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EVALUATING THE RESPONSE OF MAIZE TO DIFFERENT FERTILIZER TIMINGS

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DEDICTION

I dedicate this dissertation to my parents Mr and Mrs Mugurachachani, Unique, Uniphah and Gratitude

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ABSTRACT

Optimal timing of top dressing nitrogen fertilizer application is crucial for maximizing maize grain yield and reducing impacts of maize productivity. The objective of this study was to evaluate the effects of five different top dressing fertilizer applications timings on maize plant height, plant lodging, response to grey leaf spot, 1000 kernel weight and grain yield. The experiment was conducted in a complete randomized block design with five treatments. The treatments included very early application, early application, two splits, five splits and delayed application. Data collection was done starting from the vegetative stage up to the point after harvesting where final grain yield was measured. Data was analysed using analysis of variance (ANOVA) with Genstat 18th edition and Fischer's protected test least significant difference test (LSD) at 0.05 significant level to separate the treatment means. The results showed that the five splits had the highest final grain yield, while lodging was the lowest and generally performs better in all the measured parameters. These finding indicate that applying top dressing nitrogen fertilizer to maize in splits applications throughout the growing season can optimize plant growth rate, reduce disease pressure, improves root development and grain yield. The five splits timing likely provided a more consistent supply of nitrogen to the crop during critical growth stages compared to very early, early and delayed application. Therefore, it can be recommended to farmers that consider implementing splitting top dressing into at least three to five splits to improve maize productivity and resource use efficiency. In conclusion the results suggest that proper timing of top dressing fertilizer application can significantly affect growth and yield with five splits showing promising results.

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CHAPTER ONE

1.0 INTRODCUTION

1.1 Background of study

Maize is the third most vital cereal crop globally, following wheat and rice (Feyisa, 2017). As a fundamental food source, maize is deeply rooted in many regions worldwide, including Sub-Saharan Africa, where it significantly contributes to food security and sustains rural communities (Silva et al., 2018; Twumasi-Afriyie et al., 2019). Its versatility in various industries like food, feed, and biofuel makes it a driving force in global agriculture (FAO, 2020). To maximize maize production, top-dressing fertilizer application has become a widespread practice worldwide (Tang, 2010). This technique provides essential nutrients during critical growth phases (Reichel, 2022). However, the timing of application can substantially influence crop yield (Maringa, 2000). Researchers are increasingly interested in exploring how different top-dressing fertilizer application strategies impact maize productivity. These strategies include early application, split application, and delayed application, offering farmers flexible options tailored to their specific needs and constraints. Numerous studies have explored the effects of top-dressing fertilizer application timing on maize productivity. For instance, research conducted by Rehm *et al.* (2018) found that early application of top dressing fertilizer resulted in increased biomass accumulation and grain yield compared to late application. Contrariwise, a study by Limon-Ortega et al. (2016) observed that split application of top dressing fertilizer at different growth stages improved the nutrient uptake efficiency of maize plants. An understanding of the response of maize to diverse top-dressing fertilizer application timings is fundamental for optimizing resource utilization and improving crop performance. By comparing these three strategies, farmers can make informed decisions regarding fertilizer application timing, leading to enhanced maize yields and reduced environmental impact.

This research endeavors to investigate the effects of diverse top-dressing fertilizer application timings - including very early, early, split, and delayed applications - on maize performance. By conducting exhaustive experiments and analyses, this study aims to unravel the complex interplay between fertilizer application timing and maize crop productivity. The outcomes of this investigation will inform the development of data-driven guidelines for farmers, empowering them to optimize fertilizer application schedules and enhance their maize yields.

1.2 Statement of the Problem

Achieving optimal maize yields remains a challenge due to various factors, including suboptimal nutrient management practices (Tittonell *et al.,* 2013). Among these practices, top dressing fertilization plays a critical role in providing supplemental nutrients to the growing maize plants during their vegetative and reproductive stages (Morais 2016). While top-dressing fertilization is widely acknowledged as an effective strategy for enhancing maize yields, there is limited research specifically assessing the response of maize to different timing strategies for top-dressing fertilizer application. The three most common timing strategies include early application, split application, and delayed application of top dressing fertilizer.

To date, there is a lack of comprehensive studies that directly compare these three timing strategies for top-dressing fertilizer application on maize. Existing research primarily focuses on overall fertilizer rates and formulas, neglecting the potential impact of timing strategies on maize productivity (Vanlauwe *et al.*, 2008; Tetteh et al., 2015). This knowledge gap limits farmers' ability to optimize their fertilizer management decisions and may result in suboptimal yield outcomes. Therefore, there is a critical need to conduct research comparing the effects of early, split, and delayed application of top-dressing fertilizer on maize productivity to provide evidence-based recommendations for farmers and policymakers. This study aims to fill this knowledge gap and contribute to improved maize production and food security in Sub-Saharan Africa and other maize-growing regions.

1.3 Justification

Maize is one of the most important cereal crops globally serving as a staple food for millions of people and supporting various agricultural industries, (Kirirah 2024). As the demand for maize continues to increase, it is imperative to optimize its production to meet these growing needs. Fertilization is a crucial component of maize cultivation, as it provides essential nutrients necessary for plant growth and development. Top dressing fertilizers are commonly applied to maize crops to supplement nutrient availability during critical growth stages. However, the timing of fertilizer application can greatly influence its effectiveness on some growth parameters in maize and impact crop yield. The timings of top dressing application have gained attention as potential methods to enhance nutrient uptake efficiency and maximize maize productivity. Understanding how different top dressing fertilizer application timings affect maize crop response is crucial as it allows farmers to make informed decisions about when and how to apply fertilizer, optimizing resource utilization, reducing costs and farmers can avoid nutrient deficiencies or excesses, which can lead to reduced yields and environmental pollution. This knowledge can help researchers and agronomists develop targeted fertilizer management practices that maximize nutrient use efficiency, reduce nutrient losses, and promote sustainable agriculture. By understanding the relationship between fertilizer timing and crop response, farmers can minimize the risk of nutrient leaching or runoff, which can negatively impact water quality and ecosystem health. It can provide evidence-based recommendations and guidelines for fertilizer management practices, enabling farmers, researchers and policy makers to make informed decisions that promote both economic profitability and environmental sustainability.

1.3 Objectives

1.3.1 Main Objective

To evaluate the response of maize to different fertilizer application timings.

1.3.2 Specific Objective

- To assess the effects of different top dressing fertilizer timings on agronomic traits performance of maize.
- To evaluate the effects of different top dressing fertilizer timings on grain yield potential and its components of maize.

1.4 Hypothesis

- There is significant variation in the timing of top dressing fertiliser application on the agronomic traits performance of maize.
- There is significant variation in the timing of top dressing fertiliser on the grain yield potential and its components of maize.

CHAPTER TWO

2.0 LITERATURE REVIEW

Maize originated from Mexico and Central America (Hossain et al., (2016). Maize later spread to different parts of the world including America, Europe, Africa, and Asia (Hossain *et al*., 2016). In Africa, maize was introduced by the Portuguese around 1493 and spread rapidly due to its adaptability and productivity (Hossain *et al.*2016).

2.1 Origin and introduction of maize in Africa

Portuguese merchants introduced maize into Africa through their trade networks along the western and eastern coasts of Africa starting in the 16th century (McCann, 2005). There are historical records and evidence of maize cultivation in Cape Verde in 1541, Angola in 1590, and Mozambique in 1821, (McCann, 2005). The Dutch introduced maize along the southern African coast in 1658, but this maize is thought to have originated from West Africa's Guinea coast, (Miracle, 1966). In Zimbabwe, white settlers started producing maize as early as the 1890s, (Weinmann, 1972).

2.2 Importance of maize and its uses in Africa

The cereal import requirement for the marketing year 1999/2000 (April/March) was estimated at 545 000 tonnes, of which about one-half was covered by commercial imports, resulting in reduced utilization. The period since 1980 also saw an increasing proportion of maize production coming from the communal farm sector from around 31 percent in 1983 to a peak of 66 percent in 1997, (Government of Zimbabwe, 2000). These gains are likely to be compromised by the disturbances and the deepening economic problems. In Western Ethiopia, farmer's value increased grain output and marketplace prices (Abera 2013).

2.3 Maize production in Zimbabwe

Maize is a vital crop in Zimbabwe, ensuring food security and serving as a crucial raw material for agro-industrial processes (Mutambara, 2016). It is the most widely produced cereal in the country, cultivated by 90% of farmers, with 54% being small-scale farmers who produce below-average yields and 46% being large-scale farmers who produce above-average yields (Chiweta, 2012). Zimbabwe's annual maize consumption stands at 2.1 million tonnes, with 64% used for human consumption, 22% for livestock and poultry, and 14% for other purposes (Mashingaidze, 2006). Maize production is prominent in high rainfall areas, but it is also grown in drought-prone regions, where short-season varieties are preferred to mitigate the effects of climate change (Bonea, 2020). Commercial farmers produce 30-40% of maize, while small-scale communal and A1 farmers produce 60-70% (Siziba, 2019). Yields on commercial farms are generally higher due to better land quality, irrigation infrastructure, access to working capital, advanced technology, and improved agronomic management practices (Mushunje, 2011). Small-scale farmers prefer medium-maturity and early-maturity varieties, which are more suitable for their production conditions, whereas commercial farmers opt for high-yielding long-maturing varieties (Mushunje, 2011). The use of open-pollinated varieties and recycling seeds has led to deteriorating yields and grain quality, highlighting the need for improved seed systems (CIMMTY, 2007). Maize growth responds well to high temperatures in October, November, and December, making these months critical for maize production (Zinyenge, 2011). Climate change is shifting seasons, affecting small-scale farmers who rely on rainfall, leading to adjustments in planting dates and varieties used (Mugiyo, 2021). A study in Hwedza, Zimbabwe, found that most farmers grow short-season varieties, followed by medium-season varieties, and that rainy days and planting dates significantly influence maize production, emphasizing the importance of climate-smart agriculture (Mugiyo, 2021).

2.4 Maize production challenges in Zimbabwe

2.4.1 Climate change

Zimbabwe's maize production is facing significant threats from climate change, which has led to unpredictable and reduced rainfall patterns (Masuka et al., 2017). Prolonged droughts and erratic rainfall distribution have resulted in decreased maize yields, as the crop relies heavily on adequate soil moisture (Rurinda et al., 2020). Rising temperatures, particularly during critical growth stages, can cause heat stress, reduce photosynthesis, and ultimately decrease yields (Rurinda et al., 2015). Extreme heat events can also disrupt pollination and grain filling, leading to additional yield losses (Lobell et al., 2011). Climate change is causing shifts in agro-ecological zones, resulting in the expansion of marginal areas unsuitable for maize production (Rurinda 2020). This forces farmers to cultivate in regions with poorer soil fertility and less reliable rainfall patterns, which are less conducive for optimal maize growth (Zinyengere 2014). Warmer and more humid conditions associated with climate change can contribute to the proliferation and range expansion of various maize pests and diseases, such as the fall armyworm and maize lethal necrosis disease (Maphosa & Jideani, 2017). These biotic stresses can cause significant yield losses if left unmanaged (Nutter et al., 2002). Extreme weather events, such as heavy rainfalls and droughts, can lead to increased soil erosion, nutrient leaching, and overall soil degradation in Zimbabwe (Rurinda et al., 2020). The reduced soil fertility and nutrient availability negatively impact maize productivity, especially in resource-constrained smallholder farming systems (Zinyengere 2014). The combined effects of climate change on maize production have led to increased food insecurity, reduced incomes, and greater vulnerability for smallholder farmers in Zimbabwe (Masuka et al., 2017). This can exacerbate poverty and limit the ability of farmers to invest in adaptive strategies, creating a vicious cycle (Rurinda et al., 2015).

2.4.2 Abiotic stress

Zimbabwe's maize production is severely impacted by climate change, leading to frequent and prolonged droughts, which are the most significant abiotic stress affecting maize yields (Rurinda et al., 2020). Drought reduces soil moisture, causing wilting, reduced photosynthesis, and poor grain filling, resulting in substantial yield losses (Lobell, 2011). Smallholder farmers lack access to drought-tolerant maize varieties and irrigation, exacerbating drought stress (Masuka et al., 2017). Rising temperatures, especially during critical growth stages, can cause harm to maize plants, leading to pollen sterility, reduced kernel set, and accelerated crop maturity, ultimately decreasing yields (Cairns et al., 2013). The combination of drought and heat stress has synergistic negative effects on maize productivity, further reducing yields (Rurinda et al., 2020). Unexpected heavy rainfall events, exacerbated by climate change, can lead to waterlogging and flooding, impairing root growth, nutrient uptake, and causing anaerobic conditions, ultimately reducing maize yields (Mabhaudhi et al., 2018). Smallholder farmers lack resources and knowledge to manage waterlogging, soil degradation, erosion, and nutrient depletion, limiting nutrient availability and leading to nutrient deficiencies and reduced yields (Rurinda et al., 2020).

High fertilizer costs and poor irrigation management can lead to soil salinity and sodicity, negatively impacting maize production (Mabhaudhi et al., 2018). Abiotic stresses often occur in combination, compounding their effects and leading to greater yield losses (Rurinda et al., 2020). For example, drought, heat stress, and nutrient deficiencies can have synergistic negative impacts on maize performance, resulting in significant yield reductions (Cairns et al., 2013).Climate change-induced extreme weather events, such as heavy rainfall and drought, can lead to soil erosion, nutrient leaching, and overall soil degradation, further reducing maize productivity (Rurinda et al., 2020). Smallholder farmers' limited access to credit, markets, and extension services exacerbates the impacts of abiotic stresses on maize production (Masuka et al., 2017). The cumulative effects of these factors result in reduced maize yields, decreased food security, and increased poverty among smallholder farmers in Zimbabwe (Rurinda et al., 2020).).

2.4.3 Biotic stress

Maize is affected by a range of insect pests, including Stem borers (Busseola fusca) which cause significant yield losses by feeding on the plant's stem and leaves (Mwololo *et al.*, 2013). Another pest is Fall armyworm (Spodoptera frugiperda) an invasive pest that can cause up to 100% yield loss if left uncontrolled (Kumela *et al.*, 2019). Aphids (Rhopalosiphum maidis) reduce plant vigour and transmit viral diseases (Mwololo *et al*., 2013). Smallholder farmers often have limited access to effective pest management strategies, such as pesticides and integrated pest management (IPM) techniques.

Common maize diseases in Zimbabwe include Grey leaf spot (Cercospora zeae-maydis) which reduces photosynthetic area and can lead to substantial yield reductions (Benson & Hooker, 1990). Maize streak virus (MSV) transmitted by leafhoppers, can cause up to 100% yield loss (Mwololo et al., 2013). Smallholder farmers often lack access to disease-resistant maize varieties and appropriate disease management strategies. Competitive weeds, such as Cyperus rotundus, Cynodon dactylon, and Echinochloa colona, can significantly reduce maize yields by competing for resources (Nyakudya & Stroosnijder, 2014). Smallholder farmers often have limited resources and knowledge to effectively manage weeds, leading to significant yield losses. Striga (Striga asiatica) is a parasitic weed that can cause up to 100% yield loss in maize production (Nduwumuremyi *et al*., 2016). Striga infestation is exacerbated by poor soil fertility, drought, and limited access to effective control measures. Biotic stresses often occur in combination, and their effects can be compounded, leading to even greater yield losses (Kumela *et al.*, 2019). For example, the co-occurrence of pests, diseases, and weeds can have synergistic negative impacts on maize performance.

2.4.4 High inputs costs

Maize is a nutrient-intensive crop, requiring significant amounts of nitrogen, phosphorus, and potassium to achieve high yields (Mafongoya *et al.*, 2016). The cost of chemical fertilizers in Zimbabwe has been rising due to factors such as global supply chain disruptions, currency fluctuations, and limited domestic production (Nyamangara *et al.*, 2019). Smallholder farmers often lack the financial resources to afford the recommended fertilizer application rates, leading to reduced yields and soil fertility depletion. Improved, high-yielding maize varieties are essential for maximizing production, but the costs of these seeds can be prohibitive for many smallholder farmers (Mazvimavi & Twomlow, 2009). Smallholder farmers often resort to using saved or recycled seeds, which can result in lower yields and increased susceptibility to pests and diseases. Pesticides, herbicides, and other agrochemicals are necessary to manage the various biotic stresses affecting maize production (Mafongoya *et al.*, 2016). The rising costs of these inputs, coupled with limited access to subsidies or credit, make it challenging for smallholder farmers to effectively control pests, weeds, and diseases. Maize production requires various mechanized operations, such as land preparation, planting, and harvesting, which can be costly for smallholder farmers (Mafongoya *et al.*, 2016). The high cost of hiring labor for manual operations, such as weeding, can also be a significant burden for smallholder farmers. Transporting inputs and outputs to and from remote rural areas can be expensive, further increasing the overall cost of maize production (Nyamangara *et al.*, 2019). The cost of proper storage facilities to maintain the quality and quantity of maize after harvest can also be prohibitive for smallholder farmers. Smallholder farmers in Zimbabwe often have limited access to credit and other financial services that could help them afford the necessary inputs for maize production (Mazvimavi & Twomlow, 2009). The lack of collateral and high interest rates make it challenging for smallholder farmers to obtain the financing they need to invest in their maize crops.

2.5 Fertilizer requirements for maize

Maize is a crop that requires a substantial amount of nutrients to thrive, particularly phosphorus, nitrogen, and potassium (Berge et al., 2019). Additionally, it needs micronutrients like magnesium, boron, copper, zinc, and iron to maintain its health and productivity. Nitrogen is the most critical nutrient for maize growth and development, as it plays a central role in photosynthesis, plant health, and yield (Vijayalakshmi et al., 2013). It influences the crop's ability to intercept and utilize sunlight, partition reproductive organs, and synthesize proteins (Sandhu et al., 2021). Nitrogen is also a key component of chlorophyll, the pigment that absorbs light during photosynthesis, converting it into chemical energy (Han, 2016). Adequate nitrogen supply is essential for emergence, plant elongation, and yields (Bozkurt, 2006). However, nitrogen deficiency during anthesis can impact pollen quality and quantity, leading to reduced pollination and kernel set. Excessive nitrogen application can cause imbalances in the absorption of other nutrients like potassium and minor nutrients (Jipa, 2019).

Phosphorus is another critical nutrient for maize, absorbed as primary and secondary orthophosphate ions (Alley, 2019). It stimulates root growth, stalk strength, and crop quality, and contributes to metabolic functions and energy reactions like photosynthesis and respiration (Grant, 2001; Hussain et al., 2007). Phosphorus deficiency can result in stunted growth, purpling leaves, and reduced seed development and maturity (Nielsen, 2017; Below, 2014).

Potassium is vital for maize growth, regulating plant water relations, activating enzymes, and facilitating the uptake and translocation of nitrates (Berge et al., 2019). It also plays a role in moisture loss and resistance to disease and insect attack. The quantity of nutrients supplied to maize plants is crucial, and research has shown that optimum nitrogen application and balanced NPK levels significantly influence growth and grain yield (Abera et al., 2017; Laura & Suciu, 2021). Incremental NPK levels can impact the fatty acid composition of maize oil, increasing saturated fatty acids and decreasing unsaturated fatty acids (Laura & Suciu, 2021).

2.6 Effects of ammonium nitrate top dressing fertiliser in maize

Top dressing Ammonium Nitrate fertilizer provides an additional source of nitrogen (N) to the maize crop during the critical growth stages, such as tasseling and grain fill (Bender *et al.,* 2013). This helps ensure adequate N availability for optimal plant growth, development, and yield formation (Ladha *et al*., 2005). The timely application of Ammonium Nitrate fertilizer as a top dress can significantly boost maize grain yields (Fageria & Baligar, 2005). The additional N helps support increased leaf area, photosynthetic capacity, and the development of more kernels per ear and larger kernel size (Gokmen *et al.,* 2001). Top dressing with Ammonium Nitrate fertilizer can lead to a higher protein content in the harvested maize grain (Lemaire *et al.,* 2008). This is because nitrogen is a key component of amino acids, which are the building blocks of plant proteins (Sinclair & Horie, 1989). Splitting the total N application between basal and top dressing can improve the overall nitrogen use efficiency of the maize crop (Cassman *et al.,* 2002). This is because the top-dressed N is more readily available to the plants during the critical growth stages when N demand is highest (Yadav *et al.,* 1998). Top dressing Ammonium Nitrate fertilizer can help compensate for any potential nitrogen losses that may have occurred earlier in the season, such as through leaching or volatilization (Sharma & Bali, 2018). This can help ensure that the maize crop has access to sufficient nitrogen throughout its growth cycle (Rao & Reddy, 2010).

2.7 Grain and its allied traits

2.7.1 Grain yield

Top dressing Ammonium Nitrate fertilizer can significantly increase maize grain yield compared to not applying any top dressing (Fageria & Baligar, 2005). The additional nitrogen supplied by the top-dressed

Ammonium Nitrate fertilizer helps support increased ear size, kernel development, and overall grain production (Bender *et al.,* 2013). The timing and rate of top dressing Ammonium Nitrate fertilizer application can impact the magnitude of the grain yield response in maize (Cassman *et al.,* 2002). Applying the top dressing at the appropriate growth stage, such as tasseling or early grain fill, can maximize the yield benefits (Yadav *et al.,* 199yield. Splitting the total nitrogen application between basal and top dressing can improve the overall nitrogen use efficiency of the maize crop (Ladha *et al*., 2005). This is because the top-dressed Ammonium Nitrate fertilizer is more readily available to the plants during the critical growth stages when nitrogen demand is highest (Sharma & Bali, 2018). Top dressing Ammonium Nitrate fertilizer can help offset any potential nitrogen losses that may have occurred earlier in the season, such as through leaching or volatilization (Rao & Reddy, 2010). This can help ensure that the maize crop has access to sufficient nitrogen throughout its growth cycle, leading to higher grain yields (Sinclair & Horie, 1989). The benefits of top dressing Ammonium Nitrate fertilizer on maize grain yield can be enhanced when combined with other good agronomic practices, such as timely planting, proper weed control, and appropriate water management (Gokmen *et al.,* 2001). This integrated approach can maximize the overall productivity and efficiency of the maize production system (Lemaire *et al*., 2008).

2.7.2 Plant height

Top dressing Ammonium Nitrate fertilizer has been shown to significantly increase plant height in maize compared to no top dressing application (Abera *et al.,* 2016). The additional nitrogen supplied by the top-dressed Ammonium Nitrate fertilizer promotes vegetative growth, leading to taller plants (Fageria & Baligar, 2005). The timing and rate of top dressing Ammonium Nitrate fertilizer application can impact the magnitude of the plant height response in maize (Cassman *et al.,* 2002). Applying the top dressing at the appropriate growth stage, such as the knee-high or tasseling stage, can maximize the positive effect on plant height (Yadav *et al.,* 1998). Top dressing Ammonium Nitrate fertilizer can enhance the overall nutrient uptake and utilization efficiency of the maize crop (Ladha *et al*., 2005). This improved nutrient status, especially nitrogen, supports increased vegetative growth and, consequently, taller plants (Sharma & Bali, 2018). Top dressing fertilizer can help overcome any potential nitrogen deficiency that may have occurred earlier in the season, ensuring the maize plants have access to sufficient nitrogen for optimal growth (Rao & Reddy, 2010). This can lead to taller plants by preventing stunted growth due to nitrogen limitations (Sinclair & Horie, 1989). The benefits of top dressing fertilizer on maize plant height can be enhanced when combined with other good agronomic practices, such as proper soil preparation, timely planting, and appropriate pest and disease management (Gokmen *et al*., 2001). This integrated approach can maximize the overall growth and development of the maize plants, resulting in taller plants (Lemaire *et al*., 2008).

2.7.3 Days to flowering

Top dressing Ammonium Nitrate fertilizer has been shown to significantly reduce the number of days to flowering in maize compared to no top dressing application (Pal et al., 2016). The additional nitrogen provided by the Ammonium Nitrate fertilizer promotes earlier reproductive development in maize plants (Fageria & Baligar, 2005). Top dressing enhances the overall nutrient status of the maize crop, particularly the availability of nitrogen (Cassman *et al.*, 2002). This improved nutrient availability can trigger earlier flowering and reproductive maturity in maize plants (Sinclair & Horie, 1989). The timing and rate of top dressing fertilizer application can influence the magnitude of the effect on days to flowering in maize (Rao & Reddy, 2010). Applying the top dressing at the appropriate growth stage, such as the tasseling or silking stage, can maximize the impact on accelerating flowering (Abera et al., 2016). Top dressing fertilizer can help overcome any potential nitrogen deficiency that may have occurred earlier in the season, ensuring the maize plants have access to sufficient nitrogen for optimal growth and development (Sharma & Bali, 2018). This can lead to earlier flowering by preventing delayed reproductive maturity due to nitrogen limitations (Ladha *et al*., 2005). The benefits of top dressing Ammonium Nitrate fertilizer on reducing days to flowering in maize can be enhanced when combined with other good agronomic practices, such as proper soil preparation, timely planting, and appropriate pest and disease management (Gokmen *et al.*, 2001). This integrated approach can maximize the overall growth and development of the maize plants, resulting in earlier flowering (Lemaire *et al.*, 2008).

2.7.4 1000 kernel weight

Top dressing fertilizer has been shown to significantly increase the 1000 kernel weight (also known as thousand-grain weight) of maize compared to no top dressing application (Gungula *et al.*, 2005). The additional nitrogen supplied by the top-dressed Ammonium Nitrate fertilizer promotes better grain filling and kernel development, resulting in larger and heavier kernels (Binder *et al.*, 2000). Top dressing fertilizer enhances the overall availability of nitrogen, which is essential for the synthesis of starch, proteins, and other components within the maize kernels (Ciampitti & Vyn, 2013). This improved nutrient status leads to increased kernel size, weight, and density, ultimately contributing to a higher 1000 kernel weight (Tollenaar & Lee, 2002). The timing and rate of top dressing fertilizer application can influence the magnitude of the effect on 1000 kernel weight in maize (Rao & Reddy, 2010). Applying the top dressing at the appropriate growth stage, such as the silking or grain filling stage, can maximize the impact on increasing kernel weight (Abera et al., 2016). The positive effect of top dressing fertilizer on 1000 kernel weight can be further enhanced when combined with the optimal application of other essential nutrients, such as phosphorus and potassium (Gungula *et al.*, 2005). A balanced nutrient supply ensures the maize plants have access to all the necessary resources for robust grain development (Fageria & Baligar, 2005). The response of 1000 kernel weight to top dressing AN fertilizer can vary among different maize cultivars or hybrids (Tollenaar & Lee, 2002). Certain genotypes may be more responsive to the additional nitrogen supply, leading to greater increases in kernel weight (Binder et al., 2000).

2.8 Diseases in maize

Farmers always pay serious attention to disease resistance in maize because diseases tend to affect production (Zander 2022). Farmers need to create an environment that keeps the crop well fed, heath giving it the power to overcome some diseases and pests (Abera, 2013). This will therefore lower losses through diseases and use of pesticides. A satisfactory nitrogen supply can improve a plant's resistance against pests such as the autumn armyworm by increasing biomass and nutritional content (Wang 2022). Nitrogen levels influence maize development, yield, and quality (Ariraman 2020). On the pessimistic side high nitrogen levels might make maize more liable to pests like stem and cob borer resulting from excessive nitrogen leading to plant growth and pest development (Sétamou 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study site

The research was done at Mariandale farm (170S and 300E), 13km from Chinhoyi in Zimbabwe which is in agro-ecological region II. The mean annual rainfall is approximately 880mm, but this is subject to wide fluctuations and in the last 30 years has varied between 430mm and 1320mm (The Met Department, 2020) slightly more than two-thirds of the total rainfall normally falls during the months December, January and February. Mean minimum temperature ranges from 19.5º C (July) to 24.6º C (January). The area is dominated by sand-loamy soils of granitic origin with a pH ranging from 5.5- 6.5 (Nyamowa, 2019).

3.2 Experimental design

The single-factor experiment was done in an open field from November 2023 and was laid out in a Randomized Complete Block Design (RCBD) with five treatments replicated three times with slope as a blocking factor. Plot A top dressing was applied very early at two weeks after planting, plot B top dressing was applied four weeks from emergency, plot C top dressing was applied very late (delayed), plot D split into five splits, plot E top dressing was split into two which was the control. This followed a protocol by Suhane et al., (2008).

3.3 Experimental procedure

The entire field for the trial was divided into different homogenous units based on measurements taken and a random soil sampling technique was carried out on the entire field before planting. The field was separated into three strata based on three blocks which were made for replication of treatments. Land preparation was done using a disk harrow and a tractor to a depth of 30cm to obtain a fine tilth. Two-meter by one-meter plots were made leaving 30cm pathways. Planting stations were made using hoes. Plant spacing was 90cm x 30cm which gives a plant population of 37 037 plant per hectare. Each plot had two rows containing 7 plants. All agronomic practices such as keeping the crop weed-free and top dressing were done.

The plots were kept weed-free by rouging weeds or using hand hoes. For weed management glyphosate, metalochlor, and stellar star were used. Glyphosate (non-selective herbicide) was applied as part land preparation at a rate of 2litres per hectare. Its non-selective characteristic is essential for total weed eradication before planting. Metalochlor was to tank mixed with glyphosate and used as pre-emergence at a rate of 2litters per hectare. Stellar star a selective pre and post emergence herbicide for grasses and broad leaves was applied at a rate of 1litre per hectare. Uphold was full cover sprayed at sight of pest to control fall armyworms at a rate of 2litres per hectare. The crops were rain fed and irrigation was used a supplementary on periods dry spells. All the plots were irrigated uniformly periodically based on a visual assessment of crop conditions. Harvesting was done after 150 days and signs of maturity were noticed.

3.4 Data Collection

To assess the growth of maize under different top dressing levels data were collected using a random sampling method and four plants per plot were chosen. The following parameters were measured, plant height at 2 weeks' intervals, days to flowering, response to grey leaf spot, total lodging percentage, 1000 kernel weight, and the final yield after harvesting.

3.4.1 Plant height

Plant height was measured using a tape measure from the soil surface on the base of the stem to the highest point of the arch of the uppermost leaf whose tips are pointing down. The height was measured thirty days after silking (dough). Four plants were measured from each plot and an average was found.

3.4.2 Days to flowering

Days to flowering were counted from the planting date to the date when the flowering parts appeared. Maize as the monoecious plant has flowering parts in separate positions. When the ear which is the female flower appeared days to silking were counted and recorded. The tassel is the male flower where pollen is found and usually, tassels appear first before the ear.

3.4.3 Response to grey leaf spot

This parameter was recorded when all the plots had received top dressing. Response to grey leaf spot was evaluated using the tolerance of maize plants to grey leaf spot. Plants in which grey leaf spot thrives are said to be tolerant. An average of plants affected by grey leaf spots in a plot was found through visual assessment of the grey leaf spot symptoms like grey-green to light brown lesions parallel to the veins.

3.4.4 Total lodging percentage

The total lodging percentage is inclusive of root and stem lodging. Stem lodging was measured as a percentage of stems that broke below the ear. On root lodging, the total lodging percentage was the percentage of plants whose stems lean at an angle of around 450 from the vertical. Both stem and root lodging were measured a week before harvesting

3.4.5 1000 kernel weight

It was recorded from the 1000 grains withdrawn from the shelled grain. A sample from all the tagged timing was withdrawn and the weight in grams of the 1000 seeds was measured using a .digital scale

3.4.6 Final yield

For final yield analysis shelled weight of grain was used. Cobs were plucked from 4 plants in each plot and then tagged for identification and record keeping. Shelling was done manually and then grain weight (g) was measured using a digital scale the average for all different top dressing timings was found.

3.5 Data analysis

Analysis of variance (ANOVA) was performed using Genstat 18th edition software package. Significant differences ($p<0.05$) among treatments were separated using Fisher's protected least significant difference (LSD).

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of different fertilizer timing applications on days to flowering of maize (days)

The results of this study exhibited significant ($p<0.001$) differences on anthesis days and silking days except for the anthesis-silking interval of maize (Table 4.1). Treatment A was the earliest in terms of anthesis days (62 days) and silking days (64 days) among the treatments. Treatment D was the latest in terms of anthesis date (76 days), and silking date (83 days).

Table 1: Effects of different fertilizer timing applications on days to flowering of maize

Fertilizer timing applications	Anthesis days	Silking days	Anthesis – Silking Interval

Very early	62^{a}	64^{a}	2^{a}
Early	63^{ab}	66^{ab}	3^{a}
Two splits	67^{b}	74^{b}	7^{a}
Five splits	76^{c}	83^{c}	8^{a}
Late	64^{ab}	66^{ab}	3^{a}
P-value	0.001	0.004	0.203
LSD	4.76	8.57	6.09
CV%	3.8	6.40	73.5

NB: Means followed by different letters are significantly different at $p<0.05$.

4.2 Effects of different fertilizer timing applications on plant height of maize (cm)

There was a significant ($p<0.05$) difference in plant height for all the treatments (Figure 4.1). The highest mean plant height was observed in this study, Treatment D followed by Treatment E, Treatment C, and Treatment A with mean heights of 313.33cm, 288.30cm, 265cm, and 258.3cm respectively. The least mean height was observed at Treatment B at 245cm.

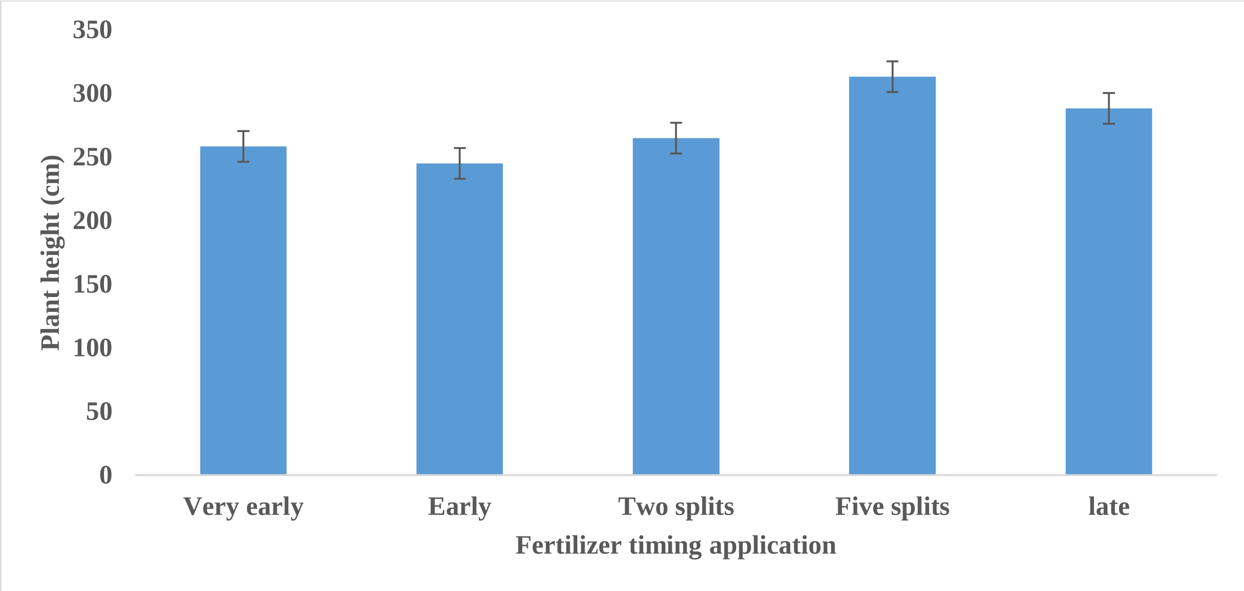

Figure 1 Effects of different fertilizer timing applications on plant height of maize (Zea mays L.). Error bars represent the least significant difference ($LSD_{0.05}$).

4.3 Effect of different fertilizer timing applications in response to grey leaf spot disease (scores)

There was no significant ($p>0.05$) difference in grey leaf spot disease among all the treatments studied (Figure 4.2). Treatment A with a mean score of 1 was found to be more tolerant to grey leaf spots followed by Treatment B, Treatment C, and Treatment E all with the same mean score of 1.33. The least tolerant amongst all the five treatments was observed on Treatment D with a mean score of 1.67.

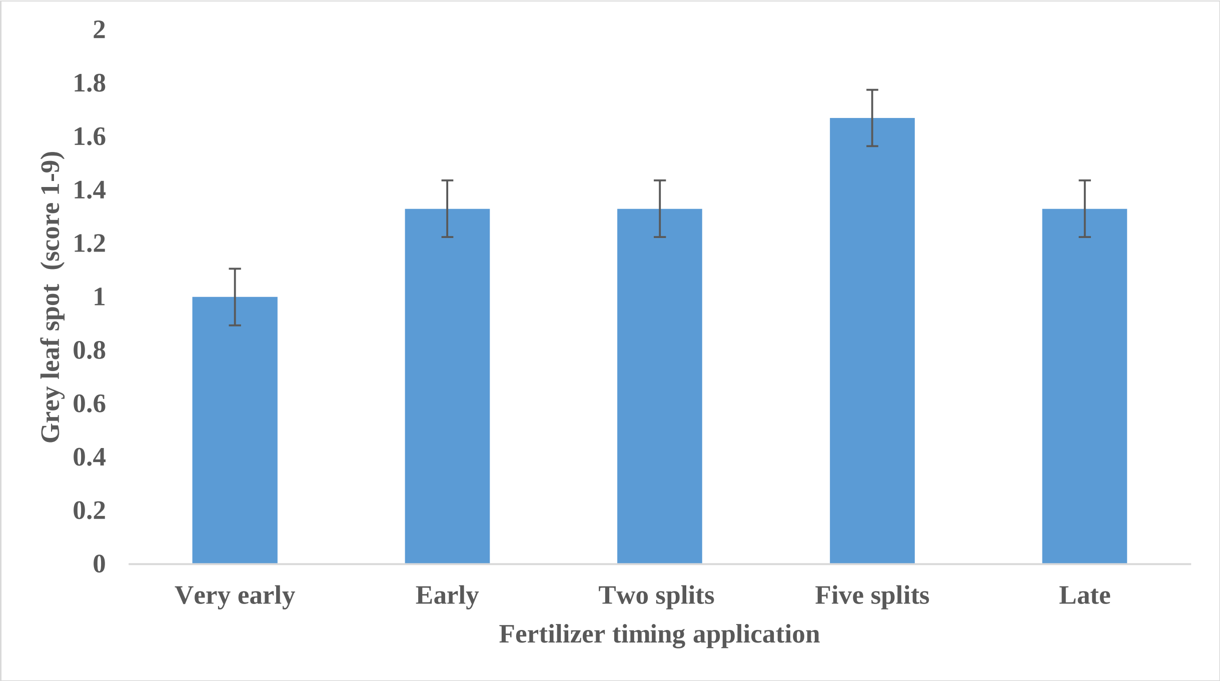

Figure 2 Effect of different fertilizer timing applications in response to grey leaf spot disease of maize (Zea mays L.). Error bars represent the least significant difference ($LSD_{0.05}$)

4.4 Effects of different fertilizer timing applications on total lodging percentage of maize (%)

The results of this study exhibited a highly significance ($p<0.001$) difference in the total lodging percentage of maize among all the treatments (Figure 4.3). The maize variety which was coupled with Treatment D showed the lowest lodging percentage with a mean of 1.67%. This was followed by Treatment C with 5.67%, and Treatment E with 13.67% in that order. Treatment A had the highest lodging percentage with a mean of 30%.

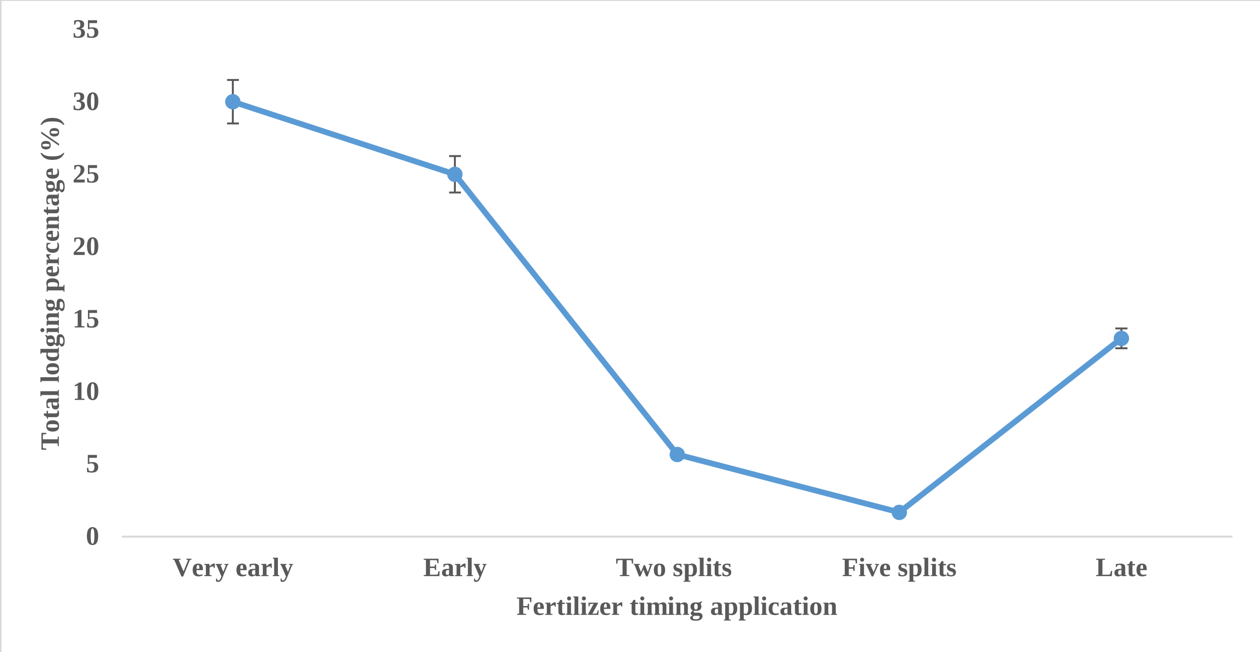

Figure 3 Effects of fertilizer timing application on total lodging percentage of maize (*Zea mays* L.). Error bars represent the least significant difference ($LSD_{0.05}$).

4.5 Effects of different fertilizer timing applications on 1000 kernel weight of maize (grams)

In this study, 1000 kernel weight was not significantly ($p>0.05$) different due to different fertilizer timing applications among all the five treatments (Figure 4.4). The highest mean kernel weight was found at Treatment E (308.3g) and Treatment D (306.70g) respectively. Treatment B was the least outstanding among all the treatments with 266.3g.

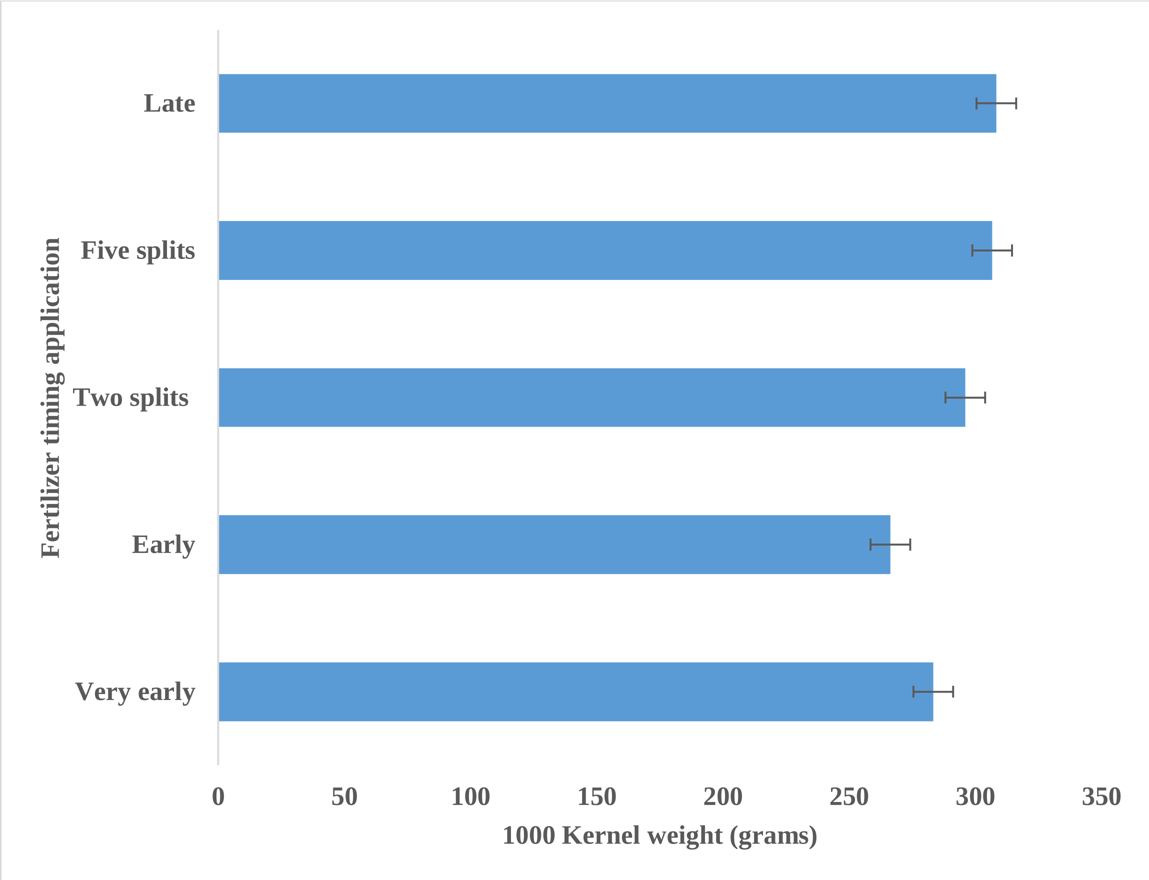

Figure 4 Different fertilizer timing application effects on 1000 kernel weight of maize (Zea mays L.). Error bars represent the least significant difference ($LSD_{0.05}$).

4.6 Effects of different fertilizer timing applications on grain yield of maize (t ha^{-1}).

There was a significant ($p<0.05$) difference in the grain yield of maize across all treatments (Figure 4.5). Treatment D had the highest grain yield of 8.87t ha^{-1}, followed by Treatment C (7.40t ha $^{-1}$), Treatment B (5.31t ha $^{-1}$), and Treatment E (5.17 t ha $^{-1}$) in that order. Treatment A had the least mean grain yield (4.72t ha $^{-1}$) of maize.

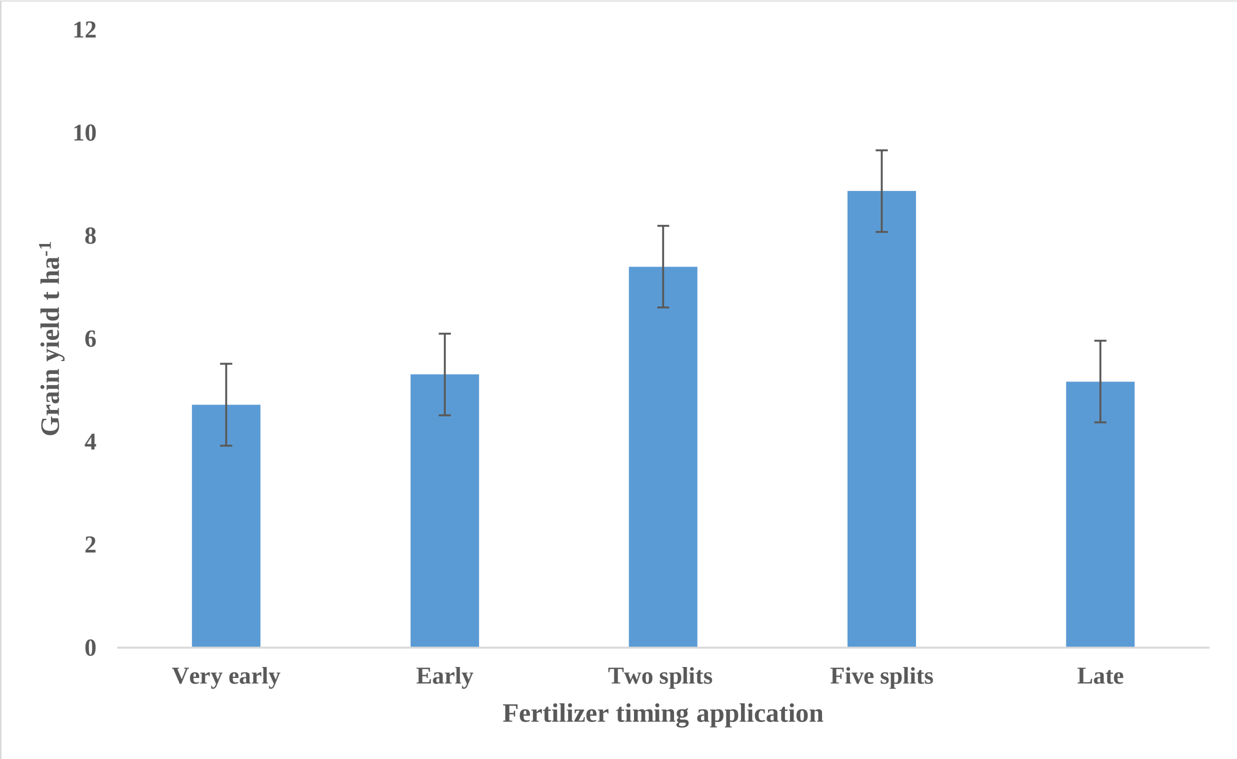

Figure 5 Effects of different fertilizer timing applications in response to grain yield of maize (Zea mays L.). Error bars represent the least significant difference ($LSD_{0.05}$).

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Effects of application timing on days to flowering of maize (days)

The anthesis stage is a crucial reproductive stage in the life cycle of maize. The results of this study displayed significant differences in anthesis days and silking days except for the anthesis-silking interval of maize. The precise number of anthesis days can vary about the environmental conditions in which it is grown (Gasura 2013). Treatment A was the earliest in terms of anthesis days (62 days) and silking days (64 days) among the treatments. Treatment D was the latest in terms of anthesis date (76 days), and silking date (83 days). Environmental factors for instance temperature, humidity, and essential nutrients have proved to affect the synchronization. This collaborates with the findings of Struik (1998) who found that high temperatures increase the rate of tassel initiation but shorten period of pollen shedding. Sharifi (2016) also concluded that time and rate of nitrogen fertilizers applied results in varying days to flowering. Timing of tassel and silk emergence influence the effectiveness of pollination thus affecting final grain yield and grain weight. Nitrogen has proved to have a contribution to maize anthesis days as it affects how silk and tassel growth is coordinated (Demari, 2016). This means the availability of nitrogen earlier in plants can influence or modify day to anthesis and silking explaining why treatment A was the earliest in days to flowering. The availability of enough nitrogen during the reproductive stage encourages tassels and silks to emerge on time, ensuring successful fertilization and pollination.

5.2 Effects of different fertilizer timing applications on plant height of maize (cm)

Analysis of field data showed that there is a relationship between plant height and the timing by which urea or topdressing is applied. The highest mean plant height observed in this study was from Treatment D. The least mean height was observed at Treatment B at 245cm. Treatment D because of the splitting of urea application had nitrogen available at all times thereby cell elongation was quickened and plant height exceeded all other timings. This is evident enough to show that macronutrients should always be readily available and the best way to do so is by splitting the applications so that availability is guaranteed at all times. Nitrogen as a macronutrient is essential for plant growth and development (cell division and elongation). The height of the plants gives it an advantage in the leaf arrangement and makes it easy to accommodate the cob without easy lodging. Vos (2009) in his studies discovered that nitrogen availability impacts leaf characteristics and stem branching in plants.

5.3 Effect of different fertilizer timing applications in response to grey leaf spot disease (scores)

All treatments showed no significant difference in grey leaf spot disease. Treatment A with a mean score of 1 was found to be more tolerant to grey leaf spot followed by Treatment B, Treatment C, and Treatment E all with the same mean score of 1.33. The least tolerant amongst all the five treatments was observed on Treatment D with a mean score of 1.67. Some factors might influence the response of maize to grey leaf spot or diseases that is not maize. Some of these factors can include temperatures, humidity, and area. All those factors can affect the response of maize to grey leaf spot despite the timing of fertilizer application.

5.4 Effects of different fertilizer timing applications on total lodging percentage of maize (%)

The application timing of top dressing exhibited a high significance difference in the total lodging percentage of maize among all the treatments. The maize variety which was coupled with Treatment D showed the lowest lodging percentage with a mean of 1.67%. This was followed by Treatment C with 5.67%, and Treatment E with 13.67% in that order. Treatment A had the highest lodging percentage with a mean of 30%. When a plant receives sufficient nutrition its growth and elongation are uniform meaning that cob won't be too heavy for the stem or the plant height overwhelming the roots. Treatment A due to the very early application of top dressing its growth pattern was affected thereby exposing the plants to stem lodging. Nitrogen availability can affect root development by influencing auxin transport (Ötvös, 2021). Crop plant's root elongation is regulated by several hormones and nitric oxide. If nitrogen lacks root development might be poor which might explain why root lodging was high in treatments A and B. At a time when macronutrients were essential to keep the roots well anchored the nutrients had been exhausted due to the very early and early application of top dressing.

5.5 Effects of different fertilizer timing applications on 1000 kernel weight of maize (grams)

In this study, 1000 kernel weight was not significantly different due to different fertilizer timing applications among all the five treatments. The highest mean kernel weight was found at Treatment E (308.3g) and Treatment D (306.70g) respectively. Treatment B was the least outstanding among all the treatments with 266.3g. Oikeh (1998) highlighted that raising nitrogen levels in maize can enhance grain production, while nitrogen fertilizer did not directly address the influence on grain quality. This supports the fact that treatments E and D may have had high grain production through the influence timing of fertiliser application but it however did not pose a significant difference in the grain quality which is why the results showed no significance

5.6 Effects of different fertilizer timing applications on grain yield of maize (t ha^{-1}).

Grain yield was noticed to be high on treatments in which top dressing was applied in splits. Treatment D had the highest grain yield of 8.87t ha-1, followed by Treatment C (7.40t ha -1). Treatment A had the least mean grain yield (4.72t ha -1) of maize. This could have been attributed to the fact that nitrogen levels influence maize production therefore if applied at the correct time it improves grain yield in maize. This agrees with Ariraman (2020) in that greater nitrogen levels result in increased growth and yield. To have a better nitrogen use efficiency and improved yields split application of urea has proved to be the way to go. On the contrary low nitrogen levels can ruin photosynthesis in maize, resulting in lower crop output (Wei 2016).

CHAPTER SIX

6.0 Conclusion

This study showed that the selected fertiliser timing application have value for use in maize cultivation. The significant variation observed in maize for most of the traits studied indicated that selection for an effective fertiliser timing application would be effective. Plots in which fertilizer was applied in splits were effective in improving the growth, grain yield and nitrogen use efficiency compared to very early and delayed fertilizer application. This can then conclude that split fertilizer application best synchronized with nutrient demand periods thereby covering the gap of low yields, lodging and others.

6.1 Recommendation

In this study farmers are recommended to increase the number of fertilizer or top dressing splits from the traditional 2 splits also depending with the soil type but an average of four splits and above. This will help the synchronization of supply and demand also nitrogen use efficiency (NUE). I would also recommend multilocational trials to evaluate the response of different top dressing timings in different areas with different soil types.

REFERENCES

Abebe, Z. and Feyisa, H., 2017. Effects of nitrogen rates and time of application on yield of maize: rainfall variability influenced time of N application. International Journal of Agronomy, 2017.

Abera, W., Hussein, S., Derera, J., Worku, M., & Laing, M.D. (2013). Preferences and constraints of maize farmers in the development and adoption of improved varieties in the mid-altitude, sub-humid agro-ecology of Western Ethiopia. African Journal of Agricultural Research, 8, 1245-1254.

Abera, G., Debele, T., & Wegary, D. (2016). Influence of nitrogen fertilizer levels on grain yield and nitrogen use efficiency of maize varieties in central rift valley of Ethiopia. East African Journal of Sciences, 10(1), 37-48.

Alley, M., Martz, M., Davis, P., and Hammons, J. 2019. Nitrogen and phosphorus fertilization of corn. Virginia Cooperativ Extension publication 424-027. Virginia Tech University.

Ariraman, R., Prabhaharan, J., Selvakumar, S., Sowmya, S., David, M.M., & Mansingh, I. (2020). Effect of nitrogen levels on growth parameters, yield parameters, yield, quality and economics of maize: A review. *Journal of Pharmacognosy and Phytochemistry*.

Below, F. 2014. Understanding nutrient requirements for high-yielding corn. Agricen. https://blog.agrien.com.

Berge, H. F. M., Hijbeek, R., Loon, M. P. Van, Rurinda, J., Tesfaye, K., Zingore, S., Craufurd, P., Heerwaarden, J. Van, Brentrup, F., Schröder, J. J., Boogaard, H. L., Groot, H. L. E. De, & Ittersum, M. K. Van. (2019). Maize crop nutrient input requirements for food security in sub-Saharan Africa. *Global Food Security*, *23*(February), 9–21. https://doi.org/10.1016/j.gfs.2019.02.001

Benson, D. M., & Hooker, A. L. (1990). Effect of gray leaf spot on yield of hybrid corn. Plant Disease, 74(9), 685-687.

Bender, R. R., Haegele, J. W., Ruffo, M. L., & Below, F. E. (2013). Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids. Agronomy Journal, 105(1), 161-170

Binder, D. L., Sander, D. H., & Walters, D. T. (2000). Maize response to time of nitrogen application as affected by level of nitrogen deficiency. Agronomy Journal, 92(6), 1228-1236.

Bonea, D. and Urechean, V., 2020. Response of maize yield to variation in rainfall and average temperature in central part of Oltenia. Romanian Agricultural Research, (37).

Bozkurt, M.A., Akdeniz, H., Keskin, B. and Yilmaz, I.H., 2006. Possibilities of using sewage sludge as nitrogen fertilizer for maize. Acta Agriculturae Scandinavica Section B-Soil and Plant Science, 56(2), pp.143-149.

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. Food Security, 5(3), 345-360.

Cassman, K. G., Dobermann, A., Walters, D. T., & Yang, H. (2002). Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources, 27(1), 315-358.

Chiweta, C. and Mushunje, A., 2012. Maize market reforms: a case study of the implications on maize production viability and house hold food security of smallholder farmers in Mazowe District, Mashonaland Central Province, Zimbabwe. African Journal of Agricultural Research, 7(47), pp. 6254-6264.

Ciampitti, I. A., & Vyn, T. J. (2013). Grain nitrogen source changes over time in maize: a review. Crop Science, 53(2), 366-377.

de Morais Oliveira, J.P., Pelá, A., Ribeiro, D., de Oliveira, B.S., da Silva, L.M., Silva, J.F. and da Silveira, P.S., 2016. Nitrogen accumulation and productivity of green corn in function of ways and seasons of top-dressing nitrogen fertilizer application. African Journal of Agricultural Research, 11(35), pp.3293-3298.

Demari, G.H., Ca, I.R., Monteiro, C.J.B. and T Pedó, T., 2016. Importance of NITR. Journal of Current Research, 8(08), pp.36629-36634.

Fageria, N. K., & Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy, 88, 97-185.

Gasura, E., Setimela, P., Tarekegne, A., P. (2013). Variability of Grain-Filling Traits in Early Maturing CIMMYT Tropical Maize Inbred Lines. *Crop Science*, *54*, 530-536.

Grant, C., Flanten, D., Tomasiewcz, D., and Sheppard, S. 2001. The importances of early season phosphorous nutrition. Canadian Journal of Plant Science 81: 211-224.

Gungula, D. T., Kling, J. G., & Togun, A. O. (2005). CERES-Maize predictions of maize phenology under nitrogen-stressed conditions in Nigeria. Agronomy Journal, 97(3), 744-751.

Gokmen, S., Sencar, O., & Sakin, M. A. (2001). Response of winter wheat to nitrogen fertilization with regard to climatic conditions. Nutrient Cycling in Agroecosystems, 61(3), 209-215.

Han, Y.L., Song, H.X., Liao, Q., Yu, Y., Jian, S.F., Lepo, J.E., Liu, Q., Rong, X.M., Tian, C., Zeng, J. and Guan, C.Y., 2016. Nitrogen use efficiency is mediated by vacuolar nitrate sequestration capacity in roots of Brassica napus. Plant Physiology, 170(3), pp.1684-1698.

Hossain, F., Muthusamy, V., Bhat, J., & Jha, S. (2016). *36,897*. *September*. https://doi.org/10.1007/978-81-322-3613-9

Hussain, N., Khan, A. Z., Akbar, H., Bangash, N. G., Khan, Z. H., & Idrees, M. (2007). *RESPONSE OF MAIZE VARIETIES TO*. *23*(4).

J. Cook et al., "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming", Environmental Research Letters Vol. 11 No. 4, (13 April 2016); DOI:10.1088/1748-9326/11/4/048002

Jipa, A.P. and Murariu, D., 2019. Researches of the influence of nitrate contents on main morphological traits of maize plants.

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L., & Tefera, T. (2019). Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya. International Journal of Pest Management, 65(1), 1-9.

Kirirah, F.K., 2014. Green Gram population and arrangement effect on Striga Hermonthica Parasitism under intercropping with Zea Mays (Doctoral dissertation).

Ladha, J. K., Pathak, H., Krupnik, T. J., Six, J., & van Kessel, C. (2005). Efficiency of fertilizer nitrogen in cereal production: retrospects and prospects. Advances in Agronomy, 87, 85-156.

Lemaire, G., Gastal, F., Plenet, D., & Prioul, J. L. (2008). Crop nitrogen, plant growth and senescence. In J. E. Palladin (Ed.), Nitrogen Metabolism in Plants (pp. 101-133). Pergamon.

Lukeba, J. C., Nkongolo, K. K., Mwabila, M. L., & Fuseki, A. (2013). Maize production challenges and soil nutrient depletion in sub-Saharan Africa. OIDA International Journal of Sustainable Development, 6(01), 49-62.

Lobell, D. B., Bänziger, M., Magorokosho, C., & Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change, 1(1), 42-45.

Mabhaudhi, T., Chibarabada, T. P., Chimonyo, V. G., & Modi, A. T. (2018). Modelling climate change impact: A case of bambara groundnut (Vigna subterranea). Physics and Chemistry of the Earth, Parts A/B/C, 105, 25-31.

M. Lynas, et al, "Greater than 99% consensus on human caused climate change in the peer-reviewed scientific literature", Environmental Research Letters Vol.16 No. 11, 114005 (19 October 2021); DOI:10.1088/1748-9326/ac2966

Mariga, I.K., Jonga, M. and Chivinge, O.A., 2000. The effect of timing of application of basal and topdressing fertilizers on maize (Zea mays L.) yield at two rates of basal fertilizer. Crop Research (Hisar), 20(3), pp.372-380.

Mafongoya, P. L., Rusinamhodzi, L., Siziba, S., & Thierfelder, C. (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.

Mashingaidze, K., 2006. Maize research and development. University of Zimbabwe (UZ) Publications/Michigan State University (MSU).

Maphosa, M., & Jideani, V. A. (2017). The role of legumes in human nutrition. In Functional Food-Improve Health through Adequate Food (pp. 103-121). IntechOpen.

Masuka, B., Atlin, G. N., Olsen, M., Magorokosho, C., Labuschagne, M., Crossa, J., ... & Cairns, J. E. (2017). Gains in maize genetic improvement in Eastern and Southern Africa: I. CIMMYT hybrid breeding pipeline. Crop Science, 57(1), 168-179.

Mazvimavi, K., & Twomlow, S. (2009). Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. Agricultural Systems, 101(1-2), 20-29.

McCann, J. (2005). *Maize and grace: Africa's encounter with a New World crop, 1500-2000.* Harvard University Press.

Miracle, M.P., 1966. Maize in tropical Africa.

Mugiyo, H., Mhizha, T., Chimonyo, V.G. and Mabhaudhi, T., 2021. Investigation of the optimum planting dates for maize varieties using a hybrid approach: A case of Hwedza, Zimbabwe. Heliyon, 7(2).

Mushunje, A., Muchaonyerwa, P., Mandikiana, B.W. and Taruvinga, A., 2011. Smallholder farmers' perceptions on Bt maize and their relative influence towards its adoption: The case of Mqanduli communal area, South Africa. African Journal of Agricultural Research, 6(27), pp.5918-5923.

Mutambara, S., 2016. Agricultural input supply challenges of smallholder irrigation schemes in Zimbabwe. Journal of Development and Agricultural Economics, 8(12), pp.260-271.

Mwololo, J. K., Mugo, S. N., Tefera, T., Okori, P., Munyiri, S. W., Semagn, K., & Ojulong, H. (2013). Resistance of tropical maize genotypes to the maize weevil Sitophilus zeamais (Motschulsky) (Coleoptera: Curculionidae). Crop Protection, 43, 73-78.

Nduwumuremyi, A., Mugisha, J., Mohale, K. C., Nzabuheraheza, F. D., & Ngamije, J. (2016). Striga weed (Striga spp.) a challenge to agricultural production in sub-Saharan Africa: a review. African Journal of Agricultural Research, 11(13), 1123-1135.

Nielsen, R.2017. Prevalent Purple Plants Perennially Producer. Purdue University Extention.

Nutter Jr, F. W., Teng, P. S., & Royer, M. H. (1993). Terms and concepts for yield, crop loss, and disease thresholds. Plant Disease, 77(3), 211-215.

Nyamangara, J., Mashingaidze, N., Masvaya, E. N., Nyengerai, K., Kunzekweguta, M., Tirivavi, R., & Mazvimavi, D. (2014). Weed growth and labor demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. Agriculture, Ecosystems & Environment, 187, 146-154.

Nyakudya, I. W., & Stroosnijder, L. (2014). Effect of rooting depth, plant density and planting date on maize (Zea mays L.) yield and water use efficiency in semi-arid Zimbabwe: Modelling with AquaCrop. Agricultural Water Management, 146, 280-296.

Pal, S., Panwar, P., & Bhatt, B. P. (2016). Morphological and physiological changes of maize under elevated CO2 and heat stress. Journal of Environmental Biology, 37(5), 885-893.

Rao, A. S., & Reddy, K. S. (2010). Nutrient management in maize. In K. R. Khurana (Ed.), Handbook of Maize: Its Biology (pp. 269-289). Springer.

Reichel, R., Kamau, C.W., Kumar, A., Li, Z., Radl, V., Temperton, V.M., Schloter, M. and Brüggemann, N., 2022. Spring barley performance benefits from simultaneous shallow straw incorporation and top dressing as revealed by rhizotrons with resealable sampling ports. Biology and Fertility of Soils, 58(4), pp.375-388.

Rurinda, J., Mapfumo, P., Van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., Chikowo, R., & Giller, K. E. (2014). Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis. Climate Risk Management, 3, 65-78.

Rurinda, J., Zambrano, P., Mapfumo, P., van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., ... & Giller, K. E. (2020). Managing soil fertility to adapt to climate change in smallholder farming systems in semi-arid Zimbabwe. Global Change Biology, 26(2), 992-1006.

Sandhu, N., Sethi., Kumar., A., Dang., Singh, J., abd Chhuneja,p.(2021). Biochemicals and genetic approaches improving nitrogen use efficiency in cereal crops: a riview. Front. Plant Sci. 12:699085. Doi: 10.3389/fpls.2021.657629

Sétamou, M., Schulthess, F., Bosque-Pérez, N.A., & Thomas-Odjo, A. (1995). The effect of stem and cob borers on maize subjected to different nitrogen treatments. Entomologia Experimentalis et Applicata, 77.

Sharma, A. R., & Bali, S. V. (2018). Nitrogen management strategies for enhancing nitrogen use efficiency. In A. Rakshit, H. B. Singh, & A. Sen (Eds.), Nutrient Use Efficiency: from Basics to Advances (pp. 199-218). Springer.

Sinclair, T. R., & Horie, T. (1989). Leaf nitrogen, photosynthesis, and crop radiation use efficiency: a review. Crop Science, 29(1), 90-98.

Siziba, S., Nyikahadzoi, K., Makate, C. and Mango, N., 2019. Impact of conservation agriculture on maize yield and food security: Evidence from smallholder farmers in Zimbabwe. African Journal of Agricultural and Resource Economics, 14(2), pp.89-105.

Sugiharto, B., Miyata, K., Nakamoto, H., Sasakawa, H. and Sugiyama, T., 1990. Regulation of expression of carbon-assimilating enzymes by nitrogen in maize leaf. Plant Physiology, 92(4), pp.963-969.

Tang, T., Wu, Z., Karhu, K., Hämäläinen, M. and Ji, Y., 2010, October. An internationally distributed ubiquitous living lab innovation platform for digital ecosystem research. In Proceedings of the International Conference on Management of Emergent Digital Ecosystems (pp. 159-165).

Tittonell, P. and Giller, K.E., 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field

Tollenaar, M., & Lee, E. A. (2002). Yield potential, yield stability and stress tolerance in maize. Field Crops Research, 75(2-3), 161-169.

Vos, J., 2009. Nitrogen responses and nitrogen management in potato. Potato research, 52, pp.305-317.

Wang, H., Zhang, X., Zhang, G., Fang, Y., Hou, H., Lei, K., & Ma, Y. (2023). Regulation of Density and Fertilization on Crude Protein Synthesis in Forage Maize in a Semiarid Rain-Fed Area. *Agriculture*.

Wei, S., Wang, X., Shi, D., Li, Y., Zhang, J., Liu, P., Zhao, B. and Dong, S., 2016. The mechanisms of low nitrogen induced weakened photosynthesis in summer maize (Zea mays L.) under field conditions. Plant Physiology and Biochemistry, 105, pp.118-128.

Weinmann, H. (1972). *Agricultural research and development in Southern Rhodesia under the rule of the British Soouth Africa Company, 1890- 1923.*

Yadav, R. L., Dwivedi, B. S., & Pandey, P. S. (1998). Rice-wheat cropping system: assessment of sustainability under green manuring and chemical fertilizer inputs. Field Crops Research, 65(1-2), 15-30.

Zander, K.K., Blaise, P. and Holm-Müller, K., 2023. Assessing German farmers' trade-offs between disease resistance and yield in winter wheat varieties. Outlook on Agriculture, 52(1), pp.67-78.

Zinyengere, N., Crespo, O., Hachigonta, S., & Tadross, M. (2014). Local impacts of climate change and agronomic practices on dry land crops in Southern Africa. Agriculture, Ecosystems & Environment, 197, 1-10.

APPENDICES

Appendix 1 Analysis of variance for plant height of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	120.0	60.0	0.30	
Treatments	4	8760.0	2190.0	11.09	0.002
Residual	8	1580.0	197.5		
Total	14	10460.0			

Appendix 2 Analysis of variance for anthesis of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	10.133	5.067	0.79	
Treatments	4	378.000	94.500	14.77	<.001
Residual	8	51.200	6.400		
Total	14	439.333			

Appendix 3 Analysis of variance for grey leaf spot of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.5333	0.2667	1.00	
Treatments	4	0.6667	0.1667	0.62	0.658
Residual	8	2.1333	0.2667		
Total	14	3.3333			

Appendix 4 Analysis of variance for grain yield of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Rep stratum	2	0.4463	0.2231	0.23	
Treatments	4	37.7785	9.4446	9.80	0.004
Residual	8	7.7098	0.9637		
Total	14	45.9346			

Appendix 5 Analysis of variance for silking days of maize

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	76.93	38.47	1.86	
Treatments	4	774.27	193.57	9.34	0.004
Residual	8	165.73	20.72		
Total	14	1016.93			

Appendix 6 Analysis of variance for 1000 kernel weight of maize

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	10324.	5162.	4.46	
Treatments	4	3425.	856.	0.74	0.591
Residual	8	9267.	1158.		
Total	14	23016.			