NIT	ACT-SOIL	ACT-SULF	ACT-UREA	CLB-NIT	T15-NIT	T15-SOIL	T15-SULF	T15-UREA	F pr.
3		17	12.33	12	11	12	8.33	9	13.33	15.67	13	0.868
4		19.33	17.33	17	12.33	15.67	8.67	10.67	11.67	16.67	17.67	0.511



5	22.67	20. 33	19. 67	17. 33	17. 33	13	18	17. 33	21	20.6 7	0.71 8
6	26.67	22	23	20. 33	20	17	21. 33	21	25.3 3	21.6 7	0.59 3
7	29	21. 67	25. 33	25	20	21	23. 67	24	29.3 3	24	0.47 4
8	11.67	13	13. 33	10. 67	10. 67	8.6 7	9	12. 33	14	11	0.29 1

With regards to the trends in the number of *C. mbila* at week 3 and 8, the fertilizer treatments could not influence ($P > 0.05$) the parameter under observation. However, the population of *C. mbila* was highly affected ($P < 0.001$) by the application of fertilizer treatments from week 4 to 7. From week 4 to 6, control plots recorded the highest number of *C. mbila* and T15-SUL caused the highest number of *C. mbila* in week 7 (Figure 4.2). It was further observed that the performance of both treatments was statistically similar from week 4 to 7. The treatment that produced the least number of *C. mbila* from week 4 to 6 was CLB-CLB. At week 7, ACT-URE produced the least number of *C. mbila* but CLB-CLB had a similar performance. The number of *C. mbila* observed in control plots was 1.38-2.23 times that of CLB-CLB plots.



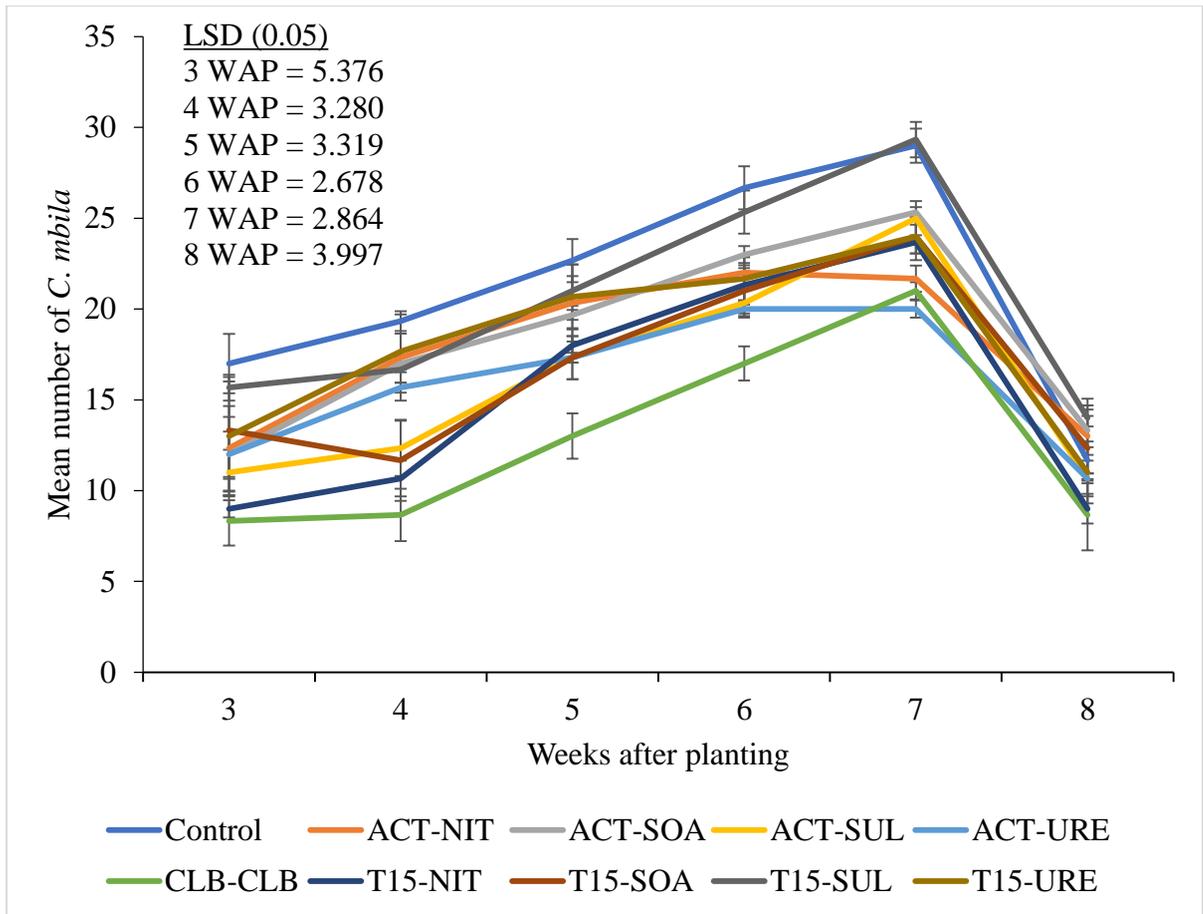


Figure 4.1: Trend of occurrence of *C. mbila* as affected by the fertilization regimes across the sampling weeks. Bars denote the standard error of means. Means comparison was conducted using least significant difference ($P < 0.05$).

4.2 Effect of fertilizer treatments on damage incidence of *C. mbila*

It was observed from the data analysis that the mean damage score for *C. mbila* was highly affected ($p = 0.001$) by the fertilizer treatments. The highest mean damage score was 27 which was produced by ACT-SOA treatment (Table 4.2). Control, T15-SUL, ACT-SUL and T15-SOA produced statistically similar mean scores as that of ACT-SOA. T15-URE was observed to have produced the least mean damage score for *C. mbila* (18). Compared to ACT-SOA, T15-URE reduced the mean damage score by 33.3%. T15-NIT,

CLB-CLB, ACT-NIT and ACT-URE did not statistically perform differently from T15-URE.

Table 4.2: Mean damage score of *C. mbila* in maize under the fertilization regimes.

WEEKS AFTER PLANTING	TREATMENTS											
		Control	AC T- NI T	AC T- SO A	AC T- SU L	AC T- UR E	CL B- CL B	T15 - NI T	T15 - SO A	T15 - SU L	T15 - UR E	Fpr.
3		18.67	14.33	19.67	16.33	12	11.33	14.33	17.33	15.67	12.67	0.853
4		20.67	14.33	23	18.33	13.33	13	17.33	17.33	16.67	13	0.548
5		23.33	18	25.67	22.33	15.33	16	19.67	20.67	23	17.33	0.983
6		27.33	20	28.33	25	18.67	19.33	22.67	25	27	19.67	0.724
7		30	22.67	31	29	20.67	23.67	24	28.67	32	22	0.964
8		35.3	24.7	35.7	35.7	33.3	31.3	30	35	35.3	24.7	0.979



There was significant ($P < 0.05$) effect of the fertilizer treatments on the damage score at week 3. Furthermore, damage scores of *C. mbila* from week 4 to 7 were highly influenced by the application of fertilizer treatments to maize plants. However, no significant ($P > 0.05$) differences due to the application of fertilizer treatments were observed in the damage score at week 8. ACT-SOA treatment produced the highest damage score from week 3 to 6 (Figure 4.2). T15-SUL produced the highest damage score of 27 at week 7. These treatments produced statistically similar damage scores with control.

CLB-CLB and T15-URE produced the least damage scores at week 3 and 4 respectively. ACT-URE produced the least damage scores from week 5 to 7 (Figure 4.2). The performance of these three treatments was statistically similar from week 3 to 7.



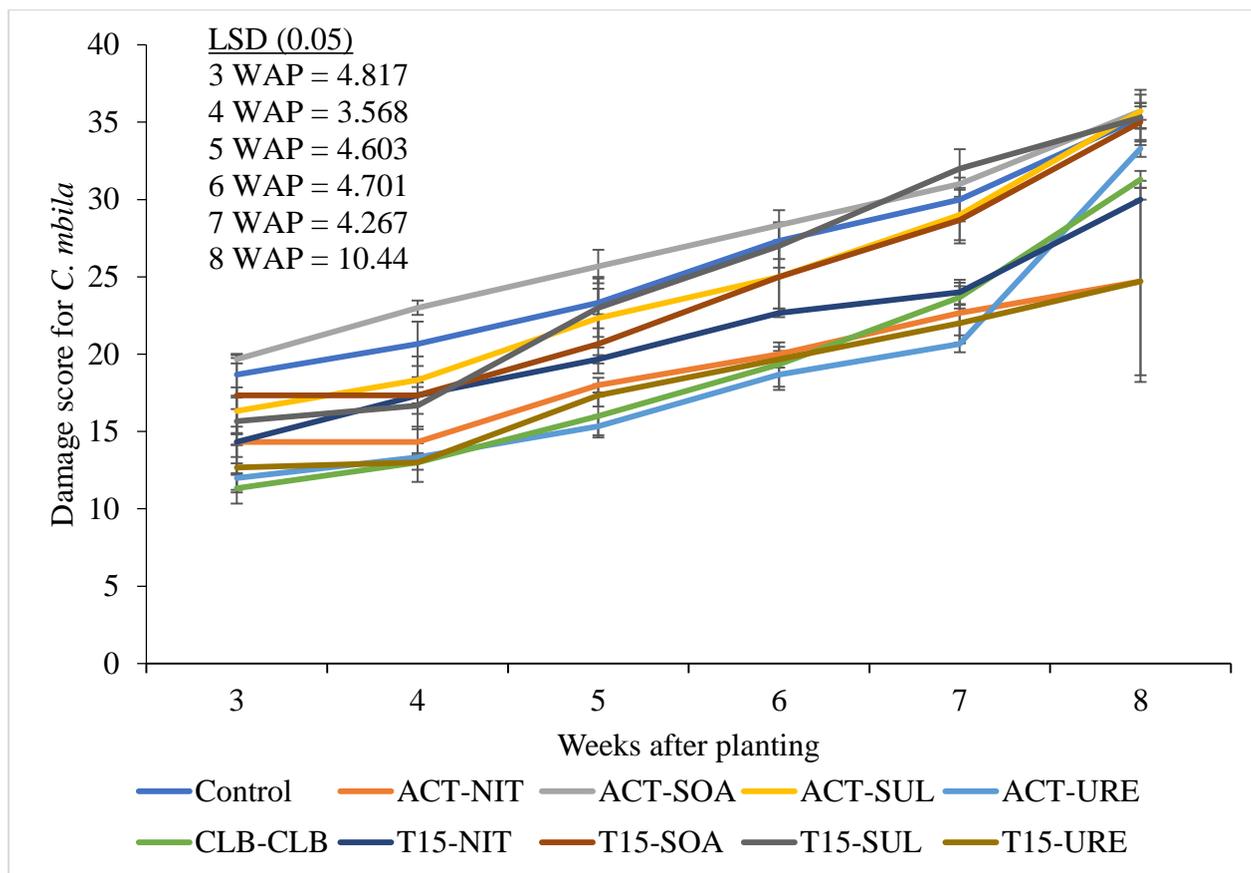


Figure 4.2: Trend of *C. mbila* damage in maize under the fertilization regimes across the sampling weeks.

4.3 Effect of fertilizer treatments on the incidence of streak disease

The incidence of streak disease over the study period was affected ($p < 0.01$) by the fertilizer treatments. The highest mean streak disease incidence score was found in maize plants in T15-SOA plots (Table 4.3). T15-SUL, ACT-SUL, control, ACT-NIT and ACT-SOA also recorded statistically similar incidence scores. The least incidence score was found in ACT-URE treated plots. CLB-CLB, T15-URE and T15-NIT produced similar incidence scores as ACT-URE. Compared to control, ACT-URE reduced the mean disease incidence score by 32%.

Table 4.3: Streak disease incidence caused by *C. mbila* under the fertilization regimes.

WEEKS AFTER PLANTING	TREATMENTS										
	Control	AC T- NI T	AC T- SO A	AC T- SU L	AC T- UR E	CL B- CL B	T15 - NI T	T15 - SO A	T15 - SU L	T15 - UR E	F pr.
3	9.33	11. 67	7.6 7	11. 33	7.3 3	7.3 3	5.3 3	9.6 7	8.33	7.67	0.52 5
4	9.67	7.6 7	9.3 3	7.6 7	8	5.3 3	4.6 7	10. 33	9.33	6.33	0.53 2
5	15.67	12. 33	11. 67	15	8.3 3	11	9.6 7	15. 33	15.3 3	10.3 3	0.94 7
6	19.33	17. 33	17. 33	18. 67	10. 67	15. 33	15. 33	20. 33	19.6 7	15.3 3	0.42 4



7	21.67	20. 67	20. 67	22. 33	12. 33	19. 33	17. 33	25	24	18.6 7	0.11 3
8	25	25. 67	24	27. 33	21. 33	24. 33	23	29	31.6 7	21.6 7	0.41 6

In the study, it was observed that the fertilizer treatments could not influence ($p > 0.05$) the incidence score of streak disease at week 3 and 4. However, highly significant ($p < 0.001$) differences were observed in incidence scores due to fertilizer application from week 5 to 7. Also, the fertilizer treatment affected ($p < 0.01$) the incidence score of streak disease at week 8. T15-SOA, T15-SUL, ACT-SUL and control statistically performed similarly in producing the highest disease incidence score (Figure 4.3). However, a reduced incidence score was observed for control in week 8. The least disease incidence scores from week 5 to 8 were produced by ACT-URE treatment.



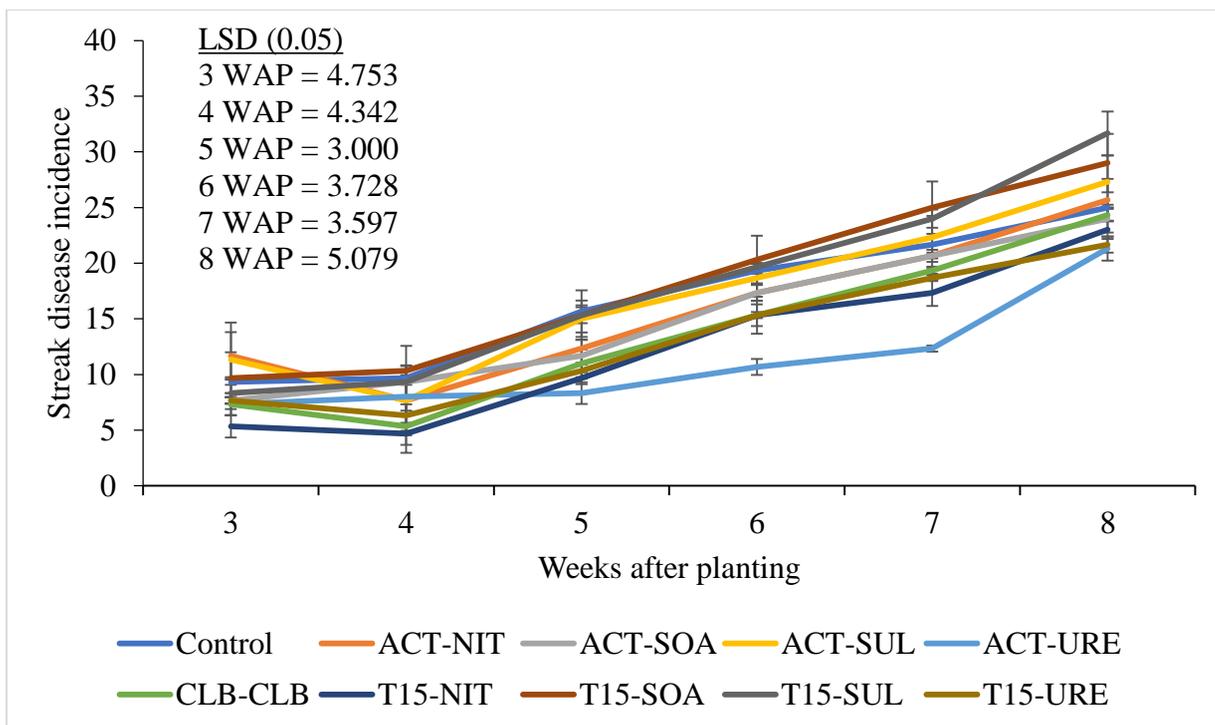


Figure 4.3: Trend of streak disease development in maize under the fertilization regimes across the sampling weeks.

4.4 Impact of fertilization on maize grain yield and quality

The fertilizer treatments caused highly significant ($P < 0.001$) differences in the grain yield produced by maize plants. ACT-URE produced the most grain yield with a mean value of 2940 kg/ha (Figure 4.4). It was also observed that its performance was statistically similar to that of ACT-NIT, T15-URE, ACT-SOA and T15-NIT. The grain yield of plants treated with ACT-URE was 16 times that of those from control plots. Control produced the least grain yield with CLB-CLB producing similar yield (275 kg/ha) to that of control.

Table 4.4: Maize grain yield obtained from the different fertilizer treatments in *C. mbila* management

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.						
TREATMENTS											
Control						CLB - CLB	T15-NIT	T15 - SOA	T15-SUL	T15-URE	
AC T-NIT											
AC T-SO											
AC T-SUL											
AC T-URE											
GRAIN YIELD	184	2746	2298	1876	2940	275	1902	1611	1437	2306	
MEAN YIELD	48.92246322	257.217159	171.099062	500.427003	280.452941	76.3195038	437.034027	305.02981	178.5405857	195.9548323	

Table 4.5: 100 seed weight of maize obtained from the use of the fertilization in *C. mbila* management

Source of	d.f.	s.s.	m.s.	v.r.	F pr.
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variati
ve

TREA TMEN T	6	13.8	2.3	0.13	0.98					
		1			9					

TREA
TMEN
TS

	Control	ACT -NIT	ACT - SOA	ACT -SUL	ACT - URE	C L B- C L B	T15- NIT	T15- SOA	T15- SUL	T15- URE
SEED WEIG HT	19.33	23.6 7	20.6 7	20	21.3 3	19	20.6 7	21.6 7	21.67	22
MEA N SEED WEIG HT	0.5443 31054	0.98 1306	0.98 1306	0.47 1404	1.18 6342	0	0.27 2165	0.27 2165	0.544 3310	0.471 4045
		76	76	52	03		53	53	54	21

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Furthermore, 100 seed weight of the maize plants was affected ($P < 0.05$) by the fertilizer treatments. The highest 100 seed weight was produced by ACT-NIT (4.5). Its performance was 22.5% higher than that of control but control did not produce the least 100 seed weight. The least performance was caused by CLB-CLB. T15-URE, T15-SOA, T15-SUL and ACT-URE produced statistically similar 100 seed weight with that of ACT-NIT.

4.5: Benefit-cost ratio of maize yield accrued from the fertilizer treatments in *C. mbila* management

The highest benefit cost ratio of 4.5 was produced by the application of ACT-URE fertilizer treatment to maize plants (Table 4.6). This was followed by ACT-NIT (4.0) and T15-URE (3.4). An interesting observation was that control and CLB-CLB treatment produced negative benefit cost ratios. Control caused the least benefit cost ratio of -0.2 while benefit cost ratio for CLB-CLB treatment was -0.1.



Table 4.5: Benefit cost ratio on maize yield accrued from the fertilizer treatments in *C. mbila* management

Treatment	Contr ol	ACT-NIT	ACT- SOA	ACT-SUL	ACT- URE	CLB- CLB	T15-NIT	T15-SOA	T15-SUL	T15-URE
Revenue items										
Grain yield (kg/ha)	184	2746	2298	1876	2940	275	1902	1611	1437	2306
Unit price per kg (GHC)	8	8	8	8	8	8	8	8	8	8
Gross revenue (GHC/ha)	1472	21968	18384	15008	23520	2200	15216	12888	11496	18448
Cost items										
Land preparation cost (GHC/ha)	300	300	300	300	300	300	300	300	300	300
Cost of seed (GHC/ha)	157.5	157.5	157.5	157.5	157.5	157.5	157.5	157.5	157.5	157.5
Labour cost for planting (GHC/ha)	375.5	375.5	375.5	375.5	375.5	375.5	375.5	375.5	375.5	375.5

Cost of fertilizer (ACT) (GHC/ha)	0	1000	1000	1000	1000	0	0	0	0	0
Cost of fertilizer (CLB) (GHC/L/ha)	0	200	200	200	200	400	200	200	200	200
Cost of fertilizer (SUL) (GHC/ha)	0	0	0	950	0	0	0	0	950	0
Cost of fertilizer (NIT) (GHC/ha)	0	1000	0	0	0	0	1000	0	0	0
Cost of fertilizer (T15) (GHC/ha)	0	0	0	0	0	0	950	950	950	950
Cost of fertilizer (SOA) (GHC/ha)	0	0	850	0	0	0	0	850	0	0
Cost of fertilizer (URE) (GHC/ha)	0	0	0	0	850	0	0	0	0	850
Labour cost for fertilizer app. (GHC/ha)	0	300	300	300	300	200	300	300	300	300

Cost for weeding (GHC/ha)	500	500	500	500	500	500	500	500	500	500
Cost of insecticide (LAMDA K-OPTIMAL) (GHC/L/ha)	60	60	60	60	60	60	60	60	60	60
Cost of labour for insecticide app. (GHC/ha)	125	125	125	125	125	125	125	125	125	125
Labour for harvesting (GHC/ha)	400	400	400	400	400	400	400	400	400	400
Total cost (GHC/ha)	1918	4418	4268	4368	4268	2518	4368	4218	4318	4218
Net returns due to insect control	-446	17550	14116	10640	19252	-318	10848	8670	7178	14230
Benefit cost ratio	-0.2	4.0	3.3	2.4	4.5	-0.1	2.5	2.1	1.7	3.4

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of fertilization on abundance and damage of *C. mbila*

It was revealed that highly significant differences were observed with regards to the abundance and damage of *C. mbila* as a result of the application of fertilizer treatments. However, the highest number of *C. mbila* was associated with maize plants in the control plots. Again, CLB-CLB treated plots had the least number of *C. mbila*. Infestation in T15-SOA, ACT-SUL AND ACT-URE was mostly statistically similar. The research has shown that applying fertilizer helps prevent *C. mbila* infestation. The findings suggest that maize from fertilized plots may have received enough nutrients to grow more robustly and healthily. The fertilized plants' ability to develop more quickly allowed them to resist any insect harm that would have resulted from slower growth. Given that fields with low potassium (K) contents had the highest concentrations of *C. mbila*, Magenya et al. (2009) suggested that the increased infestation of *C. mbila* in control plots may have resulted from low K levels in the soil. The treatment that had high potassium (K) was the YaraMila triple super phosphate (T15).

These findings corroborate Ochilo (2013) who observed that with the right soil nutrition and fertilizer management, leafhopper infestation in maize could be significantly reduced with accompanied increased yields. Also, Morales *et al.* (2001) and Mesbah *et al.* (2002) noted that plants with adequate nutrition are healthier, stronger, and more equipped to withstand pest harm than those with inadequate nutrition. Alale (2022) also observed that the fertilization regime provided adequate nutrients that served as a natural defense mechanism against pest damage. Once more, this data supports the conclusions of Huber *et al.* (2007), who found that using a balanced nutrition program reduces all wheat



diseases. The result however contradicts the findings of Rahaman (2021) who reported that abundance and damage of the various pest species were generally not significantly affected by the fertilization regimes.

The type of fertilization strategy has an impact on the damage incidence of *C.mbila*. The findings confirm those of Magenya et al. (2009), who found that the kinds and concentrations of nutritional components in host plant tissues may have an indirect impact on leafhopper population dynamics and, as a result, on the spread of the maize streak virus (MSV). While the incidence of maize streak disease (MSD) remained unchanged, the use of fertilizer had a substantial impact on its severity, leading to higher yields in fertilized plots compared to the control. Thus, the findings imply that while fertilizer treatment may not directly influence the occurrence of MSD, it may have a major effect on a plant's capacity to prevent the invasion virus from penetrating and developing (Huber et al., 2007).

The fact that MSD severity was lessened by fertilizer application may be explained by the affected plant's ability to sustain its own growth in the presence of enough plant nutrients despite the MSV infection. This conclusion is reinforced by the high prevalence and severity of MSDs observed in the control group. The study has shown that applying fertilizer can reduce the severity of MSDs. The results, however, were in conflict with those of Bua et al. (2010), who observed a substantial decline in maize production and growth.

5.2 Impact of fertilization on grain yield and quality

Grain yield is the most profitable outcome of the morphological and physiological changes that take place in the maize plant during its growth and development. There was no significant variation among the fertilization regimes, despite having the most grain yield was recorded by ACT-URE (2,940kg/ha) followed by ACT-NIT (2,746kg/ha) and



T15-URE (2,306kg/ha). The results demonstrated that the Actyva-based fertilizers performed better than Unik 15 and NPK formulations as reported by Abdulai *et al.*, (2020). The increased productivity of Actyva formulations may have resulted from the use of Sulfur as a secondary nutrient and Zinc and Boron as micronutrients. According to Daphade *et al.* (2019), B and Zn are micronutrients that can increase the availability of primary and secondary nutrients so that plants can absorb them. The findings also suggested that adding micronutrients to NPK fertilizer formulation could boost photosynthetic activity and possibly produce a large yield of grains. It is also observed that ACT-URE recorded higher yield among the Actyva treated plots and T15-URE also did well compare to the other Unik 15 formulations. The increment in the grain yield might be influenced by the concentration of Nitrogen content in Urea which is 46% higher than the other treatments. Once more, maize has a strong need for these nutrients: potassium (P), phosphorus (P), and nitrogen (N). Nitrogen (N) is the primary nutrient that typically restricts production among them. It establishes the quantity of leaves and seeds that a plant produces per cob, hence establishing the yield potential (Wiredu *et al.*, 2010). CLB–CLB treated plots recorded significantly low grain yield among the fertilization regimes which could be due to deficiency of important nutrients including N, P and K at the initial stages of growth that played a major role in the growth and development of the plants. The result is confirmed by Abdulai (2023) who reported that among the fertilization regimes used for the study CLB-CLB produced significantly low grain yield. This could further be attributed to low concentration of macronutrients such as N, P and K in CLB-CLB fertilizer formulations (Abdulai, 2023). The study confirmed the role of nitrogen and Sulphur fertilizers in increasing growth, development and yield in maize production. The supply of phosphorus could have also enhanced the yields by aiding in the production, and transport of sugars, protein and fat in the maize plant throughout its





life cycle. The findings corroborate Rahaman (2021) who reported highly significant effect on maize grain yield due to the application of fertilization regimes. It also agrees with Salifu (2022) who revealed that the fertilization regimes significantly affected maize yield and that control and CLB-CLB recorded the lowest grain yield. The low maize grain yield produced by the control could be attributed to inadequate nutrition to the plants as there was no fertilizer application to the control plots. This is similar to Arthur (2014) who reported that grain yield among plants treated with fertilizer were significantly higher than those in the untreated fertilizer plots.

The 100 seed weight of maize plants was affected by the fertilization regimes. There was no significant variation among the fertilization regimes, though the highest 100 seed weight was witnessed in ACT-NIT (23.67g) followed by T15-URE (22g), T15-SOA (21.67g) and T15-SUL (21.67g). This could have been as a result of the nutritional advantages provided by the inclusion of N, P, K, soluble Ca and Boron. Ahmad and Kanwal (2014) indicated that Boron can maximize Ca uptake and this could have given ACT-NIT and T15-URE, especially ACT-NIT an added advantage over the other treatments for enhanced yield. Moreover, it could also be attributed to the fact that the nutrients regimes used for the study had significant impact on grain filling and grain mass. The result is confirmed by Kugbe *et al.*, (2019) who reported that grain mass was significantly affected by the chemical fertilization regime. However, the findings of this study contradict Abdulai *et al.*, (2020) which showed that the nutrient regimes used for the study may not significantly impact grain filling and grain mass of maize.

5.3 Profitability of fertilization in *C. mbila* management in maize

The benefit-cost ratio was measured as a measure of a treatment's relative performance. If a treatment's benefit-cost ratio (BCR) is more than one, it is considered economically viable (Aziz *et al.*, 2012). As shown from the partial budget analysis, it will be more

profitable managing *C. mbila* using the fertilization regimes compare to unfertilized field. All fertilization regimes yielded more profit than unfertilized control except CLB-CLB. The highest profit and benefit-cost ratio obtained from ACT-URE (GH¢ 19, 252 kg/ha) among the fertilizer treatments may be due to its high yielding and ability to compensate for pest damage in maize production. However, CLB-CLB (GH¢ -318) with benefit-cost ratio (-0.1) and control (GH¢ -446) with benefit-cost ratio (-0.2) recorded the lowest profit and benefit-cost ratio. This could be attributed to inadequate nutrient supply as reported by Abdulai (2023). The findings of this study also correspond to Morales *et al.*, (2001) and Mesbah *et al.*, (2002) who revealed that plants with adequate nutrition are healthier, more resilient, and more adapted to withstand pest harm than those with inadequate nutrition.



CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The following conclusions were drawn from the study's findings:

On abundance of *Cicadulina mbila*, there was significant variation in the fertilization regimes. Control recorded significantly the highest number of *C. mbila* abundance compare to fertilization regimes. Among the fertilization regimes, T15-SUL and ACT-SOA obtained statistically higher *C. mbila* abundance whilst CLB-CLB recorded the least.

There was some level of resistance offered to maize plants against *C. mbila* infestations by the fertilization regimes. Among the fertilization regimes, ACT-SOA, T15-SUL, ACT-SUL and T15-SOA obtained higher damage incidence which is statistically similar to that of control. The lower damage incidence was recorded by T15-URE treated plots. However, there was no significant variation in damage incidence at 8WAP.

On streak disease development, T15-SOA recorded the highest streak disease incidence followed by T15-SUL and ACT-SUL. Their performance was statistically similar to ACT-NIT, ACT-SOA and control. The least disease incidence was obtained from ACT-URE which is similar to CLB-CLB, T15-URE and T15-NIT. Also, there was no significant variation in streak disease incidence among the fertilization regimes at 3WAP and 4WAP.

On maize grain yield, ACT-URE, ACT-NIT and T15-URE gave higher yields despite the abundance of *C.mbila* on those fields. Again, fertilization regimes with ACT-NIT, T15-URE, T15-SOA and T15-SUL showed higher seed quality despite abundance of *C.mbila* in those treatments.



The partial budget analysis demonstrated a positive value of profit increment for all the fertilization regimes compared to control. Among the fertilization regimes, CLB-CLB yielded less profit and benefit-cost ratio, whilst the highest profit and benefit-cost ratio was obtained from ACT-URE. The second and third profit was recorded from ACT-NIT and T15-URE respectively. The lowest profit and benefit-cost ratio was obtained from the control.

6.2 RECOMMENDATIONS

The findings of the research led to the following recommendations being made:

- For better yield and maximum profitability per hectare, ACT-URE or ACT-NIT is most recommended.
- It is recommended that, in the absence of ACT-URE or ACT-NIT, farmers can substitute it with T15-URE or T15-NIT better management of *C. mbila*, better yields as well as high profitability.
- Sole application of crop-lift Bio fertilizer as basal and top dressing is not recommended for maximum yield and profitability.
- The percentage composition of macro nutrients especially N, P, K in CLB biofertilizer should be reviewed upward to enhance its productivity.
- For further research work, multi-locational trial using the same fertilization regime can be conducted within the savanna ecology and the results compared.



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APPENDICES

Appendix 1: ANOVA for number of leaf hopper 3WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	145.867	72.933	7.43	
REP.*Units* stratum					
TREATMENT	9	190.300	21.144	2.15	0.079
Residual	18	176.800	9.822		
Total	29	512.967			

Appendix 2: ANOVA for number of leaf hopper 3WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.7784	1.3892	7.48	
REP.*Units* stratum					
TREATMENT	9	3.7183	0.4131	2.22	0.071
Residual	18	3.3441	0.1858		
Total	29	9.8408			

Appendix 3: ANOVA for number of leaf hopper 4WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
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REP stratum	2	96.200	48.100	13.16	
REP.*Units* stratum					
TREATMENT	9	344.300	38.256	10.47	<.001
Residual	18	65.800	3.656		
Total	29	506.300			

Appendix 4: ANOVA for number of leaf hopper 4WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.71997	0.85999	12.68	
REP.*Units* stratum					
TREATMENT	9	6.31293	0.70144	10.34	<.001
Residual	18	1.22073	0.06782		
Total	29	9.25363			

Appendix 5: ANOVA for number of leaf hopper 5WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	69.267	34.633	9.25	
REP.*Units* stratum					
TREATMENT	9	201.200	22.356	5.97	<.001
Residual	18	67.400	3.744		
Total	29	337.867			

Appendix 6: ANOVA for number of leaf hopper 5WAP transformed



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.90900	0.45450	9.47	
REP.*Units* stratum					
TREATMENT	9	2.79515	0.31057	6.47	<.001
Residual	18	0.86415	0.04801		
Total	29	4.56830			

Appendix 7: ANOVA for number of leaf hopper 6WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	43.467	21.733	8.92	
REP.*Units* stratum					
TREATMENT	9	200.833	22.315	9.16	<.001
Residual	18	43.867	2.437		
Total	29	288.167			

Appendix 8: ANOVA for number of leaf hopper 6WAP transformed.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.49163	0.24582	9.31	
REP.*Units* stratum					
TREATMENT	9	2.24821	0.24980	9.46	<.001
Residual	18	0.47515	0.02640		
Total	29	3.21499			

Appendix 9: ANOVA for number of leaf hopper 7WAP.



Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
REP stratum	2	14.600	7.300	2.98	
REP.*Units* stratum					
TREATMENT	9	257.633	28.626	11.69	<.001
Residual	18	44.067	2.448		
Total	29	316.300			

Appendix 10: ANOVA for number of leaf hopper 7WAP transformed.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.14205	0.07103	2.92	
REP.*Units* stratum					
TREATMENT	9	2.55382	0.28376	11.68	<.001
Residual	18	0.43728	0.02429		
Total	29	3.13316			

Appendix 11: ANOVA for number of leaf hopper 8WAP.

Source of variation	d.f.	s.s	m.s	v.r.	F pr.
REP stratum	2	68.267	34.133	6.29	
REP.*Units* stratum					
TREATMENT	9	85.367	9.485	1.75	0.150
Residual	18	97.733	5.430		
Total	29	251.367			

Appendix 12: ANOVA for number of leaf hopper 8WAP transformed.



Source of variation	d.f	s.s.	m.s	v.r.	F pr.
REP stratum	2	1.5374	0.7687	6.22	
REP.*Units* stratum					
TREATMENT	9	1.9373	0.2153	1.74	0.151
Residual	18	2.2252	0.1236		
Total	29	5.7000			

Appendix 13: ANOVA for total number of leaf hopper transformation.

Source of variation	d.f.	s.s.	m.s.	v.r	F pr.
REP stratum	2	5.5125	2.7563	16.18	
REP.*Units* stratum					
TREATMENT	9	14.3494	1.5944	9.36	<.001
Residual	18	3.0660	0.1703		
Total	29	22.9280			

Appendix 14: ANOVA for feeding symptom 3WAP.

Source of variation	d.f.	s.s	m.s.	v.r.	F pr.
REP stratum	2	54.067	27.033	3.43	
REP.*Units* stratum					
TREATMENT	9	213.367	23.707	3.01	0.022
Residual	18	141.933	7.885		
Total	29	409.367			

Appendix 15: ANOVA for feeding symptom 3WAP transformed.



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.8320	0.4160	3.29	
REP.*Units* stratum					
TREATMENT	9	3.4183	0.3798	3.00	0.023
Residual	18	2.2767	0.1265		
Total	29	6.5270			

Appendix 16: ANOVA for feeding symptom 4WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	24.800	12.400	2.87	
REP.*Units* stratum					
TREATMENT	9	309.633	34.404	7.95	<.001
Residual	18	77.867	4.326		
Total	29	412.300			

Appendix 17: ANOVA for feeding symptom 4WAP transformed.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.39635	0.19818	3.20	
REP.*Units* stratum					
TREATMENT	9	4.38706	0.48745	7.88	<.001
Residual	18	1.11383	0.06188		
Total	29	5.89724			

Appendix 18: ANOVA for feeding symptom 5WAP



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	29.067	14.533	2.02	
REP.*Units* stratum					
TREATMENT	9	320.800	35.644	4.95	0.002
Residual	18	129.600	7.200		
Total	29	479.467			

Appendix 19: ANOVA for feeding symptom 5WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.33432	0.16716	2.02	
REP.*Units* stratum					
TREATMENT	9	3.87929	0.43103	5.21	0.001
Residual	18	1.48869	0.08270		
Total	29	5.70229			

Appendix 20: ANOVA for feeding symptom 6WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	24.800	12.400	1.65	
REP.*Units* stratum					
TREATMENT	9	368.300	40.922	5.45	0.001
Residual	18	135.200	7.511		
Total	29	528.300			

Appendix 21: ANOVA for feeding symptom 6WAP transformed



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.24293	0.12147	1.58	
REP.*Units* stratum					
TREATMENT	9	3.87635	0.43071	5.61	<.001
Residual	18	1.38149	0.07675		
Total	29	5.50077			

Appendix 22: ANOVA for feeding symptom 7WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	35.267	17.633	2.85	
REP.*Units* stratum					
TREATMENT	9	470.300	52.256	8.44	<.001
Residual	18	111.400	6.189		
Total	29	616.967			

Appendix 23: ANOVA for feeding symptom 7WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.34961	0.17480	3.03	
REP.*Units* stratum					
TREATMENT	9	4.41980	0.49109	8.51	<.001
Residual	18	1.03819	0.05768		
Total	29	5.80760			

Appendix 24: ANOVA for feeding symptom 8WAP.



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	110.60	55.30	1.49	
REP.*Units* stratum					
TREATMENT	9	515.37	57.26	1.55	0.206
Residual	18	666.73	37.04		
Total	29	1292.70			

Appendix 25: ANOVA for feeding symptom 8WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.4246	0.7123	1.61	
REP.*Units* stratum					
TREATMENT	9	5.5398	0.6155	1.39	0.261
Residual	18	7.9435	0.4413		
Total	29	14.9079			

Appendix 26: ANOVA for feeding symptom average transformation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.39604	0.19802	2.74	
REP.*Units* stratum					
TREATMENT	9	3.39020	0.37669	5.21	0.001
Residual	18	1.30056	0.07225		
Total	29	5.08680			

Appendix 27: ANOVA for disease symptom 3WAP



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	98.467	49.233	6.41	
REP.*Units* stratum					
TREATMENT	9	102.700	11.411	1.49	0.226
Residual	18	138.200	7.678		
Total	29	339.367			

Appendix 28: ANOVA for disease symptom 3WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	2.6229	1.3115	6.65	
REP.*Units* stratum					
TREATMENT	9	2.5306	0.2812	1.43	0.249
Residual	18	3.5487	0.1971		
Total	29	8.7022			

Appendix 29: ANOVA for disease symptom 4WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	186.667	93.333	14.57	
REP.*Units* stratum					
TREATMENT	9	98.167	10.907	1.70	0.161
Residual	18	115.333	6.407		
Total	29	400.167			

Appendix 30: ANOVA for disease symptom 4WAP transformed



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	7.5473	3.7736	14.23	
REP.*Units* stratum					
TREATMENT	9	4.0020	0.4447	1.68	0.168
Residual	18	4.7746	0.2653		
Total	29	16.3238			

Appendix 31: ANOVA for disease symptom 5WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	88.267	44.133	14.43	
REP.*Units* stratum					
TREATMENT	9	196.133	21.793	7.12	<.001
Residual	18	55.067	3.059		
Total	29	339.467			

Appendix 32: ANOVA for disease symptom 5WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.70871	0.85435	14.97	
REP.*Units* stratum					
TREATMENT	9	3.84966	0.42774	7.50	<.001
Residual	18	1.02707	0.05706		
Total	29	6.58544			

Appendix 33: ANOVA for disease symptom 6WAP



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	21.667	10.833	2.29	
REP.*Units* stratum					
TREATMENT	9	225.200	25.022	5.30	0.001
Residual	18	85.000	4.722		
Total	29	331.867			

Appendix 34: ANOVA for disease symptom 6WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.29481	0.14741	2.22	
REP.*Units* stratum					
TREATMENT	9	3.54239	0.39360	5.92	<.001
Residual	18	1.19630	0.06646		
Total	29	5.03350			

Appendix 35: ANOVA for disease symptom 7WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	40.200	20.100	4.57	
REP.*Units* stratum					
TREATMENT	9	353.467	39.274	8.93	<.001
Residual	18	79.133	4.396		
Total	29	472.800			

Appendix 36: ANOVA for disease symptom 7WAP transformed



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.44424	0.22212	4.72	
REP.*Units* stratum					
TREATMENT	9	4.65288	0.51699	10.99	<.001
Residual	18	0.84656	0.04703		
Total	29	5.94369			

Appendix 37: ANOVA for disease symptom 8WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	58.200	29.100	3.32	
REP.*Units* stratum					
TREATMENT	9	286.300	31.811	3.63	0.010
Residual	18	157.800	8.767		
Total	29	502.300			

Appendix 38: ANOVA for disease symptom 8WAP transformed

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.52399	0.26199	3.31	
REP.*Units* stratum					
TREATMENT	9	2.62969	0.29219	3.69	0.009
Residual	18	1.42683	0.07927		
Total	29	4.58051			

Appendix 39: ANOVA for disease symptom average transformation



Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.02274	0.51137	8.95	
REP.*Units* stratum					
TREATMENT	9	2.44278	0.27142	4.75	0.002
Residual	18	1.02883	0.05716		
Total	29	4.49435			

Appendix 40: ANOVA for effect of fertilization regimes on maize grain yield

Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
REP stratum	2	280452.	140226.	0.37	
REP.*Units* stratum					
TREATMENT	9	23405793.	2600644.	6.88	<.001
Residual	18	6803012.	377945.		
Total	29	30489257.			

Appendix 41 : ANOVA for effect of fertilization regimes on 100 seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.200	2.100	1.04	
REP.*Units* stratum					
TREATMENT	9	51.333	5.704	2.82	0.029
Residual	18	36.467	2.026		
Total	29	92.000			



