EVALUATING THE EFFECTIVENESS OF APEX10 AS A PLANT GROWTH BIO-STIMULANT AND SOIL CONDITIONER IN MAIZE PRODUCTION

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ABSTRACT

Maize (*Zea mays)* is a staple food cereal crop in Zimbabwe which is widely grown in almost all the farming regions of Zimbabwe. Despite the advancement in the use of many farming products that increase yield, maize output has declined drastically in our Zimbabwe. A study was carried out at Holland Farm in Mvurwi to evaluate the beneficial use of bio-stimulants and soil conditioners in maize production focusing on growth in terms of stem height, belowground and above ground biomass and final yield of maize. The study employed Apex 10 which is a plant bio-stimulant and soil conditioner in maize. The experiment utilized a 2 × 4 factorial treatment structure, laid in a randomized complete block design (RCBD) with three replications and slope was used as the blocking a factor. The bio-stimulant was applied in four different rates which are 3*l* ha^{-1} (30 ml per plant 100%), 2.25*l* ha^{-1} (22.5 ml per plant 75%), 1.5*l* ha^{-1} (15mls per plant.50%) and 0*l* ha^{-1} (0 ml per plant 0%) and two different maize varieties that is SC 659 and ZS265 were used to evaluate the effects of Apex 10. The data collected during the experiment was subjected to statistical analysis of variance using R software (version 4.5.0). statistical package at 5% level of significance. The results showed that an increase in the bio-stimulants and soil conditioner concentration to 3l h^{-1} (100%) showed higher performance on all parameters with the highest yield, stem height, below and above ground biomass. The reduction in application rate of Apex 10 resulted in reduction in the above stated parameters with the control treatment with 0l ha^{-1} performed poorly on all the growth and yield parameters tested. The application of bio-stimulant and soil conditioner can therefore be used to increase plant growth in stem height, below and above plant biomass and the yield of maize at 3l ha^{-1} to achieve the highest yield. Apex 10 should be integrated with high performing varieties such as SC659 leads to even greater returns.

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I Alexio Pukuta, (B211801B) attest that this research report is entirely my own, independent work, and I have fully acknowledged all of the references and mentioned sources that I used. This report has never been turned in for a test or research.

Student's Signature: Date: 14/09/2025

SUPERVISOR Mr J Chitamba

I have supervised the research project for the above mentioned student and I am convinced that the research can be submitted.

Signature Date 03/07/2025

Departmental Chairperson

Mr Mutsengi Signature Date

DEDICATION

I dedicate this research to my beloved father Mr. Pukuta and my cherished family, whose unwavering love, support and encouragement have been a foundation through this journey. I also extend my heartfelt gratitude to my supervisor, Mr. Chitamba for his invaluable guidance and mentorship which have shaped this work. Above all I dedicate this endeavor to God whose grace and strength have sustained me and made this achievement possible.

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Contents

List of tables

List of figures

CHAPTER 1: INTRODUCTION

1.1 Background

Maize (*Zea mays L.*) is a monocotyledonous plant that originated from Mexico and spread to southern Africa through trade (Matsuoka *et al*., 2002).Globally maize is regarded as one of the most grown crops since it's used in industries for feed and mealie-meal production. Maize is Zimbabwe's main cereal crop and is grown across all the ten provinces due to its high value as a staple food, as well as its stover demand as animal feed, fuel and for construction purposes.It is the most consumed crop in the rural areas as it takes the bigger proportion of part of their meals (Lunduka *et al*., 2019). Maize is the major source of carbohydrates and has multiple use in Zimbabwe and approximately about 88% of the maize produced is used as food as green mealies or as dried maize processed either to mealie-meal or other products (Sardana *et al*., 2017). This places maize on the top of the ranking list of cereal crop production in Zimbabwe as it is associated with multiple uses. It is also a strategic commodity in Zimbabwe in which the government through GMB is the main funder in the production level and also the buyer.It is also used in the agro industries to manufacture cooking oil, mealie-meal and feeds (Lunduka *et al*., 2019; Wen *et al*., 2016). Annually the country consumes an estimated amount of 2.1 million metric tonnes leading to 14 percent contribution to the country's agricultural gross domestic product.

The current production of maize in Zimbabwe has declined far below the country's maize production potential. According to ZIMSTATS (2024), the average annual yield for 2023-24 is 0.84 MT ha^{-1}. Despite that, maize remains the most grown cereal crop in Zimbabwe, the yield reduction is as a result of a combination of factors which range from poor farming practices, changes in climatic conditions, drought due to El nino, lack of inputs and lack of knowledge on the management of soil fertility (Mugiyo *et al*., 2023). The growth and yield of maize can be low if its grown under poor crop management as this will affect plant nutrient use efficiency and water use efficiency (Mutsvanga *et al*., 2022).

Farmers have been growing drought tolerant varieties and also making use of bio-stimulants such as omniboost, biocel and cosmorot. The use of an ideal crop variety and bio-stimulant and soil conditioner enhances higher nutrient and water use efficiency by the plant and ensures that the soil environment becomes favourable in terms of pH levels and microorganisms activities that symbiotically interact with plants (Ocwa *et al*., 2024). Apex 10 which constitute of peat, humic and fulvic acid plays a crucial role in modifying the soil environment hence making it favourable for the crop growth.

Small-scale farmers who are under resourced have been making use of other plant bio-stimulant and soil conditioners but are failing obtain expected yield per hectare (Canellas *et al*., 2025). This is attributed to factors such as soil nutrient depletion, inadequate plant hormones to stimulate plant growth, unpredictable rainfall patterns, and limited resources for adopting advanced agricultural techniques (Szőke *et al*., 2021).

For the past, farmers have been depending on organic fertilizers from manure and crop residues, to augment soil fertility and increase crop output (Mtangadura *et al*., 2017). However the accessibility of these natural resources is frequently restricted, and their utilisation alone may not be adequate to fulfil the nutrient requirements of maize. This has resulted in several farmers to opt for using artificial fertilisers such as AN and Compound D, to improve crop production however they can be expensive and they have the potential to do harm to the environment if not used carefully (Pasley *et al*., 2019).

For the past few years, there has been an increasing attention in investigating an effective strategy that involves utilising bio-stimulants to counter the effects of climate change and erratic rainfall to optimise crop growth and productivity, to complement synthetic and organic fertilisers (Achiri *et al*., 2025).

APEX10, which is a unique combination of humic acid, fulvic acid, micro nutrients and peat extracts has demonstrated encouraging results in enhancing crop production and soil health across diverse agricultural environments (Vujinović *et al*., 2020). However, the extent to which it improves crop yield in various soil fertility levels in Maize (Zea Mays) has not been thoroughly investigated, particularly in region two in Mazowe district, places such as Mvurwi, Zimbabwe.

This study aims to evaluate the impact of APEX10 on maize in fertilized conditions. The goal is to gain valuable knowledge about the potential of this innovative product as a sustainable solution for improving maize production in farming systems to counter the effects of climate change with limited resources. The results of this study have the potential to aid in the creation of successful approaches for enhancing food security, decreasing expenses related to inputs, and advocating for ecologically sustainable farming methods among small-scale farmers in Zimbabwe and similar dry locations.

1.2 Problem statement

A lot of smallholder and commercial farmers in Zimbabwe are producing lower yields of maize far below the expected yield output due to challenges such as soil degradation, nutrient deficiencies, and droughts as a result of climate change and unavailability of enough capital to boost their production (Gotosa *et al*., 2019).

On average farmers in Zimbabwe are yielding 0.84 metric tonnes per hectare of maize in the country as compared to doubled yielding or more by other farmers in our region and globally (Petrovic and Sherland, 2023). The use of commercial fertilizers alone has proven not to be sustainable as farmers are still failing to produce high yields in maize production and also experiencing yield decline even with the use of improved hybrid varieties (Pasley *et al*., 2019). The use of APEX 10 that is a soil conditioner and a bio-stimulant with inorganic fertilizers is not very common with most farmers due to the absence of adequate knowledge on the use of inorganic products to overcome the adverse effects of climate change. Whilst several companies have been producing soil conditioners and bio-stimulants internationally, little is known about the use of these soil conditioners and bio-stimulants and the specific quantities to apply in Zimbabwe (Moyo and Masowa, 2024) especially for maize production. The use of APEX 10 has not been fully investigated on maize; this includes the application rates and method of application and time of application so as to ensure that maize production increases. Hence, it is necessary and very important to carry out this research to find out the application rate, time and benefits of Apex10 in maize growth and yield.

1.3 Justification

The evaluation of the effectiveness of APEX10 as a plant growth bio-stimulant and soil conditioner becomes pivotal as the production of maize has declined in our country. APEX10, having been derived from the plant-based sources, it is anticipated to alleviate plant growth stressors through its mechanism of enhancing soil fertility and plant health. Bio-stimulants, such as APEX10, are known to boost plant growth and improve yield through mechanisms such as enhanced nutrient uptake and physiological transformations within plants (Li *et al*., 2022). For instance, studies have shown that the application of a plant-based bio-stimulant resulted in significantly higher yields in tomato plants, with treated plants yielding up to 111.67% more than untreated controls (Francesca *et al*., 2020).

This research will help farmers to increase their yield output and enhances cost effectiveness especially to small scale farmers who are resource constrained. In Zimbabwe, where climate unpredictability is a threat to maize production, the use of bio-stimulants have the potential to provide the resilience needed by the crop. This will also allow the agricultural companies to formulate and produce bio stimulant products that will perform much better in crop production.

1.4.0 OBJECTIVES

1.4.1 Main objective

To evaluate the effectiveness of Apex 10 on the growth and yield of maize.

1.4.2 Specific objectives.

1. To assess the effect of Apex10 on the growth of two maize varieties.

2. To assess the effect of Apex10 on the yield of two maize varieties.

3. To evaluate the effect of Apex 10 on the maize above and below ground biomass.

1.4.3 Hypotheses (H_1)

1. Apex10 has significant effect on growth of two maize varieties.
2. Apex10 has significant effect on the growth of two maize varieties
3. Apex10 has significant effect on the below and above-ground biomass of two maize varieties.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview of maize production

Maize (*Zea mays* L.) is an important cereal crop globally, serving as a staple food for over 900 million people, mainly in the developing countries (Mafongoya P,. et al., 2011). It can be used for human consumption, livestock feed, and industrial raw material for products like ethanol and starch. Global maize production has been increasing over the past decades, due to advancements in agricultural technology, improved varieties, and increased cultivation areas (FAOSTAT, 2023). However, climate change, soil degradation, and pest outbreaks continue to threaten its productivity, especially in Zimbabwe which heavily relies on rain-fed agriculture (Petrovic,S,. and Sherland M 2023).

2.2.1 Current status and trends in maize farming

Maize farming in Zimbabwe is largely dominated by smallholder farmers who contribute one third of the total agricultural output (Muhinji,T,. etal, 2008). Maize output has been reduced in Zimbabwe due to climate change and climate variability, economic policies that are not matching with what the farmers need and limited access to agricultural inputs (Jayne et al., 2016). The government has intervened through government initiatives, which include the Presidential input scheme and the Command Agriculture to increase maize yields. Despite all that the maize output remained low due to heavy reliance by farmers on conventional farming methods and having limited availability of modern technologies being used in agriculture (Sikhumulo and Mjimba, 2020).The interest in smart agriculture and drought tolerant maize varieties is increasing in Zimbabwe to copy up with the erratic and unreliable rainfall that is being received throughut the whole country (Chiputwa et al., 2017). This shows an increasing awareness of the need for sustainabl agricultural practices to increase maize yields despite having many environmental challenges caused by climate change.

2.2.2 Challenges affecting maize yield and soil health

Maize, is a very important crop in Zimbabwe which has been adversely affected in its production due to climate, climate variability and some social and economic contraintsl. For example, in the 2023-24 farming season inadequate rainfall was received which was poorly distributed, this resulted in maize failing to reach maturity as most of the maize crops they were at tasseling stage when the rains stopped resulting in disturbing the development of the grain and grain filling (Mazuruse, 2025).

Food insecurity was experienced by about 90% of the people in Zimbabwe as maize is the staple food for Zimbabwe which is also the most consumed cereal (Lunduka et al., 2019; Muzhingi et al., 2008). Unreliable weather patterns they have affected negatively the planting dates and time of harvesting and physiological processes of maize (Liu et al., 2021; Maviza and Ahmed, 2021). Small holder farmers have been mostly affected by this due to financial constraints to supplement irrigation and procure some drought tolerant maize varieties (Makate and Makate, 2019). Furthermore, the prices of maize are very discouraging to farmers and insufficient suitable farm infrastructure, further increases yield decline of maize. (Tibugari et al., 2019). The changes in climate has caused mutations and evolution of new pests like Prostephanus truncates. Its emergence resulted in about 40% storage losses, adds to these difficulties (Muatinte et al., 2019).

2.2.3 Importance of maize in Zimbabwe's food security and economy

The staple crop of Zimbabwe is maize, which is mostly grown by both commercial and small holder farmers in Zimbabwe to ensure that there is food security and economic stability due to the returns after some sales. (Lunduka et al., 2019). The production of maize contributes a bigger proportion to Zimbabwes GDP in agriculture. This makes maize a very important crop for both rural and urban economics (Mafongoya et al., 2016). Increasing of maize production in Zimbabwe through employing better farming practices and techniques, use of relevant and adequate inputs and inclusion of soil conditioners can result in improving yields and empowers people economically (Ocwa et al., 2023). Increasing the production of maize result in further increasing the employment opportunities for people across the whole agricultural value chain which result in having economic growth and reduction poverty (Mugiyo et al., 2023). This crop has been one of the major exported crops by our nation for the past years and the reduction in maize yields in our nation to depend on foreign aid and importation of maize from countries such as Zambia and South Africa (Odunze, 2019). According to Maviza and Ahmed, 2021 the historical data reflects that the production of maize and maize output has declined in Zimbabwe due to socioeconomic factors and climate change which has resulted in having highly unreliable rainfall.

2.3 Soil Health and Fertility Management

2.3.1 Role of soil in crop productivity

Soil is the natural medium in which the crop grows and it provides anchorage and supply nutrient and water to crops. The soil must have proportion of inorganic matter, organic matter and the biotic component which constitute of microorganism to ensure adequate nutrient availability to plants due to nutrient mineralization and also having a symbiotic interaction with the crop to increase the yield of the crop and tolerance to some environmental stresses. (Bünemann et al., 2018). Soil organic matter plays a crucial role in improving water retention and nutrient availability, critical for crops in Zimbabwe’s semi-arid regions where rainfall is erratic (Nyagumbo et al., 2019). The soil’s physical structure which are soil porosity and soil texture, they facilitates root penetration and water infiltration which directly impacts crop performance. Studies that have been conducted in sub-Saharan Africa show that soils rich in secondary and micronutrients, such as calcium and zinc, showed a relationship with higher maize yields under smallholder systems (Mutambanengwe et al., 2021). Degraded soils they mostly have low fertility which reduce crop productivity hence increasing food insecurity. Soil biodiversity, including microbial communities that support nutrient cycling and suppression of diseases, enhancing long-term productivity (Lal, 2020). In Zimbabwe the health of the soil is pivotal for most of the crops including staple crops like maize and sorghum as yields can be reduced by up to 50% (Mapfumo et al., 2013). Effective soil management practices which include integrated soil fertility management that combine organic and inorganic inputs to optimize soil health and sustain crop productivity, particularly in resource-limited settings (Vanlauwe et al., 2015). Maintaining soil health remains essential for agricultural sustainability and food security in Zimbabwe.

2.3.2 Common soil degradation issues in Zimbabwe

Soil degradation in Zimbabwe is associated with nutrient depletion and soil erosion. This increase the challenges to agricultural productivity. Nutrient depletion is a result of continuous cropping without adequate replenishment of nutrients. This is increased by low fertilizer use among smallholder farmers due to cost and availability constraints (Mugwira et al., 2017). Studies that have been conducted indicated that Zimbabwean soils lose approximately 50–100 kg of nitrogen per hectare annually, depleting soil fertility and drastically reducing crop yields (Mapfumo et al., 2013). Soil erosion mainly being caused by heavy rainfall, deforestation, and poor land management, removes and transports nutrient-rich topsoil increasing the degradion of arable land. Erosion rates are in Zimbabweas communal areas they can reach 20–30 tons per hectare per year, mostly in sloping regions (Nyagumbo et al., 2019). This loss of soil through erosion damages the soil structure and reduces the water-holding capacity which in turn increases vulnerability of crops to drought. Additionally, soil acidification and organic matter decline are prevalent due to poor agricultural practices such as monoculture and limited use of organic fertilizers (Mutambanengwe et al., 2021). The land degradation issues are compounded by climate change, which increases rainfall variability and erosion risks in most parts of Zimbabwe (Lal, 2020). Smallholder farmers, who form the backbone of Zimbabwe's agriculture, often lack access to technology, skills, and knowledge needed to combat land degradation, trapping them in a cycle of declining crop yields (Vanlauwe et al., 2015). These issues should be solved through the use of conservation farming and adequate access to fertilizers so as to improve soil fertility and enhance sustainable agricultural farming practices in Zimbabwe.

2.3.3 Conventional and alternative soil management practices

The management of soil in Zimbabwe heavily relies on synthetic fertilizers and tillage to improve yield. Employing of these methods result in loss of soil fertility and heavily degrade the soil with time. Primary and secondary tillage they result in damaging the soil structure especially when practiced when the soil is too wet or too dry. Tillage also increases the susceptibility of the soil to erosion which can result in carrying away the fertile and organic rich top soil hence loss of soil fertility. The overuse of synthetic fertilizers also results in increasing the acidification of the soil due to hydrogen ion accumulation (Mugwira et al., 2017). Correspondingly the use of other alternative soil management practices by farmers such as practicing of conservation agriculture and integrated soil fertility management they result in solving problems associated with soil degradation hence sustainable agriculture. Conservation agriculture it's a set of practices that are employed by farmers to ensure that the soil is properly used and managed. It includes practices such as reduced or minimal tillage, use of crop rotation, and cover cropping hence there is reduction in soil erosion and enhances soil organic matter accumulation in the soil which in turn increases water retention and nutrient availability to crops (Nyagumbo et al., 2019). ISFM involves the use of organic input which can be manure and compost with minimal use of synthetically manufactured fertilizers to address nutrient reduction whilst prioritizing the biodiversity of the soil (Vanlauwe et al., 2015). In Zimbabwe, ISFM has increased maize yields by 20–30% mostly in smallholder systems (Mapfumo et al., 2013). Alternative practices that include contour farming and agroforestry they also play a critical role in mitigating soil erosion and enhancing soil fertility as it integrates trees that have the ability to fix nitrogen (Mutambanengwe et al., 2021). However the adoption of alternative practices encounter barriers such as labor demands and limited access to organic inputs (Lal, 2020). Recent studies suggest that the combination of conventional and alternative soil fertility management approaches, such as precision fertilizer application with CA, optimizes soil health and productivity in Zimbabwe's diverse agroecological zones (Nyagumbo et al., 2019). Increasing the scale of these practices requires a set of measures that include farmer education, policy support, and access to resources to ensure long-term soil sustainability.

2.4 Plant Growth Bio-stimulants

2.4.1 Definition and classification of bio-stimulants

Plant growth bio-stimulants are defined as natural substances or microorganisms that are applied to plants or soil so as to enhance plant growth by improving nutrient uptake, crop resilience to abiotic stresses, and the overall crop quality (Caradonia et al., 2019). These substances have different types based on their origins and mechanisms of action - usually including humic acids, protein hydrolysates, seaweed extracts, and beneficial microorganisms (for example, arbuscular mycorrhizal fungi and N-fixing bacteria) (Sun and Shahrajabian, 2023).

2.4.2 Mechanisms of action

Bio-stimulants are substances or microorganisms that are applied to plants or soils to play a critical role in enhancing the growth, nutrient uptake, and stress tolerance without serving as primary nutrient sources for the plant or pesticides (Du Jardin, 2015). Mechanisms of action of bio-stimulants differs, reflecting their different compositions, which include humic substances, seaweed extracts, amino acids, and some microbial inoculants. The key mechanism is the enhancement and increase of nutrient uptake. Humic substances they stimulate root growth by promoting cell division and elongation, thereby increasing root surface area for nutrient absorption (Canellas et al., 2015). Seaweed extracts, rich in phytohormones like auxins and cytokinins, regulate cell division, promote shoot growth, and enhance root elongation, improving plant structure (Khan et al., 2009).Abiotic stresses in plants can also be reduced by bio-stimulants through some physiological and molecular modification mechanisms. The products of these physiological and molecular mechanisms such as amino acids and protein hydrolysates they act as osmoprotectants, resulting in maintaining cellular turgor of the plant under drought conditions and salinity (Calvo et al., 2014). Upregulation of antioxidant enzyme genes such as catalase is done hence neutralizing reactive oxygen species (ROS) in the plant during drought or stress periods (Ertani et al., 2013). Microbial bio-stimulants they increasing soil nutrient availability as microorganism such as Pseudomonas and Baccillus, they release pytohormones such as Indole-3-3acetic acid in the soil (Vessey, 2003). Hormonal signalling pathways are also enhanced by bio-stimulants, they include jasmonic acid and absciscic acid through regulation of stress responses and growth. (Yakhin et al., 2017). Notably, seaweed extracts activate jasmonate pathways, this result in the strengthening plant defense system against biotic stress (Sharma et al., 2014). Soil microbiome modulation is also a very crucial mechanism. The humic substances and microbial inoculants they cause an increase in the biodiversity and populations of microbes promoting and enhancing symbiotic interactions which increases nutrient availability to plants and high rates of nutrient cycling resulting in a health plant (Nardi et al., 2016). The above effects they mostly depend on the type of the bio-stimulant, species of the plant and environmental conditions which affects efficiency and determines the complexity to adhere to when applying (Bulgari et al., 2019).

2.4.3 Benefits of bio-stimulants in crop production

Previous researches have indicated that the use of bio-stimulants is associated with a lot of soil health benefits. These bio-stimulants they can be extracted from sea weeds or humic acids. They impart chemical and physical benefits to soil hence increasing orgaic matter content of the soil and availability of minor nutrients. (A.S. et al., 2023)

The use of bio-stimulants results in addressing the biggest threats of crop production such as the effects of climate change to plants and depletion of soil nutrients. Crop yield and qulity is also improved which result in ensuring sustainable farming. Seaweed extracts and protein hydrolysates they promote an increase in the size of fruits and they regulate control sugar levels and result in increasing of shelf life in crops like strawberries and tomatoes (Colla et al., 2017). For example, the use of humic acid in wheat resulted in increasing the grain yield by 10-20% this is attributed to an increase in photosynthesis and nutrient uptake and assimilation which resulted in increased yield potential (Dobbss et al., 2010).

Bio-stimulant they increase the capability of the plant to tolerate and resist abitic stresses such as salinity, drought and extremely high temperatures. Bio-stimulants that are amino acid based they result in increasing the plant water use effiency and hydraulic conductance which also gives a higher chance to obtain higher yields despite having droughts and stresses (Calvo et al., 2014). For example, the inoculation of maize by Azospirillum brasilense in a drought condition resulted in increasing the maize output by 15% (García et al., 2017).Bio-stimulants they also have the same effects of reducing the impact of salinity to the crop which causes a decline in the uptake of sodium and increase the accumulation of potassium (Van Oosten et al., 2017).

Use of biostimulants is likely to be the solution to most farmers as biostimulants offer a key to sustainable agriculture (Berruti et al., 2016. Increasing reliance on biostimulants especially those that are from microbes such as arbiscular mycorrhzial fungi in improved uptake of phosphorous uptake by plants which can cause a decrease in the uptake of fertilizer by the plant with no yield loss occurring (Savci, 2012) .Enhancement of soil fertility and increase in organic matter in the soil due to higher nutrient cycling rates is associated with microbe bio-stimulants which results in long term sustainability of crop production due to long-term fertility(Nardi et al., 2016).

Moreover, bio-stimulants they increase the plants ability to resist biotic stresses. This is due to the seaweed extracts and microbial inoculants that activate systemic resistance through defense-related genes, resulting in reduced attack of crops by diseases in crops like wheat and tomatoes (Sharma et al., 2014). The use of Trichoderma applications reduces fungal disease in tomatoes by 25% through increasing pathogenesis-related protein expression (Shoresh et al., 2010). Biostimulants they boost post-harvest quality which increases nutritional content and marketability of the produces.The use of amino acids to treat tomatoes increased the levels of lycopene,inceasing the nutritional value of tomatoes (Ertani et al., 2015).

However, the effectiveness of bio-stimulants depends on a variety of factors which include the application timing, dosage and environmental conditions in which its being applied. Inconsistence product composition and lack of disclosure due to lack of standardized regulations results in having a lot challenges (Bulgari et al., 2019). Still this keeps biostimulants the key to sustainable agriculture which improves yield, tolerance of the plant to stress and increases quality whilst minimizing the damage of the environment .

2.5 Soil Conditioners

2.5.1 Definition and types

Soil conditioners are materials added to soil to increase the soil physical, chemical, and biological properties , enhancing the suitability of the soil for farming(Lal, 2020). Soil conditioners they mostly focus on improving the structure of the soil, ensuring that microbial activities take place in the soil in a favourable environment and soil water retention. They are in two categories which are organic and inorganic types. Organic soil conditioners, they include compost, manure, biochar, and green manure and they are from the remains of plant and animal matter. Gypsum, lime, and synthetic polymers such as polyacrylamide are some of the examples and types of inorganic soil conditioners (Sojka et al., 2007). In sub-Saharan Africa (SSA) the more common soil conditioners are the organically manufactured ones. This is due to the abundant availability of plant matter that can be used to make organic conditioners and affordability.The use of inorganic conditioners is very limited though its mainly used in few cases mostly in big commercial farms to resolve the issue of soil sodicity (Abrol et al., 2016). Farmers choice of soil conditioner is based on a variety of factors such as soil type ,cost of the the soil conditioner, climate of the farming region and farming practices that the farmers uses (Vanlauwe et al., 2015).

2.5.2 Effects on soil structure, water retention, and microbial activity

Soil structure is influenced by soil conditioners. This determines the water retention and activities of microbes in the soil which are the key factors to ensure sustainable agriculture in Sub Saharan Africa. Organic amendments such as compost and biochar they improve soil aggregation through increasing organic matter levels which results in better soil porosity and reduced erosion (Lehmann et al., 2021). The application of biochar in sand soils increases the stability of soil aggregates which resulting in increased root growth as soil compaction is reduced (Busscher et al., 2010). The use of inorganic conditioners such as gypsum enhances soil structure in mostly in sodic soils by exchanging sodium for calcium, encouraging flocculation and reducing crusting (Qadir et al., 2018).

Soil conditioners they increase water retention especially in areas that receive erratic rainfall that reduces crop growth. The application of compost and biochar improves the water holding capacity of the soil optimizing pore distribution and the content of organic matter in the soil (Glaser et al., 2017). Research that was conducted in Kenya reviewed that that biochar increased soil moisture retention of the soil by up to 20%, hence improving maize yields during periods droughts (Kätterer et al., 2019). Synthetic polymers like polyacrylamide they reduce evaporation hence increased water retention and its use is very low in Sub Saharan Africa due to its exorbitant cost (Sojka et al., 2007).

Microbial activities are enhanced by soil conditioners as the soil conditioners they supply carbon to microorganisms which enhances moisture retention and pore spaces in the soil. Organic amendments such as manure and compost they play a very important role in supporting diverse microbial populations, improving nutrient cycling and soil fertility (Vanlauwe et al., 2015). Microbial growth is favoured by biochar as biochar provides a suitable porous place for the microbes with studies conducted from Ethiopia revealing that there was an increase in biomass after application of biochar (Lehmann et al., 2021). However, the overuse and over application of inorganic conditioners like lime alters microbial balance by changing soil pH, hence the need to be very cautious when applying it. (Abrol et al., 2016).

2.5.3 Examples relevant to sub-Saharan African agriculture.

In Sub-Saharan Africa soil conditioners, mostly the organic type are used by farmers to address problems of soil infertility. These soil conditioners are mostly from organic matter which is made from crop residues from maize stalks and groundnuts (Tumuhairwe et al., 2019).

The process of pyrolysis that is done on waste from crop residues such as maize cobs is increasing its popularity in SSA. Researches that were conducted in Zambia, on biochar revealed that biochar increased the pH of the soil that was acidic and resulted in having high yields of maize. (Cornelissen et al., 2018). Biochar last for many years in the soils making it a sustainable choice for carbon storage and soil health (Lehmann et al., 2021). The use of green manure, such as leguminous cover crops like Mucuna pruriens to increase soil fertility through increasing nitrogen availability to crops ,improve soil structure and controlling of weeds has been done in Malawi. (Ngwira et al., 2017).

Inorganic conditioners are less used but mostly they are used in few specific cases with conditioners such as gypsum being used. In South Africa, famers they used gypsum on sodic soils and this resulted in improved permeability and crop establishment (Qadir et al., 2018). However, smallholder farmers are deterred by its very high cost and availability. smallholders. The use of synthetic polymers is very rare despite its cost by smallholder farmers in SSA (Sojka et al., 2007).

2.6 Apex10: Composition and Claimed Benefits

2.6.1 Overview of Apex10's ingredients

The exact composition of Apex10 is not fully disclosed in publicly available literature, a common practice for proprietary agricultural products. According to the manufacturer's website, Apex10 is described as a bio-stimulant containing organic compounds designed to improve soil microbial activity and plant growth (Apex10 Agricultural Solutions, 2023). Industry trends suggest such products often include humic substances, fulvic acids, microbial inoculants, or plant-derived extracts (Calvo et al., 2014). These elements are recognized for improving nutrient accessibility and soil composition. However, without precise details on Apex10's composition, inferences rely on comparable products. For instance, biofertilizers which are claimed to have similar effects they constitute nitrogen-fixing bacteria (Rhizobium) or phosphate-solubilizing microorganisms such as Bacillus that improves soil fertility (Vessey, 2003). There is lack of clear information about the components of Apex10 which disturbs thorough scientific researches as there is need to research more on the constituents before researching on its effect (Bhardwaj et al., 2014).

2.6.2 Claimed physiological and agronomic effects

Apex10 is marketed for its capacity to improve the productivity, increase fruit output, and enhance soil fertility. These claims are in consistent with research on soil amendments that showed their impact in enhancing agronomic characteristics such as greater leaf count, plant height, and improved dry matter quality.A study conducted on Flue cured tobacco indicated that Apex 10 reduces the chance of tobacco plant to be infected with black shank and also improved nutrient uptake and increased leaf size (Li et al., 2023). The manufacturer of Apex10 claims comparable advantages, including increased harvest yields due to increased photosynthetic activities and resilience to environmental stress, though there is lack of peer-reviewed studies directly supporting and validating these claims for Apex10 itself .

From a physiological perspective, bio-stimulants like Apex10 are thought to promote root growth, nutrient absorption, and stress resistance by activating plant metabolic processes (du Jardin, 2015). For example, humic acids, a frequent component in bio-stimulants, expand root surface area and enhance water retention (Canellas et al., 2015).Agronomically, Apex10's purported microbial enhancement may parallel bio fertilizers, which improve soil biological activity and nutrient cycling (Vessey, 2003). However, the absence of controlled trials specific to Apex10 raises questions about the magnitude and consistency of its effects across different crops and soil types. Broader literature suggests that bio-stimulant efficacy varies with environmental conditions and application rates, highlighting the need for context-specific research (Calvo et al., 2014).

2.6.3 Comparison to other commercial products, if applicable

Comparing Apex10 to other commercial soil amendments is challenging due to limited data on its composition and performance. However, products like BioAg's humic-based fertilizers or microbial inoculants such as Mycorrhizal Applications' MycoApply offer similar benefits, including enhanced nutrient uptake and yield improvement (BioAg, 2022; Mycorrhizal Applications, 2023). A key difference lies in marketing: Apex10 emphasizes its proprietary formula, while competitors often provide detailed microbial or chemical profiles (*Trichoderma spp.* in MycoApply).

Studies comparing bio-stimulants show variable efficacy; for instance a meta-analysis found that microbial inoculants increased crop yields by 15–20% on average, but results depended on soil conditions (Schütz et al., 2018). Without equivalent data for Apex10, its competitive advantage remains unclear.

Biofertilizers another comparator, are well-studied for their role in sustainable agriculture. A review of biofertilizers highlighted their ability to enhance soil physical, chemical, and biological properties, reducing reliance on synthetic fertilizers (Santos et al., 2024). Apex10's claims of soil health improvement suggest overlap with these products, but its proprietary nature complicates direct comparisons. Additionally, products like Vermicompost or seaweed extracts offer similar agronomic benefits but are often less expensive, potentially limiting Apex10's market edge unless superior efficacy is demonstrated (Khan et al., 2009).

2.7 Previous Studies on Apex10 or Similar Products

2.7.1 Review of research done using Apex10 or similar bio-stimulants and soil conditioners

There has been an increase in researches on bio-stimulants and soil conditioners with the same properties as Apex10 due to their critical role in improving crop productivity through imparting stress tolerance and increasing water and nu use efficiency by plants which in-turn improves the crop yield. There are limited peer-reviewed research available on Apex-10 specifically, but studies on products that are humic-based bio-stimulants offers insights on its potential effectiveness. Humic substances, such as humic and fulvic acids, are organic compounds from decomposed plant and animal matter, extensively researched for enhancing nutrient absorption, improving soil structure, and boosting plant growth (Canellas and Olivares, 2014). For example, Nardi et al. (2016) demonstrated that humic acids promote root development and nutrient uptake by enhancing soil microbial activity and chelating key micronutrients. Likewise, bio-stimulants with seaweed extracts, amino acids, and microbial inoculants have been shown to increase plant vigor and resilience to abiotic stresses like drought and salinity (Du Jardin, 2015). Apex-10's reported benefits, such as supporting plant metabolic processes and improving drought resistance, align with these findings (Apex-10 Zimbabwe, 2021). Broadly, bio-stimulant research underscores their value in sustainable agriculture. A meta-analysis by Calvo et al. (2014) showed that bio-stimulants enhance nutrient use efficiency and reduce reliance on chemical fertilizers. However, Apex-10-specific studies are mostly proprietary or anecdotal, often found in marketing materials rather than peer-reviewed journals

(Apex-10, 2021), limiting critical evaluation of its efficacy compared to other humic-based products.

2.7.2 Reported outcomes in terms of crop yield, plant health, and soil improvement

Bio-stimulants like Apex-10 reportedly enhance crop yield, plant health, and soil quality. Research on humic substances shows consistent yield improvements; for example, Rose et al. (2014) reported a 10–15% maize yield increase under nutrient-deficient conditions due to better phosphorus availability. Apex-10 claims similar yield boosts by improving nutrient uptake and metabolic efficiency (Apex-10, 2021). For plant health, bio-stimulants improve stress resilience. Van Oosten et al. (2017) found humic substances reduce drought stress by enhancing gene expression and water efficiency, a benefit echoed in Apex-10's claims of improved drought tolerance (Apex-10 Zimbabwe, 2021). They also promote root growth, with Canellas et al. (2015) noting a 20% increase in root length. Soil-wise, humic products enhance structure, water retention, and microbial activity. Puglisi et al. (2013) observed increased soil organic matter and microbial biomass, improving fertility. Apex-10 is marketed as a soil conditioner, though data on its microbial or long-term fertility impact is lacking (Apex-10, 2021). Humic substances also improve soil nutrient retention (Laird et al., 2010). However, efficacy varies by crop, soil, and application, with Verlinden et al. (2010) noting better results in nutrient-poor or stressed soils, highlighting the need for localized Apex-10 studies.

2.7.3 Gaps in literature, particularly in Zimbabwean or sub-Saharan contexts

Despite the increasing in the number of research on bio-stimulants, gaps significantly exist particularly in Zimbabwe and the who parts of sub-Saharan Africa (SSA). Various studies on humic-based products have been conducted mostly in temperate regions, though there is limited data on their performance in tropical or semi-arid environments typical of SSA (Mupambwa and Mnkeni, 2018). Zimbabwe has been characterized by erratic rainfall, increased rates of degraded soils and smallholder-dominated agriculture which shows unique challenges that needs context-specific research. The unavailability of peer-reviewed researches and studies on Apex-10 in Zimbabwe or SSA limits its applicability to local farming systems.

One major gap is the lack of long-term field trials. While short-term studies show yield improvements, the sustainability of bio-stimulant effects on soil health and crop productivity remains underexplored (Rose et al., 2014).There is need for intensive research on products such as Apex 10 especially in Sub Saharan Countries due to the increased rate of soil degradation and high frequency of droughts to gebuinelly asses the capability of products like Apex 10 to restore soil fertility or not over a given period of time. Additionally, it is very unclear on how Apex 10 due to unavailability of data on how it interacts with indigenous varieties and our local soil types, This is very important for smallholder farmers in Zimbabwe (Mupambwa and Mnkeni, 2018).

Another gap unavailability of adequate funds by small holder farmers. Small holder farmers mostly in SSA they face financial challenges making them unable to purchase this substance. The cost effectiveness of Apex10 and other bio-stimulants is not often addressed. The unavailability in the literature (Calvo et al., 2014). The lack of clear data on the return on investment is affecting the use of such products by farmers. Furthermore, it is quite unclear on how the bio-stimulant can affect the environmental aspects such as pH and microbial activities and diversity (Puglisi et al., 2013).

Finally, there are no clear regulations to be followed on the testing, use and approval of biostimulants. The differences that exist in the constituents of these products in their composition makes it difficult to compare with different studies already undertaken (Du Jardin, 2015). For Apex-10 there are claims dominating the narrative, but there is lack of substantiative data on its formulation, its performance in the field and finally its efficacy in Zimbabwean soils remains speculative.

2.8 Integration of Bio-stimulants and Soil Conditioners in Maize Production

2.8.1 Synergistic effects

The combined use of bio-stimulants and soil conditioners creates synergistic benefits for maize production, particularly in demanding environments like Zimbabwe. Bio-stimulants improve nutrient absorption and root development, amplifying the advantages of enhanced soil structure and water retention offered by soil conditioners (Bulgari et al., 2019). For example, a soil conditioner such as biochar enhances soil physical properties, fostering an ideal environment for beneficial microorganisms introduced by microbial bio-stimulants (Buisset et al., 2025; Luan et al., 2023). This increased microbial activity improves nutrient cycling, making essential nutrients more accessible to maize crops, which then leverage bio-stimulants' capacity to optimize internal metabolic processes for growth and stress resilience (Jahan et al., 2024; Moyo and Masowa, 2024). In Zimbabwe, where erratic rainfall and degraded soils are prevalent, this combined strategy can produce more resilient maize plants better able to cope with drought and nutrient shortages, leading to higher and more consistent yields.(Lunduka et al., 2019; Pasley et al., 2019).

2.8.2 Best practices and application methods.

Successful use of bio-stimulants and soil conditioners in maize production hinges on following best practices and precise application techniques. For bio-stimulants, timing is critical, with optimal results achieved when applied at key maize growth stages like planting, tillering, or tasselling to enhance root growth, nutrient uptake, and stress resilience (Chen et al., 2023; Chipomho et al., 2024; Jahan et al., 2024). Application methods—seed treatment, foliar sprays, or soil drenching—vary based on the product and desired outcome. Soil conditioners, when mixed into the soil during land preparation or applied as top-dressing, improve soil properties such as water retention and aeration (Chen et al., 2023). In Zimbabwe's rain-fed smallholder farming systems, aligning applications with seasonal rainfall is essential. For instance, adding organic conditioners like compost before rains can boost soil moisture retention for maize (Pasley et al., 2019). Integrating approaches, such as combining biochar soil incorporation with bio-stimulant seed treatment or foliar sprays, enhances soil and plant vitality (Liu et al., 2021; Luan et al., 2023).

2.8.3 Potential challenges or limitations.

Despite their potential, incorporating bio-stimulants and soil conditioners into maize production in Zimbabwe faces significant hurdles. Smallholder farmers, constrained by limited finances, find these products costly and hard to access (Chikowo et al., 2014). They often opt for locally available compost and manure over expensive, specialized commercial bio-stimulants and soil conditioners, which are scarce in rural areas. The absence of standardized regulations and quality control in the market leads to variable product effectiveness, fostering farmer skepticism (Bulgari et al., 2019). Additionally, farmers may lack the expertise and training needed for proper application timing and rates, reducing these inputs' efficacy (Vanlauwe et al., 2015). Environmental factors, such as severe droughts or floods, further compromise the performance of these products, yielding inconsistent outcomes (Verlinden et al., 2010). Moreover, the proprietary nature of many commercial bio-stimulants, such as Apex10, obscures their composition and mechanisms, complicating independent validation and comparison (Bhardwaj et al., 2014).

CHAPTER 3: METHODOLOGY

3.1 Site description

The experiment was carried out at Holland farm which is located in Mvurwi, Mazowe North district in Mashonaland Central Province. Mvurwi is 96 km from Harare. The farm is 20 km South East from Mvurwi along the Mvurwi-Centenary highway. The farm is found on the geographical coordinates 16°53'30S, 30°52'26 E. The altitude of Mvurwi is 1480m above the sea level.The trial site is situated in agro-ecological region IIb which receives an average rainfall amount of about 750 mm to 1000mm per annum. The mean annual temperature ranges from 21 to 28 ^{o}C. The soils are predominantly clay loam on an even slope of less than 2%. The farm relies on rainfall and it does not have irrigation system. The soil pH was 6 as shown in Appendices 1.

3.2 Experimental design and field layout.

The research was carried out to evaluate the effectiveness of Apex10 as a plant growth bio-stimulant and soil conditioner on two maize varieties SC659 and ZS265. This research employed a factorial experiment in a randomized complete block design with three replications. The experimental treatments comprised of two maize varieties which are SC659 and ZS265. These were subjected to four levels of Apex10 application rates which were 3*l* ha^{-1} (30 mls per plant 100%), 2.25*l* ha^{-1} (22.5 mls per plant 75%) ,1.5*l* ha^{-1} (15mls per plant.50%) and 0*l* ha^{-1} (0 mls per plant 0%) as shown in Table 3.1. The blocking factor was the gentle slope of 2%. The experimental field layout is shown on Fig. 3.1.

Table 3.1: Treatment description

Maize variety	Apex10 application rate (l ha^{-1}	Volume per plant (mls)	% of maximum rate
SC659	3.0	30	100
SC659	2.25	22.5	75
SC659	1.5	15	50
SC659	0	0	0
ZS265	3.0	30	100
ZS265	2.25	22.5	75
ZS265	1.5	15	50
ZS265	0	0	0

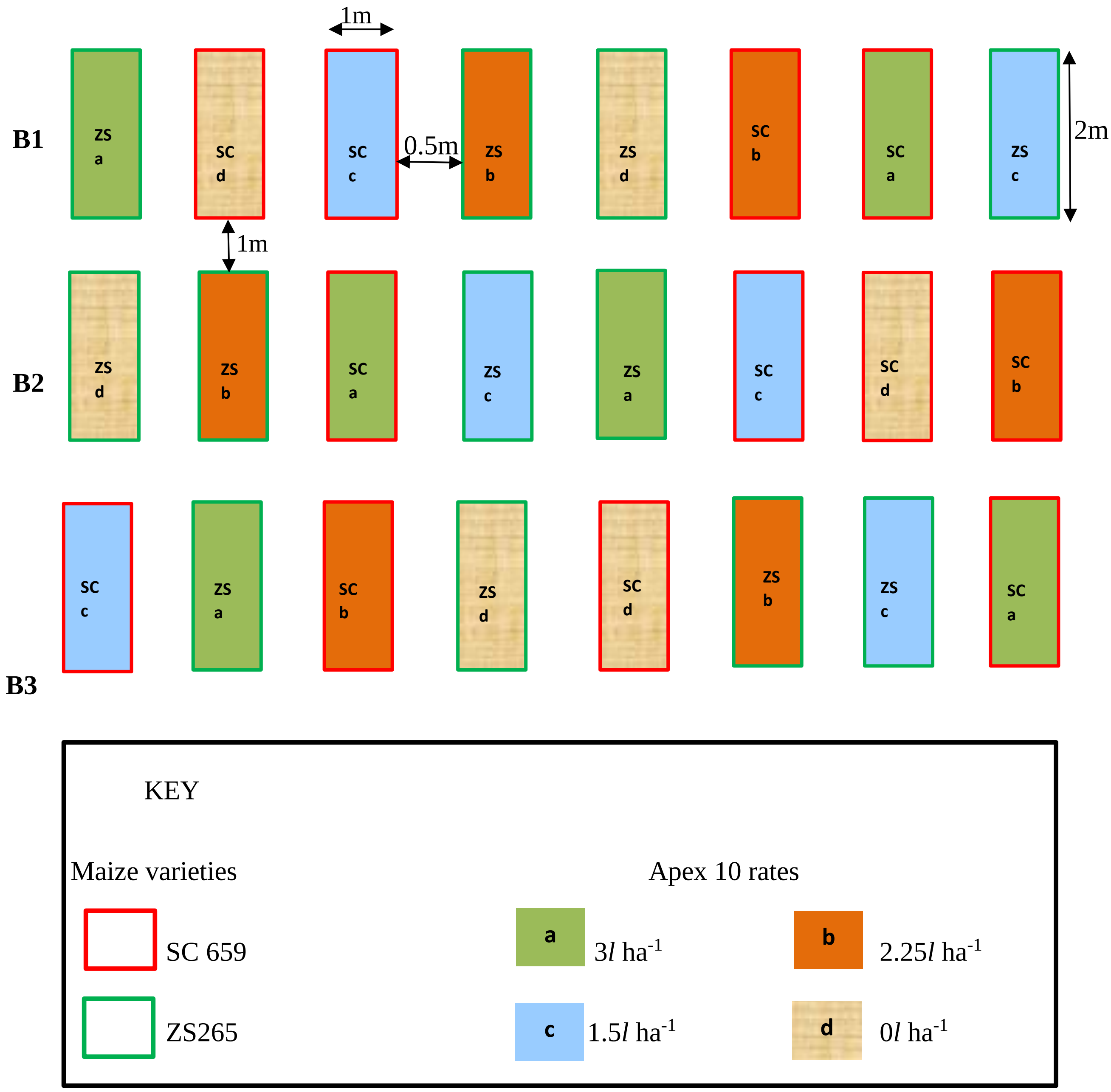

Figure 3.1: Experimental field layout

3.3. Agronomic Procedures

3.3.1 Land preparation

The experimental site was cleared using to remove natural weeds and previous crop residues. The land was ploughed to 40cm depth using a tractor drawn disc plough. A disc harrow was used soon after primary tillage to disc the land to produce a fine tilth. This was done to enhance seed soil contact to promote higher germination percentage and also proper root growth and development. This can improve anchorage for the crop. Soil samples were collected at the experimental site using a hoe at a depth of 20cm. These samples were then sent to ZFC for laboratory analysis. The results are shown in appendices 1. Three blocks that were measuring 16m x 2m each were pegged and marked using hoes. Each block had 12 plots with 4 different treatment levels and 4 different rates of bio-stimulants and soil conditioner. Each treatment was replicated thrice. The plots measured 2m×1 were constructed for the planting and a pathway of 0.5m was left between the plots. The treatments were assigned to the plots randomly. The net plot consisted of one mid row of the bed with 13plants. Compound D (N7: P14: K7) was applied at the rate of 400kg ha^{-1} as a basal dressing during planting and Ammonium nitrate (34.5% N) was applied at the rate of 200kg ha^{-1}.

3.3.2 Planting

Maize was planted on the same day after receiving 30mm rainfall that supplied the soil to more than 35%moisture content. The planting holes were made using a hoe. The inter-row spacing was 0.75m and the in row spacing was 0.20m. Compound D fertilizer was applied in the holes and covered with a small layer of soil to avoid direct seed fertilizer contact. Each planting station had two seeds and the holes were covered by soil. Thinning was done three weeks after planting.

3.3.3 Application of Apex 10

Apex 10, a bio-stimulant and soil conditioner, was diluted with 100*l* of water to come up with the different application rates. Application of Apex 10 was done a day after planting. Apex 10 was applied through drenching into the holes where maize was planted.

3.3.4 Weed control

Application of a post emergence herbicide (S-matalachlor) was done on the second day after planting. At three weeks after germination halosulfron and nicosulfron were applied as post emergence herbicides for the control of weeds such as *Rottboellia cochinchinensis.*

3.4 Data collection.

The data collected for this research included, plant height, biomass and yield. The data was only collected from the net plot area. Twenty centimeters were subtracted from each plot (excluding 2 plants from each borderline) to get the net plot. The net plot consisted of a total of 12 maize plants – 6 from each row. Figure 3.2 shows the net plot area.

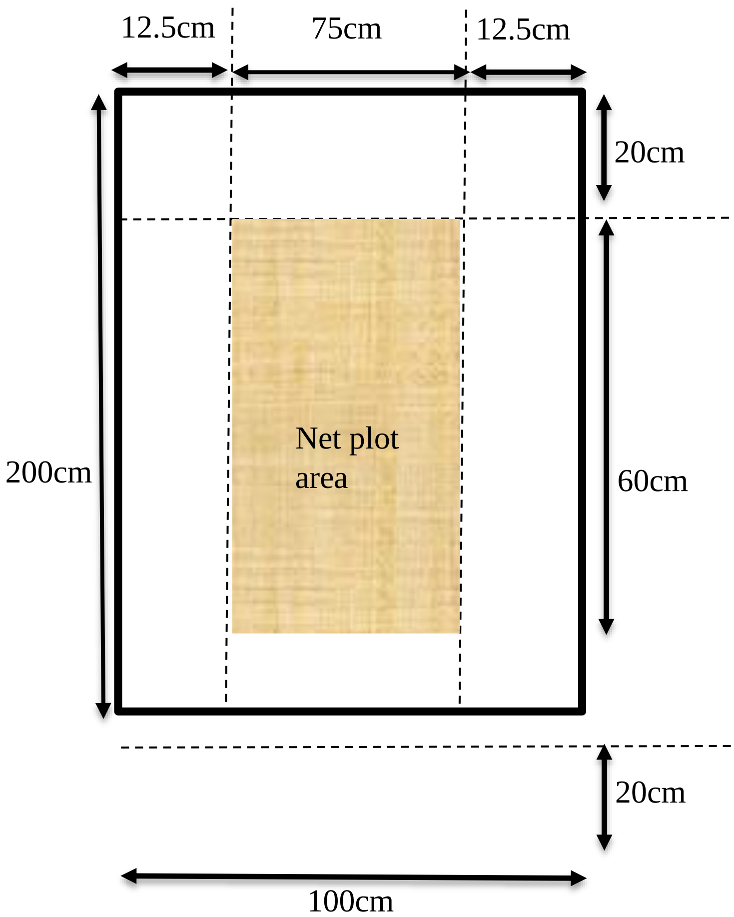

Figure 3.2: The net plot area

3.4.1 Plant height

Plant height was measured using a 5m tape measure. The tap measure was placed from the from the soil surface to the highest point of the arch of the upper most leaf that has its tip pointing down. All the 12 plants within the net plot were measured. That is 12 plants × 12 plots = 144 data readings per each maize variety. The plant height was measured once every two weeks.

3.4.2 Yield

Ear weight

The maize ears were collected from the maize stalks. The maize husks were removed. The ears were then placed in a net bag and weighed on a scale. The weight of maize ears per plot were recorded in grams. These weights were then recorded on data sheets and later transferred to Microsoft excel.

Grain weight

The maize ears were collected from the field and oven dried at 60ºC for 48 hours. The maize ears were then threshed using a maize sheller machine to separate the grain and cobs. The large debris such as cobs and stalks were removed by hand. The grain was then winnowed, and a small fan was used to blow the chaff and dust away. The cleaned grain was then weighed on a scale. The grain yield per hectare was calculated using the following formula:

$$Grain\ yield\ (kg/ha) = \frac{weight\ of\ grain\ per\ plot\ (kg)}{Plot\ area\ (\mathrm{m}^2)} \times 10000\mathrm{m}^2$$

3.4.3 Above ground biomass

The plant stalks were cut from the base of the stem using a sickle. The 12 stalks from each plot were cut into small pieces and then packed into the net bags. The hand held scale was then used to record the weight in grams. These were later quantified to tonnes per hectare.

3.4.4 Root biomass

The root biomass of maize was collected using the excavation method. A trench was dug using a hoe around the maize plants in a row. The maize roots were collected intact, and washed in water to remove soil debris. They were then placed in small net bags, hand shook for one minute to remove excess water and weighed on a scale. The roots in the netbags were later placed in an oven, heated at 60^{o}C for 72 hours. The dry biomass was weighed on a scale. Both the fresh and dry weights were recorded on data sheets and later transferred to Microsoft excel.

3.5 Data Analysis

Statistical analyses were performed using R software (version 4.5.0). The initial data preparation involved importing the raw Excel file using *readxl*, standardizing column names with *janitor*, and converting variable types using *dplyr*. For repeated plant height measurements, the data was reshaped to a long format using *tidyr::pivot_longer()*, with time points extracted by *readr::parse_number()*. For single-measurement response variables (grain weight, biomass, ear weight), the analysis of variance (ANOVA) models were fitted using the base R *aov()* function, with Apex10 application rates, variety, and their interaction as fixed effects, and block as a blocking factor. The significance of effects was assessed using the *Anova()* function from the *car* package. For plant height, a Linear Mixed-Effects Model (LMEM) was employed using the *lmer* function from the *lme4* package, including Apex10 rates, variety, time point, and their interactions as fixed effects. The p-values for the LMEM fixed effects were obtained via *lmerTest::anova*(). Where the significant effects were detected by ANOVA or LMEM, means comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level, utilizing *TukeyHSD0()* for ANOVA models and the *emmeans* package for LMEM estimated marginal means.

CHAPTER 4: RESULTS

4.1 Effect of Apex 10 bio-stimulant on plant height of two maize varieties

The different Apex 10 application rates had highly significant effect ($p<0.001$) on maize plant height from 5WAP through to 15 WAP. Higher Apex 10 application rates resulted in taller plants compared to lower rates. The plant height was highest in the maize applied 3 and 2.25*l* ha^{-1} compared to other application rates as shown in (Figure 4.1). However, variety had no significant effect ($p>0.05$) on maize plant height.. Moreover, there was no significant interaction ($p>0.05$) of Apex 10 and variety on maize plant height (Appendix 2.1 to 2.7).

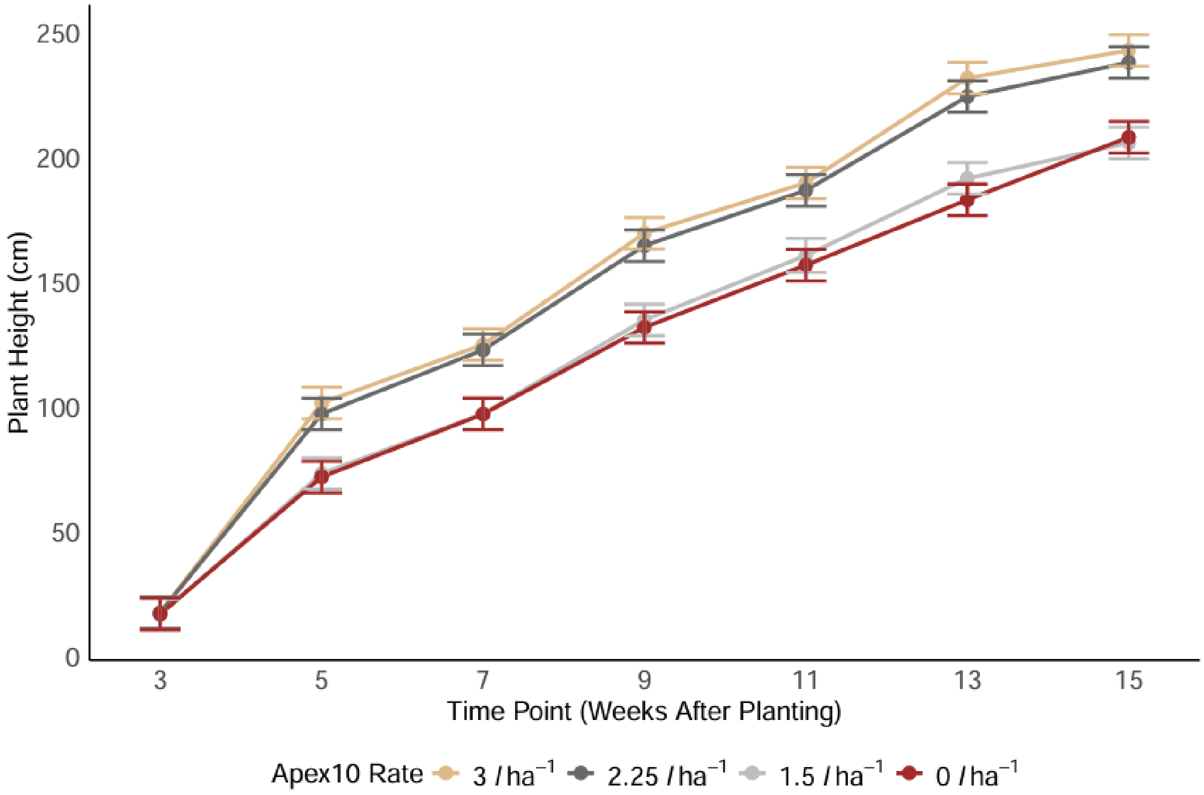

Figure 4.1: Effect of different Apex 10 application rates on maize plant height

4.2 Effect of Apex 10 bio-stimulant on biomass of two maize varieties

4.2.1 Above ground biomass

The different Apex 10 application rates had a highly significant effect ($p<0.001$) on the maize above ground biomass (AGB). The results showed an increase in Apex 10 application increased the maize AGB. The 3*l* ha^{-1} and the 0*l* ha^{-1} Apex 10 application rates had the highest and lowest ABG respectively as shown in Figure 4.2. However, variety had no significant effect ($p>0.05$) on the maize AGB. Moreover, there was no significant interaction ($p>0.05$) of Apex 10 and variety on the maize AGB (Appendix 2.8).

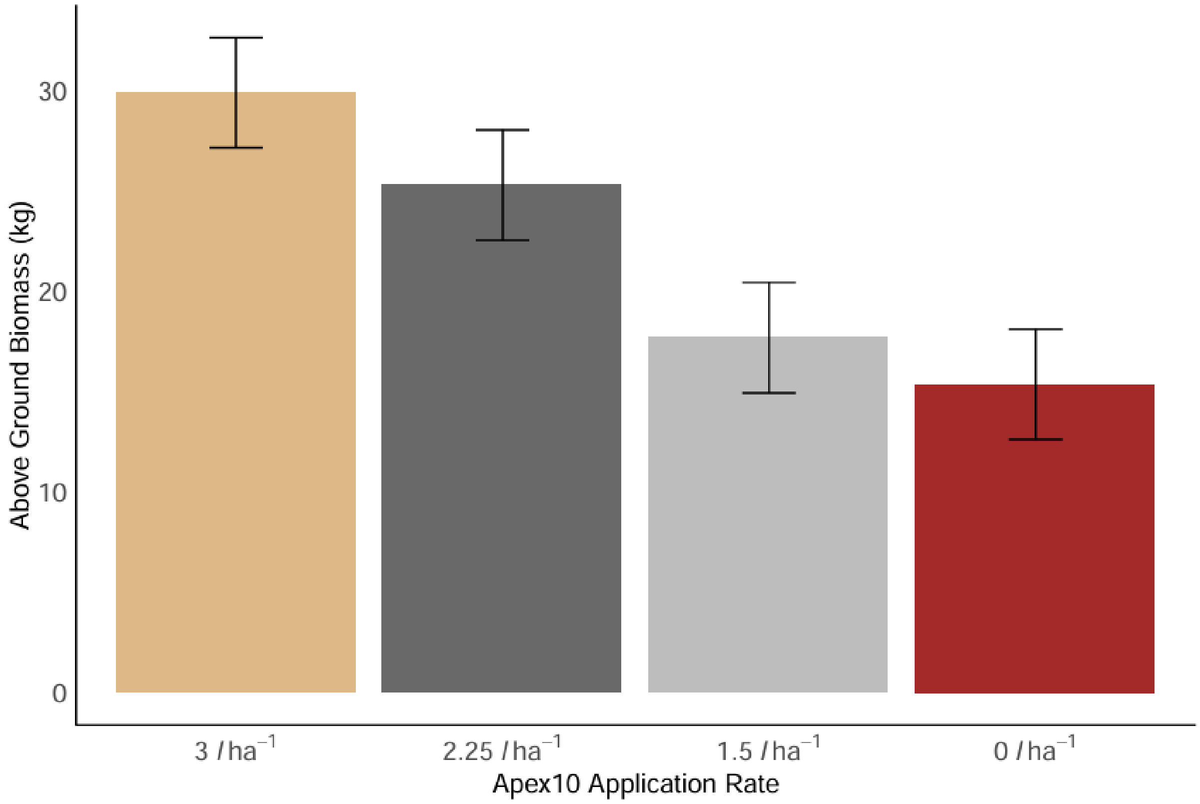

Figure 4.2: Effects of different Apex 10 application rates on the maize above ground biomass

4.2.2 Below ground biomass

The different Apex 10 application rates had a highly significant effect ($p<0.001$) the maize below ground biomass (BGB). The 3*l* ha^{-1} Apex 10 application rate had the highest root biomass in both SC659 and ZS265 whilst the 0*l* ha^{-1} had the lowest root biomass in both varieties as shown in Figure 4.3. However, variety had no significant effect ($p>0.05$) on the maize BGB. Moreover, there was no significant interaction ($p>0.05$) of Apex 10 and variety on the maize BGB (Appendix 2.9)

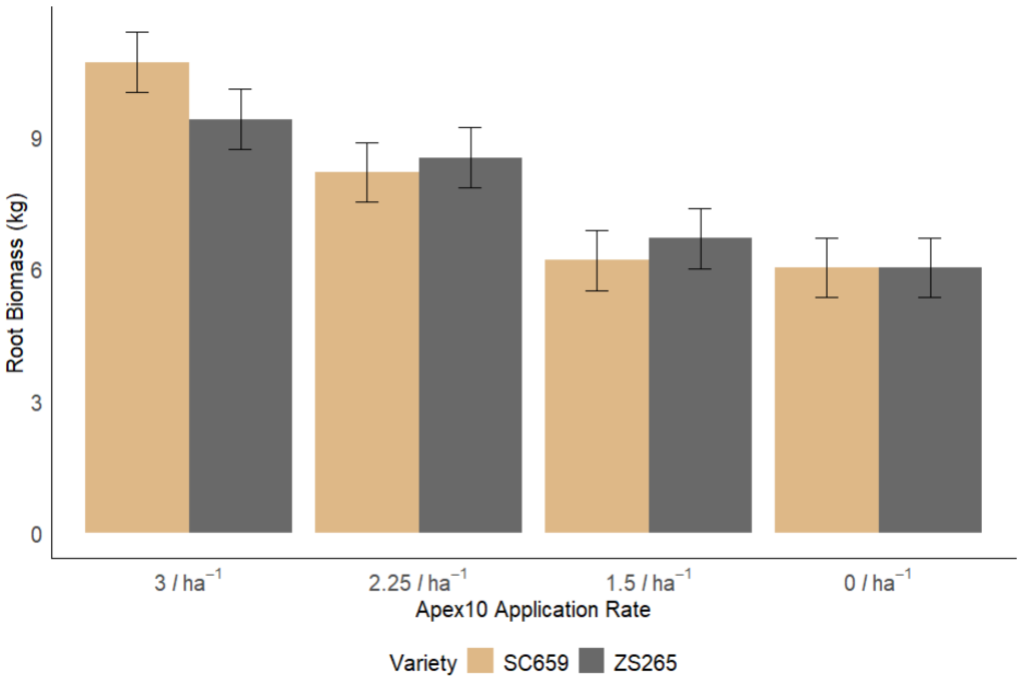

Figure 4.3: Effects of different application rates on the maize below ground biomass

4.3 Effect of Apex 10 bio-stimulant on yield of two maize varieties

The different Apex 10 application rates had a highly significant effect ($p<0.001$) on maize ear weight and maize grain weight. An increase in Apex 10 concentration increased the maize ear weight and maize grain weight as shown in table 4.1. However, the Apex 10 by variety interaction did not significantly influence ($p >0.05$) (Appendix 2.10 and 2.11) the maize ear weight and grain weight as shown in Table 4.1. The Apex 10 × variety interaction did not significantly influence the ear weight (p>0.05). The SC659 had the highest ear weight compared to the ZS265.

Table 4.1 Effect 0f Apex 10 application rate on maize ear weight and maize grain weight

Apex 10 application rate	**Ear weight (g)**	**Grain weight (tha^{-1})**
0.5 lha^{-1}	100.67^{a}	5.7933^{a}
1.5 lha^{-1}	135.83^{b}	7.2233^{b}
2.25 lha^{-1}	176.67^{c}	8.7700^{c}
3.0 lha^{-1}	214.83^{d}	9.7467^{d}
Grand mean	157.00	7.8833
Fprob	<0.001	<0.001
l.s.d	1.051	0.5988
CV%	1.5	0.7

Means followed by a different superscript letter are significantly different at P < 0.05.

Variety had a highly significant effect (p<0.001) on maize ear weight and maize grain weight. The SC659 had the higher ear weight and grain weight than the ZS265 as shown in table 4.2.

Table 4.2: Effect of variety on maize ear weight and maize grain weight

Variety	**Ear weight (g)**	**Grain weight (tha^{-1})**
SC659	159.67[a]	7.9608[a]
ZS265	154.33[b]	7.8058[b]
Grand mean	157.00	7.8833
Fprob	<0.001	<0.001
l.s.d	0.743	0.04234
CV%	1.5	0.7

Means followed by a different superscript letter are significantly different at $P < 0.05$.

The different Apex 10 concentrations and the maize varieties (SC659 and ZS265) tested significantly influenced ($p<0.05$) the grain weight. The SC659 had the highest grain weight across all the different Apex 10 application rates used. A trend observed is an increase in Apex 10 concentration increases the maize grain weight (Table 4.1). However, there was no significant interaction ($p>0.05$) of Apex 10 and variety on the maize grain weight.

CHAPTER 5: DISCUSSION

5.1 Effect of Apex 10 bio-stimulant on plant height of two maize varieties

This research found out that increasing the dosage of Apex 10 bio-stimulant and soil conditioner increases the maize plant height. The bio-stimulant increases the vegetative growth of maize. The results of this study aligns with Ancín *et al*., (2024) who highlighted that bio-stimulants can positively influence plant growth dynamics, encouraging plants to grow taller and healthier compared to control treatments. This is also consistent with Jahan *et al*. (2024) who observed that bio-stimulants such as Apex 10 often contain the phytohormones such as auxins, gibberellins and cytokinins, microorganisms and amino acids which promote cell elongation and multiplication resulting in increased plant growth. Apex 10 as a soil conditioner, improve the maize root architecture and the microbial activity in the rhizosphere encouraging improved nutrient assimilation that facilitaes plant growth. The maize plant height was similar between ZS265 and SC659. This may point to similar genotype specific responses to the bio-stimulant as well as the environment (Vultaggio *et al*., 2025) allowing enhanced nutrient uptake.

5.2 Effect of Apex 10 bio-stimulant on biomass of two maize varieties

5.2.1 Above ground biomass

Apex 10 enhances the agronomic performance of maize. An increase in above ground biomass correlated with higher Apex 10 application rates. This reinforces the fact that bio-stimulants increase biomass accumulation in plants. This is in agreement with Toscano *et al*. (2023) reported that bio-stimulants play a crucial role in enhancing growth and nutrient uptake, subsequently influencing crop biomass positively. Bio-stimulants improve above ground biomass by enhancing the photosynthetic efficiency through improved chlorophyll content thereby optimizing carbon assimilation. Bio-stimulants reduce the effects of abiotic stress allowing plants to allocate more energy towards growth than stress response (Jahan *et al*., 2024; Mamun *et al*., 2024). Varietal differences were not significant suggesting that SC659 and ZS265 responded the same way to Apex 10 and the environment.

5.2.2 Below ground biomass

An increase in the Apex 10 application rate increases the maize below ground biomass (root biomass). The highest root biomass was observed in the 3l ha^{-1} Apex 10 application rate in both SC659 and ZS265. This could be attributed to the fact that bio-stimulants enhance root growth by creating a favourable environment for plant root and microbial interactions (Chen *et al*., 2023; Wen *et al*., 2016). Apex 10 could have enhanced the presence of microbes such as mychorrhizal fungi growth which enhance water, nutrient fixation and uptake. A high root biomass as contributed by water and nutrient uptake, indicates an increased capacity for resource exploration as facilitated by high Apex 10 application rates.

5.3 Effect of Apex 10 bio-stimulant on yield of two maize varieties

5.3.1 Maize ear weight

The results from this study found out that higher Apex 10 application rates effectively enhanced maize ear weight. This could be attributed to the fact that bio-stimulants promote the growth traits in maize, particularly ear size and weight by enhancing the plant physiological processes. This is in agreement with Al-Temimi and Al-Hilfy (2021) who observed that the application of bio-stimulants significantly improved the growth parameters and chlorophyll production in maize, allowing enhanced photosynthesis and nutrient uptake resulting in enhanced ear weight. This is consistent with (Luan *et al*., 2023) who reported that bio-stimulants facilitate maize growth by promoting root and rhizosphere interactions which increases maize biomass and yield. The SC659 had the highest ear weight compared to ZS265 indicated a genetic variation in yield potential. SC659 may be possessing traits for heavier ears compared to ZS265. The interaction of Apex 10 and variety suggests that Apex 10 effect on ear weight was additive and consistent in both varieties and not specific to one maize variety.

5.3.2 Maize grain weight

Regardless of the maize cultivars, the maize grain weight increased with higher concentrations of Apex 10. This is consistent with the findings of Silva *et al*. (2022) who observed that maize yield is enhanced when bio-stimulants are used as they allow nutrient reconfiguration and increased efficiency in nutrient uptake. This is also in agreement with Othibeng *et al*. (2021) who reported that bio-stimulants led to metabolic changes that favored crop growth thus supporting the observed increase in grain weight with increasing the Apex10 concentrations. Moreover, Achiri *et al*. (2025) noted that this biochemical network is essential for utilizing nutrients more effectively, encouraging the full potential of maize varieties, such as, in this case, SC659. Higher overall grain yield could be attributed to the fact that Apex 10 improves nutrient translocation to developing grain. SC659 was higher across all Apex 10 concentrations which could be attributed to its superior yield potential compared to ZS265 despite Apex 10 exerting a positive effect on grain filling and development.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study investigated the effect of different Apex 10 bio-stimulant and soil conditioner application rates on the growth and yield of maize varieties SC659 and ZS265. The results consistently indicated that higher application rates of Apex 10 particularly the 3l ha^{-1} had the highest plant height, above and below ground biomass, ear weight and grain yield. The control treatment with 0l ha^{-1} performed poorly in all the growth and yield metrics tested. Even though the SC659 maize variety was superior in terms of ear weight and grain yield compared to ZS265, indicating the inherent genotypic differences, the beneficial effects of Apex 10 were observed in both varieties for all the measured parameters.

6.2 Recommendations

- Farmers are recommended to incorporate Apex 10 bio-stimulant and soil conditioner at 3l ha^{-1} in maize production to achieve the highest yield. Integrating Apex 10 with high performing varieties such as SC659 leads to even greater returns.
- Since this study was carried out at one site, there is need to validate these findings under different soil types and climatic conditions as well as by optimal timing and method of application.
- Further research on the effect of Apex 10 bio-stimulant can be carried out using different varieties in different seasons.

REFERENCES

Achiri, D.T., Ndode, E.E., Mbeboh, M.N., Ngone, M.A., Ndzeshala, S.D., Ruppel, S., Tening, A.S., Ngosong, C., 2025. Bio-inoculant consortium and organic amendment comprising plant bioactive extract increased maize yield by improving soil nutrient availability and mitigating pest damage. Plant Soil. https://doi.org/10.1007/s11104-025-07250-8

Al-Temimi, A.H.M., Al-Hilfy, I.H.H., 2021. Effect of the application of biostimulants on the agronomic parameters of corn varieties. Agraria 16, 1–6. https://doi.org/10.5039/agraria.v16i2a9257

Ancín, M., Soba, D., Picazo, P.J., Gámez, A.L., Le Page, J., Houdusse, D., Aranjuelo, I., 2024. Optimizing oilseed rape growth: Exploring the effect of foliar biostimulants on the interplay among metabolism, phenology, and yield. Physiologia Plantarum 176, e14561. https://doi.org/10.1111/ppl.14561

A.S., A.-A., N.A., S., M.Aa., R., 2023. Effect of humic acid and seaweed extract rates on yield and yield components of barley (Hordeum vulgare L.). Alexandria Science Exchange Journal 44, 459–463. https://doi.org/10.21608/asejaiqjsae.2023.316895

Buisset, E., Soust, M., Scott, P.T., 2025. The Isolation of Free-Living Nitrogen-Fixing Bacteria and the Assessment of Their Potential to Enhance Plant Growth in Combination with a Commercial Biostimulant. Microbiology Research 16, 69. https://doi.org/10.3390/microbiolres16030069

Canellas, L.P., Canellas, N.A., Martinez-Balmori, D., Silva, R.M., Rosa, R.C.C., Olivares, F.L., 2025. Farm-Produced Plant Biostimulant: Case Study with Passion Fruit. Agronomy 15, 681. https://doi.org/10.3390/agronomy15030681

Caradonia, F., Battaglia, V., Righi, L., Pascali, G., La Torre, A., 2019. Plant Biostimulant Regulatory Framework: Prospects in Europe and Current Situation at International Level. J Plant Growth Regul 38, 438–448. https://doi.org/10.1007/s00344-018-9853-4

Chen, D., Li, Z., Yang, J., Zhou, W., Wu, Q., Shen, H., Ao, J., 2023. Seaweed extract enhances drought resistance in sugarcane via modulating root configuration and soil physicochemical properties. Industrial Crops and Products 194, 116321. https://doi.org/10.1016/j.indcrop.2023.116321

Chikowo, R., Zingore, S., Snapp, S., Johnston, A., 2014. Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa. Nutr Cycl Agroecosyst 100, 1–18. https://doi.org/10.1007/s10705-014-9632-y

Dzawanda, B., Matsa, M., Nicolau, M., 2024. Sustainable Development Goals in Zimbabwe: Setbacks Encountered During the COVID-19 Pandemic, in: Abubakar, I.R., Da Silva, I., Pretorius, R., Tarabieh, K. (Eds.), SDGs in Africa and the Middle East Region, Implementing the UN Sustainable Development Goals – Regional Perspectives. Springer International Publishing, Cham, pp. 1451–1475. https://doi.org/10.1007/978-3-031-17465-0_16

Francesca, S., Arena, C., Hay Mele, B., Schettini, C., Ambrosino, P., Barone, A., Rigano, M.M., 2020. The Use of a Plant-Based Biostimulant Improves Plant Performances and Fruit Quality in Tomato Plants Grown at Elevated Temperatures. Agronomy 10, 363. https://doi.org/10.3390/agronomy10030363

Gotosa, J., Kodzwa, J., Nyamangara, J., Gwenzi, W., 2019. Effect of Nitrogen Fertiliser Application on Maize Yield Across Agro-Ecological Regions and Soil Types in Zimbabwe: A Meta-analysis Approach. Int. J. Plant Prod. 13, 251–266. https://doi.org/10.1007/s42106-019-00045-9

Jahan, M.S., Hasan, M.M., Rahman, M.A., 2024. Editorial: Hormones and biostimulants in plants: physiological and molecular insights on plant stress responses. Front. Plant Sci. 15, 1413659. https://doi.org/10.3389/fpls.2024.1413659

Li, J., Van Gerrewey, T., Geelen, D., 2022. A Meta-Analysis of Biostimulant Yield Effectiveness in Field Trials. Front. Plant Sci. 13, 836702. https://doi.org/10.3389/fpls.2022.836702

Liu, Y., Zhang, L., Yin, X., Zou, X., Chen, F., 2021. Influence of climate change and mechanized harvesting on maize (*ZEA MAYS* L.) planting and northern limits in northeast China. J Sci Food Agric 101, 3889–3897. https://doi.org/10.1002/jsfa.11027

Luan, J., Fu, Y., Tang, W., Yang, F., Li, X., Yu, Z., 2023. Impact of Interaction between Biochar and Soil Microorganisms on Growth of Chinese Cabbage by Increasing Soil Fertility. Applied Sciences 13, 12545. https://doi.org/10.3390/app132312545

Lunduka, R.W., Mateva, K.I., Magorokosho, C., Manjeru, P., 2019. Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe. Climate and Development 11, 35–46. https://doi.org/10.1080/17565529.2017.1372269

Mafongoya, P., Rusinamhodzi, L., Siziba, S., Thierfelder, C., Mvumi, B.M., Nhau, B., Hove, L., Chivenge, P., 2016. Maize productivity and profitability in Conservation Agriculture systems across agro-ecological regions in Zimbabwe: A review of knowledge and practice. Agriculture, Ecosystems & Environment 220, 211–225. https://doi.org/10.1016/j.agee.2016.01.017

Makate, C., Makate, M., 2019. Interceding role of institutional extension services on the livelihood impacts of drought tolerant maize technology adoption in Zimbabwe. Technology in Society 56, 126–133. https://doi.org/10.1016/j.techsoc.2018.09.011

Mamun, A.A., Neumann, G., Moradtalab, N., Ahmed, A., Nawaz, F., Tenbohlen, T., Feng, J., Zhang, Y., Xie, X., Zhifang, L., Ludewig, U., Bradáčová, K., Weinmann, M., 2024. Combination of Silicate-Based Soil Conditioners with Plant Growth-Promoting Microorganisms to Improve Drought Stress Resilience in Potato. Microorganisms 12, 2128. https://doi.org/10.3390/microorganisms12112128

Manzeke, M.G., Mtambanengwe, F., Watts, M.J., Hamilton, E.M., Lark, R.M., Broadley, M.R., Mapfumo, P., 2019. Fertilizer management and soil type influence grain zinc and iron concentration under contrasting smallholder cropping systems in Zimbabwe. Sci Rep 9, 6445. https://doi.org/10.1038/s41598-019-42828-0

Marondedze, A.K., Schütt, B., 2021. Predicting the Impact of Future Land Use and Climate Change on Potential Soil Erosion Risk in an Urban District of the Harare Metropolitan Province, Zimbabwe. Remote Sensing 13, 4360. https://doi.org/10.3390/rs13214360

Marondedze, A.K., Schütt, B., 2020. Assessment of Soil Erosion Using the RUSLE Model for the Epworth District of the Harare Metropolitan Province, Zimbabwe. Sustainability 12, 8531. https://doi.org/10.3390/su12208531

Matsuoka, Y., Vigouroux, Y., Goodman, M.M., Sanchez G., J., Buckler, E., Doebley, J., 2002. A single domestication for maize shown by multilocus microsatellite genotyping. Proc. Natl. Acad. Sci. U.S.A. 99, 6080–6084. https://doi.org/10.1073/pnas.052125199

Maviza, A., Ahmed, F., 2021. Climate change/variability and hydrological modelling studies in Zimbabwe: a review of progress and knowledge gaps. SN Appl. Sci. 3, 549. https://doi.org/10.1007/s42452-021-04512-9

Mazuruse, I., 2025. Exploring Rural Women’s Livelihood Resilience Strategies Impacts Of The 20232024 El Niño-Induced Drought In Zimbabwe A Case Of Mutawatawa In Mashonaland Province, Zimbabwe. N 215–239. https://doi.org/10.71458/pa8r2y95

Moyo, K., Masowa, M.M., 2024. Eco-organic system and silicon-based biostimulant as a strategy for vegetable production under multistress conditions in South Africa: A review. JAH 26. https://doi.org/10.37855/jah.2024.v26i01.16

Mtangadura, T.J., Mtambanengwe, F., Nezomba, H., Rurinda, J., Mapfumo, P., 2017. Why organic resources and current fertilizer formulations in Southern Africa cannot sustain maize productivity: Evidence from a long-term experiment in Zimbabwe. PLoS ONE 12, e0182840. https://doi.org/10.1371/journal.pone.0182840

Muatinte, B.L., Kavallieratos, N.G., Boukouvala, M.C., García-Lara, S., López-Castillo, L.M., Mvumi, B.M., 2019. The threat of the larger grain borer, *Prostephanus truncatus* (Coleoptera: Bostrichidae) and practical control options for the pest. CABI Reviews 1–25. https://doi.org/10.1079/PAVSNNR201914041

Mugiyo, H., Magadzire, T., Choruma, D.J., Chimonyo, V.G.P., Manzou, R., Jiri, O., Mabhaudhi, T., 2023. El Niño's Effects on Southern African Agriculture in 2023/24 and Anticipatory Action Strategies to Reduce the Impacts in Zimbabwe. Atmosphere 14, 1692. https://doi.org/10.3390/atmos14111692

Mutsvanga, S., Gasura, E., Setimela, P.S., Nyakurwa, C.S., Mabasa, S., 2022. Nutritional management and maize variety combination effectively control Striga asiatica in southern Africa. CABI Agric Biosci 3, 47. https://doi.org/10.1186/s43170-022-00108-4

Muzhingi, T., Langyintuo, A.S., Malaba, L.C., Banziger, M., 2008. Consumer acceptability of yellow maize products in Zimbabwe. Food Policy 33, 352–361. https://doi.org/10.1016/j.foodpol.2007.09.003

Ocwa, A., Harsanyi, E., Széles, A., Holb, I.J., Szabó, S., Rátonyi, T., Mohammed, S., 2023. A bibliographic review of climate change and fertilization as the main drivers of maize yield: implications for food security. Agric & Food Secur 12, 14. https://doi.org/10.1186/s40066-023-00419-3

Ocwa, A., Mohammed, S., Mousavi, S.M.N., Illés, Á., Bojtor, C., Ragán, P., Rátonyi, T., Harsányi, E., 2024. Maize Grain Yield and Quality Improvement Through Biostimulant Application: a Systematic Review. J Soil Sci Plant Nutr 24, 1609–1649. https://doi.org/10.1007/s42729-024-01687-z

Odunze, D.I., 2019. Zimbabwe's Special Maize Programme for the Import Substitution (Command Agriculture) Scheme: A Hit-and-Miss Affair. J. Rev. Global Econ. 8, 1329–1338. https://doi.org/10.6000/1929-7092.2019.08.116

Othibeng, K., Nephali, L., Ramabulana, A.-T., Steenkamp, P., Petras, D., Kang, K.B., Opperman, H., Huyser, J., Tugizimana, F., 2021. A Metabolic Choreography of Maize Plants Treated with a Humic Substance-Based Biostimulant under Normal and Starved Conditions. Metabolites 11, 403. https://doi.org/10.3390/metabo11060403

Pasley, H.R., Cairns, J.E., Camberato, J.J., Vyn, T.J., 2019. Nitrogen fertilizer rate increases plant uptake and soil availability of essential nutrients in continuous maize production in Kenya and Zimbabwe. Nutr Cycl Agroecosyst 115, 373–389. https://doi.org/10.1007/s10705-019-10016-1

Petrovic, S., Sherland, M., 2023. Zimbabwe, in: Petrovic, S. (Ed.), World Energy Handbook. Springer International Publishing, Cham, pp. 137–149. https://doi.org/10.1007/978-3-031-31625-8_16

Sardana, V., Mahajan, G., Jabran, K., Chauhan, B.S., 2017. Role of competition in managing weeds: An introduction to the special issue. Crop Protection 95, 1–7. https://doi.org/10.1016/j.cropro.2016.09.011

Sun, W., Shahrajabian, M.H., 2023. The Application of Arbuscular Mycorrhizal Fungi as Microbial Biostimulant, Sustainable Approaches in Modern Agriculture. Plants 12, 3101. https://doi.org/10.3390/plants12173101

Szőke, L., Moloi, M., Kovács, G., Biró, G., Radócz, L., Hájos, M., Kovács, B., Rácz, D., Danter, M., Tóth, B., 2021. The Application of Phytohormones as Biostimulants in Corn Smut Infected Hungarian Sweet and Fodder Corn Hybrids. Plants 10, 1822. https://doi.org/10.3390/plants10091822

Tibugari, H., Chikasha, T., Manyeruke, N., Mathema, N., Musara, J.P., Dlamini, D., Mapuranga, R., Mapanje, O., Banda, A., Parwada, C., 2019. Poor maize productivity in Zimbabwe: Can collusion in pricing by seed houses be the cause? Cogent Food & Agriculture 5, 1682230. https://doi.org/10.1080/23311932.2019.1682230

Toscano, S., Romano, D., Patanè, C., 2023. Effect of Application of Biostimulants on the Biomass, Nitrate, Pigments, and Antioxidants Content in Radish and Turnip Microgreens. Agronomy 13, 145. https://doi.org/10.3390/agronomy13010145

Vujinović, T., Zanin, L., Venuti, S., Contin, M., Ceccon, P., Tomasi, N., Pinton, R., Cesco, S., De Nobili, M., 2020. Biostimulant Action of Dissolved Humic Substances From a Conventionally and an Organically Managed Soil on Nitrate Acquisition in Maize Plants. Front. Plant Sci. 10, 1652. https://doi.org/10.3389/fpls.2019.01652

Vultaggio, L., Bellitto, P., Mancuso, F., Campana, E., Ciriello, M., Consentino, B.B., Rouphael, Y., Colla, G., Karavidas, I., La Bella, S., Sabatino, L., 2025. Genotype-biostimulant association reveals the guidelines for an improved cherry tomato soilless cultivation. Scientia Horticulturae 343, 114097. https://doi.org/10.1016/j.scienta.2025.114097

Wen, Z., Shen, J., Blackwell, M., Li, H., Zhao, B., Yuan, H., 2016. Combined Applications of Nitrogen and Phosphorus Fertilizers with Manure Increase Maize Yield and Nutrient Uptake via Stimulating Root Growth in a Long-Term Experiment. Pedosphere 26, 62–73. https://doi.org/10.1016/S1002-0160(15)60023-6

APPENDICES

Appendix 1: Accumulated soil test results for the research site

Experimental site	Dry Sample	Wet Sample
Ph	6.2	5.87
PBray1 (mg/kg)	39	27
PBray2 (mg/kg)	40	33
N (mg/kg)	17	17
K (mg/kg)	52	50
Ca (mg/kg)	323	325
Mg (mg/kg)	87	94
Exchangeable acid (Cmol H+/Kg Soil)	0	0
%Ca	67.5	66.8
%Mg	18.1	19.4
%K	10.9	10.3
%N	3.6	3.5

Appendix 2: Analysis of variance (ANOVA) Tables

Appendix 2.1: Analysis of variance for plant height (cm) at 3 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	1.5658	0.7829	1.50	
Apex 10 appl. rate	3	3.1100	1.0367	1.99	0.162
Variety	1	0.7350	0.7350	1.41	0.255
Apex 10 AR × Variety	3	0.9483	0.3161	0.61	0.621
Residual	14	7.2942	0.5210		
Total	23	13.6533			

Appendix 2.2: Analysis of variance for plant height (cm) at 5 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	169.98	84.99	1.59	
Apex 10 appl. rate	3	4356.46	1452.15	27.22	<.001
Variety	1	58.28	58.28	1.09	0.314
Apex 10 AR × Variety	3	150.28	50.09	0.94	0.448
Residual	14	746.93	53.5		
Total	23	5481.94			

Appendix 2.3: Analysis of variance for plant height (cm) at 7 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	108.73	54.36	2.57	
Apex 10 appl. rate	3	4304.62	1434.87	65.19	<.001
Variety	1	1.00	1.00	0.05	0.834
Apex 10 AR × Variety	3	138.28	46.09	2.09	0.147
Residual	14	308.13	22.01		
Total	23	4860.76			

Appendix 2.4: Analysis of variance for plant height (cm) at 9 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	751.75	375.87	5.46	
Apex 10 appl. rate	3	6958.53	2319.51	33.67	<.001
Variety	1	0.18	0.18	0.00	0.960
Apex 10 AR × Variety	3	80.39	26.80	0.39	0.763
Residual	14	964.37	68.88		
Total	23	8755.23			

Appendix 2.5: Analysis of variance for plant height (cm) at 11 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	595.86	297.93	8.03	
Apex 10 appl. rate	3	5310.98	1770.33	47.73	<.001
Variety	1	15.36	15.36	0.41	0.530
Apex 10 AR × Variety	3	156.67	52.22	1.41	0.282
Residual	14	519.28	37.09		
Total	23	6598.15			

Appendix 2.6: Analysis of variance for plant height (cm) at 13 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	324.96	162.48	4.73	
Apex 10 appl. rate	3	10409.66	3469.89	100.91	<.001
Variety	1	7.15	7.15	0.21	0.655
Apex 10 AR × Variety	3	55.61	18.54	0.54	0.663
Residual	14	481.39	34.38		
Total	23	11278.78			

Appendix 2.7: Analysis of variance for plant height (cm) at 15 WAP

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	134.63	67.31	1.40	
Apex 10 appl. rate	3	6845.57	2281.86	47.46	<.001
Variety	1	13.50	13.50	0.25	0.862
Apex 10 AR × Variety	3	35.63	11.88	0.25	0.862
Residual	14	673.11	48.08		
Total	23	7702.44			

Appendix 2.8: Analysis of variance for maize above ground biomass (kg)

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	19.051	9.525	0.96	
Apex 10 appl. rate	3	818.425	272.808	27.61	<.001
Variety	1	0.700	0.700	0.07	0.794
Apex 10 AR × Variety	3	28.165	9.388	0.95	0.443
Residual	14	138.329	9.881		
Total	23	1004.670			

Appendix 2.9: Analysis of variance for maize below ground biomass (kg)

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	1.6525	0.8263	2.72	
Apex 10 appl. rate	3	61.8283	20.6094	67.93	<.001
Variety	1	0.0817	0.0817	0.27	0.612
Apex 10 AR × Variety	3	2.9950	0.9983	3.29	0.052
Residual	14	4.2475	0.3034		
Total	23	70.8050			

Appendix 2.10: Analysis of variance for maize ear weight (g)

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	93.2500	46.6250	64.74	
Apex 10 appl. rate	3	44117.6667	14705.8889	20418.09	<.001
Variety	1	170.6667	170.6667	236.96	<.001
Apex 10 AR × Variety	3	6.3333	2.1111	2.93	0.070
Residual	14	10.0833	0.7202		
Total	23	44398.0000			

Appendix 2.11: Analysis of variance for maize grain weight (t/ha)

Source of variation	d.f.	s.s.	m.s.	F. value	F pr.
Block	2	0.048933	0.024467	10.46	
Apex 10 appl. rate	3	54.371333	18.123778	7751.51	<.001
Variety	1	0.144150	0.144150	61.65	<.001
Apex 10 AR × Variety	3	0.022183	0.007394	3.16	0.0586
Residual	14	0.032733	0.002338		
Total	23	54.619333			