

BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCES
DEPARTMENT OF CROP SCIENCE

**EVALUATION OF MAIZE HYBRIDS UNDER LOW NITROGEN CONDITIONS IN
ZIMBABWE.**

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***A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE HONOURS IN
CROP SCIENCE 4.2***

JUNE

2026

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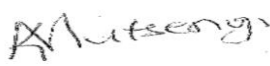
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DEDICATION

This dissertation is dedicated to my family (from my parents, brother and sisters), whose belief in me and their unwavering support, and encouragement in my abilities made this work possible.

ACKNOWLEDGEMENTS

Firstly, I would like to thank God for everything that He has done for me throughout this process for His assurance in my life made this possible. I would like to express my sincere gratitude to my supervisor Dr Goche for guidance and unwavering support throughout this research. I also acknowledge CIMMYT Zimbabwe for their part they did during my project for providing experimental sites, seed materials and technical support during this research. Special thanks to my family and friends for their continuous encouragement. I would also like to thank Professor Chingwaru and Ms Chingwaru for their critical analysis and support throughout this research.

ABSTRACT

Maize (*Zea mays* L.) a crop considered as a staple dietary requirement in Zimbabwe and other parts of Sub-Saharan Africa, is being hindered by inadequate availability of soil nitrogen, especially with regard to small-scale farmers with no access to nitrogen fertilizer. Thus, evaluating and selecting maize varieties that possess better nitrogen use efficiency will thus be very necessary for the improvement of sustainable maize production under low inputs. For this study, the objective was to identify and evaluate hybrids of maize and its performance, yield and quality under low nitrogen stress. At CIMMYT research station which is in Harare, Zimbabwe, it is where the experiments necessary for the study were done. The trials were done using a design known as an alpha lattice and replicated three times, and thirty hybrids of maize were evaluated under controlled low nitrogen stress. Yield of grain, height of plants and ears (cob), anthesis-silking interval, position of ears, number of ears on each plant, ear rot, moisture content in grain, grain texture, and plant stand were measured. ANOVA was used to analyse the data and the values of mean treatments were measured up using a LSD (Least Significant Difference) test. From the findings of the study, there was a reveal of considerable genetic diversity among the tested maize hybrids for all agronomic and

quality traits. Hybrid ZMH22404 registered the highest grain yield at low nitrogen treatment (6.07 t ha^{-1}), thus being more tolerant to nitrogen stress than the other hybrids. Some of the hybrids with high yields even when subjected to nitrogen stress include SC305 and CZH22039. The study also found considerable variation in plant architecture, reproduction, and grain quality traits. This study reveals that hybrid ZMH22404 and other high-yielding hybrids have the potential of performing well under low input systems in Zimbabwe and can be used as genetic materials for future breeding programs.

Keywords: Maize (*Zea mays* L.), low nitrogen stress, maize hybrids, nitrogen use efficiency, grain yield, agronomic traits, genetic diversity, low-input farming, hybrid evaluation, Zimbabwe.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
ASI	Anthesis-Silking Interval
CIMMYT	International Maize and Wheat Improvement centre
CV	Coefficient of Variation
DR&SS	Department of Research and Specialist services
EH	Ear Height
EPO	Ear Position
EPP	Ears Per Plant
ER	Ear Rot
FAO	Food and Agriculture Organisation of the United Nations
GY	Grain Yield
LSD	Least Significant Difference

MOI	Moisture Content
N	Nitrogen
NP	Number of plants
NUE	Nitrogen Use Efficiency
OPVs	Open-Pollinated Variety
PH	Plant Height
RCBD	Randomized complete block design
SD	Silking Date
AD	Anthesis Date
TEX	Grain Texture

USDA-FAS United States Department of Agriculture – Foreign Agricultural Service

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CHAPTER 1

INTRODUCTION

1.1 Background

Maize production (*Zea mays L.*) has recently declined significantly and the country continues to rely on the importation of maize, and it has been estimated that 450 metric tonnes approximately are needed to meet the demands influenced by population growth and recurrent production shortfalls (FAO, 2024; USDA-FAS, 2025). Consequently, this has impacted maize production and availability as it is regarded as a vital crop in Zimbabwe, in terms of dietary purposes and an economic resource for millions of smallholder households. As a primary food source across Sub-Saharan Africa, maize is central to local livelihoods, providing over half of the daily calorie intake for approximately 13.1million individuals in Zimbabwe (FAO, 2021; CIMMYT, 2020). It is grown in various agro-ecological zones, from high-rainfall areas to semi-arid regions (FAO, 2021), making it a dominant cereal crop in Zimbabwe

Although various factors, both biotic and abiotic, have contributed to low maize productivity, such as disease occurrence, it is primarily limited by soil fertility issues, particularly nitrogen deficiency (Bänziger *et al.*, 2000; Mafongoya *et al.*, 2006). Nitrogen is a macronutrient that, like other essential macronutrients, has a significant in production of maize by promoting growth, photosynthesis and grain development (Marschner, 2012; Ciampitti & Vyn, 2012). Consequently, it is considered as a limiting nutrient for cultivating maize in sub-Saharan Africa. Similar to other major nutrients like potassium and phosphorus, research has shown that nitrogen deficiency impacts key agronomic traits such as leaf expansion, chlorophyll synthesis, and overall biomass accumulation (Moll *et al.*, 2019).

Low nitrogen availability in Zimbabwe disproportionately affects resource-poor farmers, who often cannot afford or access costly nitrogen fertilisers (Mutegi *et al.*, 2020). Consequently, research has focused on developing maize hybrids that tolerate low nitrogen conditions while

maintaining yield and grain quality. Creating such hybrids is crucial for sustainable production (Amegbor *et al.*, 2022). Modern breeding programmes prioritise maize varieties that have a better performance under low nitrogen plus retaining desirable traits.

There has been extensive research and development of maize hybrids tolerance to abiotic stresses like low nitrogen availability (Bänziger *et al.*, 2006). Lately, there has been an increase in a global perspective as breeding varieties have been progressed into varieties that can withstand low nitrogen stress (Bänziger *et al.*, 2006). Zimbabwe made history by becoming the first African country to put hybrid maize on a commercial scale in 1948, thus Zimbabwe is not foreign to maize breeding. Since then, the national maize breeding program has evolved to not only focus on developing hybrids that are of high yields but are also able to withstand various stresses, which include low nitrogen and high nitrogen. For the past two decades, numerous hybrids have been released, and they target low-input environments, aiming to improve grain yield under adverse conditions. Integrating modern breeding technologies and the focus on stress tolerance during maize production are fundamental to meeting demands in the future especially in the face of climate change and increasing population pressures.

Although efforts have been made for maize hybrids to adapt to nitrogen-deficient soils while preserving high agronomic performance and grain quality, there still continues to be a key research gap. Many currently available hybrids perform poorly under low N conditions, which necessitates for the identification and development of maize varieties with enhanced nitrogen use efficiency (Bänziger *et al.*, 2006).

1.2 Problem statement

Production of maize in Zimbabwe is facing significant challenges because of low soil nitrogen availability, a key constraint that limits crops from growing and developing plus yield potential (*et al.*, 2000; Mafongoya *et al.*, 2006). In Zimbabwe, small-holder farmers make up the majority of farmers in the country, and their access to synthetic fertilisers is limited because of

high costs, leading to their fields having inadequate nutrient conditions (Zingore *et al.*, 2007; Mutegei *et al.*, 2020). Low nitrogen use efficiency results in yield gaps of up to 50-70%, thus exacerbating food insecurity and economic volatility in the country (CIMMYT 2014; Worku *et al.*, 2012). Also, due to the reliance on locally adapted farming resources by small-scale farmers to improve soil fertility, it results in being affected by nitrogen deficiency. Because they are unable to afford and apply nitrogen fertilisers, it results in consistently low productivity, further threatening their livelihoods and household food security. Therefore, despite hybrid breeding advancements, region-specific data on NUE- linked agronomic performance remains scarce, limiting adoption among resource- poor famers.

1.3 Justification

Firstly, there is a need to address the challenges with which small-scale farmers face. Since they primarily rely on rain-fed agriculture with minimal fertiliser inputs due to limited finances and fertiliser accessibility, which results in poor yields, thus threatening food security and livelihoods. Only after taking note of these challenges can we take the first step in identifying maize hybrids that perform well under low nitrogen conditions, which can help mitigate this challenge. Also, there is a need to shift from traditional maize varieties as they require high nitrogen yields to maximise yield. Improving nitrogen use efficiency through hybrid selection can ensure better productivity in nitrogen-deficient soils, thus reducing dependence on synthetic fertilisers and lowering production costs. Evaluating hybrids that can sustain higher yields in poor soils will have a direct influence in and economic resilience in rural communities. Hence, the study conducted for this research will have an important contributions to the academics, policy makers, extension services and farmers. In terms of academics and research, the study will have a contribution on technical knowhow in the field of plant breeding, agronomy, plant physiology and smart agriculture through provision of data essential for different academic departments and giving a deeper understanding on plant breeding

terminologies, which will be used as reference for future studies on low- input maize production systems in Zimbabwe and Sub-Saharan Africa. The Zimbabwean government i.e., the policy makers can also use these findings to create and enforcing food security policies which will guide investment decisions in agricultural research and rural development programmes. Small holder farmers, who are the main concern for this research project as they often face challenges in accessing fertilisers and experience erratic rainfall, are going to be the major beneficiaries of this study as the findings will help farmers distinguish and identify maize hybrids that perform better under low nitrogen conditions thus enables them to achieve better yields under resource limited conditions. In a nutshell, the findings from this study will provide practical, scientific and policy- oriented solutions that improve maize production under low nitrogen conditions.

1.4 Objectives

1.4.1 Main

To identify and evaluate maize variety that perform well in low nitrogen stress conditions and determine hybrids with high Nitrogen Use Efficiency.

1.4.2 Specific

1. To assess agronomic performance (plant aspect, ear aspect and plant height (cm)) of selected maize hybrids under low N stress conditions
2. To determine yield of grain (kg) and grain quality characteristics (e.g. moisture content (%), grain texture) of selected maize hybrids under low N stress conditions.

1.5 Hypothesis

1. H_0 : there is no significance in the agronomic performance (i.e. plant aspect, ear aspect and plant height (cm)) among maize hybrids grown under optimum versus optimum nitrogen across different agro-ecological zones.

2. H_0 : There is no significance in grain yield (kg/ha) and its quality characteristics (e.g. moisture content, grain texture) of maize hybrids.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Maize (*Zea mays L.*) continues to be a source of food in Zimbabwe and sub-Saharan Africa as a whole. However, its productivity remains below world standards and with rising global demand for it as an essential food commodity, it warrants a more thorough understanding of the factors shaping its productivity globally. This is especially so for nitrogen deficiency, which has become one of the main limiting factors in declining soil fertility that induces persistent yield gaps (Van Ittersum *et al.*, 2016). Despite adding information regarding the role of nitrogen in crop productivity, a vast knowledge gap remains regarding maize performance in nitrogen stress environments. Given that low nitrogen demand is tied to complexities, notably in rain-fed farming zones, this highlights the need to assess the effectiveness of different maize hybrids.

This chapter synthesizes research on the effects of nitrogen levels through the synthesis of literature reviews that include nitrogen dynamics, N use efficiency (NUE), maize physiological and agronomic responses to nitrogen stress and breeding strategies for tolerant performance. Most attention has been directed to Zimbabwe-based studies, such as those out of the (DR&SS) (Department of Research and Specialist Services) or CIMMYT (International Maize and Wheat improvement centre) context. The chapter concludes by acknowledging some gaps that warrant assessing maize hybrids in ambient low-nitrogen environments. Due to the complexity of low-nitrogen environments, especially in the rain-fed agricultural zones, it is therefore important to evaluate maize hybrids and how they adapt.

2.2 Maize and its importance in Zimbabwe and Sub-Saharan Africa

In Zimbabwe and Sub-Saharan Africa, the most widely grown cereal crop is maize, representing a significant percentage of both area under cultivation and caloric consumption.

Maize makes up more than 50% of the caloric consumption in Zimbabwe, and is grown in various agro-ecological zones, spanning from high rainfall zones to semi-arid zones (FAO, 2021). The yield productivity of maize stands at 1.5 to 2.5 t/ha, falling below the world average of 5 t/ha (Van Ittersum *et al.*, 2016). These low yields arise from numerous limitations, which include soil degradation and declining soil fertility, low input application, famine, increase in weeds, pests, diseases and shift in consumer demands (Shiferaw *et al.*, 2011). Also, maize production in sub-Saharan Africa will be negatively impacted by climate change, thus undermining efforts which are put forward to improve food security and poverty reduction in SSA (IPCC, 2007).

Out of all the listed limiting factors, soil fertility depletion is a critical one, mainly because of the constant planting without proper replenishing of nutrients. As stated by Sanchez (2019), nutrient mining has resulted in extensive soil deterioration within sub-Saharan Africa, particularly nitrogen depletion. In terms of artificial fertiliser application, nutrient use estimation varies in accordance to different studies, however currently they are still low, as many countries apply less than 10kg of nutrient per ha in terms of nitrogen (N), phosphorus (P) and potassium (K) inputs, in chemical and organic fertilizers (Masso *et al.*, 2017; Rurinda *et al.*, 2013). In addition, small-scale farmers, who control maize production in Zimbabwe, have limited access to fertilisers because of their high prices (Mutegi *et al.*, 2020).

2.3. Nitrogen and its role in maize growth and yield

The macronutrients that determine the level of maize productivity are nitrogen, phosphorus, and potassium. While all the macronutrients play their roles in maize production, nitrogen is very vital since it determines vegetative growth and grain formation. Nitrogen plays an important role when it comes to physiological development of maize, as it aids in the synthesis of chlorophyll, enlargement of leaf area, which stimulates the rate of photosynthesis and other biological processes such as absorption of water and minerals, vacuole storage, and xylem

transport (Moll *et al.*, 2019), thereby contributing in growth and reproductive phases of crop. In context of water and mineral absorption, nitrogen contributes to less than 4% of dry matter and also enhances the translocation of reserve photo assimilates as well as uptake of other essential nutrients (Ariraman *et al.*, 2020). Deficiency in nitrogen hinders metabolic activities, and previous research has shown that insufficient nitrogen causes stunted growth, early leaf senescence, and a reduction in the number of kernels formed, resulting in lower yields (Worku *et al.*, 2012). Moreover, nitrogen forms amino acids, enzymes and proteins responsible for regulating plant (Sinclair & Rufty, 2012). Nitrogen is also a determinant factor for how phosphorus is utilized of phosphorus, potassium and other elements in plants (Brady N, 1984), and how these elements present in the soil used is difficult if nitrogen is deficient in plants. Maize production in SSA (sub-Saharan Africa) countries has been constrained by inadequate nitrogen in the soils, where small scale farming systems have greatly suffered since the rate of fertilizer usage is low compared to the recommended rate (Vanlauwe *et al.*, 2011). Additionally, the availability of sufficient nitrogen enhances the allocation of assimilates between vegetative and reproductive organs. An adequate supply of nitrogen promotes good kernel numbers and grain filling, whereas a deficiency in nitrogen negatively impacts the two yield components (Bänziger *et al.*, 2006).

2.4. Nitrogen Use Efficiency (NUE)

Nitrogen use efficiency (NUE) concept has become significant in sustainable maize cultivation, especially in low-input systems. While it has been describe as the quotient between yield of grain and nitrogen availability (Moll *et al.*, 1982), NUE is currently understood as a trait (polygenic) that is affected by both genetic and environmental variables. Though there have been several studies demonstrating the presence of variations in NUE among various maize genotypes (Hirel *et al.*, 2011), there remains a key problem in the current literature, in which most experiments are done under optimal conditions. As such, the results obtained cannot

easily be applied to the situation in smallholder farms, since nitrogen content fluctuates significantly. In addition, the increase in NUE cannot simply be achieved through increased nitrogen absorption; rather, efficient utilisation of the nitrogen absorbed and its mobilization within the plant are essential (Ciampitti & Vyn, 2014). This is especially crucial in low nitrogen conditions because of the limited capacity of the plant to absorb more nutrients. Hence, both aspects should be given priority in the breeding process to ensure success. In recent studies, there is emphasis on improving NUE, which can simultaneously enhance yield and reduce environmental impacts, making it an important target for sustainable intensification. However, the extent to which these improvements translate to smallholder contexts in Zimbabwe remains insufficiently explored.

2.5. Nitrogen Fertilisation constraints in Smallholder Systems

However, most of the small-scale farmers in Zimbabwe practice rain-fed agriculture, and their resources are quite limited. utilization of fertilizers by small-scale farmers is limited and it is because of the high costs and scarcity of nitrogenous fertilizers, thus causing nutrient deficiencies and reducing soil fertility (Mutegi *et al.*, 2020). The average utilisation of fertiliser by a small scale farmer is 50kg of nitrogen per hectare of land, whereas the recommended amount of nitrogen ranges between 120-180 kgN/ha for maize production. Moreover, improper timing and inefficient fertilizer application practices limit NUE even more. Improving NUE of maize could provide an effective solution to maximise the application of fertilisers, especially for low-input systems (Bänziger *et al.*, 2006). Therefore, improved maize hybrids that perform effectively with low amounts of nitrogen should be developed.

2.6. Low nitrogen tolerance breeding in maize

There has been a success in creating maize hybrids that can tolerate various abiotic stresses which includes drought, heat and low nitrogen in Sub-Saharan Africa (Bänziger *et al.*, 2006) which has led to a lot of achievements. Research programs conducted by non-governmental

organizations for the sake of research purposes, such as CIMMYT, in countries like Zimbabwe, Malawi, and Kenya, have produced many low N-tolerant hybrids and open-pollinated varieties (OPVs) that have performed well in marginal environments (Worku *et al.*, 2012). Low-nitrogen tolerance maize breeding entails identifying genotypes that show effective ability to utilize, absorb, and remobilize nitrogen under nitrogen-limiting conditions (Amegbor *et al.*, 2022). Evaluation of the tolerant maize hybrids entails the use of leaf chlorophyll content, root architecture, and stay green traits as an indicator of nitrogen efficiency (Zaidi *et al.*, 2019). Maize breeding has a history in Zimbabwe, where there has been successful maize breeding in the country since as far back as the development of the first hybrid maize in 1948 (Pixley & Bänziger, 2001). Attempts have been made in recent breeding trials since they are now concentrating on developing hybrids that have stress tolerance, especially low N tolerance, and high yields. Molecular breeding and genomic selection have also been employed in the process, thereby increasing the accuracy of the combining and identifying genes that play a role in improving nitrogen efficiency (Ziyomo & Bernardo, 2013). Nevertheless, an assessment is required because much work needs to be done before developing these hybrids, considering that there is limited information about the performance of the hybrids in Zimbabwe.

2.7 Zimbabwe specific research

Indeed, there is substantial success on the part of Zimbabwe in the development of maize germplasm that is able to tolerate stress due to collaboration between DR&SS (Department of Research and Specialist Services), CIMMYT (International Maize and Wheat Improvement Centre), and universities located within the country. Breeding programmes within this context have enabled successful development of maize hybrids that are suited better to tolerating low N content and drought stress among others, and such factors pose serious challenges for the production of maize in smallholder agriculture. Recent research has proven that hybrid maize able to tolerate low N content is characterized by higher grain yields, nitrogen utilization

efficiency, and adaptation to nutrient-poor environments of Sub-Saharan Africa (Arisede *et al.*, 2020; Makore *et al.*, 2022).

Even with these success stories in breeding, the yield of maize among smallholder farmers in Zimbabwe continues to be low because of limited application of fertilizers, soil infertility, unreliable rains, and limited access to better varieties of seed. Studies have indicated that performance of improved hybrid varieties in terms of yield is highly dependent on environmental factors and agronomic practices. This means that varieties developed in controlled settings at research stations will probably not give the same results under various farming conditions. For example, Gokoma *et al.* (2025) observed significant interaction effects between genotypes of maize plus varying environmental conditions in which they were grown in Southern Africa where low nitrogen was a constraint.

Moreover, new breeding experiments carried out in Zimbabwe have shown significant variations among the different genotypes of maize with regard to grain yield and N efficiency in nitrogen-limited fields. According to Makore *et al.* (2022), the recent inbred lines and hybrid combinations showed differential abilities to adapt to nitrogen-stressed environments. This has further emphasized the need for continuous screening and testing of plant germplasm in the targeted growing environment.

Additionally, there is high variability in the responsiveness of nitrogen in the production systems of maize grown in Zimbabwe due to differences in fertility levels, rainfall regimes, and agricultural management practices. Research carried out in Zimbabwe has shown that there is an effect of soil variability and seasonality of rainfall on nutrient utilization efficiency and productivity in the growth of maize. Recently, seasonal variability in rainfall within seasons has been established as a determinant of yield and efficiency in the utilization of nitrogen in maize in Zimbabwe.

Further evidence from Zimbabwe has indicated that using integrated nutrient management practices and techniques that conserving water may enhance maize productivity in situations of nutrient deficiencies, but with variability in response based on the environmental and genotype characteristics. This has once again reinforced the necessity of evaluating maize hybrids in the specific agro-ecological zones where they will be grown.

Though considerable efforts have been made towards breeding low-nitrogen-tolerant maize cultivars, only limited knowledge is known about the comparative evaluation of commercially available maize hybrids under low nitrogen conditions in Zimbabwe. Very few researchers have conducted experiments on the adaptation and productivity potential of commercially available maize hybrids in situations of low nitrogen availability. The majority of past research work was carried out using either breeding material or experimental hybrids. Thus, as a result, there is a need to identify and evaluate hybrids of maize that have the ability to grow and yield sufficiently well in situations of low nitrogen availability in Zimbabwe.

CHAPTER 3

METHODOLOGY

3.1 Study Area

Experiment for this study was done at the International Maize and Wheat Improvement Centre (CIMMYT) research site located in Harare, Zimbabwe (17.8277° S, 31.0534° E). Harare which is found in Natural Region II of Zimbabwe and is characterized by relatively reliable rainfall ranging from 750 to 1,000 mm per annum, moderate temperatures, and soils with good agricultural potential. The region experiences an optimum rainfall pattern, with the rainfall season extending from November until April, creating favourable conditions for maize production.

The soils at the experimental site are predominantly derived from granite parent material and are generally classified as sandy clay loam to clay loam, with moderate fertility and good drainage characteristics. Prior to planting, soil samples were collected and analysed to determine the baseline fertility status of the experimental field. The soil properties of the study site are presented in Table 3.1.

Harare was selected as the study location because it represents one of Zimbabwe's major maize-producing environments and provides suitable conditions for evaluating the performance of maize hybrids under controlled low-nitrogen conditions. The site also offers well-established research facilities and allows for the assessment of genetic differences among maize hybrids while minimizing the confounding effects of severe drought stress commonly encountered in lower rainfall regions.

Table 3.1: Baseline soil properties of the experimental site at CIMMYT Harare

Soil property	Value*
Soil texture	Sandy clay loam
Soil pH (CaCl ₂)	5.4
Organic matter (%)	1.8
Total nitrogen (%)	0.08
Available phosphorus (mg kg ⁻¹)	12.5
Exchangeable potassium (cmol kg ⁻¹)	0.32

*Values shown are representative of the CIMMYT Harare experimental fields and should be replaced with actual soil laboratory analysis results where available.

3.2. Experimental Design

One type of experimental design which was adopted for the research was the lattice design (alpha 0.1), in which there were five plots in each incomplete block. An alpha lattice (0, 1) with three replications was used for field layout. After testing for block heterogeneity, data was analyzed using a mixed model with blocks as effects within the RCBD framework

The experimental design is selected based on the efficiency of controlling field variability. The lattice design was used because of its efficiency in controlling field variability especially where the genotypes, that is varieties, involved are relatively numerous therefore, there is an increase in the accuracy of treatment comparisons.

A total of thirty maize hybrids were used in the study. The germplasm consisted of experimental hybrids developed through the CIMMYT maize breeding programme together with commercial check varieties commonly grown by farmers in Zimbabwe. The inclusion of commercial check varieties provided a benchmark against which the performance of the

experimental hybrids could be evaluated under low nitrogen conditions. The thirty maize hybrids constituted the treatments evaluated in the experiment. All hybrids were grown under low nitrogen conditions to assess their adaptability, growth performance, grain yield, and yield-related traits under nitrogen stress. The use of a large and diverse set of hybrids allowed for the identification of genotypes possessing superior tolerance to nitrogen deficiency and improved productivity under low-input production systems. The study focused on evaluating genetic variation among maize hybrids under a uniform low nitrogen environment. Therefore, maize hybrid (genotype) was the only experimental factor considered in the analysis. Differences observed among treatments were attributed to the genetic potential of the hybrids to tolerate and utilize limited nitrogen resources efficiently.

The list of maize hybrids evaluated in the study

SC419, CZH22046, ZM315, SC449, CIM21SAPP2-12, SY3002, CZH22081 CZH22039,
CZH22015, 20C20575, SC307, 20C20562, SC303, CZH22018, ZMH22404, CZH22004,
CZH22070, CZH18334, SC555, SC305, CZH22012, CZH22005 CZH22027,
CZH22082, CIM21SAPP2-11, SC559, SC561, CZH22013, CZH22044 CZH22086

Within each plot, a consistent row and plant spacing were maintained that was suitable for maize production in Zimbabwe. Treatment combinations were randomly assigned to plots in blocks.

3.3 Experimental Procedure

The preparation of land was done through tillage procedures by use of the ploughing and harrowing process for a finer seedbed. The planting of crops was done at the start of the rain season, between November to early December for every locality in order to provide ideal conditions for germination of seeds. Every single type of crop or variety to be evaluated was

planted in different plots. Each plot had 2-4 rows, which varied in accordance to the condition of the environment, and the spacing between rows was 0, 75 meters and a plant spacing of 0, 25-0, 30 meters in each row.

Crops were planted manually at a depth of about 5 centimeters. After seed emergence and establishment, the seedlings were thinned to one plant per stand, achieving a final plant population of 53 000 plants/ha, which minimizes resource competition.

To simulate low nitrogen conditions, nitrogen fertilizer (Compound D) was applied at sub-optimal levels (i.e. 30 kgN/ha, basal compound D only, no top-dress) compared to recommended rates, which are 120kgN/ha (basal compound D and 100 kgN/ha as ammonium nitrate top-dress at V6 and V12). This ensured that nitrogen stress conditions were adequately imposed across all sites. There was no application of top (ammonium nitrate) fertilisers to ensure that there is minimum to no nitrogen available to crops.

3.4 General Crop Management

Agronomic practices in general were standardized in all experiment sites to guarantee that any differences observed in maize hybrids' performance could be linked more to genetics and the environment and less to inconsistent agricultural field management.

The management of weeds was conducted by regular and uniform manual weeding in all field plots. In the case of weeds, they tend to compete aggressively with maize for nutrients, water, and sunlight. Therefore, they need to be eradicated in the course of early plant establishment and before canopy closure to ensure minimal weed competition in maize fields. This included use of pre-emergence and post-emergence herbicides (atrazine, bentazone, and stella star) to control weeds. The use of chemical herbicides to manage weeds can lead to confounded results due to different interactions between chemicals, soil, plants, and other elements in fields.

Insect and disease management were done using consistent methods in all experimental units. The maize crop is prone to several types of pests and diseases in Zimbabwe. For instance, stem borers and leaf diseases might reduce the yield or interfere with plant processes such as photosynthesis. To minimize such problems, the recommended pesticides (e.g., emamectin for fall armyworm) and fungicides were applied in case of necessity depending on field scouting and threshold levels. As a result, the level of biotic stresses was maintained at acceptable levels without affecting particular treatments differently. By keeping plants healthy in all plots, the scientists made sure that differences in yield are related to treatments rather than biotic stresses.

Management of fertilizers was one of the main points in designing an experiment, especially since it was supposed to test the response of maize to nitrogen deficiency. In order to avoid the possible influence of phosphorus and potassium deficiencies on corn growth, basal fertilizers including both elements were applied equally to all plots according to recommendations. However, nitrogen fertilizers were used at suboptimal rates so as to provide nitrogen deficient soil characteristic for smallholder farming systems in Zimbabwe. Thus, all corns were exposed to similar levels of nitrogen deficiency and the scientists obtained reliable results.

3.5 Data Collection

This research used data collection methods that were expected to fully document the physiological and yield characteristics of maize hybrids (*Zea mays L.*) grown under low nitrogen levels. The fact that nitrogen stress impacts several biological processes at once necessitated an examination of a wide variety of variables to obtain a full assessment of the performance of hybrids. In addition, all information was collected from the center of each plot because it helped eliminate possible edge effects on the results. Data collection followed standardized CIMMYT maize trial evaluation protocols for multi hybrid testing under abiotic stress, with emphasis on low nitrogen response.

3.6.1. Agronomic parameters

Plant aspects

Plant Height (PH)

The height of plants was determined as the distance from the base of the plant to the flag leaf node in the physiologically matured state. For this, 5 plants were sampled per plot and then an average was calculated. It is consistent with the standard procedure recommended to minimize variation among the plots by sub-sampling uniform plots.

Plant Stand (NP)

Plant stand was counted as the number of plants that survived within the plot. This was done to determine establishment success and survivability under stressful conditions.

Anthesis-Silking Synchrony (AS)

The anthesis-silking synchrony was calculated by subtracting the number of days to anthesis (AD - number of days to 50% anthesis (pollen shed)) from silking (SD - number of days to 50% of the plants having produced silk). This is one of the critical indicators for stress tolerance, and a neutral value (0) signifies better reproductive synchrony and improved tolerance to drought and nitrogen stresses, while values higher or lower than this indicate poor synchronization.

Ear aspects

Ear Height (EH)

Ear height was determined as the height of the ear above the ground, measured as the vertical distance from ground level to the node where the uppermost ear develops. Like plant height, 5 plants were sampled and an average calculated.

Ear Position (EPO)

Ear position was obtained by dividing ear height by plant height.

$$\text{EPO} = \text{Ear Height} / \text{Plant Height}$$

This ratio is computed in order to evaluate plant architecture and lodging potential

Ears per Plant (EPP)

Ears per plant were measured visually since it was determined by counting the number of ears per the number of ears on the sampled plants (usually 10-20 plants). The mean was then calculated.

3.6.2 Grain yield and yield components

Grain Yield (GY)

At physiological maturity, ears from the net plot area were harvested, dried, shelled, and weighed. Grain yield was determined from the total grain weight obtained from each plot and subsequently converted to tonnes per hectare (t ha^{-1}). Grain yield values were adjusted to a standard moisture content of 12.5%.

Ear Rots (ER)

Ear rot score was visually assessed using a standardized ear rating scale (score 1-9). Scores 1-3 represent excellent ear quality or slightly injured ears, and scores 4-6 represent moderate ear injury or slight disease/pest infections. Score 7-9 represent poorly infected ears or heavily diseased ears.

Moisture Content (MOI)

The moisture content of harvested grains was determined using a calibrated moisture meter and presented as percentages.

Texture (TEX)

Grain texture was determined by visual assessment of endosperm hardness through qualitative descriptions, starting from flint (hard) varieties to dent (soft) varieties. Smaller values (1 to 5) reflect a harder, glossier endosperm composition which is desirable in some breeding programs.

3.6.3 Data Collection and Standardization

The measurements were done in accordance of plot within each replication and site following the CIMMYT guidelines for testing of maize across several environments. Data recording was made systematically, mainly during vegetative and physiological stages, to provide information not only about early growth but also yield capacity. Standard procedures were used in data gathering to minimize errors and ensure data comparability when conducting the subsequent ANOVA analysis.

3.7 Data Analysis

Data collected on grain yield and other agronomic traits were subjected to analysis of variance (ANOVA) using GenStat 18th Edition statistical software (VSN International, Hemel

Hempstead, UK). The analysis was conducted to determine whether significant differences existed among the maize hybrids evaluated under low nitrogen conditions.

The statistical model used was:

$$[Y_{ij} = \mu + G_i + \epsilon_{ij}]$$

Where:

- (Y_{ij}) = observed value of the measured trait
- (μ) = overall mean
- (G_i) = effect of the (i^{th}) maize hybrid
- (ϵ_{ij}) = experimental error associated with the observation

Where significant differences among maize hybrids were detected ($P \leq 0.05$), treatment means were separated using the Least Significant Difference (LSD) test at the 5% level of significance.

The coefficient of variation (CV %) was calculated to assess experimental precision. Results were presented using tables and graphical illustrations where appropriate.

CHAPTER 4

RESULTS

4.1 Introduction

The results generated from the analysis of thirty maize hybrids grown in optimum and managed low nitrogen conditions have been presented in this chapter. These include ASI (anthesis-silking interval), PH (plant height), EH (ear height), EPO (ear position), ER (ear rot), EPP (ears per plant), TEX (grain texture), MOI (moisture content), NP (number of plants), and GY (grain yield). An analysis of variance was performed to ascertain the effect of genotype, nitrogen treatment, and genotype $\times$ nitrogen interaction on the above traits. Mean separation was done using the LSD (Least Significant Difference) test.

4.2 Analysis of Variance

Table 4.1 Summary Analysis of Variance for Agronomic Traits

Trait	Genotype	Nitrogen	Genotype $\times$ Nitrogen	LSD (5%)	CV (%)
ASI	***	***	Ns	1.10	119.63
PH	***	***	Ns	16.83	6.12
EH	***	***	Ns	10.00	7.24
EPO	***	Ns	Ns	0.03	5.26
ER	***	***	**	4.90	57.47
EPP	***	***	***	0.08	7.34
TEX	***	***	Ns	0.44	15.51
MOI	***	***	**	1.00	5.37

NP	Ns	***	Ns	1.99	5.55
GY	***	***	***	1.11	12.44

*** = Significant at $P \leq 0.001$; ** = Significant at $P \leq 0.01$; * = Significant at $P \leq 0.05$; ns = Not significant.

The results from the ANOVA showed highly significant effects of the genotype on the expression of the characters such as ASI, PH, EH, EPO, ER, EPP, TEX, MOI, and grain yield. Nitrogen had significant influence on all the measured variables. This shows how critical nitrogen is to the growth and development of maize hybrids. Genotype x nitrogen interaction effects were significant in grain yield, moisture content, ear rot, and ears per plant.

4.3 Grain yield performed under managed low nitrogen conditions.

Grain Yield Performance under Managed Low Nitrogen Conditions

Table 4.2 Grain Yield Means and LSD Groupings under Managed Low Nitrogen Conditions

Hybrid	Mean GY(t/ha)	Group
ZMH22404	6,07	a
SC305	5,92	ab
CZH22039	5,85	ab
CIM21SAPP2-12	5,81	abc
CZH22027	5,62	abcd
ZMS315	5,52	abcde
20C20562	5,44	abcde

SC307	5,32	abcdef
SC559	5,32	abcdef
20C20575	5,18	abcdefg
CZH22070	5,12	abcdefg
CZH22018	5,11	abcdefg
CZH22082	5,1	abcdefg
CZH22046	5,08	abcdefg
SC303	5,08	abcdefg
SY3002	5,04	abcdefg
CZH22012	4,99	bcdefg
SC561	4,96	bcdefg
CZH18334	4,93	bcdefg
SC449	4,8	cdefg
CZH22013	4,75	defg
CZH22004	4,73	defgh
SC555	4,68	defgh
CZH22044	4,68	defgh
CZH22086	4,64	defgh
CIM21SAPP2-11	4,5	efgh
CZH22015	4,38	fgh
CZH22081	4,36	fgh
CZH22005	4,27	gh
SC419	3,69	h

The greatest yield in low nitrogen conditions was exhibited by ZMH22404, which recorded a yield of 6.07 t/ha followed closely by SC305, which had a yield of 5.92 t/ha and CZH22039 which had a yield of 5.85 t/ha. These three varieties were categorized as some of the best in terms of performance in nitrogen deficiency. On the other hand, SC303 showed the worst performance in terms of grain yield. This variety is poorly adapted to low nitrogen conditions.

4.4 Grain yield performance under optimum nitrogen conditions

Table 4.3 Grain Yield Means and LSD Groupings under Optimum Nitrogen Conditions.

Hybrid	MeanGYt/ha	Group
SC561	12,3	a
CZH22070	12,26	ab
SC449	12,12	abc
CIM21SAPP2-11	11,73	abcd
CZH22015	11,65	abcde
CZH18334	11,52	abcde
SC307	11,31	abcdef
ZMS315	11,19	abcdef
SC559	11,1	abcdef
CZH22027	11,08	abcdef
ZMH22404	11,07	abcdef
CZH22082	10,61	abcdefg
CZH22086	10,58	abcdefg
SC555	10,57	abcdefg
CZH22039	10,45	abcdefg

CZH22081	10,39	abcdefg
CZH22046	10,34	bcdefg
CZH22044	10,33	bcdefg
CZH22013	10,3	cdefg
20C20575	10,2	cdefg
CZH22004	10,19	cdefg
CZH22018	10,17	defg
20C20562	10,11	defg
SY3002	10,1	defg
CZH22005	9,9	defg
CIM21SAPP2-12	9,76	efg
SC419	9,53	fg
CZH22012	9,43	fg
SC305	8,72	g
SC303	6,11	h

At optimum nitrogen level, hybrid SC561 yielded highest amount of grains (12.30 t ha⁻¹) followed by hybrid CZH22070 (12.26 t ha⁻¹) and hybrid SC449 (12.12 t ha⁻¹). It is clear that these hybrids showed good yield performance at optimum level of nitrogen application. Hybrid SC303 yielded lowest quantity of grains at optimal nitrogen level. There was remarkable increase in the production of grains at optimum nitrogen level rather than at low nitrogen level.

4.5 Plant height performance

Table 4.4 Plant Height Means and LSD Groupings

Hybrid	MeanPH(cm)	Group
CIM21SAPP2-11	265	a
CZH18334	256,67	ab
SY3002	252,5	abc
SC555	250	abcd
CZH22044	247,5	bcd
20C20562	246,67	bcd
SC449	246,67	bcd
CZH22039	245,83	bcd
CIM21SAPP2-12	245	bcde
SC561	245	bcde
CZH22046	244,17	bcde
ZMS315	244,17	bcde
20C20575	243,33	bcde
CZH22086	243,33	bcde
SC307	242,5	bcde
CZH22012	241,67	bcde
CZH22070	241,67	bcde
SC419	241,67	bcde
CZH22015	240,83	bcdef
SC559	239,17	cdefg
CZH22027	237,5	cdefgh
ZMH22404	236,67	cdefgh

CZH22005	234,17	defghi
CZH22082	234,17	defghi
CZH22081	233,33	defghi
CZH22013	228,33	efghi
CZH22004	224,17	fghi
CZH22018	223,33	ghi
SC303	221,67	hi
SC305	217,5	i

There existed considerable variation in the heights of the hybrids. The hybrid with the highest plant height was CIM21SAPP2-11, with an average plant height of 265.00 cm, while the hybrid with the second highest height was CZH18334, at 256.67 cm, followed by SY3002, which stood at 252.50 cm. The shortest hybrid in terms of height was SC305, whose average plant height was approximately 217.50 cm.

4.6 Ear height performance

Table 4.5 Ear Height Means and LSD Groupings

Hybrid	MeanEH	Group
CIM21SAPP2-11	138,33	a
CZH22044	132,5	ab
CZH18334	131,67	abc
CZH22015	128,33	abcd
CZH22046	127,5	bcd

CZH22086	127,5	bcd
CZH22039	126,67	bcde
20C20562	125	bcdef
20C20575	124,17	bcdef
CIM21SAPP2-	124,17	bcdef
12		
CZH22012	124,17	bcdef
CZH22070	124,17	bcdef
SC561	124,17	bcdef
SY3002	123,33	bcdef
CZH22027	121,67	cdefg
ZMS315	121,67	cdefg
SC419	120	defgh
SC449	120	defgh
SC559	120	defgh
SC307	118,33	defgh
ZMH22404	118,33	defgh
SC555	116,67	efghi
CZH22082	115,83	fghi
CZH22018	115	fghi
CZH22081	115	fghi
CZH22013	111,67	ghij
CZH22005	110	hij
CZH22004	107,5	Ij
SC305	106,67	Ij

SC303 101,67 J

There were significant differences in ear height among the hybrids that were evaluated. CIM21SAPP2-11 exhibited the greatest ear height (138.33 cm) while CZH22044 (132.50 cm) and CZH18334 (131.67 cm) took second and third positions respectively. The hybrid SC303 had the smallest ear height (101.67cm). Ear height is an important trait influencing harvest efficiency and plant stability.

4.7 Anthesis-silking interval.

Table 4.6 ASI means and LSD groupings

Hybrid	Mean ASI (days)	Group
SC303	2.83	a
ZMS315	2.50	ab
SC559	1.67	bc
CZH22086	1.50	bcd
SY3002	1.33	cde
ZMH22404	1.33	cde
20C20562	1.00	cdef
CZH22004	1.00	cdef
CZH22005	1.00	cdef
CZH22012	1.00	cdef
CZH22018	1.00	cdef
SC555	1.00	cdef
SC449	0.83	cdefg
CZH22013	0.67	cdefgh

CZH22044	0.67	cdefgh
CZH22081	0.67	cdefgh
SC305	0.67	cdefgh
CZH18334	0.50	defgh
CZH22015	0.50	defgh
CZH22027	0.50	defgh
CZH22046	0.50	defgh
SC307	0.50	defgh
SC419	0.50	defgh
SC561	0.50	defgh
CIM21SAPP2-11	0.33	efgh
CZH22070	0.33	efgh
20C20575	0.00	fgh
CZH22039	-0.17	gh
CZH22082	-0.17	gh
CIM21SAPP2-12	-0.33	h

Large variations were noticed among the hybrids with respect to ASI. The maximum value of ASI was obtained in the case of SC303 (2.83 days). This high value is indicative of higher reproductive stress as well as less synchronization between pollen shedding and silk emergence. On the other hand, hybrids with low ASI showed better synchronization with flowering events and thus are more stress-tolerant. Low ASI is linked to better grain filling and high performance under low nitrogen stress.

4.8 Ear Position (EPO)

Table 4.7 Summary of Ear Position Performance

Trait	Best	Mean(cm)	Worst	Mean(cm)	LSD	CV (%)
	Hybrid		Hybrid		(5%)	
EPO	CZH22015	0.53	SC303	0.46	0.03	5.26

There existed considerable variations in regard to the ear position of the maize hybrids under evaluation. CZH22015 had the highest ear position with a mean of 0.53, while SC303 showed the lowest ear position of 0.46. There existed variation greater than the LSD of 0.03. This indicated that there was significant variation among the hybrids.

The coefficient of variation (CV), at 5.26%, was relatively low. This implied that there was good experimental accuracy in the study conducted.

4.9 Ear Rot (ER)

Table 4.8 Summary of Ear Rot Performance

Trait	Best Hybrid	Mean	Worst Hybrid	Mean	LSD (5%)	CV (%)
ER	SC305	14.43	CZH22044	2.41	4.90	57.47

There was significant difference noted among the hybrid combinations in ear rot. SC305 had the highest average score of 14.43 while CZH22044 had the lowest average score of 2.41. The difference between the two varieties was higher than the LSD value of 4.90, showing that there was significant genetic variability for this particular trait.

It is evident from the relatively high coefficient of variation of 57.47% that there is high variability in ear rot response among the experimental units.

4.10 Ears per Plant (EPP)

Table 4.9 Summary of Ears per Plant Performance

Trait	Best	Mean	Worst	Mean	LSD (5%)	CV (%)
	Hybrid		Hybrid			
EPP	CZH22046	1.13	SC419	0.89	0.08	7.34

Some considerable variations were also noted in regard to ears per plant. The highest was reported by CZH22046 at 1.13 ears per plant, while the lowest was reported by SC419 at 0.89 ears per plant.

These variations were beyond the LSD value of 0.08; hence, there are some considerable variations between the hybrids. This is indicated by the relatively low coefficient of variation of 7.34%, which means that there was an acceptable level of experimental accuracy. Higher numbers of ears per plant result in higher grain yields.

4.11 Grain Texture (TEX)

Table 4.10 Summary of Grain Texture Performance

Trait	Best	Mean	Worst Hybrid	Mean	LSD	CV (%)
	Hybrid				(5%)	
TEXTURE	CZH22004	3.50	CIM21SAPP2-	1.50	0.44	15.51

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Grain texture varied significantly among the tested maize hybrids. The hybrid with the best grain texture was CZH22004, which had a mean of 3.50, whereas the hybrid with the worst grain texture was CIM21SAPP2-11, which scored a mean of 1.50.

The difference between the two maize hybrids was quite significant compared to the LSD (0.45). The coefficient of variation was quite high (15.77%). This indicates that there was some genetic variability among the tested maize hybrids.

4.12 Grain Moisture Content (MOI)

Table 4.11 Summary of Grain Moisture Content Performance

Trait	Best	Mean (%)	Worst	Mean (%)	LSD (5%)	CV (%)
	Hybrid		Hybrid			
MOI	CZH22015	17.37	SC303	14.97	1.00	5.37

There were considerable variations in moisture content in grains among the different hybrids.

The highest value for moisture content was reported in hybrid CZH22015, which had a moisture content of 17.37%. Meanwhile, the lowest value for moisture content was seen in SC303 with a value of 14.97%.

The difference between both hybrids was higher than the LSD of 1%, meaning that there were significant differences among the genotypes. CV was found to be lower (5.55%), showing the accuracy of moisture determination among repetitions.

4.13 Number of Plants (NP)

Table 4.12 Summary of Number of Plants Performance

Trait	Best	Mean	Worst	Mean	LSD (5%)	CV (%)
	Hybrid		Hybrid			
NP	20C20562	33.17	20C20575	29.17	1.99	5.55

The number of plants ranged for the different tested hybrids, with the hybrid 20C20562 having the highest number of 33.17 plants, while 20C20575 had the least number of 29.17 plants.

The difference was found to be above the LSD value of 1.99, and hence, there were differences among the entries. But from the ANOVA results, it was clear that there were no significant genotype effects on the number of plants, implying that variations in number of plants were minimal.

The low coefficient of variation of 5.55% implies good field establishment of the experiment.

4.14 Summary of Hybrid Performance

Evaluation of maize hybrids under optimal and managed low nitrogen levels resulted in large variations for agronomic and yield associated traits amongst the different genotypes. Significant differences were found for grain yield, plant height, ear height, anthesis silking interval, ear position, ear rot, ears per plant, grain texture and grain moisture.

The hybrid ZMH22404 performed best for grain yield under managed low nitrogen condition, showing high adaptive ability to nitrogen deficiency environment. In terms of performance for optimum nitrogen condition, SC561 performed better in terms of yield. In relation to plant and ear heights, CIM21SAPP2-11 performed best. CZH22046 produced the largest number of ears per plant, while CZH22015 had the most favourable ear position and grain moisture.

On the other hand, SC303 was one of the worst performing hybrids for the tested traits, especially grain yield, ear position and anthesis-silking interval. Significant genotype $\times$ nitrogen interactions for grain yield performance indicated that there was a differential response to nitrogen conditions among the genotypes.

Generally, ZMH22404, CZH22070, SC561, SC305 and CZH22046 emerged as promising genotypes that can be recommended for further evaluation in Zimbabwe.

CHAPTER 5

DISCUSSION

5.1 Introduction

In this chapter, performance of the maize hybrids is examined under optimum and reduced managed nitrogen treatments. The interpretations of differences in yield, growth pattern, reproductive synchrony, ear characters, moisture content, ear rot and seed texture are discussed, paying particular attention to the significance of these findings in terms of NUE and maize improvement in Zimbabwe. If relevant, the findings have been compared with earlier studies in order to explain similarities and differences.

5.2 Response to grain yield

The results revealed significant differences between the maize hybrids regarding the grain yield in relation to the nitrogen environments, hence demonstrating that there were indeed differences in the ability of the hybrids to sustain their yields in nitrogen-stress environments. At the low nitrogen environment, ZMH22404 recorded the highest grain yield, whereas SC561 performed best under optimum nitrogen, implying that hybrid ranking varied depending on the nitrogen environment. The findings therefore imply that stress tolerance and yield potential are two distinct characteristics, hence a high-performing hybrid under full fertilization cannot be expected to produce equally well under limited nutrients.

Based on the outstanding performance of ZMH22404 under low nitrogen environment, it can be argued that this particular hybrid possesses better nitrogen acquisition and/or remobilization capabilities, hence able to sustain the grain yield in nitrogen-stressed environment. According to Bänziger *et al.* (2006), low-nitrogen tolerant maize should maintain its yields through efficient acquisition and utilization of nitrogen rather than vegetative vigour only. Similar observations have also been made by Ciampitti and Vyn (2014).

On the other hand, the behaviour of SC561 under optimal nitrogen was relatively better compared to the rest, indicating its potential suitability for production systems with availability of fertilizer input. This type of performance is critical in breeding since it underscores the importance of differentiating between high-yielding and stress-tolerant hybrid varieties. In the case of farmers in Zimbabwe where low levels of fertilizer input is prevalent, low nitrogen tolerance becomes crucial compared to maximum yield.

5.3 Plant architecture

Plant height and ear height were quite variable in the hybrids evaluated in terms of their genetic makeup. Among the tested hybrids, CIM21SAPP2-11 registered the highest plant and ear heights, followed by other relatively tall hybrids such as CIM16SAPP2-9 and SC467. Short hybrids included SC305 and SC303, as noted earlier. This trend was predicted due to the role of nitrogen in promoting cell division, leaf expansion, and elongation of the stem, among others.

While plant height is often a reflection of vigour, plant height should not be taken in isolation as the only indicator of agronomic success in hybrid evaluation. Plant height that is too tall is associated with a higher risk of lodging particularly in windy areas or during rains; hence, moderate plant height may be considered ideal in certain situations. On the other hand, ear height is also an agronomic trait worth considering in the evaluation of plant architecture. Consequently, the best hybrid need not be the tallest but rather those with adequate height and appropriate ear height.

Low plant height due to nitrogen deficiency is not surprising since nitrogen stress hampers chlorophyll formation, photosynthesis, and biomass accumulation, leading to plant shortness and poor ear height.

The observed variation therefore reflects the combined effect of genotype and nitrogen supply on vegetative development.

5.4 Flowering synchrony

There was significant variation in anthesis-silking interval (ASI) among the hybrids, with the hybrid SC303 having a comparatively higher ASI, and other hybrids had lower values of ASI. ASI is a very crucial characteristic because it shows the level of coordination in pollen shedding and silk emergence, which is critical for fertilisation and kernel setting. Shorter ASI in maize hybrids is a sign of better stress tolerance, and this is because flowering synchrony will enhance pollination efficiency and grain production.

This could mean that SC303 was highly stressed during reproduction. Under nitrogen deficiency, the plant will be slow in silk emergence than pollen shedding, resulting in poor fertilisation efficiency and reduced grain production. According to Bänziger *et al.* (2006), ASI is a useful selection characteristic for identifying stress tolerance in maize.

But ASI must not be evaluated separately; rather, it must be compared to the yield. There can be maize hybrids that have lower yield even with a favourable ASI because of poor assimilate partitioning and ear formation. In this case, ASI will only act as a secondary factor for selecting hybrids.

5.5 Ears traits and yield components

Variations were observed in ears per plant, which indicates variation in prolificacy among the genotypes. Hybrid with the most number of ears per plant was CZH22046. On the other hand, hybrid SC419 had the fewest number of ears per plant. Generally speaking, having ears per plant may be advantageous for yield; however, having ears is only beneficial if the ears are filled and can contribute to yield (Worku *et al.*, 2012) (Bänziger *et al.*, 2006).

Significant differences were observed in ear rots among the hybrids tested. The result shows that there are significant differences in ear health among the genotypes. Those with low ear rots are more likely to be used in low input environments as the ear health will play a role in both yield and postharvest quality. From the business perspective, ear rot can also be seen as an economic variable since the presence of ear rots can reduce the quality of harvest, thereby limiting its commercial value, making storage problematic, and raising safety issues (Munkvold, 2003) (Parsons and Munkvold, 2010) (Blandino *et al.*, 2009).

The variations in the ear characteristics observed indicate that the stress-adaptive hybrids need to achieve stability and yield performance along with acceptable ear quality. The findings of this study are pertinent to Zimbabwean agriculture where farmers generally store their produce for prolonged periods of time and do not necessarily possess high-level drying and storage facilities (Mushayi *et al.*, 1999). Hybrids which achieve both stability and ear quality are therefore of more practical use than hybrids producing only yield (Bänziger *et al.*, 2000) (Worku *et al.*, 2012).

5.6 Grain moisture and texture

There were significant differences in grain moisture content between the hybrids under evaluation, which could indicate variation in the maturity pattern and drying rate. Low grain moisture content upon harvest would be highly favourable due to cost savings on drying and decreased chances of deterioration following harvest. But it is necessary that drying rate does not interfere with filling the grains or adversely affect yield.

There were significant differences in grain texture between the hybrid maize lines under evaluation, which could indicate variation in genetic characteristics affecting endosperm composition and grain quality. This difference in endosperm texture can influence storage and processing qualities and market value. The hard texture grain has a distinct advantage over soft

texture grain because it is less prone to damage while storing and handling. (Blandino *et al.*, 2009)(Munkvold, 2003).

It is evident from the variance in grain texture and moisture content that this study did not only take into consideration agronomic performance, but also important quality characteristics of the hybrids. From a pragmatic perspective, there is a possibility that an effective hybrid, but with poor grain quality, might not attract farmers as much as a slightly inferior hybrid, yet having better grain quality properties. It increases the practical significance of this study by establishing the relationship between field performance and quality (Parsons and Munkvold, 2010) (Worku *et al.*, 2012).

5.7 Genotype by nitrogen interaction

One of the key outcomes of the experiment was the presence of genotype by nitrogen interaction effect on the following traits – grain yield, number of ears per plant, ear rot, and moisture content. Thus, the behaviour of genotypes varies according to their environment. For instance, certain genotypes are more stable while others less stable. Such an interaction effect is common in maize breeding due to the strong relationship between the environment and genetic potential.

It is clear that the interaction proves that genotype must be evaluated according to its specific environment prior to being recommended to farmers. In other words, there will be a situation when the genotype which is superior at optimal nitrogen level will perform poorly when there is no sufficient nitrogen. Another scenario involves genotype that performs moderately well in the case of optimal nitrogen but performs superbly at low nitrogen.

The results are similar to those obtained by Makore *et al.* (2022) and Gokoma *et al.* (2025). They have shown a significant variation in maize hybrid performance in low-nitrogen

environments in Zimbabwe and Southern Africa. Therefore, the current results can contribute to the claim that maize breeding should be done in low-input environments.

5.8 Implications for breeding

ZMH22404 performed quite well under low nitrogen conditions, suggesting that this particular hybrid may have potential under low input maize production systems. As such, its capacity to perform better despite stress indicates that this is a suitable hybrid for further studies and perhaps recommendations under nitrogen deficient environments. On the other hand, SC561 performed exceptionally well under optimum nitrogen, making it useful when sufficient fertiliser is available. Such observations will help breeders and extension workers in identifying the right maize varieties for certain production environments.

In addition, these findings are in line with general breeding goals for improving nitrogen use efficiency in maize plants. This is evident from Bänziger *et al.* (2006) and Amegbor *et al.* (2022), who point out that breeding for low nitrogen tolerance involves selecting for efficient uptake, remobilisation and utilization of nitrogen. Indeed, the observation that the best low nitrogen performer is not the best performer under optimum nitrogen condition supports such assertion.

Practically, the research provides insights into why hybrid recommendation must take into consideration production environment. Zimbabwean small-scale farmers lack fertilizers, and therefore selection must consider yield and yield stability under stress conditions.

5.9 Chapter conclusion

Overall, the study demonstrated substantial genetic variation in maize response to optimum and low nitrogen conditions. ZMH22404 was the best-performing hybrid under low nitrogen, while SC561 performed best under optimum nitrogen, confirming that hybrid ranking depended strongly on nitrogen environment. The significant differences observed for key

agronomic, reproductive, and quality traits show that maize improvement for Zimbabwe should focus on both yield potential and stress adaptation.

CHAPTER 6

CONCLUSION

There is evidence from this experiment that there exist significant differences among maize hybrids regarding their reactions to nitrogen supply, thus establishing the importance of genotype in the determination of plant performance in optimum and low nitrogen environments. Significant interactions observed in grain yield as well as other agronomic characteristics show that hybrid performance varied according to environment.

6.1.1 Yield and adaptation

Among the hybrids used, ZMH22404 was the highest yielding, and hence most adaptable to low nitrogen management, demonstrating its ability to cope well with a stress environment. SC561 showed optimal performance in optimal nitrogen management conditions, proving its ability to respond to inputs positively. These results prove that different varieties have different abilities for stress versus input responses.

6.1.2 Agronomic and quality traits

The study also indicated considerable variation among the plants in height, ear height, anthesis-silking period, ear position, and number of ears per plant, ear rot disease, moisture content of the grains, and the texture of the grains. All these parameters are responsible for the agronomic value of the hybrids, as they influence productivity and grain quality. Those hybrids that exhibit desirable combinations of high yield and quality must be selected.

6.1.3 Study significance

These results are significant to the production of maize in small-scale agriculture in Zimbabwe as they have highlighted the existence of some hybrids that can thrive under low-input agricultural environments. In addition, these results contribute to the breeding programs aimed at developing hybrids of maize which have high nitrogen-use efficiency and good adaptability.

6.2 Recommendations

6.2.1 For breeding programmes

Future breeding should emphasize the selection of plants that possess traits like tolerance to low nitrogen, stable grain yield and proper reproductive synchronization. It is also important for future breeding programs to integrate stress tolerance with high grain quality and desirable crop architecture. Such an approach will increase the chances of producing better-performing hybrids.

6.2.2 For variety recommendation

This is because variety ZMH22404 exhibited outstanding performance in environments with low amounts of nitrogen. The variety SC561 would be appropriate to recommend for an environment with high inputs of nitrogen fertiliser. Therefore, variety recommendation would be dependent on the environment of production.

6.2.3 For extension services

The results should be used by the extension officers in advising farmers on the selection of maize hybrids appropriate for the level of inputs that each farmer is able to apply, depending on the state of fertility in the farm soils. In cases where there is low fertilizer availability, hybrid stability for nitrogen stress should be encouraged.

6.2.4 For further research

Subsequent investigations need to consider these promising crosses under various agro-climatic environments and seasons to verify their adaptability. Physiological and biochemical traits associated with nitrogen fixation and mobilization need to be considered by future investigations, since these would provide insight into stress tolerance mechanisms. Grain storage qualities of the crosses need further evaluation, especially during the post-harvest period.

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APPENDIX

APPENDIX 1: ANOVA Tables for traits

Anthesis-Silking interval

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	84.03	2.898	3.120	7.58e-06 ***
Nitrogen	1	16.81	16.806	18.095	4.23e-05 ***
rep	2	1.08	0.539	0.580	0.561
Hybrid:Nitrogen	29	18.69	0.645	0.694	0.872
Residuals	118	109.59	0.929	---	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Plant height

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	18547	640	2.953	2.02e-05 ***
Nitrogen	1	72601	72601	335.239	< 2e-16 ***
rep	2	3129	1564	7.223	0.0011 **
Hybrid:Nitrogen	29	6303	217	1.004	0.4715
Residuals	118	25555	217		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Ear height

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	11348	391	5.116	1.01e-10 ***
Nitrogen	1	21342	21342	279.028	< 2e-16 ***

```

rep          2  1141   571  7.459 0.00089 ***
Hybrid:Nitrogen 29  2299   79  1.037 0.42777
Residuals    118  9026   76

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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

=====

Ear position

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	0.05758	0.001985	2.853	3.64e-05 ***
Nitrogen	1	0.00180	0.001805	2.594	0.10994
rep	2	0.00729	0.003645	5.238	0.00661 **
Hybrid:Nitrogen	29	0.02491	0.000859	1.234	0.21475
Residuals	118	0.08211	0.000696		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Ear rot

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	1368.9	47.2	2.570	0.000192 ***
Nitrogen	1	704.7	704.7	38.374	8.81e-09 ***
rep	2	133.3	66.7	3.630	0.029525 *
Hybrid:Nitrogen	29	1109.9	38.3	2.084	0.003168 **
Residuals	118	2167.0	18.4		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

EPP

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	0.6710	0.0231	4.272	1.00e-08 ***
Nitrogen	1	0.7450	0.7450	137.525	< 2e-16 ***
rep	2	0.0035	0.0017	0.319	0.728
Hybrid:Nitrogen	29	0.6919	0.0239	4.404	4.78e-09 ***
Residuals	118	0.6392	0.0054		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Texture

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	45.67	1.575	10.591	<2e-16 ***
Nitrogen	1	26.83	26.835	180.456	<2e-16 ***
rep	2	0.62	0.310	2.083	0.129
Hybrid:Nitrogen	29	5.04	0.174	1.169	0.275
Residuals	118	17.55	0.149		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Moisture

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	59.2	2.0	2.657	0.000116 ***
Nitrogen	1	1488.4	1488.4	1938.069	< 2e-16 ***
rep	2	2.4	1.2	1.571	0.212239
Hybrid:Nitrogen	29	42.8	1.5	1.920	0.007868 **

Residuals 118 90.6 0.8

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Number of plants

=====

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	111.5	3.8	1.268	0.188
Nitrogen	1	423.2	423.2	139.647	<2e-16 ***
rep	2	5.7	2.9	0.946	0.391
Hybrid:Nitrogen	29	121.8	4.2	1.386	0.114
Residuals	118	357.6	3.0		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

=====

Grain yield

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	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Hybrid	29	71.7	2.5	2.648	0.000122 ***
Nitrogen	1	1347.9	1347.9	1442.538	< 2e-16 ***
rep	2	7.3	3.6	3.900	0.022905 *
Hybrid: Nitrogen	29	76.5	2.6	2.823	4.35e-05 ***
Residuals	118	110.3	0.9		

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX 2: Traits means, LSD values and CV%

TRAIT: Anthesis-silking interval

=====

	Hybrid	Mean (days)
1	20C20562	1.0000000
2	20C20575	0.0000000
3	CIM21SAPP2-11	0.3333333
4	CIM21SAPP2-12	-0.3333333
5	CZH18334	0.5000000
6	CZH22004	1.0000000
7	CZH22005	1.0000000
8	CZH22012	1.0000000
9	CZH22013	0.6666667
10	CZH22015	0.5000000
11	CZH22018	1.0000000
12	CZH22027	0.5000000
13	CZH22039	-0.1666667
14	CZH22044	0.6666667
15	CZH22046	0.5000000
16	CZH22070	0.3333333
17	CZH22081	0.6666667
18	CZH22082	-0.1666667
19	CZH22086	1.5000000
20	SC303	2.8333333
21	SC305	0.6666667
22	SC307	0.5000000
23	SC419	0.5000000
24	SC449	0.8333333
25	SC555	1.0000000
26	SC559	1.6666667
27	SC561	0.5000000
28	SY3002	1.3333333

29	ZMH22404	1.3333333
30	ZMS315	2.5000000

LSD (5%) = [1] 1.10181

CV (%) = [1] 119.63

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TRAIT: Plant height

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	Hybrid	Mean (cm)
1	20C20562	246.6667
2	20C20575	243.3333
3	CIM21SAPP2-11	265.0000
4	CIM21SAPP2-12	245.0000
5	CZH18334	256.6667
6	CZH22004	224.1667
7	CZH22005	234.1667
8	CZH22012	241.6667
9	CZH22013	228.3333
10	CZH22015	240.8333
11	CZH22018	223.3333
12	CZH22027	237.5000
13	CZH22039	245.8333
14	CZH22044	247.5000
15	CZH22046	244.1667
16	CZH22070	241.6667
17	CZH22081	233.3333
18	CZH22082	234.1667
19	CZH22086	243.3333
20	SC303	221.6667

21	SC305	217.5000
22	SC307	242.5000
23	SC419	241.6667
24	SC449	246.6667
25	SC555	250.0000
26	SC559	239.1667
27	SC561	245.0000
28	SY3002	252.5000
29	ZMH22404	236.6667
30	ZMS315	244.1667

LSD (5%) = [1] 16.82515

CV (%) = [1] 6.12

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TRAIT: Ear height

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	Hybrid	Mean (cm)
1	20C20562	125.0000
2	20C20575	124.1667
3	CIM21SAPP2-11	138.3333
4	CIM21SAPP2-12	124.1667
5	CZH18334	131.6667
6	CZH22004	107.5000
7	CZH22005	110.0000
8	CZH22012	124.1667
9	CZH22013	111.6667
10	CZH22015	128.3333
11	CZH22018	115.0000
12	CZH22027	121.6667

13	CZH22039	126.6667
14	CZH22044	132.5000
15	CZH22046	127.5000
16	CZH22070	124.1667
17	CZH22081	115.0000
18	CZH22082	115.8333
19	CZH22086	127.5000
20	SC303	101.6667
21	SC305	106.6667
22	SC307	118.3333
23	SC419	120.0000
24	SC449	120.0000
25	SC555	116.6667
26	SC559	120.0000
27	SC561	124.1667
28	SY3002	123.3333
29	ZMH22404	118.3333
30	ZMS315	121.6667

LSD (5%) = [1] 9.999085

CV (%) = [1] 7.24

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TRAIT: Ear position

=====

	Hybrid	Mean (cm)
1	20C20562	0.506667
2	20C20575	0.511667
3	CIM21SAPP2-11	0.521667
4	CIM21SAPP2-12	0.5083333

5	CZH18334	0.5116667
6	CZH22004	0.4800000
7	CZH22005	0.4750000
8	CZH22012	0.5150000
9	CZH22013	0.4883333
10	CZH22015	0.5333333
11	CZH22018	0.5150000
12	CZH22027	0.5116667
13	CZH22039	0.5150000
14	CZH22044	0.5333333
15	CZH22046	0.5200000
16	CZH22070	0.5150000
17	CZH22081	0.4916667
18	CZH22082	0.4950000
19	CZH22086	0.5216667
20	SC303	0.4566667
21	SC305	0.4916667
22	SC307	0.4883333
23	SC419	0.4966667
24	SC449	0.4866667
25	SC555	0.4683333
26	SC559	0.5016667
27	SC561	0.5066667
28	SY3002	0.4883333
29	ZMH22404	0.5000000
30	ZMS315	0.5000000

LSD (5%) = [1] 0.0301593

CV (%) = [1] 5.26

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TRAIT: Ear rots

=====

	Hybrid	Mean
1	20C20562	10.090000
2	20C20575	9.766667
3	CIM21SAPP2-11	4.816667
4	CIM21SAPP2-12	4.095000
5	CZH18334	5.690000
6	CZH22004	11.118333
7	CZH22005	4.953333
8	CZH22012	8.361667
9	CZH22013	9.968333
10	CZH22015	9.988333
11	CZH22018	8.100000
12	CZH22027	5.723333
13	CZH22039	5.900000
14	CZH22044	2.411667
15	CZH22046	7.025000
16	CZH22070	7.075000
17	CZH22081	3.666667
18	CZH22082	2.526667
19	CZH22086	6.901667
20	SC303	7.205000
21	SC305	14.430000
22	SC307	8.773333
23	SC419	9.575000
24	SC449	7.558333
25	SC555	11.925000
26	SC559	8.678333
27	SC561	5.788333

28	SY3002	8.485000
29	ZMH22404	4.455000
30	ZMS315	8.655000

LSD (5%) = [1] 4.899558

CV (%) = [1] 57.47

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TRAIT: EPP

=====

	Hybrid	Mean
1	20C20562	0.9200000
2	20C20575	1.0900000
3	CIM21SAPP2-11	1.0216667
4	CIM21SAPP2-12	1.0683333
5	CZH18334	0.9933333
6	CZH22004	0.9833333
7	CZH22005	1.0266667
8	CZH22012	1.0133333
9	CZH22013	1.0700000
10	CZH22015	0.9500000
11	CZH22018	1.0466667
12	CZH22027	1.0200000
13	CZH22039	1.0700000
14	CZH22044	1.1033333
15	CZH22046	1.1300000
16	CZH22070	1.1066667
17	CZH22081	0.9766667
18	CZH22082	1.0366667
19	CZH22086	0.9433333

20	SC303	0.9250000
21	SC305	0.9500000
22	SC307	1.0116667
23	SC419	0.8866667
24	SC449	0.9900000
25	SC555	0.9283333
26	SC559	0.9683333
27	SC561	0.9583333
28	SY3002	0.9683333
29	ZMH22404	0.9633333
30	ZMS315	0.9700000

LSD (5%) = [1] 0.08414846

CV (%) = [1] 7.34

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TRAIT: TEX

=====

	Hybrid	Mean
1	20C20562	2.333333
2	20C20575	2.666667
3	CIM21SAPP2-11	1.500000
4	CIM21SAPP2-12	1.666667
5	CZH18334	3.333333
6	CZH22004	3.500000
7	CZH22005	2.833333
8	CZH22012	2.333333
9	CZH22013	2.500000
10	CZH22015	2.166667
11	CZH22018	3.166667

12	CZH22027	2.833333
13	CZH22039	2.333333
14	CZH22044	1.833333
15	CZH22046	1.500000
16	CZH22070	2.833333
17	CZH22081	2.666667
18	CZH22082	2.666667
19	CZH22086	2.333333
20	SC303	1.833333
21	SC305	2.500000
22	SC307	2.500000
23	SC419	2.750000
24	SC449	2.500000
25	SC555	3.000000
26	SC559	2.333333
27	SC561	2.000000
28	SY3002	2.166667
29	ZMH22404	2.833333
30	ZMS315	3.166667

LSD (5%) = [1] 0.4408872

CV (%) = [1] 15.51

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TRAIT: MOI

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	Hybrid	Mean
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1	20C20562	15.88333
2	20C20575	16.26667
3	CIM21SAPP2-11	16.46667

4 CIM21SAPP2-12 16.03333

5 CZH18334 15.78333

6 CZH22004 16.95000

7 CZH22005 16.30000

8 CZH22012 15.90000

9 CZH22013 16.20000

10 CZH22015 17.36667

11 CZH22018 16.66667

12 CZH22027 17.20000

13 CZH22039 16.60000

14 CZH22044 17.03333

15 CZH22046 15.90000

16 CZH22070 16.83333

17 CZH22081 15.90000

18 CZH22082 16.00000

19 CZH22086 16.91667

20 SC303 14.96667

21 SC305 15.36667

22 SC307 15.36667

23 SC419 16.31667

24 SC449 16.41667

25 SC555 17.15000

26 SC559 16.66667

27 SC561 16.58333

28 SY3002 15.88333

29 ZMH22404 16.81667

30 ZMS315 16.06667

LSD (5%) = [1] 1.001931

CV (%) = [1] 5.37

=====

TRAIT: NP

=====

	Hybrid	Mean
1	20C20562	33.16667
2	20C20575	29.16667
3	CIM21SAPP2-11	31.83333
4	CIM21SAPP2-12	31.50000
5	CZH18334	30.83333
6	CZH22004	32.00000
7	CZH22005	31.16667
8	CZH22012	30.16667
9	CZH22013	30.83333
10	CZH22015	32.16667
11	CZH22018	31.33333
12	CZH22027	32.00000
13	CZH22039	31.33333
14	CZH22044	32.00000
15	CZH22046	30.16667
16	CZH22070	31.50000
17	CZH22081	31.50000
18	CZH22082	31.16667
19	CZH22086	31.66667
20	SC303	30.66667
21	SC305	32.00000
22	SC307	30.66667
23	SC419	30.66667
24	SC449	32.66667
25	SC555	31.16667
26	SC559	32.00000

27	SC561	31.00000
28	SY3002	31.66667
29	ZMH22404	31.00000
30	ZMS315	32.00000

LSD (5%) = [1] 1.990316

CV (%) = [1] 5.55

=====

TRAIT: GY

=====

	Hybrid	Mean
1	20C20562	7.773333
2	20C20575	7.691667
3	CIM21SAPP2-11	8.113333
4	CIM21SAPP2-12	7.781667
5	CZH18334	8.226667
6	CZH22004	7.458333
7	CZH22005	7.086667
8	CZH22012	7.211667
9	CZH22013	7.526667
10	CZH22015	8.015000
11	CZH22018	7.643333
12	CZH22027	8.351667
13	CZH22039	8.146667
14	CZH22044	7.503333
15	CZH22046	7.710000
16	CZH22070	8.688333
17	CZH22081	7.375000
18	CZH22082	7.858333

19	CZH22086	7.608333
20	SC303	5.595000
21	SC305	7.318333
22	SC307	8.315000
23	SC419	6.610000
24	SC449	8.460000
25	SC555	7.625000
26	SC559	8.206667
27	SC561	8.630000
28	SY3002	7.566667
29	ZMH22404	8.570000
30	ZMS315	8.353333

LSD (5%) = [1] 1.105156

CV (%) = [1] 12.44

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