Performance of water-efficient maize variety under variable planting densities and nitrogen fertilizer rates at two localities in North West Province, South Africa

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DECLARATION

I, Abidemi Ruth Adebayo, declare that this thesis, submitted for the degree of Doctor of Philosophy in Agronomy at the North-West University is my own work. It has not been submitted before for any other degree or examination at any other university. All information used or quoted has been properly designated and acknowledged by means of complete references.

Signature: .... Date: 25-05-2019

DEDICATION

I dedicate this project to God Almighty, my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this programme and on His wings only have I soared. I also dedicate this work to my husband, the crown of my head, Enoch Abolaji, who has encouraged me all the way, and whose encouragement has made sure that I give it all it takes to finish that which I have started. Thank you. My love for you can never be quantified. God bless you. My mother, sweet Mother, thanks for all your sacrifice, and my siblings (Adejare, Bolakale and Kehinde Adebayo), thanks for your love.

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"…Not by might, nor by power, but by my Spirit, says the Lord Almighty, you will succeed because of my Spirit, though you are few and weak. Therefore, no mountain, however high, can stand before Zerubbabel! For it will flatten out before him! And Zerubbabel will finish building this Temple with mighty shouts of thanksgiving for God's mercy, declaring that all was done by grace alone" (Zechariah 4:6-7 TLB). First and foremost, I would like to thank the almighty God, who is powerful and controls everything, who has opened the doors of education for me from my childhood and brought me to this level, and has been with me through the ups and downs of life. He is truly a gracious God. It is by His divine grace, goodness, and mercy that I have come thus far. I am grateful to Him, may His holy name be forever praised.

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GENERAL ABSTRACT

Water Efficient Maize for Africa (WEMA) variety is a newly-released drought-tolerant maize variety that is being adopted at increasingly high rates by South African smallholder farmers. Nonetheless, information on the improved agronomic practices required to maximize its production is currently limited. Two years field experiment was conducted at two localities (Molelewane and Taung) in North West Province, South Africa to investigate the performance of WEMA variety under different nitrogen fertilizer rates and plant density. Similarly, greenhouse studies were carried out to investigate water use efficiency of WEMA variety as influenced by different nitrogen fertilizer rates, soil moisture level and soil types.

The field experiment was laid out during the 2016/17 and 2017/18 planting seasons in a split plot arrangement fitted into a randomized complete block design with four replications in each location. Plant density of 44,444, 55,555 and 33,333 plants/ ha constituted the main plot effect, while nitrogen fertilization rates of 0, 60, 120, 180 and 240 kg N /ha were applied to the sub-plots at each of the sites. On the other hand, greenhouse trial was laid out in 5 x 2 x 2 factorial, fitted into complete randomized design with three replications. The treatments comprised five nitrogen fertilization rates (0, 60, 120, 180 and 240 kg N /ha), two soil moisture levels (45 % and 100% field capacity (FC)) and two soil types (Ferric Luvisol and Rhodic Ferralsol soil types). The growth, and dry matter parameters, root system architecture, yield and its components, nutritional composition and water-use efficiency were measured. Data were subjected to an analysis of variance test of Genstat 11th edition and the means were separated with LSD ($p \leq 0.05$). The relationships between the treatment factors were analyzed using regression, correlation and path analyses.

Planting season x location x plant density x nitrogen rates had a significant ($P<0.05$) effect on the growth parameters and analysis. The tallest plant height (309.35 cm) was recorded during 2016/17 planting season at Molelwane under 55,555 plants/ha on plots supplied with 240 kg N/ha. The highest net assimilation index of 1.180 g/g/day was recorded during 2015/16 from Molelwane trial under 33,333 plants/ha plant density with 240 kg N/ha fertilizer. The predicted optimum N fertilizer rate for better growth ranged between 180 – 225 kg N/ha depending plant density.

The root architecture system was significantly affected by interaction between planting season, location, planting density and N rates. The highest deep and steep brace root angle of 73.75° was obtained during 2016/17 planting season at Taung at a plant density of 33,333 plants/ha in the unfertilized plots. The deepest and steepest crown root angle (84.25°) was recorded during the 2016/17 planting season at Taung was under 44,444 plants/ha supplied with 180 kg N/ha. The interactions amongst planting season, location, planting density and N rates had significant ($P<0.05$) effect on yield and yield components. WEMA had highest grain yield (7.78 t/ha) in plots with 55,555 plants/ha and fertilized with 120 kg N/ha during 2016/17 planting season at Molelwane. The WEMA showed highest harvest index (0.81) during 2016/17 planting season at Molelwane under 33,333 plants/ha in unfertilized plots. The interaction between the nitrogen fertilizer rates and plant densities indicated an optimum nitrogen level of 148 kg N /ha at a plant density of 44, 444 plants /ha The interaction effect of planting season x location x plant density x N rates had significant ($P<0.05$) effect on the nutritional composition of WEMA variety. The highest starch content (5 166.00kg/ha) was obtained at Taung during 2016/17 growing season at a plant density of 55, 555 plants/ha from plots fertilized with 180 kg N/ha, and highest protein yield (1 592.00 kg/ha) from plots in Taung with palnt density of 33,333 plants/ha supplied with 120 kg N/ha during 2015/16 planting season. In the greenhouse experiments, the interaction amongst nitrogen fertilizer rates x soil moisture levels x soil types had significant ($P<0.05$) effect on growth parameters, grain yield, yield components and water use efficiency of WEMA Maize. Highest number of leaves was recorded in Ferric Luvisol treated with 240 kg N/ha under 45 % soil moisture level. Furthermore, the Ferric Luvisol produced the highest grain yield (3.49 t/ha) with applications of 180 kg N/ha under 100 % FC. WEMA had highest (41.73 %) water use efficiency on Rhodic Ferralsol soil supplied with 180 kg N/ha had at 45 % FC. In conclusion WEMA 3127 performed better under moderate drought condition and revealed significant locational responses with better performance recorded at Molelwane than at Taung. This maize variety had better water use efficiency in Rhodic Ferralsol than in Ferric Luvisol.

Keywords: WEMA, nitrogen rates, , plant density, root system architecture , soil moisture levels

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CHAPTER ONE

1.1 Introduction

Maize is the third cereal crop of major importance in the world and an important source of food, animal fodder, and industrial raw materials (Shiferaw et al., 2011). It has high yield potential because of its great photosynthetic efficiency since it is a C_4 plant. As such, it is commonly referred to as the queen of cereals (Hossien et al., 2013). Maize is the most basic food crop in sub–Saharan Africa and covers about 20% of the calorie intake. Furthermore, the plant occupies 13% of the total cultivated land area globally (Silva et al., 2013). Nonetheless, maize yields from the fields throughout the production provinces of South Africa are generally low, with averages of < 1.5 t ha^{-1} and < 3.0 t ha^{-1} under dryland and irrigation condition respectively (DAFF, 2016). This low productivity has been recognized as a result of low soil fertility levels and the drought-stress conditions. Agricultural lands used for maize cultivation in South Africa are generally under intensive cultivation but are faced with problems of poor fertility management and the high cost of chemical fertilizers. Drought affects maize production by reducing the plant density during the seedling stage, impairing the development of the leaf area and the rate of photosynthesis during the pre-flowering period. The retardation of the ear and kernel set during the two weeks of bracketing and flowering, and the declining rate of photosynthesis during this stage as well, can be attributed to drought, which also induces early senescence during the grain-filling stage in the development of the kernel. By way of explanation: - maize is considered to be a significant consumer of nutrients, but under minimal nutrient-sustaining conditions, the maize grain yield is adversely affected. In the same vein, plants obtain nutrients in the soluble form and the greater the moisture condition of the soil, the greater the volume of nutrients that are taken up by the plants. Hence, in water-deficit conditions, the nutrient uptake becomes compromised, thus impairing the performance of the plant negatively.

Maize is most sensitive to variations in plant population than any other cereal crop (Akmal et al., 2010). Plant density is one of the major cultural variables in agronomy that determine the grain yield of maize. The plant density of a maize field varies from 40, 000 to 90, 000 plants per hectare under irrigation (Yada,2011). On account of a poor canopy architecture and mutual shading, a high plant population density affects the net photosynthetic process of the crop thus reducing the accumulation of the photosynthate and partitioning the incoming light that penetrates through the crop canopy. Barrenness is the upshot of a high plant density.The ear becomes smaller in size and is susceptible to to lodging, disease and pest while a sub-optimum plant population density leads to lower yields per unit area (Carcova and Otegui, 2001). Maize does not have a tillering capacity to adjust to variations in the plant stand.Therefore, an optimal plant density level for grain yield and forage is important.

Besides plant density, the availability of nutrients also affects the maize grain yield. Nitrogen is the second-most deficient nutrient in South African soils (Van Averbete and Yaganthen., 2003). Baloyi (2010) reported that nitrogen is considered to be the most important and limiting nutrient for profitable maize production in most African soils. Most of the South African soils are widely deficient in nitrogen (Van Averbete and Yaganthen, 2003). Nitrogen has vivid effects on the growth, development and grain yield of the maize plant. Many studies have shown the effects of nitrogen on plant height, leaf area index, plant nitrogen uptake and shoot weight (Sent et.al., 2012; Eivazi and Habibi, 2013). In most maize-producing areas, an increase in the rate of nitrogen supply results in a higher leaf area index and larger quantities of leaf nitrogen (Akmal et al., 2010). Variations in the nitrogen supply affect crop growth, and development and potential of the kernel, its set, and the grain yield. The leaf area index, leaf area duration, crop photosynthetic rate, radiation interception and radiation-use efficiency are increased by the nitrogen supply.

A decline in the supply of nitrogen would reduce crop growth. However, the response of the plant to nitrogen is also modified by the water supply under the field conditions of the soils. The greatest effects of nitrogen deficiency are obvious in the reduction in the leaf area index, light interception, biomass production, and grain yield (Luque et al., 2006, Szeles and Nagy 2012). Tajul et al. (2013) concluded that 180 kg N/ha was optimum for maize, while Singh et al (2000) observed that an application of 200 kg N/ha increases the grain yield of maize.

The application of nitrogen fertilization remains an important agronomic practice for maize production in that it produces high crop yields under low levels of nitrogen in the soil, or, in that, under high levels of nitrogen in the soil, it fosters an efficient conversion of nitrogen into a prolific maize yield. Problems with nitrogen-use efficiency have been commonly recognized because an overuse of nitrogen is costly to maize growers and harmful to the environment (Tilman et.al., 2002; Sent et al.., 2012). Improved efficiency in the use of nitrogen will reduce the amount of fertilizer applied and thereby reduce the emission of greenhouse gases into the atmosphere, and also control the washing of the leached element into water bodies (Li et al., 2010, Varshney et al., 2011).

The effective functioning of the root system depends on the plant density and the availability of nutrients. In maize production, crops with a good root system architecture are better positioned for the acquisition of nutrients and water. Better root architecture influences nutrient uptake with positive impacts on crop growth and yields, especially under limiting water conditions. The effect of efficient nitrogen fertilizer uptake under drought conditions, as influenced by an adequate root system architecture on the maize grain yield, cannot be overemphasized (Ciaglo-Androsiuk, 2012). High biomass accumulation and grain yield are associated with an adequate root architectural system (Ciaglo-Androsiuk, 2012). Plant density and the application of nitrogen fertilizeraffect the direction of growth of the brace root. A high plant density reduces the availability of soil moisture per plant (Hauk et al., 2015). An optimal root system architecture for capturing plant nitrogen under high plant density conditions depends on the roots of the neighbouring plants.

Water Efficient Maize for Africa (WEMA) is a drought-tolerant maize variety grown in Africa, particularly in the Southern African Development Community (SADC). It is purposely bred to cope with increasing drought conditions brought about by climatic variability in many parts of Africa. It was launched in 2008 by the African Agricultural Technology Foundation (AATF), and was developed through conventional breeding, but speeded up by marked assisted selection procedures. It is a partnership project between AATF, Monsanto's, and the National Agricultural Research Institute (NARS). Target countries for its use include Kenya, Mozambique, South Africa, Uganda and Tanzania. The major aim behind the development of this variety, as opposed to the common varieties, was to increase yields by 20 to 30% under moderate drought conditions and by 12 to 24% under high intensity drought conditions.

This variety has been estimated to produce two million additional tons of food, that is enough to feed 14 to 20 million people. It was launched commercially in the USA in 2013. Through a private or public sector partnership, and as early as 2017, WEMA hopes to release the first biotechnology drought tolerant maize as early as 2017 in sub-Saharan Africa where the need for drought tolerance is greatest. Mashigaidze and James (2012) reported that WEMA will increase and stabilize maize production and provide food self-sufficiency at the household level. The WEMA variety will give farmers the potential to manage the risk of crop failure and to generate more income as they produce food for their communities (Mashigaidze and James, 2012). However, these benefits will be realized only as long as the agronomic requirements of this variety are understood. In spite of the great potential of WEMA in alleviating poverty, in increasing the growers' income and in ensuring food security, little is known about the optimal agronomic practices required to ensure that the potential yield of WEMA genotype is actualized. There is the need to understand how WEMA genotypes would perform under moisture deficit condition as influenced by different nitrogen fertilizer rates and plant population densities.

1.2 Problem Statement

South Africa is an arid region with less than 500 mm rain on average recorded annually over about two thirds of its area (Paul et al., 2013). It is the 30th driest country in the world (Giovanna,2017). The major agriculture and economic activities of South Africa are largely suited to semi-arid conditions. The The Intergovernmental Panel on Climate Change (IPCC) 2014 predicted that the South African coastal region would experience a mean increase in temperature of approximately 1 to 2^{o}C by 2050 and of 3 to 4^{o}C by 2100. Maize production in South Africa is expected to be affected significantly by the temperature change, and the IPCC (2014) observed that the interior regions of South Africa will experience a temperature increase of 1.2^{o}C by 2050 and of 1.4 ^{o}C by 2100.

Amede et al. (2002) reported that the instability in the maize yield from small-scale farmers is mainly due to recurrent droughts, declines in soil fertility, and incorrect choices of intercropping plants and more importantly of cultivars. Maize is very sensitive to water stress, especially at the flowering stage (one week prior to and two weeks subsequent to the anthesis-silking interval). Drought stress from the mid to late grain-filling stages reduces the grain yield (Banziger et.al., 2009, Gowda et al., 2009). The African Agricultural Technology Foundation reported that approximately 20 million metric tons of potential tropical maize production is lost each year on account of drought, while Zinyengere et al. (2013) concluded that on account of drought, maize yields are projected to decline by 18% in this century.

This has unfavourable implications for food security in South Africa, where maize is the common determinant of food security, especially in the smallholder farming communities.

Researchers have shown that sustainable agronomical practices, resource management and the use of crop varieties that are tolerant to heat stress and drought stress, and also resistant to pests and diseases, are essential in limiting the vulnerability of communities to the effects of climate variability and change. Besides, maize production in South Africa takes place under difficult conditions, which are characterized by poor soils (especially low nitrogen content), water scarcity, salinity, low yielding varieties, inadequate access to yield-enhancing inputs such as fertilizers and improved seeds, a variable climate and environment, erratic rainfall and extremely high temperatures (FARA, 2009). Furthermore, the agronomic management for any crop depends on factors such as soil fertility, fertilizer requirements, the plant population and water requirements. There is limited information on the response of this drought-tolerant maize variety to different plant densities and nitrogen fertilizer in North-West Province, of South Africa. Therefore, there is a need to investigate the effect of plant density, the efficiencies of nitrogen- and water-use in respect of the Water Efficient Maize for Africa variety under contrasting field conditions and different fertilizer rates

1.3 General Aim

This research was carried out to investigate the performance of Water Efficient Maize (WEMA) variety under different nitrogen fertilizer rates and plant density at two locations of North-West Province, Republic of South Africa.

1.4 Justification

Maize is a basic grain crop in South Africa and represents the most important feed grain and staple food of the majority of the South African population (DAFF, 2011). It is the largest field crop produced locally in South Africa (Mouton, 2014); and also represents a crop specifically developed to positively affect food security and agricultural income (Shoko, 2014). The North West province is one of the grain-producing regions of South Africa that contributes the largest input to the total maize production system (NDA, 2009). Yet, most part of the Province experience severe drought that could potentially impact on maize productivity due to thes high degree of vulnerability of crop (DAFF, 2016) .

The WEMA variety released in South Africa in 2017 aims to assist farmers particularly, the resource-poor farmers to cope with increasing climate variability as a result of insufficient rainfall and increase temperature. Generally, water is one of the basic requirements for optimum growth performance and maximum grain yield in maize production. Others factors such as N fertilizer requirement and optimum plant density are of great importance in the production of maize. Therefore, it is necessary to understand and optimize critical agronomy practices such N fertilizer requirement and optimum plant density required for optimum growth performance and maximum grain yield of WEMA maize.

1.5 Specific Objectives

The specific objectives of this study were to:

i. assess the effect of different plant density on growth and yield of WEMA maize
ii. evaluates the optimum nitrogen fertilizer rate for improved growth and yield of WEMA maize
iii. evaluates the N utilization efficiency of WEMA variety grown under different nitrogen fertilizer rates and plant density.
iv. Investigate the influence of different nitrogen fertilizer rates and plant density on root architecture of WEMA variety
v. determine the effect of plant density and nitrogen fertilizer on nutrient uptake and nutritional quality of WEMA variety
vi. examine performance of WEMA maize grown in soils with variable inherent characteristics and moisture content

1.6 Hypotheses of study

The following hypotheses were conceived for the study:

(i). Growth and yield of WEMA will not be affected by plant density

(ii). WEMA variety will respond differently to varying nitrogen fertilizer rates

(iii). Performance of WEMA maize variety will not be affected by variation in soil physical and chemical characteristics under varying water regimes

(iv). Root architecture of WEMA variety will respond differently to nitrogen fertilizer rates

(v). N utilization will not be affected by different plant density

(vi). Nutrient uptake and nutritional quality of WEMA will not be affected by varying nitrogen fertilizer rates and plant density.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Maize is one of the main food crops in the world (Shiferaw et al., 2011). Maize with rice and wheat, provides no less than 30% of the total calorie production to over 4.5 million people in 94 developing countries. Maize is preferred as the staple food by approximately 900 million impoverished consumers in the world (Shiferaw et al., 2011). South Africa is ranked as the seventh maize producer in the world and as the sixth maize exportern the world (www.em.wikipedia.org) and as also classed as the largest producer of maize in Africa (Schulze, 2016). Maize is the country's basic crop, a nutritional staple, a source of fodder for livestock, and an export crop (Schulze, 2016). Maize production provides for at least 150,000 jobs per annum, and with an adequate rainfall sustaining cultivation, its contribution as virtually the most important input in the modern agricultural sector is well recognized (FAOSTAT, 2009). Schulze (2016) and CEC (2013) reported that approximately 91% of the maize produced in South Africa is produced under rain-fed conditions,.and that about 71% of the maize is produced in two of the country's moderately "drier" regions, namely the Freestate and North West Province which together contributed 55 to 60% of the national production.

The major types of maize produced in South Africa are white and yellow maize. White maize is produced mainly for human consumption, while yellow maize is used in animal feeds (Kapuya and Sihiloba, 2014). The two maize types were found to occupy 61% and 39 % of the planted areas respectively (Schulze, 2016). About 90 % and 85 % respectively of both maize types are cultivated under rain-fed conditions and 10% and 15% respectivel;y are grown under irrigation (Schulze 2016). The maize production in South Africa is restricted mainly by low soil fertility, drought stress and poor cultural practices.Walker and Schulze (2006) revealed that just one percent (1%) of South Africa has both a suitable climate and appropriately fertile soils for rain-fed production. However, a mere three percent (3%) of the country actually has fertile soil.

2.2 Maize production requirements

Maize performs well on any well-drained sandy loam or loamy soil. The optimal pH range required for superior performance is 5.5 to 7.0 (Du Plessis, 2003). Large-scale maize production usually takes place on soils with a clay content of either less than 10% (sandy soil) or in excess of 30% (clay and clay-loam soils). Soil textural classes of between 10 and 30% clay have air and moisture regimes that are best suited for healthy maize production (Du Plessis, 2003). Maize requires a hot, frost-free climate, and grows best when temperatures are minimal (12 – 24 °C) and maximum (26 – 29°C). An optimum mean daily temperature of 18°C and a minimum temperature of 10℃ are required for seed germination. Flowering occurs best at temperatures ranging from 19 to 25°C. The critical temperature that detrimentally affects maize yield is approximately 32°C. Frost can harm maize at any of the developmental stages, and a frost-free period of 120 to 140 days is required to prevent damage (DAFF, 2016). Maize generally requires 450 to 600 mm rainfall in the October-March growing season to attain its optimal production potential in South Africa. However, the largest maize-producing provinces in South Africa only receive an annual average of 500 mm of rainfall (Du Plessis, 2003). A yield of 3,152 kg/ha requires between 350 and 450 mm of rain per annum, while at maturity, each maize plant would have used 250 litres of water in the absence of moisture stress (Laker et al., 2012) .

The average amount offertilizer consumed in maize production in South Africa is 176 kg N, 73 kg P_2O_5, and 17 kg K_2O (Natural Resource Management and Environment Department, 2008).

2.3 The economic importance of maize

Maize is a multipurpose cereal crop and all parts of the plant have economic value. The leaves, stalk, tassel, cob and grain can all be used to produce a significant assortment of food and non-food products. Maize is a vital source of carbohydrate, protein, vitamin B and minerals for human consumption in sub-Saharan Africa (SSA). Maize grains are used in pharmaceutical and industrial products such as glues, absorbents, soaps, biodegradable plastics, skincare products, antibiotics and enzymes (Ranum et al., 2014). Maize is used as vegetable oil in some countries such as North America and South Africa. The leaves, stalks and tassels are used as fuel, or livestock feed in either the green (fodder or silage) or the dried (stover) form. Maize residues are used for compost and sometimes recycled *in situ* to enhance the soil quality and in carbon sequestration. Through new technology, maize is now being used as a bio-fuel (Ranum et al., 2014). It is used largely in livestock feeds and in raw materials for industrial products in the industrialized countries.

The global average annual per capita consumption of maize in developing countries is 20 kg, while in South Africa, the average per capita consumption stands at 60 kg (M’mboyi et al., 2010).

2.4 Maize production in South Africa

Maize is the dominant staple crop grown by the vast majority of South African rural households. It is a summer crop, which is mostly grown in the semi-arid regions of the country. It is highly susceptible to changes in precipitation and temperature. Maize production constitutes 70% of the grain production, and the plant covers 58 to 60% of the cropping area in South Africa (ARC-GCI, 2006). In South Africa, the largest area of farmlands is used for planting maize, followed by wheat and to a lesser extent sugarcane and sunflower (Fruit et al., 2013). Over 9, 000 commercial maize producers and 12 000 small-scale farmers are reported to be producing maize yearly (Fruit et al., 2013). Maize is mainly produced in the Free State, North West province, on the Mpumalanga Highveld, and in the Kwazulu-Natal Midlands. The maize production from these provinces contributes 25 to 33% to the country`s total gross agricultural production (Kunz et al., 2015).

The amount of maize required for local consumption is about 8 million metric tons while the surplus produced is often exported. Maize cropping regions in South Africa extend from 15 to 35°S and from 10 to 40°E. The crop thrives best on belts such as the semi-arid plains, coastal regions, along rivers and in valleys, and on undulating terrain and mountain slopes (Wickens, 2013). Maize is preferably grown as a monocrop but it can also be intercropped with vegetables or legumes (Krishna, 2012).

Table 2 1: South Africa maize production in 2010/11-2012/13 planting seasons

Years	**2010/11**	**2011/12**	**201/13**
Commercial Corn			
White Corn	7,830000	6,302,000	6,3330,000
Yellow Corn	4,985,000	4,533,000	5,400.000
Sub-total	12,815,00	10,855,000	11,730,000
Subsistence Corn			
White Corn	422,000	396,000	390,000
Yellow Corn	184,000	168,000	180,000
Sub-total	606,000	564,000	570,000
Sub-total	13,421,00	11,419,000	12,380,00

Source: Extracted from Agritrade data (http//www.South Africa maize production down/cereals/commodities/Home –Technical cue.

2.5 Constraints to maize production in South Africa

South Africa is a country that is endowed with rich natural agricultural resources. It has a total land surface area of 122 million hectares, almost 86% of which is used for the production of agricultural resources; 74% being natural veld and 14% arable land (Luan et al., 2014). Nearly 91% of the country is arid, semi-arid (dry) on account of the generally low, unevenly-distributed and unreliable rainfall. About 1.6 million hectares of land are currently under irrigation (DAFF, 2015). Maize production in South Africa is constrained by many limitations that often lead to low productivity. Maize farmers, particularly the resource-poor smallholder and the emerging farmers, are faced with problems that include drought, low soil fertility arising from degradation, nutrient-starved soils, and high soil salinity and acidity levels; diseases, pests, weeds (parasitic weed); inadequate inputs such as fertilizers, limited access to high-yielding and improved seed varieties, irrigation, labour, poorly-developed markets, an inadequate rural infrastructure and nutritional problems.

Most of the maize cultivated in South Africa is grown by small-scale farmers who cultivate less than 10 hectares of land with more than one variety of maize (Fanadzo et al., 2010). Some of these farmers apply less than 10 kg of fertilizer per hectare, which leads to low grain yields averaging 1.2 t/ha (Sanchez, 2002; Vanlauwe et al., 2011). These constraints are classified as biophysical constraints, economic constraints, and health constraints, while the biophysical constraints are further classified as biotic and abiotic constraints. Biotic constraints are diseases, pests and weeds, while abiotic constraints include drought and low soil fertility (M'mboyi et al., 2010).

The main economic constraint to maize production in South Africa is the selling price. Maize is referred to as “wage good’’ because the selling price of maize is indirectly linked to the supply of labour and the wage level in South Africa (Mofokeng, 2012). Kotze (2013) reported that the sharp grain price fluctuations in South Africa have been as a result of inadequate supply stocks and droughts experienced inter-continentally. The maize price is determined by supply and demand (Shoko 2014). It is based on the South African Foreign Exchange (SAFEX). DAFF (2011) reported that a number of fundamental factors play diverse roles in determining the domestic price of maize. These factors include the international maize prices, the exchange rate, local production levels (influenced by climatic conditions and the area under cultivation), local consumption, production levels in the Southern African Development Community region (South Africa is usually the main source of white maize for these countries in times of shortage), and stock levels (both domestic and international). The maize price is subject to major fluctuations on both the local and the international markets.

2.5 Low soil fertility incidences in semi-arid regions

South African soils are well-known for their limited fertility owing to the continued extraction (mining) of nutrients without adequate replenishment (Laker et al., 2012). Most of the semi-arid soils, including those of South Africa, are sandy-clay-loam textured, and generally contain sandstone, with less than 0.5% organic matter and very low in respect of cation- exchange capacities (Du Plessis, 2003). Soil fertility is rapidly declining because of the intensification of land use and the rapid decline in fallow periods, coupled with increased agricultural production levels on marginal lands with no to suboptimal use of fertilizers (Kutu, 2012).

Many South African farmers cannot afford inorganic fertilizers because the cost of fertilizers is two to six times higher than that in Europe, North America and Asia, thus resulting in declining yields (M'mboyi et al., 2010). Past studies have estimated that Africa loses an equivalent of USA $4 billion per year on account of soil nutrient mining, with a very high average annual depletion rate of 22 kg of nitrogen, 2.5 kg of phosphorus, and 15 kg of potassium per hectare of cultivated land (Lal, 2004; Sanchez, 2002).

2.6 Drought as a major abiotic constraint to maize production

Drought is a climatic characteristic with features such as unfavourable weather conditions that lead to a scarcity of the freshwater resource, high temperatures, and strong winds (Pauls et al., 2013). Edmeades (2013) reported that maize is the only cereal with an annual global production level (the highest), estimated at 829 M t as opposed to 690 million tons for rice, and 675 M t for wheat. Maize grain yields in the temperate world of North America and Europe average 8.7 t/ha versus 3.7 t/ha on the less-developed tropical continents of Asia and Africa. In both production environments, drought is the greatest abiotic stress or constraining and destabilizing maize grain production (FAOSTAT, 2012). Its effect is severe, particularly in Southern and East Africa where most maize is cultivated under rain-fed conditions. For instance, the mean maize yield produced by South Africa had a coefficient of variation (CV) of 23% during the period 1990 to 2009 versus the seven percent (7%) for the US at a mean yield of 4.1 and 9.8 tons/ha respectively (Edmeades, 2013).

The erratic distribution of the rainfalland its unreliability, is an imperative constraint to maize production in South Africa. Bänziger et al. (2006) explained that drought affects maize at different stages in the development of the plant, starting from the establishment of the crop up until the grain-filling stage of the kernel. Grain yield is affected to some degree at almost all of the growth stages. However, as opposed to the other stages, the crop is more susceptible to water deficits during the flowering stage. Drought affects maize production by reducing the plant population density during the seedling stage, obstructing the development of the leaf area and the rate of photosynthesis during the pre-flowering period, reducing the ear and kernel set during the two weeks when bracketing and flowering take place, and by reducing the rate of photosynthesis and inducing early senescence during the grain-filling stage (Yada, 2011).

Beyond the food insecurity level, Otunge et al. (2010) reported the more systemic effects of droughtto include reductions in household income, the loss of assets on account of the forced slaughter of livestock, health threats owing to the lack of water for hygienic and household purposes, environmental degradation, and less sustainable land-management practices.

2.7 Pests and diseases associated with maize production

The major diseases that infect maize in South Africa are downy mildew, rust, stalk and ear rot, the maize streak virus, leaf blight and leaf spot. According to IITA (2009), reported that several stem borers are ranked as the most devastating maize pests in sub – Saharan Africa. This insect pest causes 20 – 40% losses during cultivation and 30 – 90% postharvest losses during the storage stage. The most prevalent weed species affecting maize production in South Africa are *the Amaranthus retreflexus* (redroot pigweed), *Sorghum halepensa* (crab finger-grass), *Tagetes minuta* (khaki weed), *Setoria viridis* (green foxtail), *Chenopodium album* (common lambsquarters), *Cyperus esculentus* (yellow nutsedge), *Vicia villosa* (hairy vetch grass) and *Striga spp* (Zaremahezahieh and Ghairi, 2011).

2.8 Ear-rot diseases of maize

The main fungal pathogens that severely infect maize in South Africa are *Fusarium* ear rot (FER), Gibberella ear rot (GER), *Aspergillus* ear rot (AER) and *Diplodia* ear rot (DER). The Fasrium ear rot and Gibberella ear rot are of the greatest economic significance to the farmers in South Africa (Boutigny et al.., 2012; Schoeman and Flett, 2012; Mouton, 2014). The *Fusarium* species adapt to those areas under high rainfall and warmer conditions (Munkvold, 2003b; Mouton, 2014). Boutigny et al (2012) and Mouton (2014) reported that a high level of infection of *Fusarium* ear rot has been recorded in the North West, the western areas of the Free State and the Northern Cape provinces, while *Gibberella* ear rot prevails in the cooler regions such as the eastern Free State, Mpumalanga and Kwazulu-Natal. This *Fusarium* species produces secondary metabolites commonly known as “mycotoxins”. Mycotoxins result in mycotoxicoses when ingested by humans and animals (Mouton 2014). Mycotoxins reduce the nutritional qualities of maize. The toxins produced by these *Fusarium spp*. cause diseases such as cardiovascular, reproductive, gastrointestinal and pulmonary diseases in humans and animals (Suleima and Kurt, 2013). This fungal species also causes crown root and stalk rot in maize, which in its turn causes additional yield losses in maize (Ishizuka, 2014).

2.9 *Striga* weed

Striga is also prominently known as “witchweed” (Mbuvi, 2017). *Striga* is a parasitic weed and remains a problem in some developing grain production areas of South Africa (Coleman, 2018). *Striga* can cause up 100% yield loss in crop production (Mbuvic, 2017, Ejeta, 2007). The common types of *striga* in Africa are *Striga hemonthic*. (Del.) and *Striga asiatica* **(***L***)** *kuntze***.** *Striga asiatica (L*) *kuntze* is the most widespread parasitic weed affecting cereals, with maize being the crop falling victim to this obnoxious weed (IITA, 2009). The level at which *Striga* weed attacks crops and causes yield losses depends on soil fertility, rainfall distribution, seed density, the cereal host species and the variety grown. (Khan, 2006).

Generally, researchers have reported that the *striga* weeds invading a maize crop can be controlled through agronomic practices such as the application heavy inputs of nitrogen fertilizer (both the inorganic and organic types, since unfertile soils favour *striga* growth, recommended plant densities, adequate irrigation, and the use of resistant varieties (Teshome, 2013;Wycliff, 2013; Mbuvic, 2017). For instance, et al. (2009) indicated a reduction in *striga* invasion and damage with the application of N fertilizers in respect of various maize varieties. *Striga* infestations in the north-eastern regions of Nigeria were significantly reduced at 120 kg N/ ha in the early variety, and at 60 and 120 kg N /ha in the late varieties.

2.10 Climate change and maize production in South Africa

Climate change can be defined as “a change in the statistical distribution of weather patterns when that change lasts for an extended period of time” or it may refer to “a change in the average weather conditions, or in the time variation of the weather within the context of longer-term average conditions”.

Benhin (2006) and Tshililo (2017) revealed that climate change will not only have adverse effects in South Africa but also in southern Africa at large, since South Africa is the main source of food for the region. South Africa supplies 50% of the total output of maize in southern Africa. Therefore, a decline in maize yield could intensify food insecurity in the region (Akpalu et al., 2003: Tshililo, 2017).

The growth and development of maize strongly depend on temperature. Maize grows faster when temperatures are warmer, and more slowly when temperatures are cooler. Harrison et al. (2011) explained that ambient temperature affects many major crops in two ways, namely in their phenology and physiology.

According to Bita and Gerats (2013), warmer growing-season temperatures could directly reduce yields in three important ways:

(i) when higher temperature accelerates the growth of crops, whose phenology is predominantly regulated by temperature, as in the case of maize, it also reduces the time for plant and grain development, and ultimately the attainment of the yield potential;

when extreme heat occurs during the flowering stage, such as during the silk-tasseling phase, pollination may be inhibited, and the development of the grain may be prevented.

(ii) when temperature increases accelerate plant development, the reproductive stage that requires water is most seriously affected.

Harrison et al., (2011) reported the effect of temperature in reducing the length of the growth cycle, especially in the grain-filling phase.

Many studies have observed that maize yield is a function of the number of grains (kernels) and the grain weight. The full potential of the grain weight is achieved when the rate of grain filling and the duration of the filling period are both at a maximum (Borills et al., 2015). Heat or drought stress during the tasseling-silk phase (flowering and pollination) of the maize plant could reduce the yields by as much as seven per cent (7%) per day of stress, which is a greater yield reduction than that for all of the other potential climatic stressors (Lobell, 2011).

Hot and dry weather both enhance pollen shedding and also delay silk emergence, thus narrowing the duration of the period over which the cob develops (Barker et al., 2005) and increasing the effect of climatic factors causing severe reductions in the yield. However, the effects on silking and tasseling are difficult to identify because of the short duration of that particular period . (Porter and Semenov, 2005, Harrison et al., 2011).

2.10 Plant Density

Plant density is one of the major agronomic management factors that intensely and repeatedly affect resource availability in maize production (Brekke et al. , 2011). It is defined as the number of plants per given area of land (m^2). Various researchers have found that the maize grain yield is more intensely affected by variations in the plant population than the yields of other members of the grass family on account of the former’s monoecious floral organization, low tillering ability and the presence of a brief flowering period (Brekke et al. 2011; Fancelli and Dourado Neto, 2000; Vega et al. 2001). Testa et al. (2016) explained that plant density has a great influence on maize growth and grain yield because of its competitive effect both on the vegetative and reproductive development. Reddy and Reddi (2004) similarly revealed that high plant densities enhance intra-plant competition for assimilates, particularly during the period of bracketing and silking, thus favouring apical dominance and reducing the yield per plant. Borrás et al. (2002), as well as Brekke et al. (2011) reported that the plant density increases the light attenuation within the canopy, enhances post–flowering and the source-sink ratio, and reduces the protein contents of the grain and the senescence by the grain-set restriction that improves the availability of the post-flowering assimilate. Drought stress, particularly when combined with high plant population densities, can cause the complete loss of grains, particularly if severe stress occurs during the tasseling and silking stages of reproduction (Barnabás et al., 2008). Many grains may not develop under dense plant population densities, which in some hybrids are mostly due to poor pollination resulting from a delayed silking period, as opposed to tassel emergence and a limitation in the assimilation of the supply that caused the abortion of the grain and cob (Brekke et al.,2011).

Brekke et al. (2011) and Tokatlidis (2017) indicate that high plant density delay canopy closure; they reduce the seasonal interception of the incidence of solar radiation, thus leading to high grain production per plant but low production per area. However, on the other hand, low plant density produce limited grain yields as a result of an inadequate number of plants. Factors that affect plant densities generally are the availability of water, soil fertility, cultivar maturity, row width, and climatic effects, while the two important factors to consider in defining the optimum plant densityfor the maize crop specifically are plant architecture and water availability (Luque et al., 2006; Mansfield and Mumm, 2014; Ye et al., 2013).

Several researchers have revealed that high plant density in tolerant maize cultivars are characterized by the rapid completion of the silk extrusion process, the rapid growth of the first ear, the rapid appearance of the cob and the silk, prolificacy, a reduced tassel size, the efficient production of grain per unit leaf area and the maintenance of leaf senescence (Yada, 2011; Sharifi and Namver, 2016; Mekonen, 2018). High plant population density in susceptible maize cultivars are characterized by delayed vegetative and reproductive development, a markedly reduced level of leaf production, a reduced ability to exploit the available space, and poor leaf senescence (Cattivelli et al., 2008; Luque et al., 2006).

2.11 Nitrogen fertilizer and maize production

Nitrogen fertilization is a dominant tool in increasing the yield of cultivated plants, especially cereals, while plant density is the second-most-important agronomic management factor that significantly affects the availability of the resources in the maize field (Lashkari et al., 2011).

Nitrogen fertilizer is a very costly input for maize production in developing countries (Gallais and Hirel, 2004; Hirel et al., 2007). Hirel et al. (2007) confirmed that the increase in agricultural food production worldwide over the past four decades has been linked with a seven-fold upsurge in the use of N fertilizer. Nitrogen is the most essential nutrient for plant growth; and makes up 1- 4 % of the dry matter in plants (Onasanya et al., 2009). It increases the protoplasm content, cell size, leaf area and photosynthetic activity (Sen et al.., 2012) and also represents the presence of constituents such as protein and nucleic acids (Eivazi and Habibi, 2013). The growth of the plant is reduced when the amount of nitrogen in the soil is below the optimal level. It is a vital plant nutrient and a major factor regulating the yields in maize production (Eivazi and Habibi, 2013; Noor, 2017).

Dobermann (2006) reported that on a global scale cereal yield and the consumption of nitrogen fertilizers have increased over the past 40 years in a near-linear fashion. It was predicted that the global cereal demand would increase by 38% by 2025 but that this could only be met through a 30% increase in the application of nitrogen fertilizer in the cultivation of cereal crops, even though, concomitantly , the harvesting areas for cereal crops would have to be increased by 20%.

Edmonds et al. (2009) reported that in order to fill the gap between food insecurity and the population of the RSA, 90,569 additional tons of nitrogen fertilizer would be required at a nitrogen-use efficiency level of 50% and assuming a 1.25% total nitrogen value in the maize grain content.

Bänziger(2000) showed that based on the period of nitrogen deficiency experienced in the growing plant, different yield-determining factors would be affected. When an insufficient quantity of nitrogen is available, nitrogen stress might develop during the grain-filling stage, that in its turn affects the weight of the kernel. On the other hand, the development of nitrogen stress during the flowering stage results in increased incidences of kernel abortion (Fageria et al., 2006). Nitrogen deficiency levels before the flowering stage thwart the development of the leaf area, the photosynthetic rate and the development of potential kernel ovules, and as such, their number (Monneveux et al., 2005). Furthermore, a severe nitrogen insufficiency delays both pollen shedding and the emergence of silks, such that the anthesis-silking interval (ASI) widens. (Elazab et al ., 2015).

Several studies have revealed that nitrogen-stress-tolerant maize hybrids are categorized by increased leaf longevity (Badu-Apraku et al. 2014), increased water and nutrient uptake (Weber et al., 2012), a greater assimilation propensity to supply the grain-filling process (Mayer et al., 2012) and a larger number of ears and kernels than in the case of the hybrids more susceptible to nitrogen stress (Sen et al., 2012; Tollenaar and Lee, 2002).

Eivazi and Habibi (2013) explained that the quantity of nitrogen required for maize production depends on the condition of the soil, the plant varieties, and the purpose for which the yield is produced. Generally, the application of nitrogen fertilizer in maize cultivation are usually determined on the basis of previous yields and the expected yield subsequent to soil testing for the available nitrate. This leads to possible over-fertilization in some areas and under-fertilization in others (Mamo et al., 2003; Sen et al., 2012).

2.12 Nitrogen-use efficiency and maize production

Gallais and Hirel (2004) defined N-use efficiency of maize as the grain yield per unit of N available from the soil and also including the nitrogen fertilizer applied to the soil. From an agronomic perspective, N-use efficiency of a crop represents its capacity to produce a supplementary yield quantity for each added unit of N fertilizer (Gallais and Hirel, 2004). Past studies have revealed that N-use efficiency is a vital tool to meeting the global demand for food, animal feeds and fibre and for mitigating environmental problems (Moser, 2004; Edmonds et al., 2009;).

Edmonds et al. (2009) estimated that there would be an increase in the use fertilizer to the extent of 130 million tons of nutrient by 2020. However, among the major constraints to nitrogen -use efficiency in the RSA are the limited supplies of nitrogen, the continual rise in price and the elevated economic risks of applying nitrogen fertilizer in combination with the prevailing low yield levels of cereal production. Hence, there is a need to improve N-use efficiency in order to secure staple food resources for the increasing global population in the face of global climate change challenges and the high costs of energy, fertilizers and water (Edmonds et al., 2009; Sen et al., 2012).

Several researchers have confirmed that maize yields are generally high with high dosages of fertilizer since maize grain yields are highly responsive to supplemental quantities of nitrogen. Nonetheless, large quantities of nitrogen fertilizer applied to maize crops have had a negative impact on the environment, as in the case of their contribution to the degradation in the quality of the soil, air and water apart from the increasing input costs (Sen et al., 2012). Malagoli et al. (2005) and Sen et al. (2012) estimated that regardless of the level of nitrogen fertilization, the ratio of the nitrogen content of the plant to the supplied nitrogen does not exceed 50% in cereal crops

The nitrogen-uptake efficiency is defined as a quotient of the plant uptake (Nupt) and the total amount of nitrogen supplied to the crop (Nsup , Nsup i.e fertilizer plus soil mineral nitrogen). Nitrogen-uptake efficiency is also known as the Nitrogen-Recovery Efficiency (REN), which is defined as the ability of the plant to acquire nitrogen from the soil (Samborski et al., 2008; Sen et al., 2012). Cassman et al. (2002) described the nitrogen efficiency of cropping systems as the proportion of all nitrogen inputs that are removed in the biomass of the harvested crop, contained in the recycled crop residues, and incorporated into the organic and inorganic nitrogen pools of the soil.

Edmonds et al. (2009) used the following formula to determine the nitrogen-use efficiency (NUE) level of the soil as:

$$NU\varepsilon = \frac{T_{CN} - N_S + N_{DR}}{F_{CN}} \qquad (1),$$

Where: $NU\varepsilon$ = Nitrogen-use efficiency;

T_{CN} = total cereal N removed

N_S = N coming from the soil,

N_{DR} = N deposited in rainfall and

F_{CN} = N fertilizer applied to cereals.

Eivazi and Habibi (2013) emphasized that N-use efficiency in cereal crops is classified into three categories, namely: agronomic N-use efficiency (crop efficiency), physiological N-efficiency (physiological performance) and apparent N-use recovery (the efficiency of absorption). Agronomic N-use efficiency can be defined as nutrient consumption per unit grain. It determines the efficiency of the system, and is also known as economics efficiency (Eivazi and Habibi, 2013).

Physiological N-use efficiency reveals the crop`s capacity to generate an indication or sign of economic performance (yield) and is mainly affected by the plant genotype and the environmental stressors. The definition of this term is based on the biological production per unit of the absorbed food element.

The apparent N-use recovery of the plant measures the uptake of nitrogen, which is usually affected by climatic conditions.

2.13 Equations for calculating the three categories of NUE in cereal crops

The following are the equations used for calculating the three categories of NUE (Beukema and van der Zaag, 1990; Eivazi and Habibi, 2013; Vahabzadeh et al., 2006)

$$A_{\varepsilon} = \frac{G_{YF} - G_{Y}}{C_{F}} \qquad (2)$$

Where: A_{ε} = Agronomic Efficiency

G_{YF} = grain of plants with fertilizer

G_{Y} = grain yield of plants without fertilizer

C_{F} = consumed fertilizer

$$P_{\varepsilon} = \frac{G_{YF} - G_{Y}}{N_{UF} - N_{U}} \qquad (3)$$

Where: P_{ε} = Physiological Efficiency;

G_{YF} = grain yield of plants with fertilizer,

G_{Y} = grain yield of plants without fertilizer,

N_{UF} = nitrogen uptake by plants with fertilizer,

N_{U} = nitrogen uptake by plants without fertilizer.

$$A\varphi = \frac{N_{UF} - N_{U}}{C_{F}} \qquad (4),$$

Where: $A\varphi$ is apparent recycling (%).

N_{UF} = nitrogen uptake by plants with fertilizer

N_U = nitrogen uptake by plants without fertilizer

C_F = consumed fertilizer

Cassman et al. (2002) explained that a crop's physiological requirements for nitrogen are governed by the efficiency with which nitrogen in the plant is converted to biomass and grain since cereal crops are harvested for their grain products. Two factors that affect the physiological efficiency of crops are the genetic mode of photosynthesis and the accumulation of nitrogen through the grain.

2.14 Root architectural system and crop production

Smith and De Smet (2012) reported that root system development, the adaptive use of the prevailing soil nutrients and an upsurge in stress tolerance improve the grain yield while reducing the necessity for heavy fertilizer applications. He (2017) revealed that the root system architecture has a large impact on both the plant yield and the proficiency of a plant to be adjusted in a marginal environment. Moreover, Hauck et al. (2015) suggested that considering the growth and architecture of the root system, there is the potential for the utilization and manipulation of root properties to bring about an upswing in the crop yields and also to intensify the use of the agricultural land.

The Root system architecture describes the spatial distribution of all of the root components in a specific growth environment. Lynch (2015) and Trachsel et al. (2011) described steep, cheap and deep ideotype root systems, which consist of several root parameters that may increase the level of nitrogen and the acquisition of water by the maize root system to improve the exploitation of the subsoil. The "steep and deep" roots refer to the architectural parameters such as the root-growth angles (brace and crown roots) and the complete elongation of the shoot-borne roots used to access water and N in the deeper soil layer. On the other hand, "cheap" refers to the architecture and anatomical parameters that reduce the metabolic cost of soil exploration, which is a significant constraint to root growth and development (Lynch, 2009). The term "ideotype" is defined as a combination of morphological and/or physiological characteristics or traits or their genetic bases that improve crop performance with regard to a specific biophysical environment, a crop management system and an end use (Gong et al., 2015; Martre et al., 2015).

Root architecture has a basic effect on the acquisition of nutrients and water by positioning root foraging, as well as activity, in particular soil purviews in time and space. The key factors affecting root system architecture are root length, the number of crown roots, root angles, soil structure and soil bulk density (Singh et al., 2000; Trachsel et al., 2011), while root angles on the field are mainly affected by soil temperature, water status, the level of phosphorus (P), soil strength, changes in soil depth, variations in soil permeation resistance or the presence of plough pan (Nieuwenhuis and Wills, 2002; Chen and Vyn, 2017). Root system architecture with steep root angles are considered advantageous when water and nutrients in solution are found in the deeper soil layer under terminal drought conditions, and in soils with a long nutrient-retention capacity (Chen and Vyn, 2017). Furthermore, Chen and Vyn (2017) reported that roots with a vertical angle tend to mostly explore the subterranean soil layers for water. Hauck et al. (2015) showed that according to the plant’s requirements, the root system responds vigorously to the local slopes of moisture and nutrients with directional growth and shape adaptations to explore the heterogeneous soil matrix.

Maize roots can be shallow or steep, with varied root angles, according to the availability of nutrients and their distribution in the soil. Thus, given its potential effect on yield under drought conditions and the efficiency of nitrogen uptake, the root system has a huge impact on the economics of commercial maize production (Hauck et al., 2015). Postma et al. (2014) explained that sparsely-spaced lateral roots with fewer than seven branches/cm, and long lateral roots, areoptimal for the acquisition of nitrates while densely-spaced and short lateral roots that consist of more than nine branches/cm are optimal for the acquisition of phosphorus. Lynch (2015) reported that greater lateral branch depths intensify the fluxes in root/shoot allocation, which obfuscate the correlation of the branching depth of the lateral roots with sustained root growth, nutrient uptake and plant growth. Both shallowness and the increasing depths of the lateral root branches reduce nitrate uptake (Postma et al., 2014).

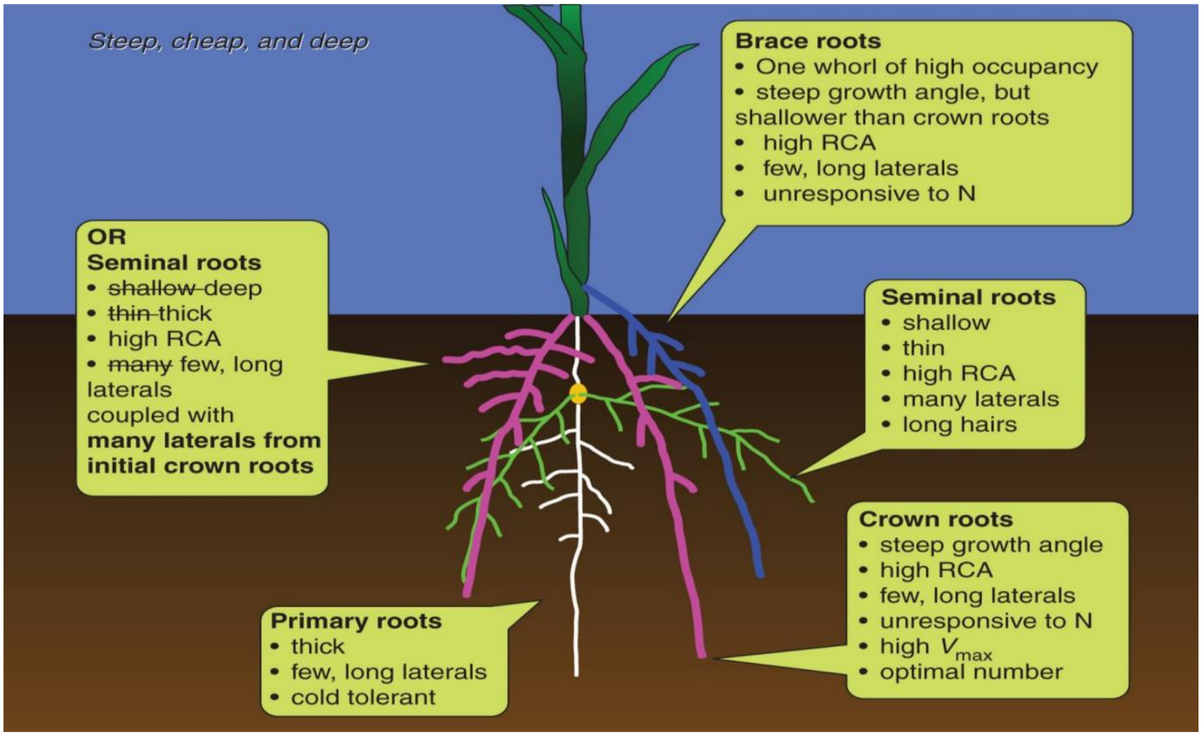

Figure 2.1: The 'steep, cheap, and deep' ideotype for optimal acquisition of water and N by maize root systems (Source: Extracted from the Annals of Botany (2013) 112: 348 doi:10.1093/aob/mcs293)

2.15 Water-use efficiency and maize production

Awika (2011) refers to maize as the most efficient user of water among cereals in terms of its total dry matter production. It is potentially the highest-yielding grain crop. Water-use efficiency, defined as the ratio of biomass accumulated as opposed to the water transpired, has been traditionally considered to be the crucial determinant of drought tolerance (Evans and Sadler, 2008). Sadras et al. (2011) define water-use efficiency as the yield of plant product (grain, silage, forage, tuber or other product of concern) produced per unit of water. Several studies have also reported the water-use efficiency in maize, sunflower, and wheat, also called the ratio of "the commercial yield per biomass", which varies significantly in response to the water deficit (Asare et al., 2011; Greaves and Wang, 2017).

Under agronomic studies, water-use efficiency is classified into physiological or agronomic water-use efficiency and transpiration efficiency. Physiological or agronomic water-use efficiency is defined as the ratio of economic yield to the cumulative plant water used to produce the yield. Transpiration efficiency is referred to as the ratio of biomass produced per unit of water transpired (Ali and Talukder, 2008; Velázquez et al., 2017). Nwachukwu and Ikeadigh (2012) describe water-use efficiency as a consistent indicator of crop biomass production relative to water consumption, and the ratio between physiological (transpiration and photosynthesis) and agronomic (yield and crop water use) entities. Nwachukwu and Ikeadigh (2012) and Chimonyo (2015) and other scholars found that water-use efficiency is very proficient when optimal advantage is gained from the least amount of water available to the plant and it may be evaluated in terms of the water-use efficiency of biomass growth or the" Harvest Index". Different plants have different properties enabling them to utilize water, and their water-use efficiency may differ from region to region. Water-use efficiency is highest under limited irrigation, such as during the dry season in the tropics, and at the point of the highest biomass production (Bodner et al., 2015; Jha et al., 2016).

Several authors have repported that water-use efficiency in maize is a function of multiple factors, including the physiological characteristics of maize, genotype, soil properties such as the water-holding capacity of soil, meteorological conditions and agronomic practices (Ogola et al., 2002; Kato et al., 2009; Nwachukwu and Ikeadigh, 2012). Kato et al. (2009) suggested that water-use efficiency could be improved through various strategies, including genotype improvement through breeding and agronomic practices. It has been observed that skip-row-spacing improves water-use efficiency (Abunyewa et al., 2017).

Residue retention and plastic mulch have also been practiced in subtropical and humid tropical areas to improve water-use efficiency, including effective weed control (Peterson and Westfall, 2004; Rahman et al., 2005; Huang et al., 2011). Ogola et al. (2002) showed that the application of N increases the water-use efficiency of maize, while the use of silicon, although not recognized as a plant nutrient, is also reported to improve water-use efficiency in water-stressed plants by reducing leaf transpiration and the water-flow rate in the xylem vessels (Gao et al., 2005).

Nwachukwu and Ikeadigh (2012) revealed that soil structure and soil texture are major soil properties that affect the water-use efficiency of plants. For instance, crops on deep clays and peat soils tend to show higher water-and nitrogen-use efficiency and require relatively small amounts of sub-irrigation water, while sandy soils require relatively large volumes of sub irrigation water. However, the ineffective use of water and nitrogen results in a low biomass level (Rimski-Korsakov et al., 2009).

Conclusion

Maize is an important multipurpose cereal crop and a staple food in South Africa. Any damage to maize plants through either biotic or abiotic stress to the maize plant will affect food security in South Africa. Maize production in South Africa is confronted by many constraints such as drought, low soil fertility, diseases, pests, weeds (parasitic weeds), inadequate inputs as in the case of fertilizers, unimproved seeds, limited irrigation prospects, poor cultural practices such as plant spacing, etc. The most severe constraints are low soil fertility, drought, poor agronomic management practices such as optimizing the fertilization rates and plant density.

From the foregoing, it is clear that if there is no measure put in place to address the constraints described above, the effects of such challenges may continue in the SADC community, including South Africa. The literature review revealed that these constraints will continue over a long period of time in the SADC community. Despite all of these challenges, maize production is expected to increase by at least 3% yearly. The researchers reported that the most adaptive measure to implement is to improve technology levels and to plant maize varieties that are able to toleratedrought. In past studies, the effects of plant density and N fertilizer rates were investigated separately. The Water Efficiency Maize of Africa (WEMA) variety is a drought-resistant, white, single-cross and three-way conventional variety, as well as a transgenic hybrid, that will provide a yield improvement of at least 20% under moderate drought conditions as opposed to the offerings of other maize varieties (Mashingadze 2012).

This research focused on the effect of different plant densities and N fertilizer rates on the growth, yield, root architecture, nutrient uptake, and nutritional quality of the WEMA variety. The outcome of this research is expected to enable the researcher to make recommendations for optimal plant density and N fertilizer levels for maximum grain yields in the North West province.

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CHAPTER THREE

GROWTH AND GROWTH ANALYSIS INDICES OF WATER EFFICIENCY MAIZE VARIETY AS AFFECTED BY NITROGEN FERTILIZER RATES AND PLANT DENSITY UNDER CONTRASTING FIELD CONDITIONS

ABSTRACT

A 2-year field experiment was carried out during 2015/16 and 2016/17 planting seasons at Taung and Molelwane to investigate the effect of different nitrogen fertilizer and plant densities on growth attributes of water efficient maize WE 3127 variety. The experiment laid out in split plot arrangement, was fitted into randomized complete block design (RCBD) with four replicates. Plant density (33,333 44,444 and 55,555 plants ha^{-1}) constituted the main plot effect, while the nitrogen levels (0, 60, 120, 180 and 240 kg N/ha^{-1}) constituted the sub-plot. Measured growth parameters included plant height, chlorophyll content, leaf area, number of leaves and stem diameter. The indices of growth analysis determined included absolute growth rate, crop growth rate, net assimilation rate, relative growth rate, and leaf area duration. Data were analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences in the mean values for the respective treatments were tested by the Least Significant Difference (LSD) test at a 5 % level of probability. The relationship between growth and growth analysis, N rates and plant density were estimated using regression and correlation analyses. All measured growth parameters showed variable responses to the various treatment factors and their interactions, with better performance during 2016/17 planting season, particularly at Taung trial.

The measured growth parameters were most favored at 120 kg N/ha across trial sites and seasons. Optimum N rate ranged from 180-225 kg/ha depending on plant density and optimal plant density is 44,444 plants/ha. The highest crop growth rate and net assimilation index of 2.308g/m^2/day and 1.180 g/g/day, respectively were both obtained from the 2015/16 trial at Molelwane under 33,333 plants/ha fertilized at 60 and 240 kg N/ha, respectively.

These results suggest that this maize variety was better able to optimize environmental efficiency at Molelwane. WEMA performed better at 120 kg/ha fertilizer at Molelwane. Based on the interaction effects on plant height, number of leaves, chlorophyll content, leaf area index, absolute growth rate and relative growth rate were better in the plot fertilized with 120 kg N/ha.

It is recommended that WEMA maize variety should been sown at 44,444 plants/ha and fertilized with 120 kg N ha^{-1} North West Province of South Africa.

Keywords: Maize, growth analysis, planting season, optimum N rate, plant density

3.1. Introduction

Maize is the grain crop that is the most common to be cultivated in South Africa. Furthermore, it is grown throughout the country and under different environmental conditions (Du Plessis, 2003). It is one of the most sensitive crops to the application of nitrogen fertilizer and reacts differently in terms of the density of the plant population. Application of N fertilizer and varying plant density are agronomic practices that have consistently changed over the past six eras (Noor, 2007; Sher et al. 2017), and are incessantly being studied in respect of maize production (Sher et al., 2017; Testa et al., 2016). Nitrogen as the main nutrient in maize production has proved to be representative of a necessary constituent in several photosynthetic processes and contributes enormously to harvest yields (Hokmalipour and Darbandi, 2011). It represents a key component in chlorophyll and protein which both closely correlate with leaf colour, crop growth status, and yield (Wang et al., 2014). A deficiency of nitrogen often leads to smaller leaves and a lower chlorophyll content (Wang et al., 2014) while also delaying the appearance of leaves, despite the fact that the final number of leaves to a plant is relatively similar at both low and high nitrogen levels (Mi et al., 2016).

Plant density on the other hand is an important determinant factor in modern cropping representing the key factor determining the degree of competition between plants (Craine and Dybzinski, 2013). Plants that grow within an intense canopy under high plant density obtain a different quality of light, deepened on Far Red (FR) and impoverished in Red (R) radiation (Gu et al., 2018). Amanullah et al. (2009) reported that high plant density had 10 cm taller plants than low plant density. Imran et al. (2015) showed that higher plant density of 95, 000 plants/ha produced taller plants as opposed to the height of the plants grown under lower plant density of 65,000 plants/ha. Kgasago (2006) and Karadavut et al. (2010) reported that the relationship between the ability of a crop to photosynthetically intercept active radiation and synthesize carbohydrates for its growth is a non-linear function. Wang et al. (2014) observed insignificant interactional effects between N rates and plant density respectively and plant height, number of leaves and leaf area while the interaction were significant on leaf area index.

The best approach to understanding the response of plants to different environmental conditions under different growing stages is through growth analysis. As a result, plant growth analysis is often used to evaluate plant productivity and environmental efficiency (Azarpour et al., 2014).The main factors that affect plant growth analysis include plant density, the rate of N fertilization and the climatic conditions of the area in which the plant grows (Gul et al., 2013). The indices of growth analysisthat are often measured include amongst others absolute growth rate, relative growth rate, crop growth rate, net assimilation rate, leaf area ration (Rana and Rana, 2014).

The crop growth rate (CGR) refers to the increase in dry matter in grams per unit area per unit of time, while relative growth rate measures the increase in dry matter with a given amount of assimilatory material at a given point in time (Fageria et al., 2006). The crop growth rates refers to as product of leaf area index and relative growth rate known as efficiency index Rana and Rana (2014).

Azarpour et al. (2014) described net assimilation rate (NAR) as the dry matter produced per unit leaf area. The Leaf area duration (LAD) is at the heart of the leaf area and the growth period (Hunková et al., 2011) both of which are also described by Huang et al. (2017) as the photosynthetic potential of the plant.

Valadabadi and Farahani (2010) reported an increase in maize growth analysis resulting from high plant density while increased N fertilization rates at a lower plant density also result in an increased plant growth rate. Both relative growth rate and crop growth rate are indicators of high plant productivity under drought conditions (Gul et al., 2013).

Leaf area duration has been found to be strongly correlated with the biomass and seed yield of chickpea in Southern Spain (Ozalkan et al., 2010; López-Bellido et al., 2008).

Water efficient maize (WEMA) is a newly released drought tolerant maize variety. It was first widely distributed to South Africa farmers for cultivation in the 2016/17 summer planting season by Agricultural Research Council (ARC) who is one of the global partners involved in the breeding programme and on-station agronomic evaluation.

Information on the optimum N fertilizer requirement and appropriate plant density for this newly released maize variety in South Africa are still scanty. Yet, considering the variable edaphic factors and environmental conditions in South Africa, attention to both of these aspects has had a great effect on maize production in the country. For instance, over fertilization causes environmental pollution through leaching. Similarly, planting maize above the optimum plant density per unit area causes vast pressure on the soil nutrients, and competition for water and light, all of which drastically affect growth and development.

This study aims to investigate the effect of different N rates fertilizer and plant density on growth parameters and growth analysis indices of WEMA maize in two different localities of North West Province, South Africa. The hypothesis for the study is that growth parameters and growth analysis indices of this new maize variety will respond differently to varying N fertilizer rates and plant densities.

3.2. Materials and Methods

3.2.1. Description of study area

The experiment was carried out at the Molelwane North-West University (NWU) Research Farm (25^0 48^1S, 45^0 38^1 E.; 1,012 m asl) and Taung Experimental Station (27 30^1S, 24 30^1E; 1,111 m asl)of the Provincial Department of Agriculture Research Station during 2015/2016 and 2016/2017 planting seasons. Both sites are located in the North West Province of South Africa (Figure 1).

The NWU research farm is located in a semi-arid tropical savanna region that receives a mean annual summer rainfall of 571 mm (Kasirivu et al., 2011), while the Taung trial site receives a mean annual rainfall of 318 mm (Saexplorer 2019). Approximately 68% of the annual precipitation at the NWU farm falls between November and January in a few relatively heavy downpours, with a pronounced dry season from April to September.

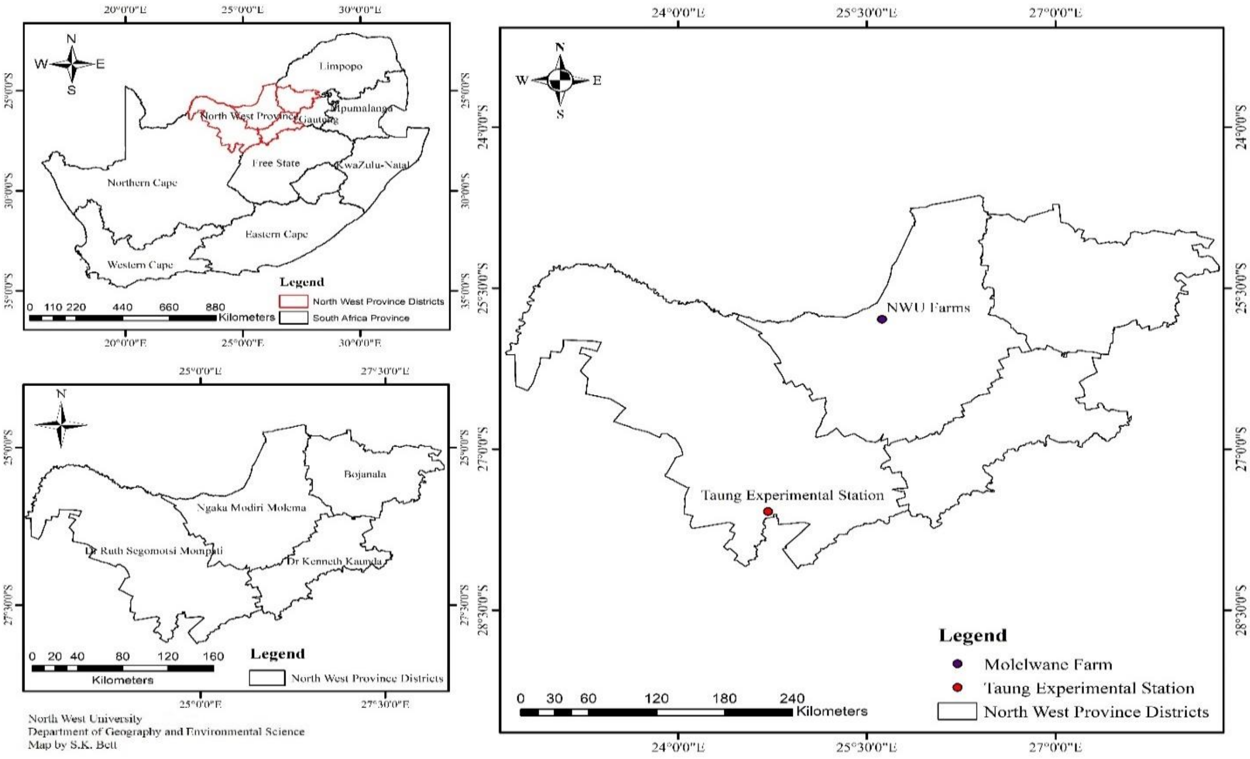

Figure 3.1: Map of North West Province, South Africa showing field trial sites

The mean maximum temperatures are 37°C while the mean minimum temperature ranged from 7°C– 11°C. The Taung Experimental Station had average maximum temperature of 35 °C and the mean minimum temperature ranged between 5°C– 18.5°C. The annual average pan evaporation of North-West is 1023 mm (Kasirivu et al., 2011).The soil at the two sites is deep, fine and freely drained; dominated by yellow and red, and eutrophic with aeolian deposits (Staff, 1999). According to the South African Soil Classification Guidelines, the soils belong to the Hutton series, (Molope, 1987;Kasirivu et al., 2011). The soil at the NWU Research Farm is a Ferric Luvisol, while that of Taung is Rhodic Ferralsol (WRB, 2016).

3.2.2. Pre-planting soil sampling and analysis

Pre-plant soil samples collected (0-15 and 15-30 cm) from the trial sites were analysed in the laboratory analysis following standard procedures. The results presented in Table 1 suggest that the soils at both sites are low in total N and phosphorus (P). The soil at Molelwane is sandy loam while that at Taung is loamy sand.

Table 3 1 : Physico-chemical properties of experimental sites during 2015/16 and 2016/17 planting seasons

Physico-chemical Properties	2015/2016 trial				2016/2017trial			
	0-15 cm		0-30 cm		0.15 cm		0-30 cm	
	Molelwane	**Taung**	**Molelwane**	**Taung**	**Molelwane**	**Taung**	**Molelwane**	**Taung**
Sand (%)	82	85	82	85	82	85	82	85
Silt (%)	1	1	1	1	1	1	1	1
Clay (%)	18	14	18	14	18	14	18	14
Texture	Sandy Loam	Loam sandy	Sandy loam	Loam sandy	Sandy Loam	Loam sandy	Sandy Loam	Loam sandy
Total N %	0.08	0.12	0.03	0.1	0.17	0.19	0.18	0.15
Available P mg/kg	6	5	10	3	80	49	11	8
K mg/kg	279	366	322	304	238	180	203	185
pH (H_2O)	4.31	6.45	4.18	4.50	4.50	4.30	4.30	5

3.2.3. Meteorological data during experimental period

Planting of the trial took place during December 2015 to May 2016 at Molelwane NWU farm site while it was done between December 2015 and July 2016 at Taung experimental station. Likewise in 2016/17, the planting of the trial seeds took place from December 2016 to May 2017 at the Molelwane NWU farm site, while it was carried out from December 2016 to June 2017 at the Taung Experimental Station.

The summary of climatic condition at the sites during those planting seasons as obtained from South Weather Service (Johannesburg) was presented in Table 2. Owing to the much lower amount of rainfall experienced during 2015/16 planting season at both experimental sites, the provision of supplementary irrigation from planting through the early vegetative stage was to guarantee good crop establishment whereas no supplementary irrigation during 2016/17 planting season because the rainfall throughout that growing period was adequate. However, due to facility constraint the total amount of supplementary irrigation applied was not quantified.

Table 3.2: The meteorological data of experimental locations

Climate data	Molelwanne	Taung
2015/16 summer planting season		
Temperature (°C)		
Minimum	15.24	13.77
Maximum	27.00	31.32
Mean daily	22.17	22.47
Total Rainfall (mm)	257.40	231.20
Relative humidity (%)		
Minimum	13.77	22.57
Maximum	74.86	74.00
Mean	50.29	48.86
2016/17 summer planting season		
Temperature (°C)		
Minimum	13.16	11.57
Maximum	27.23	29.09
Mean daily	20.16	20.42
Total Rainfall (mm)	646.40	598.80
Relative humidity (%)		
Minimum	34.14	24.29
Maximum	86.43	82.89
Mean	61.86	54.14

Source: South African Weather Services (2018)

3.2.4. Experimental Design and Treatments

The layout of experiment at each location was in split plot arrangement fitted into a randomized complete block design with four replicates. The main plot effect was the three plant densities (33,333, 44,444 and 55,555 plants/ha) while the five N fertilizer rates (0.60, 120,180 and 240 kg N/ha) constituted the sub plot effect. Each subplot measured 6 m x 4 m with a total experimental plot size of 30 m x 76 m (0.228 ha) at each site. Maize (WE 3127) seed sowing was done at inter and intra row spacing of 1m x 0.3m, 0.75 m x 0.3m and 0.9 m x 0.2 m to achieve the density of 33,333, 44,4444, and 55,555, respectively.

3.2.5. Cultural Practices

Basal fertilizer application of a third of the each rate using NPK 20:7:3 was done at planting while two-third and a third of the remaining amount from each rate was applied as top dressing at 3 and 5 weeks after seedling emergence (WAE) using lime ammonium nitrate (LAN, 28%). Manual weeding was carried out at three and seven weeks subsequent after seed sowing to maintain a weed-free condition.

3.2.6. Data collection

Five plants were tagged in each plot at both sites for growth data measurements at the tasseling stage (84 days after sowing, DAS) and at physiological maturity (115 DAS). The data collected included plant height with aid of a steel measuring tape, number of leaves per plant by counting, stem a diameter using a vernier caliper, and chlorophyll content with the aid of hand held chlorophyll meter model CCM-200 plus. Leaf area estimation following leaf length and width measurement was as described by (Otegui, 1997) while leaf area index (LAI) was calculated as follows:

LAI = $\frac{A X N}{10{,}000}$ (Equation 1; Fageria et al. , 2006)

where: A= Leaf area cm^2,

N = Plant density/plot.

Determination of growth analysis indices entails separation of randomly uprooted two plants from each plot at tasseling and physiological maturity stages into leaf, shoot and reproductive parts. Washing of samples was with tap water, rinsed with distilled water, oven-dried at 70°C to constant weight, and weight recorded.

Estimation of absolute growth rate, crop growth rate, net assimilation rate and relative growth rate of the dried plant samples was done using the following equations:

Absolute growth rate (cm/day) = $\frac{h2-h1}{t2-t1}$

(Equation 2; Rana and Rana 2014)

where: h1 and h2 are the respective plant heights at time) time;

t1= tasseling stage; and

t2 = physiological maturity stage.

Net assimilation rate (g/g /day) $=\frac{W2-W1}{t2-t1}\, x\, \frac{(\mathrm{Loge}\, L2-\mathrm{Loge} L1)}{(L2-L1)}$

(Equation 3; Fageria et al. , 2006)

where: W1 and W2 are the dry weights of the whole plant at: namely

time t_1 = tasseling stage; and

time t_2 = the physiological maturity stage;

Log_e= 2.3026;

L_1 and L_2 are the weights of a given leaf area at time:

at times t_1 and t_2 respectively.

Relative growth rate $= \frac{\mathrm{loge}\, W2-\mathrm{loge}\, W1}{t2-t1}$

(Equation 4; Fageria et al., 2006)

where: W_1 and W_2 is the dry weight of the whole plant at time:

time t_1 = tasseling stage; and

time t_2 = physiological maturity stage;

Log_e= 2.3026.

Crop growth rate = NAR X LAI

(Equation 5; Fageria et al., 2006, Rana and Rana 2014)

where: NAR = Net assimilation rate;

LAI = leaf area index

Leaf area duration (cm^2/day) $= \frac{(L1+L2)\ X\ (t2-t1)}{2}$

(Equation 6; Rana and Rana 2014)

where: L_1 = Leaf area index at the first stage;

L_2 = Leaf area index at the second stage;

Time t_2 – to time t_1 = time interval in days.

3.2.7. Statistical Analysis

All data obtained from the two years field trial were combined and analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences among treatments mean were tested using Duncan multiple range Test (DMRT) at 5% probability level. Regression analysis was performed manually using Excel program to estimate optimum fertilizer rate and plant density. The responses of chlorophyll content and other growth parameters to different N fertilizer rates and plant density were estimated using the quadratic polynomial equation ($Y= a+b_1X+b_2X^2$).The value of ‘Y’ in the equation represents the chlorophyll content.

In respect of all the other growth parameters measured,....

- ‘a’ is the intercept;
- ‘b’ is the coefficient of the quadratic equation; and
- ‘X’ is the nitrogen fertilization rate (Moswatsi et al., 2013).

The quadratic polynomial was used to determine the line of best fit for all of the growth data measured, but with the exception of the response of plant height and plant density, both of which were determined using the logarithmic model ($Y = a + b\ln x$).

In the letter case, ...

- ‘Y’ in the equation represents the plant height,
- ‘a’ is the intercept,
- ‘b’ is the coefficient of the logarithmic equation, and
- ‘x’ is the plant density.

Both of the model equations were manually calculated using Excel programme.

3.3. Results

3.3.1 Treatment factors effect on measured growth attributes

The ANOVA results showed that all measured the growth parameters differed significantly (p=0.001) across us plant densities while none of the measured . parameters differed across growth parameters (Table 3.3). The different N rates exerted significant (p=0.001) effect on all measured growth parameters except for the number of leaves while similarly, the planting season similarly had significant (p=0.001) effect on all measured parameters, except for the stem diameter and leaf area. All measured parameters except for the leaf area and leaf area index (LAI) differed significantly across the trial sites (Table 3.3). Moreover, the 2-way ANOVA interaction revealed that plant density x nitrogen fertilizer rates had significant effect on chlorophyll content, stem diameter, leaf area and LAI. Furthermore, plant density and planting season showed significant ($p<0.001$) effects on plant height, chlorophyll content, number of leaves, leaf area and LAI. The interaction between planting season and location had significant effect on plant height, chlorophyll content, number of leaves, stem diameter and leaf area (Table 3.4).

All of the 3-way ANOVA results had significant (p=0.001) effect on the leaf area index (LAI) (Table 3.4). The order of significance of the three-way ANOVA interaction on the measured growth parameters ranged from LAI >chlorophyll content > leaf area > plant height > stem diameter > number of leaves (Table 3.4).

3.3.2. Effect of treatment factors on growth analysis parameters

The results of statistical analysis indicated that growth analysis parameters were significantly ($p\leq 0.05$) affected by main treatment factors, single treatment interaction factors and multiple treatment interaction factors, but with the exception of absolute growth rate (Table 3.5).

Table 3.3: Effects of treatment factors on measured growth parameters

Treatments	**Plant height (cm)**	**No . leaves per plant**	**Chlorophyll content (SPAD unit)**	**Stem diameter (cm)**	**Leaf area (cm^2)**	**LAI**
Season						
2015/16	225.29b	14.21b	48.38b	2.24b	648.70b	48.38b
2016/17	249.92a	15.34a	54.88a	2.97a	712.50a	54.88a
LSD$_{(0.05)}$	2.97	0.10	0.50	0.02	5.89	0.50
Location/Site						
Molelwane	234.75b	14.68b	48.92b	2.32b	683.60a	48.92b
Taung	240.45a	14.88a	54.34a	2.88a	680.60a	54.34a
LSD$_{(0.05)}$	2.97	0.10	0.50	0.02	5.89	0.50
Plant density						
33 333	240.16a	14.80a	49.21c	2.56b	2.71a	49.21c
44 444	243.59a	14.96a	52.14b	2.70a	2.16c	52.14b
55 555	229.06b	14.57b	53.54a	2.57b	2.51b	53.54a
LSD$_{(0.05)}$	3.64	0.12	0.60	0.08	0.01	0.60
N rates (kg/ha)						
0	233.65b	14.64c	50.30d	2.52b	2.26d	50.30d
60	237.07b	14.71b	52.57b	2.62a	2.35c	52.57b
120	235.33b	14.68b	49.83c	2.62a	2.46b	49.83e
180	241.94a	14.96a	53.50a	2.67a	2.55b	53.50a
240	240.01a	14.89a	51.94b	2.60a	2.70a	51.94c
LSD$_{(0.05)}$	4.70	0.15	0.77	0.11	0.15	0.02

Table 3.4: ANOVA table of treatments interaction effect on growth parameters

Treatment factors	**Df**	**Plant height**	**Number of leaves**	**Chlorophyll content (SPAD unit)**	**Stem diameter (cm)**	**Leaf area (cm^2)**	**Leaf area index**
PD x N	8	3460.50^{ns}	2.27^{ns}	856.20**	0.99**	93231.00**	2.50**
PD x L	2	625.80**	7.57*	1157.03**	0.50^{ns}	142057.00**	65.66**
PD x S	2	4732.50**	10.65**	900.18**	0.44^{ns}	253364.00**	1.58**
N x L	4	2371.80^{ns}	2.60^{ns}	254.22^{ns}	1.18^{ns}	15086.00**	0.68**
N x S	4	10031.90	7.90^{ns}	2298.75**	1.48*	59352.00**	1.04**
S x L	1	329.20**	10.51**	832.13**	0.00**	43295.00**	0.01**
PD x S x L	2	2558.30**	0.58**	1237.80**	0.21^{ns}	56126.00**	0.23**
N x PD x S	8	14351.50^{ns}	10.83**	1249.53**	2.32^{ns}	254175.00**	1.93**
N x PD x L	8	7207.10^{ns}	333.87**	194.59^{ns}	1.06^{ns}	30394.00^{ns}	0.82**
N x S x L	4	5736.70**	5.23^{ns}	714.85^{ns}	2.25^{ns}	8595.00^{ns}	1.40**

Notes: PD = Planting density, N = Nitrogen rates, L = Trial sites and S = Planting season, df = degrees of freedom, ns = not significant * and ** implies significance at a 5% and a 1% probability level respectively.

Table 3.5: Effect of treatment factors on growth analysis parameters

Treatment factors	df	AGR (cm/day)	RGR (g/g/day)	CGR (g/m^{2}/ day)	LAD (cm^{2}/day)	NAR (g/m^{2}/ day)
N	4	2.40*	2.21**	2.30**	0.00142**	0.273**
PD	2	0.39^{ns}	2.55**	2.27**	0.000702**	0.781**
S	1	0.41^{ns}	172.63**	102.37**	0.0000012**	18.60**
L	1	0.44^{ns}	2.62**	4.45**	0.00189**	0.375**
N x P	8	5.83**	0.53**	0.81**	0.00189**	0.184**
N x S	4	3.93**	2.18**	2.59**	0.0251**	0.378**
PD x S	2	0.15^{ns}	1.73**	1.85**	0.00056**	0.320**
N x L	4	0.90^{ns}	1.49**	1.57**	0.00142**	0.084**
PD x L	2	1.97**	0.86**	1.08**	0.0825**	0.221**
S x L	1	3.01**	1.66**	1.53**	0.000125**	0.045**
N x P x S	8	5.17**	5.17**	0.83**	0.0024**	0.120**
N x P x L	8	4.68**	4.68**	1.03**	0.00145**	0.079**
N x S x L	4	0.50**	0.50**	1.36**	0.07300**	0.153**
PD x S x L	2	0.03**	0.03**	0.60**	0.00411**	0.077**

Notes: PD = planting density, N = Nitrogen rates, L = trial sites and S = planting season, df = degrees of freedom, AGR = absolute growth rate, RGR = relative growth rate, crop growth rate = CGR, LAD =leaf area duration, NAR =net assimilation rate, ns = not significant * and ** implies significance at a 5% and 1% probability level respectively.

3.3.3 Treatment interaction effect on measured growth parameters

3.3.3.1 Plant height and number of leaves per plant

The significant ($p<0.05$) interaction effect of planting season x location x plant density x N fertilizer rates was observed for plant height and mean number of leaves per plant at the tasseling and physiological maturity (Table 3.6). The tallest maize plant (309.35 cm) during the physiological maturity stage was recorded during the 2016/17 planting season at the Molelwane trial during the tasseling stage at a plant density of 55,555 plants/ha on plots supplied with 240 kg Nha. However, the tallest maize plant height (291.65 cm) was recorded during the 2016/17 planting season under 33,333 at Taung trial when treated with 120 kg N/ha. At this site, the tallest maize plant height during the physiological maturity stage was 5.7% lower than the tallest maize plant height during the tasseling stage.

On the other hand, significantly ($p<0.05$) highest number of leaves per plant (17.5) at the tasseling phase was similarly obtained during the 2016/17 planting season at both locations with plant density of 33,333 plants/ha on plots fertilized with 240 kg N/ha. However at physiological maturity stage, the highest number of leaves per plant noted during the 2016/17 planting season at Molelwane (15.80) at a plant density of 44, 444 plants/ha and fertilized with 120 kg N/ha was statistically higher than (14.33) recorded at the Taung trial with a plant density of 33,333 plants/ha with 120 kg N/ha applied.

3.3.3.2 Chlorophyll content and stem diameter

The interaction effect of planting season x location x plant density x nitrogen fertilizer rates were significant ($p<0.05$) on the chlorophyll content and stem diameter of maize plants (Table 3.7). The highest chlorophyll content (64.31 SPAD – units) was obtained at the tasseling stage during the 2015/16 growing season at Taung trial with a plant density of 55,555 plants/ha from plots supplied with applications of 120 kg N/ha. The highest chlorophyll content in the maize plants at the physiological maturity stage (57.77 SPAD – units) during the 2016/17 growing season was similarly obtained at the Taung trial under 55,555 plants/ha fertilized with 120 kg N/ha.

The highest stem diameter (3.83 mm) at the tasseling stage was recorded at Taung during the 2016/17 planting season, at a plant density of 44,444 plants/ha with applications of 180 kg N/ha. The thickest maize stem diameter (3.70 mm) during 2016/17 planting season at the physiological maturity stage was obtained from Taung trial under 33,333 plants/ha in plots fertilized with 180 kg N /ha rate.

Table 3.6: Interaction effect of various treatment factors on plant height and number of leaves

Location	N fertilizer (kg /ha)	Plant density	Plant height (cm)		Number of leaves		Plant height		Number of leaves	
			Tasseling	Maturity	Tasseling	Maturity	Tasseling	Maturity	Tasseling	Maturity
			2015/16				2016/17			
Molelwane	0	33,333	216.80	224.00	13.60	12.95	235.88	255.73	16.00	15.27
		44,444	215.78	226.10	13.80	12.89	260.60	226.96	16.05	14.80
		55,555	234.30	221.50	13.45	10.15	253.90	246.20	15.65	13.55
	60	33,333	235.65	221.25	13.60	12.85	277.25	256.13	17.10	14.30
		44,444	226.19	218.75	14.10	11.75	245.90	262.47	15.95	15.80
		55,555	212.47	237.00	13.60	11.58	284.60	270.90	16.80	14.80
	120	33,333	218.05	212.87	13.40	12.10	267.35	274.64	16.15	15.60
		44,444	205.45	229.12	14.30	11.25	264.55	283.15	15.55	15.80
		55,555	188.14	223.35	14.20	10.88	277.45	278.67	16.65	15.45
	180	33,333	213.08	211.06	13.60	12.90	282.75	254.66	16.70	14.78
		44,444	229.30	227.25	15.30	11.85	266.15	274.64	15.50	15.15
		55,555	209.23	236.00	15.05	10.96	261.55	266.62	16.55	14.10
	240	33,333	219.90	230.84	14.27	13.31	268.30	275.82	17.50	15.78
		44,444	215.85	214.83	14.65	12.80	288.90	271.27	15.85	13.85
		55,555	218.80	227.50	14.75	12.73	309.35	277.80	16.95	14.80
Taung	0	33,333	215.25	202.00	13.30	12.70	248.95	261.33	14.35	13.13
		44,444	226.25	209.00	13.80	13.55	237.00	275.33	15.60	13.40
		55,555	214.88	220.75	13.60	12.43	250.00	263.78	14.75	13.13
	60	33,333	218.73	194.75	12.40	11.98	216.70	289.24	15.00	13.85
		44,444	234.03	237.70	13.70	13.40	240.75	272.38	14.20	13.40
		55,555	205.80	213.00	13.45	12.35	277.58	262.85	15.10	13.25
	120	33,333	168.15	225.40	13.78	13.00	224.95	291.65	16.15	14.33
		44,444	226.80	209.72	13.70	13.90	244.70	265.47	15.15	13.65
		55,555	210.05	193.67	14.00	14.00	265.75	260.04	14.95	12.55
	180	33,333	209.70	212.75	14.05	12.85	264.45	269.53	16.70	13.40
		44,444	226.60	232.00	14.35	13.38	247.00	280.72	15.90	13.10
		55,555	214.85	227.98	13.85	13.35	261.76	277.35	15.00	12.90
	240	33,333	203.45	227.00	13.05	13.50	240.75	269.82	17.50	13.20
		44,444	209.63	221.25	13.45	14.15	260.95	271.50	15.85	13.00
		55,555	214.70	202.50	14.05	13.40	273.13	268.47	16.95	13.53
	LSD $_{(0.05)}$		9.98	25.67	1.37	0.84	9.98	25.67	1.37	0.84

Table 3.7: Interaction effect of various treatment factors on chlorophyll content and stem diameter

Location	**N fertilizer (kg N/ha)**	**Plant density**	**Chlorophyll content (SPAD- units)**		**Stem diameter (mm)**		**Chlorophyll content (SPAD- units)**			
			Tasseling	**Maturity**	**Tasseling**	**Maturity**	**Tasseling**	**Maturity**	**Tasseling**	**Maturity**
			2015/16				**2016/17**			
Molelwane	**0**	33,333	53.91	27.74	1.87	2.15	55.72	34.38	3.16	2.29
		44,444	32.65	12.44	1.86	2.04	52.51	11.51	2.88	2.44
		55,555	38.76	23.87	1.84	1.97	50.07	12.17	3.15	2.32
	60	33,333	59.74	28.14	1.87	2.20	55.45	20.15	3.31	2.23
		44,444	31.77	26.22	1.77	2.12	52.49	13.13	2.96	3.10
		55,555	42.13	11.70	1.88	2.22	54.04	15.71	3.02	2.80
	120	33,333	43.27	34.76	1.93	2.46	51.59	18.11	3.40	2.70
		44,444	28.75	20.20	1.78	2.30	54.05	16.18	3.36	3.00
		55,555	35.44	17.48	1.98	2.23	51.35	24.94	3.07	2.80
	180	33,333	63.30	35.72	1.92	2.42	51.35	25.35	3.50	3.20
		44,444	47.39	33.31	1.88	2.12	58.44	16.38	3.26	3.00
		55,555	39.11	27.30	1.85	2.23	58.91	5.72	3.27	2.80
	240	33,333	53.98	24.67	1.90	2.38	61.90	27,39	3.33	3.30
		44,444	36.27	31.75	1.81	2.31	56.69	21.76	3.22	3.20
		55,555	29.26	28.47	1.83	2.23	63.30	32.39	3.15	3.10
Taung	**0**	33,333	55.38	24.76	1.76	2.38	60.32	16.44	3.43	3.40
		44,444	47.68	51.52	2.01	2.31	57.86	7.54	2.77	2.90
		55,555	41.48	28.07	2.03	2.23	60.51	8.85	3.61	3.30
	60	33,333	58.58	29.02	2.00	2.38	62.39	14.86	3.56	3.40
		44,444	48.50	34.88	1.98	2.31	50.86	17.38	3.32	3.10
		55,555	48.69	46.19	2.26	2.23	52.79	16.99	3.28	3.50
	120	33,333	51.52	27.99	2.00	2.36	61.03	24.45	3.73	3.20
		44,444	53.05	46.10	2.04	2.22	49.67	17.84	3.53	3.40
		55,555	53.52	57.77	2.06	2.26	52.03	18.11	2.45	3.40
	180	33,333	53.59	30.42	1.90	2.50	60.00	15.88	3.47	3.20
		44,444	51.90	47.46	1.95	2.18	56.11	8.86	3.83	3.70
		55,555	64.31	49.51	1.98	2.46	60.54	10.71	3.82	3.00
	240	33,333	46.70	28.42	1.82	2.26	59.66	14.99	3.40	3.10
		44,444	47.51	28.77	2.02	2.33	59.12	11.26	3.17	3.50
		55,555	56.23	47.77	1.97	2.46	57.53	15.40	3.30	3.30
	LSD $_{(0.05)}$		5.46	4.30	0.28	0.18	5.46	4.30	0.28	0.18

3.3.3. 3 Leaf area and Leaf Area Index (LAI)

There was a significant ($p<0.05$) interaction effect of planting season x location x plant density x N fertilizer on the maize leaf area and leaf area index (LAI) during the tasseling and physiological growth stages (Table 3.8). The highest leaf area (907.60 cm^2) at the tasseling stage was obtained at the Molelwane trial during the 2016/17 growing season from plots with a plant density of 33, 333 plants/ha and fertilized with 240 kg N/ha. However, highest maize leaf area (833.36 cm^2) at the physiological maturity stage was obtained at the Taung trial also during 2016/17 under 44,444 plants/ha when supplied with 60 kg N/ha. The highest LAI (3.93) was obtained during tasseling stage, and also during the 2016/17 planting season, was at the Molelwane trial from plots with a plant density of 55,555 plants/ha and fertilized with 120 kg N/ha application rate. However, the highest LAI of 3.40 obtained at physiological maturity also from Molelwane trial during the 2016/17 planting season was under 55,555 plants/ha in unfertilized plot. This leaf area index was marginally (1.2%) higher than the value obtained from plots at a plant density of 55, 555 plants/ha and fertilized with 240 kg N/ha rate.

3.3.4 Treatment interaction effect on growth analysis indices

3.3.4.1 Absolute growth rate, relative growth rate and crop growth rate

A 4-way ANOVA for the collected data revealed a significant ($p<0.05$) interaction effect in planting season x location x plant density x nitrogen fertilizer rates on both absolute and relative growth rates, as well as crop growth rate of WEMA maize plants (Table 3.9). The highest absolute growth rate (1.382 cm/day) was recorded during the 2015/16 planting season at the Taung trial from plots with a plant density of 33,333 plants/ha and fertilized with 120 kg N/ha. However, the highest relative growth rate of 2.963 g/g/day was obtained during the 2015/16 planting season at the Molelwane trial from plots with a plant density of 33,333 plants/ha that were fertilized with 180 kg N/ha. The highest crop growth rate (2.308 g/m^2/day) was obtained during 2015/16 planting season at the Molelwane trial from plots at a plant density of 33,333 plants/ha and fertilized with 60 kg N/ha application rate.

Table 3.8: Interaction effect of various treatment factors on leaf area and leaf area indices

Location	N fertilizer (kg N/ha)	Plant density	Leaf area (cm^2)		Leaf area indices		Leaf area (cm^2)		Leaf area indices	
			Tasseling	Maturity	Tasseling	Maturity	Tasseling	Maturity	Tasseling	Maturity
Molelwane	**0**		**2015/16**				**2016/17**			
		33,333	573.90	744.50	1.76	1.81	832.70	694.90	3.71	3.36
		44,444	643.30	587.10	2.34	2.14	832.30	743.31	2.27	1.92
		55,555	678.30	683.70	2.82	3.12	691.00	569.00	2.50	2.45
	60	33,333	598.30	550.20	1.70	2.71	804.50	703.25	3.52	3.40
		44,444	724.00	592.80	2.56	2.23	874.50	719.63	2.33	2.20
		55,555	678.70	711.60	2.87	2.63	750.00	833.36	2.74	2.86
	120	33,333	627.20	612.50	1.71	1.81	823.90	677.11	3.56	3.22
		44,444	661.50	655.70	2.41	2.40	803.90	747.90	2.20	1.82
		55,555	674.90	633.60	2.86	2.88	741.50	660.50	2.60	2.52
	180	33,333	541.20	738.40	1.83	2.74	725.90	634.00	3.93	3.06
		44,444	696.10	632.50	2.54	2.38	863.20	776.72	2.44	2.24
		55,555	700.70	758.40	3.24	3.24	868.40	761.57	3.13	2.66
	240	33,333	590.10	654.80	1.60	1.92	775.90	506.66	3.45	3.05
		44,444	692.20	714.50	2.48	2.58	907.60	716.70	2.26	2.01
		55,555	636.90	755.40	2.60	3.35	856.30	654.03	3.09	2.61
Taung	**0**	33,333	637.30	634.20	1.76	1.67	722.40	730.72	1.86	1.40
		44,444	576.80	582.80	2.32	2.27	734.60	678.47	1.86	1.47
		55,555	628.4	616.00	2.67	2.57	669.80	744.15	3.51	1.45
	60	33,333	559.40	613.60	1.57	1.44	648.50	808.35	3.05	1.41
		44,444	584.10	582.90	1.87	2.23	627.20	794.90	1.64	3.34
		55,555	647.50	658.80	2.43	2.80	674.30	762.08	2.24	1.54
	120	33,333	644.80	656.20	1.60	1.90	622.40	752.64	3.00	1.00

	44,444	551.20	549.00	2.35	2.01	614.10	747.26	1.67	1.17
	55,555	616.80	618.50	2.86	2.82	706.10	650.65	2.27	2.23
180	33,333	578.90	672.80	1.75	1.61	677.40	772.77	2.41	1.10
	44,444	591.20	421.50	2.23	2.23	627.50	747.78	1.90	1.67
	55,555	612.20	665.40	2.62	2.40	691.20	667.06	2.58	1.31
240	33,333	556.80	578.40	1.63	2.37	724.30	758.64	3.34	1.17
	44,444	555.30	542.40	2.18	1.98	694.90	733.62	2.17	1.21
	55,555	560.90	559.80	2.82	2.70	631.00	681.98	2.64	1.78
LSD (0.05)		78.99	44.50	0.19	0.10	78.99	44.50	0.19	0.10

Table 3. 9: Treatment interaction effect on Absolute growth rate, relative growth rates, and crop growth rate

Location	N fertilizer (kg/ha)	Plant density	Absolute growth rate (cm/day)	Relative growth rates (g/g/day)	Crop growth rate (g/m^2/ day)	Absolute growth rate (cm/days)	Relative growth rates (g/g/day)	Crop growth rate (g/m^2/ day)
			2015/16			**2016/17**		
Molelwane	**0**	33,333	0.240	2.468	1.608	0.172	0.166	0.303
		44,444	0.345	1.553	1.193	0.001	0.114	0.205
		55,555	-0.425	2.048	1.758	0.348	0.082	0.238
	60	33,333	-0.412	2.300	2.308	-0.227	0.140	0.272
		44,444	-0.308	2.000	1.205	0.000	0.138	0.171
		55,555	0.723	1.788	1.805	-0.120	0.084	0.221
	120	33,333	0.367	2.035	1.290	-0.127	0.142	0.328
		44,444	0.788	1.800	1.295	-0.231	0.097	0.182
		55,555	0.755	1.473	1.295	0.059	0.087	0.266
	180	33,333	-0.043	2.258	2.205	-0.164	0.160	0.357
		44,444	-0.092	1.623	1.440	-0.104	0.118	0.258
		55,555	0.752	1.778	2.078	0.001	0.073	0.256
	240	33,333	0.498	2.963	2.275	-0.242	0.145	0.266
		44,444	0.050	1.800	1.863	-0.340	0.109	0.251
		55,555	0.107	1.823	2.125	-0.287	0.090	0.177
Taung	**0**	33,333	-0.202	1.450	1.015	0.390	0.085	0.170
		44,444	-0.575	1.810	1.095	0.364	0.066	0.128
		55,555	0.020	1.338	1.277	0.120	0.052	0.094
	60	33,333	-0.720	2.275	1.118	0.365	0.097	0.134
		44,444	0.057	2.285	1.055	0.080	0.081	0.133
		55,555	0.315	2.130	2.108	0.000	0.054	0.143
	120	33,333	1.382	1.563	1.058	0.746	0.122	0.115
		44,444	-0.125	1.100	1.243	0.267	0.085	0.145
		55,555	-0.445	1.415	1.628	-0.011	0.053	0.160
	180	33,333	-0.055	1.598	0.945	0.199	0.080	0.150
		44,444	0.260	1.410	0.905	0.278	0.077	0.121
		55,555	0.392	1.338	1.010	0.075	0.060	0.148
	240	33,333	0.785	1.655	1.738	0.182	0.073	0.146
		44,444	0.393	1.228	1.225	0.070	0.063	0.130
		55,555	-0.217	1.455	1.835	0.247	0.056	0.143
	LSD $_{(0.05)}$		0.58	0.074	0.060	0.58	0.074	0.060

3.3.4.2 Leaf area duration and net assimilation rate

The leaf area duration and net assimilation rate of maize were significantly ($p<0.05$) affected by the interaction between planting season x location x plant density x nitrogen fertilizer rates (Table 3.10). The highest leaf area duration (54.05 cm^2/day) during the 2016/17 planting season was at the Taung trial from unfertilized plots at a plant density of 55,555 plants/ha. On the other hand, the highest net assimilation index (1.180 g/g/day) was recorded during the 2015/16 planting season growing season at Molelwane trial under 33,333 plants/ha plant density with 240 kg N/ha fertilizer application rate.

3.3.5 Correlation and regression analysis between measured parameters

A strong and positive relationship ($R^2 = 0.89$; $p<0.05$) was obtained between chlorophyll content and N fertilizer rates at physiological maturity stage (Table 3.11). There was a significant relationship between the leaf area index (LAI) and the measured growth analysis indices at tasseling stage, as well as the physiological maturity stage, except in the case of the absolute growth rate. The range of the coefficient of determination (R^2) values in this case was from 0.03 to 0.30 (Table 14).

3.3.7. Determination of optimum N rate and plant density

The regression analysis revealed that the optimal N fertilizer rate for this WEMA variety ranged from 180 – 225 kg N/ha depending on the growth parameter of interest (Table 3.12). Nevertheless, both 180 and 195 kg N/ha outperformed all other N rates. Based on the model used, the predicted optimum N rate for plant height and leaf chlorophyll content was 195 kg N/ha although the r^2-value for plant height was not significant. However, the predicted optimum rate of 180 kg N/ha was for both maize leaf area and LAI with significant (R^2 = 0.16 and 1). Conversely, the optimum fertilizer rate of 225 and 210 kg N/ha predicts the optimum number of leaves and stem diameter per plant, respectively with significant the (R^2 = 0.65 and 0.46). Nevertheless, leaf chlorophyll content and plant stem diameter performed better under 55,555 and 44.444plants/ha, respectively.

Table 3.10: Treatment interaction effect on Leaf area duration and net assimilation rate

Location	N fertilizer (kg/ha)	Plant density	Leaf area duration (cm^2/day)	Net assimilation rate (g/g/day)	Leaf area duration (cm^2/day)	Net assimilation rate (g/g/day)
			2015/16		**2016/17**	
Molelwane	0	33,333	23.45	0.890	33.14	0.148
		44,444	27.99	0.558	37.90	0.078
		55,555	40.29	0.563	49.42	0.052
	60	33,333	34.15	0.853	29.93	0.170
		44,444	29.32	0.540	48.23	0.056
		55,555	34.37	0.688	48.86	0.076
	120	33,333	23.43	0.710	32.92	0.168
		44,444	31.06	0.533	37.05	0.144
		55,555	37.36	0.450	45.18	0.106
	180	33,333	34.80	0.803	33.60	0.139
		44,444	31.09	0.598	40.71	0.091
		55,555	42.06	0.643	43.57	0.082
	240	33,333	24.57	1.180	31.47	0.148
		44,444	33.41	0.723	37.93	0.090
		55,555	42.82	0.638	50.09	0.057
Taung	0	33,333	21.80	0.600	30.66	0.087
		44,444	29.59	0.480	39.18	0.054
		55,555	33.51	0.498	54.05	0.037
	60	33,333	18.85	0.773	34.64	0.075
		44,444	28.57	0.470	45.10	0.046
		55,555	36.03	0.753	51.26	0.044
	120	33,333	24.25	0.553	29.01	0.060
		44,444	26.47	0.618	40.07	0.042
		55,555	36.67	0.578	48.43	0.056
	180	33,333	21.04	0.585	35.42	0.064
		44,444	29.02	0.405	42.53	0.066
		55,555	31.27	0.423	49.09	0.061
	240	33,333	30.07	0.733	32.28	0.057
		44,444	25.94	0.618	41.87	0.043
		55,555	35.19	0.683	53.62	0.040
	LSD $_{(0.05)}$		3.37	3.37	0.021	0.021

Table 3.11: Relationship between chlorophyll content versus N fertilizer rates and plant height at different plant densities

Parameters	Growth stages	Regression equation	R^2-value	p-value
Chlorophyll content	Tasseling stage	$Y = 0.2843x^2 - 0.9057x+51.206$	0.41	0.291^{ns}
Chlorophyll content	Physiological maturity Stage	$Y = -0.4514x^2 + 4.1326x+17.544$	0.89	0.050*
Plant height	Tasseling stage	$Y = 8.826\ln(x) + 232.33$	0.99	0.122^{*}
Plant height	Physiological maturity Stage	$Y = -0.221\ln(x) + 244.14$	0.02	0.823^{ns}

* implies $p<0.05$, ns = not significant

Table 3.12: Relationship between leaf area index (LAI) and growth analysis indices

Parameters	Regression equation	R^2-value	p-value
	Tasseling stage		
Absolute growth rate	$Y = -37.95x + 684.81$	0.03	0.004**
Crop growth rate	$Y = -68.70x + 738.77$	0.22	<0.001**
Leaf area duration	$Y = 0.57x + 708.82$	0.20	<0.001**
Net assimilation rate	$Y = -182.50x + 745.19$	0.30	<0.001**
Relative growth rate	$Y = -62.65x + 739.65$	0.30	<0.001**
	Physiological maturity stage		
Absolute growth rate	$Y = 17.49x + 673.36$	0.01	0.06^{ns}
Crop growth rate	$Y = -0.22x + 2.66$	0.07	<0.0001***
Leaf area duration	$Y = 0.50x + 629.85$	0.25	<0.0001***
Net assimilation rate	$Y = -0.83x + 2.77$	0.20	<0.001**
Relative growth rate	$Y = -35.3x + 708.82$	0.27	<0.001**

*** $p\leq0.001$, **$p\leq0.01$, ns = not significant at $p<0.05$ level

Table 3.13: Regression equations and predicted optimum N fertilizer rate and plant density

Growth parameters	N quadratic equation	PD quadratic equation	R^2-value (N rates)	R^2-value (PD)	Optimal N (kg N/ha)	Optimal plant density/ha
Plant height	$Y = -3.83x^2 + 30.275x + 183.85$	$Y = -0.045x^2 + 1.765x + 234.52$	1^{**}	0.45^{*}	195	44,444
Number of leaves	$Y = 0.001x^2 + 0.1324x + 14.556$	$Y = -0.035x^2 + 13.9x + 0.0405$	0.65^{*}	1^{**}	225	55,555
Chlorophyll content	$Y = 0.295x^2 - 1.297x + 52.99$	$Y = -1.165x^2 + 9.155x + 35.56$	0.1**	1**	195	55,555
Stem diameter	$Y = -0.017x^2 + 0.0865x + 2.5425$	$Y = 0.05x^2 - 0.255x + 2.84$	0.46**	1**	210	44,444
Leaf area	$y = 2.075x^2 - 12.185x + 696.08$	$y = -6.5x^2 + 45.75x + 602.8$	0.16**	1**	180	33,333
Leaf area index	$y = -0.075x^2 - 0.725x + 1.01$	$y = 0.01x^2 + 0.064x + 2.28$	1**	1**	180	33,333

N = nitrogen fertilizer rates, PD = plant density ** $p \leq 0.01$, ns = not significant

3.4 Discussion

The tallest maize plant attained during the 2016/17 planting season across the two sites can possibly be attributed to the favourable environmental conditions. This observation is in agreement with Amnaullah et al (2009) findings that the reduction in maize plant height relates to fluctuations in the distribution of rainfall and the total amount of rain falling across the planting seasons. The greater maize plant height at Molelwane as opposed to that at Taung may be due to more favourable climatic and edaphic factors. This result is similar to the observations made by Kgagoso (2006) and Yada (2011) who reported variable heights in respect of the maize plant , depending on the plant varieties and the environmental conditions.

Yada (2011) explained that maize plants grown under high plant density conditions receive light of a different quality which is improved in terms of the far red radiation (FR) and impoverished in terms of the red (R) radiation poles of the spectrum. The tallest maize plant recorded under plant density of 44,444 plants/ha at application levels of 240 kg N/ha conforms to the findings by Murányi and Pepó (2013) who reported that the plants become taller as the plant density increases. An increase in plant height with an increase in the amount of nitrogen fertilizer applied to the soil is in agreement with Sebetha and Modi (2016) suggestion that maize plants use nitrogen during their active cell division process to form building blocks of protein that are essential for cell elongation (Igbal et al., 2006: Ali and Anjum 2017).

The highest number of leaves per plant obtained from the Molelwane trial possibly relates to differences in soil texture, better rainfall distribution, and moisture availability, that together possibly enhance maize development. Similarly, on account of variations in soil texture and in the rainfall, Sebetha and Modi (2016) observed lower number of leaves per maize plant in the Taung trial than in those maize plants in the Potchefstroom and Rustenburg environments. Taung had high percent sand (over 90%) with low clay (8%) while Potchefstroom and Rustenburg had far much lower percent sand (44% and 58%, respectively) and higher clay content (49% and 30% respectively). According to Yada et al. (2015), lower plant density produce the highest number of leaves. This can possibly be attributed to the maize variety and the environmental conditions under which it is grown. The highest number of leaves was observed with applications of 120 kg N/ha. This result is corroborrated by the findings of Gungula et al. (2005) who reported a higher number of leaves per plant with applications of 120 kg N/ha in Mokwa, Nigeria. Amin (2010) attributed the highest number of leaves per plant to the application of 180 kg N/ha to increase the number of nodes.

The highest chlorophyll content obtained during the 2016/17 planting season relates to the application of nitrogen fertilizer and favourable environmental conditions. However, the least plant density of 33,333 plants/ha was accompanied by a higher chlorophyll content index on account of less competition with other maize plants. This result agrees with the results of Capici et al. (2013) who stated that the chlorophyll content decreases significantly with increasing plant density levels. The highest chlorophyll content observed on plots where 120 kg N/ha were being applied contradicts the earlier findings (Tajul et al. 2013), which reported an increase in the chlorophyll content index as the rate of nitrogen fertilizer increases.

The thicker stem diameter reported during the 20l6/17 planting season can be attributed to the favourable rainfall conditions, in tandem with the adequate fertilization rates. This agrees with the findings of Mandiċ et al. (2015), who revealed that stem elongation is influenced by climatic conditions. The maize planted at Taung had higher stem diameter, possibly due to variations in the environmental conditions and the soil factor. The thickest maize stem obtained at a plant densityof 33,333 plants/ha possibly relates to lower levels of inter-plant competition for resources and the better utilization of the applied nitrogen fertilizer. This is in consonance with the results of Mandiċ et al. (2015), who revealed that high plant density reduce photosynthesis and cause reductions in the stem diameter. The plots that received 180 kg N/ha produced the thickest stem diameter, which is in agreement with the findings by Opoku (2017), who reported that an increase in the nitrogen fertilizer supply causes the diameters of cells and stems to expand.

The highest leaf area obtained at a plant density of 44,444 plants/ha could be attributed to increased cell division and expansion that together intensify crop growth and development. Similarly, Hokmalipour and Darbandi (2011) reported that plant density affects leaf area. The highest leaf area observed with the application of 180 kg N/ha relates to high N availability. Amanullah et al. (2009) and Amin (2010) reported that higher fertilizer rates enhance cell division, which in its turn significantly promotes cell expansion, leaf development and expansion of the leaf area.

On the other hand, the highest leaf area index obtained during the 2016/17 planting season can be attributed to the availability of favourable nutrients and soil moisture during this planting season. This observation aligns with the reports by Amanullah et al. (2007) that the cropping season affects the leaf area index (LAI). The higher leaf area indices recorded at Molelwane trial site are possibly associated with the favourable environmental conditions (e.g. rainfall) and edaphic factors, as opposed to those at the Taung field.

Kgasago (2006) reported that adequate nutrients, favourable temperatures and soil moisture conditions, as well as satisfactory levels of solar radiation that are intercepted by the plant, are the basic factors that enhance crop growth and development. The highest LAI recorded under 44,444 plants/ha may have arisen as a result of favourable intra-spacing between the maize plants. This result contradicts the earlier findings by Carpici et al. (2010) and Tajul et al. (2013) who indicated that the leaf area index decreases with increasing plant density. Similar observations by Sharifi and Namvar (2016) revealed that the leaf area index on plots supporting 11 plants/m^2 gave higher leaf area indices than plots supporting seven plants/m^2.

The highest leaf area indices recorded on plots treated with 120 kg N/ha is possibly due to the relatively high temperatures prevailing during the two growing seasons. This result contradicts the findings by Ramírez et al. (2005) who reported that the maize leaf area index increases as the nitrogen fertilizer rate increases. The observed higher leaf area index at the Molelwane trial during the 2016/17 planting season might be due to the variations in the soil and climatic conditions across the planting seasons. The 2015/16 planting season recorded a higher mean temperature (30.21°C) and more erratic rainfall than these same two variables as recorded in the 2016/17 season, which could have influenced plant growth and development. Also, Harold et al. (2006) reported that owing to fluctuations in the climatic conditions, the availability of nitrogen varied significantly across the planting seasons. This is further corroborrated by Wang et al. (2007)who reported that an understanding of the concept of an ideal soil fertility level and of the response to nutrient management together provide a suitable standard for improving nutrient management.

The interaction effect of planting season x location x plant density x N rates on the measured growth parameters proved to be significant during the 2016/17 planting season at the Taung trial with a plant density of 33,333 plants/ha on the plots that received applications of 120 kg N/ha. This suggests that the initial availability of the necessary soil nutrients with ample applications of fertilizer intensified crop growth, especially as a result of the wider spacings between the plants.

Amunallah et al. (2009) reported similar observations but with no significant effects and also delayed maize growth at the tasseling stage following on applications of 180 kg N/ha at a plant density of 100, 000 plants/ha. However, the significant interaction effect of planting season x location x plant density x N fertilizer rates that were observed on the measured growth parameters in the case of the Molelwane trial on plots fertilized with 120 kg N/ha in the 2016/17 growing season and at the physiological maturity stage, suggest positive responses to the application of fertilizers. Amunallah et al. (2009) further indicated that during the physiological maturity stage, a plant density of 100,000 plants/ha was associated with increased growth parameter as opposed to those relating to plots at a plant density of 60, 000 plants/ha throughout the planting season which were treated with 60 kg and 180 kg N/ha as opposed to those treated with 120 kg N/ha .

The significant influence of planting season on the measured growth analysis indices of WEMA is in consonance with findings by Okalebo et al. (2006) and Amunallah et al. (2009) who reported that climate variations influence the growth of the plants in their environments. The better growth analysis indices in respect of the Molelwane trial , as opposed to those in respect of the Taung trial are attributable to the favourable environmental conditions and edaphic factors. Thus, they are in concordance with the earlier results by Shah et al. (2008), who reported that maize requires locationally-specific conditions on account of its differential responses to nutrient inputs that vary widely within and across agro-ecological zones. Similarly, Yan et al. (2015) reported that the climatic factors and soil properties of a specific location have a significant effect on the crop growth rate. The higher growth analysis indices observed under lower plant density of 33, 333 plants/ha possibly relate to the less interplant competition for light and other growth factors, as well as to the mutual shading of the leaves (Yada 2011). This also agrees with previous finding by Amunallah et al. (2009) who reported that plant density alters the rate of growth and growth architecture.

Ma et al. (2007) and Ullah et al. (2010) revealed that rising plant density levels above a certain threshold and that vary across different locations are inclined to negatively influence the net assimilation rate of maize. Mahesh (2015) reported that relative growth varies depending on the availability of light. The substantial response of the growth analysis parameters to the highest application of nitrogen fertilizer of 240 kg N/ha indicates the presence of an adequate supply of nitrogen for photosynthetic activities. This agrees with previous findings by Hammed et al. (2011), who reported that high nitrogen application rates enhance photosynthetic efficiency. The observed negative values of the absolute growth rate suggest that the maize plant reaches a stage of growth where its stabilizes and in fact diminishes. This oocurs at the physiological stage from whence it follows a sigmoid curve. This is in line with the findings of Wardhani and Prawira (2013) who showed that absolute growth rates have a bell shape.

The interaction effect of planting season, location, plant density and the nitrogen fertilizer rate on the growth parameters were better during the 2015/16 season at Molelwane trial at a plant density of 33,333 plants/ha on plots fertilized with 120 kg N/ha in respect of the absolute growth rate and relative growth rate and crop growth rate, than in the cases where the plots were treated with 0 kg N/ha and 60 kg N/ha for leaf area duration and net assimilation rate. This could be attributed not only to possibly more favourable agrometeorological conditions, such as the temperature and rainfall during the 2015/16 planting season, but also to plant densityi and N rate since the accumulation of dry matter is the product of environmental conditions, the quantities of fertilizer applied and the plant density. Yada (2011) reported that intra-plant competition is stronger at low plant density.

The strong and significant relationship between nitrogen fertilizer rates and the chlorophyll content that were observed during the current study underscores the importance of this nutrient in maize production. This corroborrates the earlier findings by Umeri et al. (2016), who reported that the optimal growth of maize requires adequate quantities of nitrogen fertilizer throughout the growing period. Gozubenli and Kanuskan (2010) reported that the maize plant height decreases with increased plant density up to 120 000 plants/ha. The regression analysis result suggests that N fertilizer application predicted 89% of the chlorophyll content at physiological growth stage. The observed negative association between leaf area index (LAI) and the growth analysis indices during the tasseling stage indicates that there is an inverse relationship between the leaf analysis index and the other growth parameters, whereas the positive association between these variables at the physiological maturity stage suggests that the leasf area index increases as the growth analysis indices increase, thereby leading to an increase in the photosynthetic activities of the plant(Kgasago 2006). The predicted values of optimum N rates and plant density reveal that increasing plant density would of necessity require increased applications of nitrogen fertilizer rate, notwithstanding the parameters of interest.

The optimum N fertilizer rates for the planted WEMA variety range from 180 – 225 kg /ha, with an average of 202.5 kg N/ha. This is contrary to the findings of Kgonyane (2010) who reported that Limpopo farmers under dryland farming conditions need to apply 200kg N /ha at planting and top dressing with 100 kg of nitrogen/ha in the form of lime ammonium nitrate (LAN) . The estimated plant density in this case varied from 33,333 to 55,555 plants/ha. This indicates that the WEMA variety can be planted at plant density of 33,333 plants/ha or 55,555 plants/ha. This shows that WEMA is both drought- and high-plant-density-tolerant, as opposed in the latter case to the plant density of 14, 000 plants/ha usually in practice in the dry, warm western regions of South Africa (Mqadi 2005).

Conclusion

The results of this study show that the WEMA growth parameters and analysis grow better with the application of 120 kg N/ha. The plant density 44,444 plants/ha enhanced the growth parameters, while growth analysis was improved under 33,333 plants/ha. The measured growth parameters and growth analysis indices performed better at the Molelwane trial. The conditions prevailing in the planting season of 2016/17 influenced the growth parameters, whereas on the other hand the conditions prevailing in the 2015/16 planting season influenced growth analysis. Therefore, plant density 44,444 plants/ha and 120 kg N/ha were recommended for the cultivation of WEMA maize production in both locations of North West Province of South Africa.

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CHAPTER FOUR

INFLUENCE OF DIFFERENT N FERTILIZER RATES AND PLANT DENSITY ON ROOT SYSTEM ARCHITECTURE OF WATER EFFICIENT MAIZE GROWN UNDER DIFFERENT FIELD CONDITIONS

ABSTRACT

The root system architecture is a crucial component of drought tolerance in maize and has great influence on the efficient uptake of nitrogen fertilizer and grain yield. However, information on the influence of different N rates and plant density on the root system architecture of WEMA is scarce. A two year field experiment was carried out to investigate how root architectural system of WEMA under different plant densities and N fertilizer rates would affect growth and yield of the crop. The experiment was laid out in split-plot arrangement fitted into an RCBD and replicated four times. There were two locations (Taung and Mafikeng), five N rates (0, 60, 120, 180 and 240 kg N /ha) and three plant densities (33,333, 44, 444 and 55,555 plants ha^{-1}). Data were obtained on number of lateral roots, crown root and brace traits. Brace and crown root traits were used to evaluate the steepest, cheapest and deepest (SCD) ideotype of the root system architecture. ANOVA was used to analyze the data set and means separated with LSD ($p \leq 0.05$). Planting season x location x N fertilizer rates x plant densities had significant ($p \leq 0.05$) effect on the root system architecture of the crop. The deepest and steepest angle (84.25°) of the crown root was recorded at a plant under 44,444 plants/ha and fertilized with 240 which was statistically comparable with 180 kg N/ha in the two seasons. Similarly, highest number of lateral roots (8.00) was recorded during 2016/17 at Molewane under 55,555 plants/ha in plots treated with 180 kg N/ha. It was concluded that WEMA has SCD ideotype root architecture under 44,444 plants/ha when fertilized with 180 kg N/ha in North West Province of South Africa.

Keywords: Brace root, crown root, plant density, N fertilizer rates

4.0. Introduction

The role of the root system in the plants’ acquisition of resources from the soil cannot be overemphasized. Globally, resources such as soil nutrients and water are generally limited but by improving the plant root system architecture , it is possible to attain greater proficiency in the use of water and nutrients in areas where they are of limited availability (Pound et al., 2013). Root system development has a significant influence on the economics of commercial maize production as it impacts on yields, especially under drought conditions and where the efficiency of nitrogen fertilizer uptake is an issue (Hauck et al., 2015).

The rate at which shoot system can produce photosynthates depends on the size and activity of the root (Mudgil et al., 2016). The root system architecture is an important component of the maize plant in that it allows the plant to tolerate drought (Carena and Sharma 2016). It refers to the spatial distribution of all the root components in a particular growth environment (Paez-Gercia et al., 2015; Raggiero et al., 2017) and is largely influenced by environmental conditions that control the ways in which a plant exposes itself to and responds to its surroundings (Raggiero et al., 2017). It is the most important component that determines the subterranean acquisition of resources by plants. Furthermore, it is aslso an influence in plant interactions and nutrient cycling in agriculture (Zhang 2014; York and Lynch, 2015). The specific root system variables that affect maize growth are the crown root angle, the number of crown root, and the depth and lateral branching of the root (Li 2011; York et al., 2015).

The root system of the maize plant is made of an embryonic root system, including the primary root, or the radicle, the seminal roots, and a post-embryonic root system, that is mainly shoot-borne (i.e. nodal roots). Brace roots are nodal roots formed at the nodes above the ground while those nodal roots that areunderground are called crown roots (Mi et al., 2016). The brace roots are vital in the uptake of nutrients and water because approximately 75% of the xylem (woody tissue) acts as a conduit between the root system and the stem in the brace roots (Trachsel et al., 2013).The development of a support structure in the form of brace roots results in a reduction in moisture, which causes heat stress, especially in a drought–prone environment. The brace roots reach their maximum length around the silking or early grain-filling stage, and then regress (Nu, 2006). The number of brace and crown roots will determine the overall intensity of soil exploration and will influence the carbon that accumulates (York et al., 2015).

The root system architecture can be either shallow ,deeper or-steep (Mi et al., 20016). York et al. (2015) describe root ideotypes in terms of step, deep, and cheap (SDC). This classification consists of an integrated phenotype of architectural, anatomical and physiological phenes as the ideal maize root types for the acquisition of water and nitrogen from deep soil strata. The shallower root is beneficial for boosting the spatial availability of other nutrients, such as zinc, which are distributed in the top soil particularly, and have a diffusion coefficient (Tan et al., 2009, Mi et al., 2016). Deeper roots help to exploit the downward-moving nitrate in the field throughout the entire growth period (Tracshel, 2013). Moreover, the deeper roots are able to take up minerals that occur predominantly in the subsoil (e.g. potassium (K),sulphur (S), calcium (Ca), iron (Fe), and manganese (Mn). On the other hand, the fewer and deeper crown roots are the basic target factors for the efficient acquisition of nitrogen, as in the case of cereal crops (Tracshel, 2013).

The brace roots are the main determinant of the depth that the shallow roots of the maize plant can attain in the cultivation of maize (Mi et al., 2016). Maize roots with fewer crown roots increase the quantity of nitrogen that is captured, the shoot mass and the yield in soils with limited quantities of nitrogen (Lynch, 2013). The number of crown root stimulates the uptake and distribution of water and nutrients in the maize plant, while the crown root angle is an important aspect of the root architecture in that it functions principally as a topsoil forager (York et al., 2015). The lateral root is a feature of the central root system that aids in the process of acquiring nitrogen (Postman et al., 2014). Hence, an ideal root system architecture should adapt to high plant density since there is a greater spread of brace root to reach the more open spaces between the rows (inter-row spacing) (Lynch, 2013). A high density root system architecture influences the total number of brace roots, the number of crown roots, as well as the brace and crown angles.

Jiang et al.(2013) reported that the nitrogen fertilization rate increases both the number and length of the crown roots, while Sen et al. (2012) found that root branching improves with high applications of nitrogen. Water-efficient maize is a relatively new drought-tolerant maize variety that is featuring on many South Africa farms. However, the agronomic information required for its propagation and sustainable production is currently scanty, while knowledge of its root system architectur which influences its growth under varying agronomic practices and environmental conditions, remains virtually unknown.

It is hypothesized that the various WEMA root phenes will exhibit plastic responses to variable N rates and plant density. Therefore, this study evaluated the response of drought tolerant

WEMA maize variety root system architecture to different plant density and N rates under two field growth conditions in North West Province.

4. 2. Materials and Methods

4.2.1 Description of study area

The experiment was carried out at the Molelwane North-West University (NWU) Research Farm (25^0 48^1S, 45^0 38^1 E.; 1,012 m asl) and Taung Experimental Station (27 30^1S, 24 30^1E; 1,111 m asl)of the Provincial Department of Agriculture Research Station during 2015/2016 and 2016/2017 planting seasons respectively. Both sites are located in the North West Province of South Africa.

The NWU Research Farm is located in a semi-arid tropical savanna region that receives a mean annual summer rainfall of 571 mm while the Taung trial site receives a mean annual rainfall of 318 mm (Kasirivu et al., 2011: Saexplorer 2019). The Taung Experimental Station had average maximum temperature of 35 °C and the mean minimum temperature ranged between 5°C–18.5°C. The annual average pan evaporation of North-West is 1023 mm (Kasirivu et al., 2011). Approximately 68% of the annual precipitation at the NWU farm falls between November and January in a few relatively heavy downpours, with a pronounced dry season from April to September.

4.2.2 Soil sampling and analysis

The experimental soils were Ferric Luvisol and Rhodic Ferrasol. The chemical properties of Ferric Luvisol are pH (4.31), total nitrogen N (0.08%), available phosphorus P (6 mg/kg) and Potassium P (279 mg/kg) at 0-15 cm soil depth while 0-30 cm contained soil pH (4.18), total nitrogen N (0.02%) available phosphorus P (10 mg/kg) and potassium K (322 mg/kg). The data concerning soil content, as described above, refer to the 2015/16 planting season.

During the 2016/2017 planting season, the Ferric Luvisols contained the following chemical properties, namely soil pH (4.50 and 4.30), total nitrogen (N) (0.17 and 0.18%), available phosphorus (P) (81 and 11 mg/kg) and potassium (K) (203 and 180 mg/kg) at each of the soil depths respectively.

On the other hand, the Rhodic Ferralsol has the following chemical properties, namely Soil pH (6.45), total nitrogen (0.012%), available phosphorus P (5mg/kg), potassium (K) (366 mg/kg) at soil depths of 0 to 15cm. At a greater soil depth, namely at 0 to 30 cm soil depth has these following chemical properties pH (4.50), total nitrogen N (0.1%), available phosphorus P (3 mg/kg) and Potassium P (304 mg/kg) during the 2015/16 planting season.

Similarly during the 2016/17 planting season, the Rhodic Ferralsol has the following chemical properties, namely pH (4.30 and 5), total nitrogen N (0.19 and 0.15%), available phosphorus P (49 and 8 mg/kg) and potassium P (49 and 185 mg/kg) at the 0 to 15 and 0 to 30 cm soil depths respectively.

The soil textural analysis for the Ferric Luvisol was sand (82%), silt (1%) and clay (18%), while the Rhodic Ferralsol was sand (85%), silt (1%) and clay (14%).

These chemical and physical properties of the soils were analyzed following the standard procedures described by the South African Soil Science Guidelines (1990).

4.2.3 Weather conditions during experimental period

The planting of the trial took place between December 2015 and May 2016 at the Molelwane NWU farm site, while it was carried out between December 2015 and July 2016 at the Taung Experimental Station. Similarly, in 2016/17 the planting of the trial took place between December 2016 and May 2017 at the Molelwane NWU farm site and. The sowing was also carried out from December 2016 to June 2017 at Taung Experimental Station.

The summary of climatic condition at the sites during those planting seasons as obtained from South Weather Service (Johannesburg) was presented in Table 1. Owing to the much lower rainfall experienced during the 2015/16 planting season at both trial sites, supplementary irrigation water was used from the planting stage through to the early vegetative stage to ensure good crop establishment. This was not the case during the 2016/17 planting season. On account of the rain, which fell throughout the growing period, and which proved to be adequate, no supplementary irrigation was required. However, due to facility constraint the total amount of supplementary irrigation applied was not quantified.

Table 4.1: The meteorological data of experimental locations

Climate data	Molewane	Taung
2015/16 summer planting season		
Temperature (°C)		
Minimum	15.24	13.77
Maximum	27.00	31.32
Mean daily	22.17	22.47
Total Rainfall (mm)	257.40	231.20
Relative humidity (%)		
Minimum	13.77	22.57
Maximum	74.86	74.00
Mean	50.29	48.86
2016/17 summer planting season		
Temperature (°C)		
Minimum	13.16	11.57
Maximum	27.23	29.09
Mean daily	20.16	20.42
Total Rainfall (mm)	646.40	598.80
Relative humidity (%)		
Minimum	34.14	24.29
Maximum	86.43	82.89
Mean	61.86	54.14

Source: South African Weather Service (2018)

4.2.4 Experimental Design and Treatments

The experiment was laid out in split plot arrangement fitted into a RCBD and replicated four times. There were two locations (Taung and Mafikeng), five N rates (0, 60, 120, 180 and 240 kg N/ ha) and three plant densities (33,333, 44,444 and 55,555 plants/ ha). Each subplot measured 6 m x 4 m with a total experimental plot size of 30 m x 76 m (0.228 ha) at each site. Maize (WE 3127) seed sowing was done at inter and intra row spacing of 1m x 0.3m, 0.75 m x 0.3m and 0.9 m x 0.2 m to achieve the density of 33,333, 44,4444, and 55,555, respectively.

4.2.5 Cultural Practices

Basal fertilizer application of a third of the each rate using NPK 20:7:3 was done at sowing while two-third and a third of the remaining amount from each rate was applied as top dressing at 3 and 5 weeks after seedling emergence (WAE) using lime ammonium nitrate (LAN, 28%).Manual weeding done at 3 and 7 weeks after seed sowing to maintain a weed-free condition.

4.2.6. Data collection

Root system architecture was assessed at tasseling and physiological maturity stages using two uprooted plants from the based at 30 cm in each plot (treatment). A manually designed shovelomic score board was used to score the root architecture as described by Traschel et al., (2011). Root system architectural traits assessed include brace root, crown root and lateral root with focus on the number, branching angle and depth. Root depths were classified as shallow or deep/steep as0-5 cm dept (shallow) and 5-10 cm depth (deep/steep) as described by Traschel et al., (2011). Classification of brace and crown angle was as10-50° (shallow) and 50-90° (deep and steep)while assessment of root number was by counting using the standard procedure described by Traschel et al., (2011).

4.2.7. Statistical Analysis

All data obtained were analyzed as analysis of variance (ANOVA) using the GenStat 11th edition, while the differences between the mean values of the treatmentsmeans were tested using the Least Significant Difference (LSD) test at 5% level of probability. Grain yield of WEMA maize was obtained as described by (CIMMYT, 2013; Abebe and Feyisa, 2017). Regression was used to estimate relationship between grain yield and root system architectural traits interaction .$y = b + b_{1x1} + b_{2x2} + \xi$,Y = maize grain yield, b_0 = intercept

b_1 = co-efficient of nitrogen rate, b_2 = co-efficient of plant densities, x_1 = N fertilizer rates, x_2 = plant densities, ξ = constant.

4.3. Results

4.3.1. Effect of treatment factors on brace root angle (°)

Brace root angle of the maize plants differed significantly ($p<0.05$) across planting seasons with significant higher deeper and steeper brace root angle value (60.68°) during 2016/17 compared (30.25°) in 2015/16 at tasseling stage while statistically higher brace root angle (65.48°) was similarly recorded during the 2016/17 planting season at the physiological maturity stage (Figure 4.1). The brace root angle differed significantly ($p<0.05$) across the two trial locations. Significantly shallower brace root angles (45.67° and 47.83°) were obtained from the Taung trial than for the maize plants grown in Molewane (Figure 4.2). Plant density had significant effect ($p<0.05$) on the brace root angle. The plant density of 55,555 plants/ha had significant shallowest (46.17°) brace root angle at tasseling stage while the shallowest (47.36°) brace root angle was similarly obtained under 55,555 plants/ha at physiological maturity phase but there was no significant effect (Figure 4.3). The different N fertilizer rates exerted significant ($p<0.05$) effect on brace root angle with the shallowest angle (47.63°) recorded in plots fertilized with 120 kg N/ha at the tasseling stage while plots supplied with 60 kg N/ha had shallowest brace root angle of 48.69° at the physiological maturity stage (Figure 4.4).

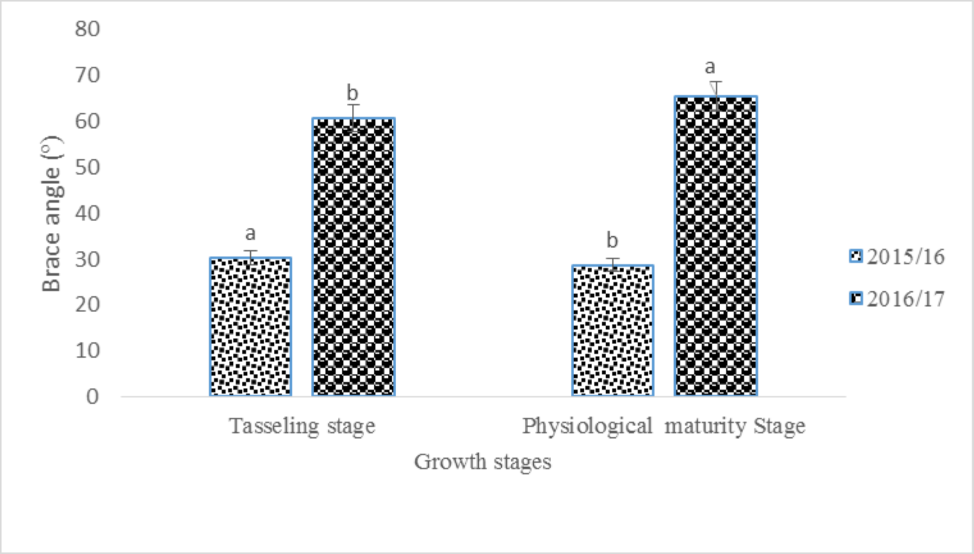

Figure 4.1: Effect of planting season on brace root angle

Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD)

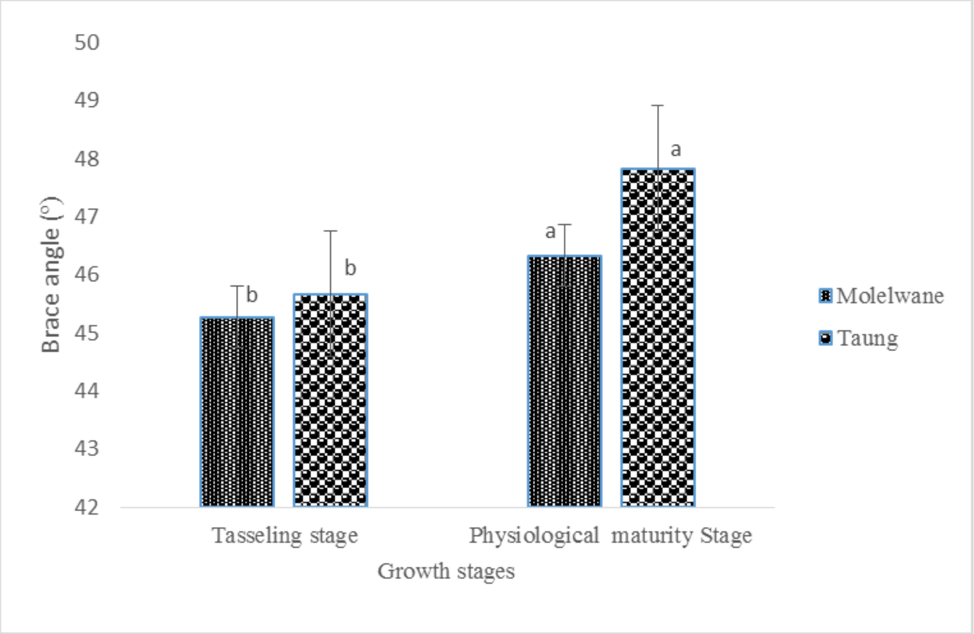

Figure 4.2: Effect of variation in trial location on brace root angle

M**e**ans with the same letter(s) did not differ significantly at p≤ 0.05 according to Least significant difference (LSD)

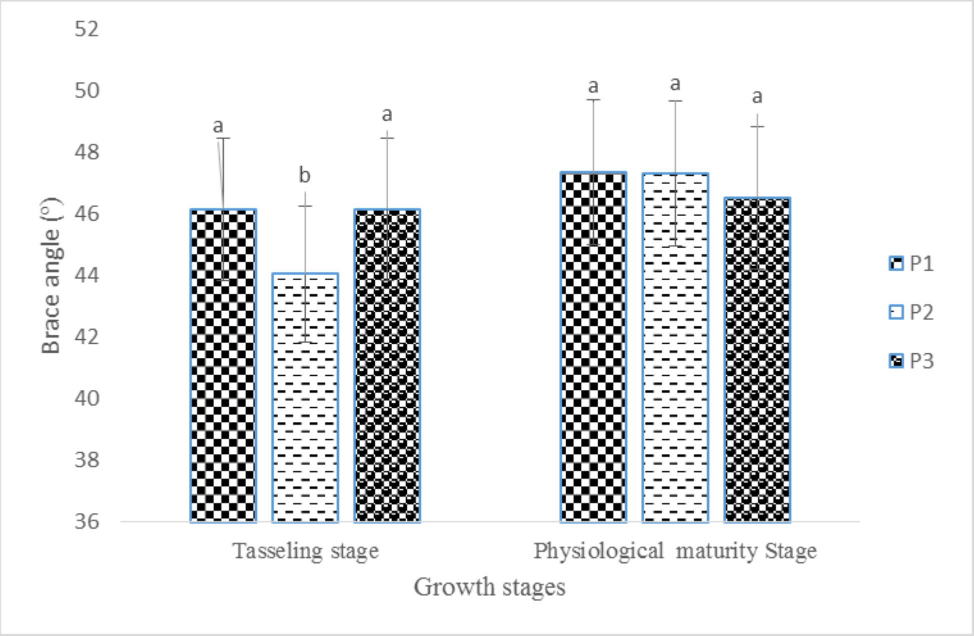

Figure 4.3: Effect of plant density on brace root angle

Means with the same letter(s) are not significantly different at p≤0.05 according to Least significant difference (LSD); P1, P2 & P3 = 33,333, 44,444 and 55555 plants/ha, respectively

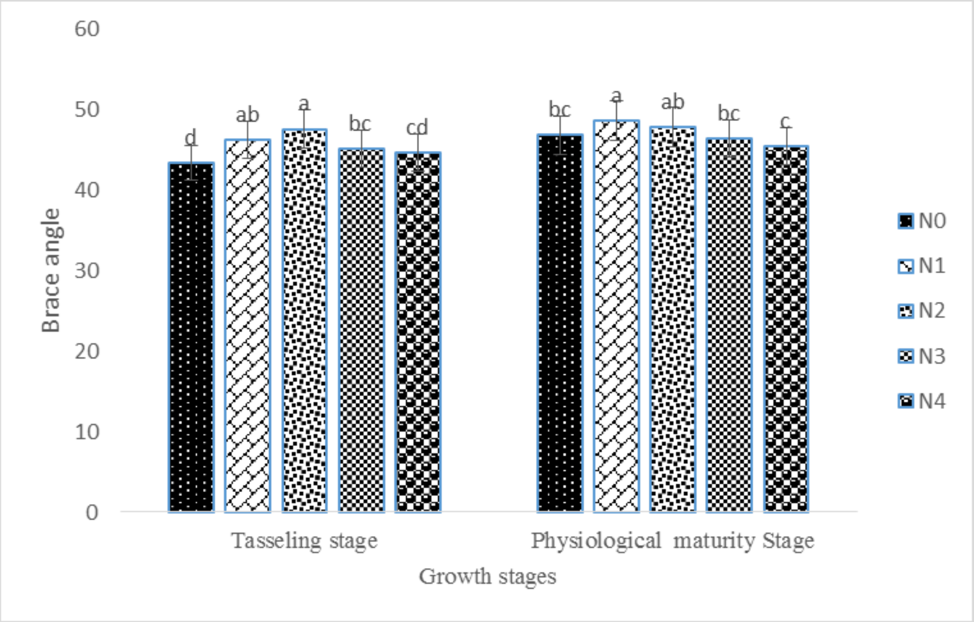

Figure 4.4: Effect of varying N fertilizer rates (kg/ha) on brace root angle

Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD); N0, N1, N2, N3 & N4 = 0, 60, 120, 180 and 240 kg N/ha, respectively).

4.3.2. Interaction effect of treatment factors on brace root angle

The brace root angle was significantly ($p<0.05$) affected by the interactions among planting season x location x plant density x N fertilizer rates (Table 4.2). The highest deep and steep brace root angle (68.75°) during the 2016/17 from Taung trial under 33,333 plants/ha was obtained when WEMA plant received 120 kg N/ha at tasseling stage. However at the physiological maturity stage, the highest deep and steep brace root angle (73.75°) was obtained during 2016/17 also at Taung under 33,333 plants/ha but in the unfertilized plots although statistically same with value under 55,555 plants/ha fertilized at 180 kg N/ha.

Table 4.2: Interaction effect of planting season x location x plant density x nitrogenfertilizer x season on brace root angle (º) at tasseling and physiological maturity stage

Location	N fertilizer (kg/ha)	Plant density	Brace root angle (º)			
			Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	37.50	25.00	55.25	62.50
		44,444	20.00	32.50	56.50	59.75
		55,555	30.00	25.00	51.25	62.25
	60	33,333	35.00	37.50	60.25	63.75
		44,444	25.00	32.50	57.25	68.00
		55,555	27.00	30.00	61.50	63.75
	120	33,333	40.00	27.50	60.75	64.75
		44,444	40.00	32.50	63.71	57.25
		55,555	37.50	32.50	59.25	62.50
	180	33,333	32.50	27.50	60.75	56.50
		44,444	37.50	30.00	58.75	60.75
		55,555	27.00	27.50	56.75	66.00
	240	33,333	31.25	25.00	60.00	64.50
		44,444	25.00	32.50	61.00	61.00
		55,555	40.00	40.00	58.75	59.00
Taung	0	33,333	20.00	35.00	66.75	67.75
		44,444	28.75	30.00	61.50	66.50
		55,555	25.00	22.50	66.50	73.75
	60	33,333	30.00	22.50	62.50	70.00
		44,444	32.50	37.50	60.75	62.25
		55,555	32.50	25.00	66.00	71.50
		33,333	37.50	30.00	68.75	72.50

120	44,444	22.50	32.50	61.00	69.25
	55,555	35.00	25.00	60.50	68.50
180	33,333	35.00	32.50	57.00	73.75
	44,444	32.50	25.00	62.00	68.00
	55,555	25.00	22.50	56.50	67.25
240	33,333	20.00	25.00	62.59	63.75
	44,444	25.00	20.00	61.75	68.75
	55,555	30.00	17.50	62.00	68.75
LSD $_{(0.05)}$		2.43	2.83	2.43	2.83

4.3.3 Effect of treatment factors on the number of brace root

The number of brace root per plant varied significantly ($p<0.05$) across planting seasons, trial locations and N fertilizer rates (Table 4.3). The highest number (16.35) brace root per plant was recorded during the 2016/2017 planting season at the tasseling stage, while at the physiological maturity stage, the largest number (17.47) brace roots per plant was noted during the 2015/2016 planting season. The number of brace roots per plant at the Taung station trial at both the tasseling (16.35) and the physiological maturity (17.41) stages was significantly higher than the values for those same variables at the Molewane trial. The number of brace roots formed by WEMA plants was significantly ($p<0.05$) affected by plant density with the highest number (15.94) at tasseling obtained under 33,333 plants/ha whereas at the physiological maturity stage, the highest number (17.41) was under 44,444 plants/ha. The highest number of brace root (16.21) and (17.48) were recorded in plots fertilized with 120 kg N/ha at the tasseling and physiological maturity stages respectively.

4.3.4 Interaction effect of treatment factors on number of brace root

Th interaction effect of planting season x location x plant density x N rates interaction exerts significant ($p<0.05$) in respect of the number of brace roots (Table 4.4). At the tasseling stage, the highest number of brace root (20.00) was recorded during the 2015/16 planting season at the Taung trial under 33,333 plants/ha in plots fertilized with 120 kg N/ha. However, at the physiological maturity stage, the highest number of brace root (23.00) was similarly obtained in 2015/16 from Taung trial but under 55,555plants/ha with application of 180 kg N/ha.

Table 4.3: Effect of treatment factors on number of brace root at tasseling and physiological maturity stages

Treatment factors	Tasseling stage	Physiological maturity stage
Planting season		
2015/2016	15.70b	17.47a
2016/2017	16.35a	16.49b
$LSD_{(0.05)}$	0.23	0.16
Location		
Molelwane	15.17b	16.55b
Taung	16.35a	17.41a
$LSD_{(0.05)}$	0.23	0.16
Plant density (plants/ha)		
33333	15.94a	16.43c
44444	15.86a	17.39a
55555	8.00b	17.13b
$LSD_{(0.05)}$	0.29	0.20
Nitrogen rates (kg/ha)		
0	15.83b	16.33c
60	15.42c	16.71bc
120	16.21a	17.48a
180	15.52bc	16.94b
240	15.81b	16.94b
$LSD_{(0.05)}$	0.37	0.25

Mmeans with same letter(s) in the same column are not significantly different at p≤ 0.05 according to Duncan multiple range test.

Table 4.4: Planting density x location x plant density x N fertilizer rates interaction effect Gon number of brace root at tasseling and physiological maturity stages

Location	N fertilizer (kg/ha)	Plant density	Brace root number			
			Tasseling	**Maturity**	**Tasseling**	**Maturity**
			2015/16		**2016/17**	
Molelwane	0	33,333	13.75	16.25	16.00	18.00
		44,444	15.00	16.75	18.50	13.50
		55,555	13.25	13.75	15.50	18.00
	60	33,333	12.50	15.75	15.00	18.00
		44,444	16.00	15.50	15.50	18.25
		55,555	12.75	16.50	14.00	17.00
	120	33,333	15.00	16.00	16.00	17.75
		44,444	15.00	17.25	16.75	15.75
		55,555	14.50	18.50	16.50	16.75
	180	33,333	14.25	17.50	18.00	18.50
		44,444	14.00	16.00	15.25	13.75

		55,555	13.75	18.00	14.25	14.00
		33,333	15.75	15.00	15.25	17.75
	240	44,444	12.25	16.25	16.25	18.75
		55,555	16.25	17.00	18.25	14.75
		33,333	16.25	17.50	16.50	15.00
	0	44,444	18.75	18.75	15.75	17.25
		55,555	16.25	19.50	14.50	17.75
		33,333	17.25	20.00	16.50	16.00
	60	44,444	16.50	14.00	14.75	14.50
		55,555	18.75	20.00	15.50	15.00
		33,333	20.25	20.00	16.75	18.00
Taung	120	44,444	16.25	15.50	17.25	18.50
		55,555	16.00	19.50	14.25	16.25
		33,333	16.75	16.25	14.75	14.75
	180	44,444	16.75	17.75	17.75	17.75
		55,555	16.75	23.00	14.00	16.00
		33,333	16.25	18.00	16.00	16.50
	240	44,444	14.25	17.75	14.75	15.00
		55,555	19.75	20.50	14.75	68.75
	LSD $_{(0.05)}$		1.28	1.70	1.28	1.70

4.3.5 Effect of planting season, location, plant density and nitrogen fertilizer on Brace branch depth

Planting season had significant ($p<0.05$) effect on brace root branch depth of the WEMA with generally higher values (13.42 cm) and (14.68 cm) respectively obtained during the 2016/17 planting season at the tasseling and physiological maturity stages compared to results obtained during 2015/16 planting season (Figure.4.5).The WEMA brace root branch depth was significantly ($p>0.05$) affected by location. The observed deeper brace root branch depths (10.62 cm) and (11.56 cm) at Taung during tasseling and physiological maturity stage respectively were comparable to those at Molewane (Figure 4.6).

Plant density showed significant ($p<0.05$) effect on brace root branch depth with 44,444 plants/ha resulting in significantly deepest brace root branch depth (10.94 cm) compared to other treatments at tasseling stage (Figure 4.7). Albeit, there was no significant effect on the depth of the brace root branch (11.44 cm) at the same plant density during the physiological maturity stage. The nitrogen fertilizer rates had no significant ($p>0.05$) effect on the depth of the brace root branches, with the deepest (10.83cm) recorded in unfertilized plots during the tasseling stage (Figure 4.8). However, at the physiological maturity stage, brace root branch depth of plot supplied with 60 kg N/ha had deepest brace root branch depth than other treatments.

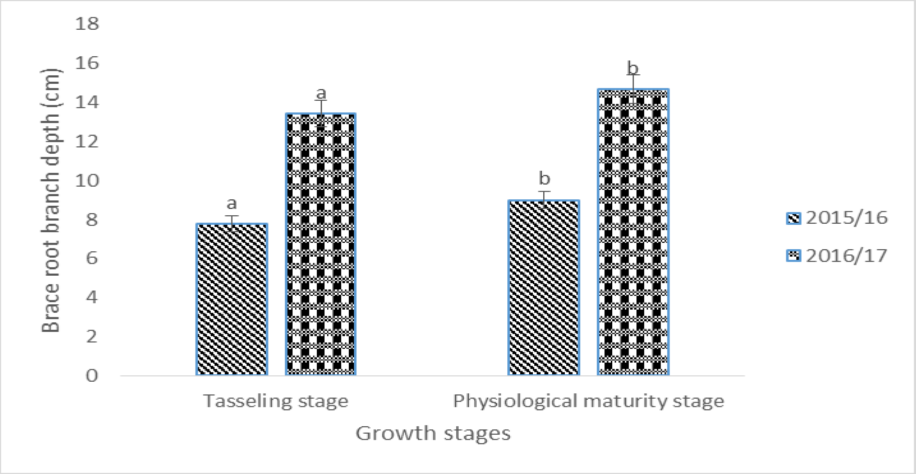

Figure 4.5: Effect of planting season on brace branch depth

Notes: Means with the same letter(s) are not significantly different at $p\leq 0.05$ according to Least significant difference (LSD).

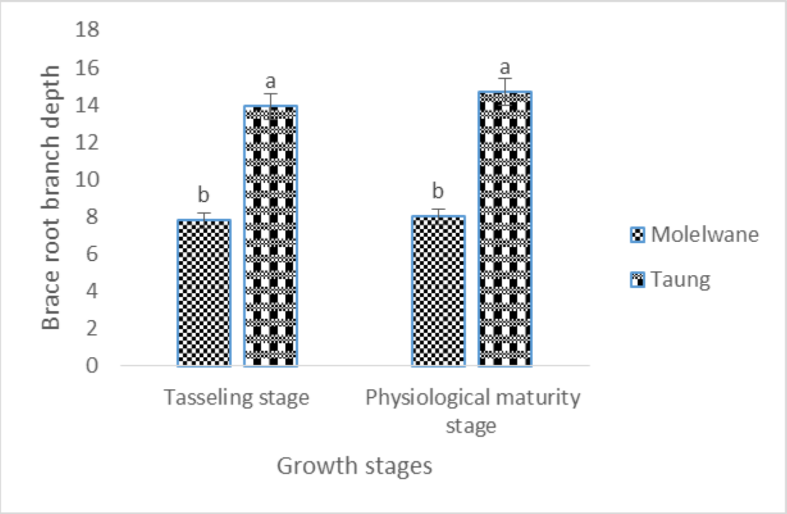

Figure 4.6: Effect of location on brace branch depth

Means with the same letter(s) are not significantly different at p≤0.05 according to Least significant difference (LSD).

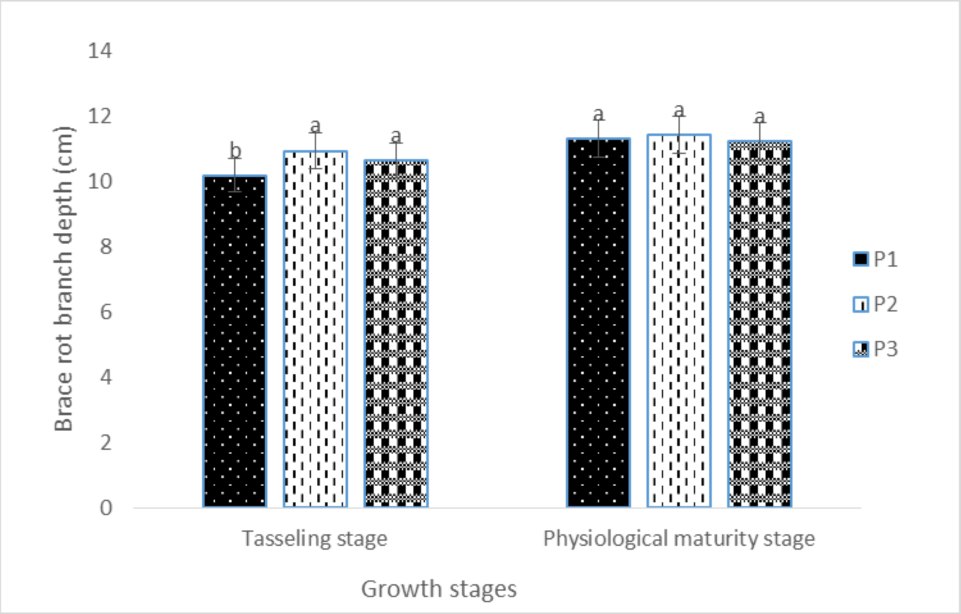

Figure 4.7: Effect of plant density on brace branch depth

Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD); P1 – 33,333 plants/ha, P2 – 44,444plants/ha and P3 – 55,555 plants/ha

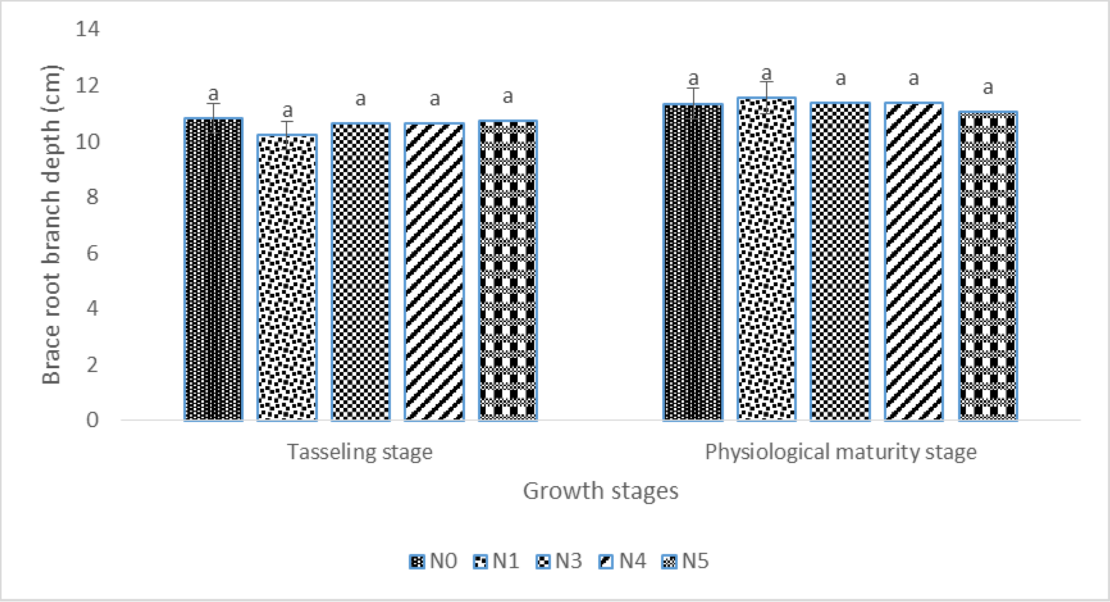

Figure 4.8: Effect of N fertilizer rates on brace branch depth

Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD).; N0– 0 kg N/ha, N1 – 60 kg N /ha, N2 – 120 kg N /ha, N3 – 180 kg N /ha and N4 – 240 kg N/ha

4.3.5: Treatment interaction effect on brace root branch depth

Significant (P<0.05) interaction was obtained among planting season x location x plant density x nitrogen fertilizer rates (Table 4.5). Likewise, brace root branch showed significant deepest depth which ranged from 11.25 cm – 15.00 cm during the 2016/17 planting season in Taung across all the plant densities and N fertilizer rates. On the other hand, the shallowest depth was recorded in unfertilized plots. However, the depth of the brace root branch was comparable to plots fertilized with 60, 120 and 180 kg N/ha under 44,444, 33,333 and 55,555 plants/ha respectively.

Table 4.5: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on brace root branch depth (cm) at tasseling and physiological maturity growth stages

Location	N rates (kg/ha)	Plant Density	Brace root branch depth (cm)			
			Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	7.50	7.50	13.75	15.00
		44,444	8.75	8.75	12.50	13.75
		55,555	7.50	10.00	12.50	15.00
	60	33,333	7.50	8.75	11.25	13.75
		44,444	8.75	10.00	11.25	15.00
		55,555	8.75	8.75	13.75	15.00
	120	33,333	7.50	8.75	11.25	15.00
		44,444	8.75	10.00	13.75	15.00
		55,555	6.25	10.00	13.75	12.50
	180	33,333	8.75	8.75	13.75	15.00
		44,444	10.00	10.00	12.50	12.50
		55,555	7.50	8.75	13.75	15.00
	240	33,333	6.25	8.75	13.75	15.00
		44,444	8.75	8.75	13.75	13.75
		55,555	10.00	7.50	13.75	15.00
Taung	0	33,333	6.25	7.50	15.00	15.00
		44,444	8.75	6.25	15.00	15.00
		55,555	7.50	7.50	15.00	15.00
	60	33,333	6.25	8.75	12.50	15.00
		44,444	10.00	7.50	11.25	13.75
		55,555	6.25	7.50	15.00	15.00
	120	33,333	8.75	6.25	13.75	15.00
		44,444	7.50	6.25	15.00	15.00
		55,555	7.50	7.50	13.75	15.00
	180	33,333	6.25	7.50	13.75	15.00
		44,444	6.25	7.50	13.75	15.00
		55,555	6.25	7.50	15.00	15.00
	240	33,333	7.50	5.00	13.75	15.00
		44,444	8.75	7.50	13.75	15.00
		55,555	7.50	6.25	12.50	15.00
	LSD $_{(0.05)}$		2.64	3.24	2.64	3.24

4.3.4: Effect of main treatment factors on crown root angle

The crown root angle of WEMA was significantly ($p<0.05$) affected by the planting season and variations in terms of the experimental locations (Table 4.6). The crown root angles (73. 63° and 79.15°) at the tasseling and physiological maturity stages respectively during the 2016/17 planting season were significantly deeper and steeper than those in the 2015/16 season. Significantly deeper and steeper crown root anglewas observed in the Molewane trial plants during the tasseling (61.72°) and physiological maturity (63.21°) stages than in the plants at the Taung station.

Plant density had no significant effect ($p>0.05$) on crown root angle, while the variable N fertilizer rates had significant effect ($p<0.05$) on WEMA crown root angle but only during the tasseling stage (Table 4.7). The deepest and steepest crown root angle (60.66°) was obtained at the tasseling stage under 55,555 plants/ha. However, the deepest and steepest crown root angle (60.98°), at the physiological maturity stage, was under 33,333 plants/ha compared to other plant densities. On the other hand, the deepest and steepest crown root angle (60.06°) was recorded in plants from plots supplied with 180 kg N/ha at the tasseling stage.

4.3.5. Treatment interaction effect on crown root angle

The crown root angle was significantly ($p<0.05$) affected by the interaction of planting season x location x plant density x N fertilizer rates (Table 4.7). The deepest and steepest crown root angle (84.25°) was attained during the 2016/17 planting season in both locations at a plant density of 44 444 plants/ha when 240 kg N/ha was applied. Also, in the unfertilized plots at Taung, the least crown angle was recorded in those plots fertilized with 0 kg N/ha but not significantly different from 60 kg N/ha plots at Molelwane under 33,333 plants/ha (Table 4.7).

Table 4.6 Effect of treatment factors on crown root angle (º)

Treatment factors	Tasseling Stage	Physiological maturity stage
Planting season		
2015/2016	45.00b	42.50b
2016/2017	73.63a	79.15a
LSD $_{(0.05)}$	1.13	1.27
Location		
Molelwane trial	61.72a	63.21a
Taung trial	56.93b	58.44b
LSD $_{(0.05)}$	1.13	1.27
Plant density Plants/ha		
33333	59.51a	60.98a
44444	59.42a	60.69a
55555	59.02a	60.81a
LSD $_{(0.05)}$	1.38	1.55
Nitrogen rates kg/ha		
0	60.02a	61.60a
60	59.37a	61.56a
120	59.73a	60.90a
180	60.06a	59.33b
240	57.42b	60.69a
LSD $_{(0.05)}$	1.78	2.00

Notes: Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Duncan multiple range test

Table 4.7: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on crown root angle (°) at tasseling and physiological maturity

Location	N fertilizer (kg/ha)	Plant density	Crown root angle(°)			
			Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	52.50	50.00	69.50	79.75
		44,444	55.00	50.00	73.25	82.26
		55,555	57.50	47.50	74.25	78.25
	60	33,333	47.50	50.00	75.00	79.75
		44,444	41.25	50.00	72.50	77.25
		55,555	55.00	55.00	72.76	79.00
	120	33,333	55.00	52.50	69.50	81.25
		44,444	45.00	45.00	76.00	79.25
		55,555	52.50	50.00	71.50	70.25
	180	33,333	50.00	40.00	73.75	82.25
		44,444	52.50	45.00	74.25	74.50
		55,555	45.00	50.00	74.00	61.75
	240	33,333	45.00	45.00	80.25	80.25
		44,444	50.00	50.00	81.25	81.25
		55,555	52.50	52.50	77.00	77.00
Taung	0	33,333	37.50	50.00	78.75	79.00
		44,444	37.50	40.00	81.25	81.25
		55,555	30.00	47.50	73.25	78.75
	60	33,333	35.00	50.00	79.25	79.00
		44,444	41.25	55.00	72.26	79.50
		55,555	45.00	52.50	75.76	81.25
	120	33,333	47.50	45.00	71.00	80.50
		44,444	40.00	50.00	74.00	81.25
		55,555	42.50	40.00	72.25	84.00
	180	33,333	42.50	45.00	73.75	81.25
		44,444	52.50	50.00	72.50	84.25
		55,555	35.00	45.00	75.00	79.00
	240	33,333	45.00	45.00	79.75	79.75
		44,444	50.00	50.00	81.25	81.25
		55,555	52.60	52.60	79.00	79.00
	LSD $_{(0.05)}$		3.12	6.94	3.12	6.94

4.3.6: Effect of treatment factors on number of crown root

The number of crown root formed was significantly ($p<0.05$) affected by the planting season and the trial location (Figure 4.9 and 4.10). A significantly larger number of crown roots (26.57) was recorded during the 2016/17 planting season than during the 2015/16 season (Figure 4.9), while the number of crown roots(23.57) observed on the plants from the Taung field was larger than those recorded at the Molelwane trial site during the tasseling stage (Figure 4.10).

Similarly, the number of crown root was significantly ($p<0.05$) affected by plant density of 55, 555 plants/ha, with plots producing the highest (19.11) number of crown roots. which was statistically similar to the number recorded on plots at a plant density of 33, 333 plants/ha at the tasseling stage (Figure 4.11). However, the largest number of crown root (14.77) was recorded at physiological maturity phase under 33,333 plants/ha compared to other plant densities.

The nitrogen fertilizer rates had no significant effect ($p<0.05$) on the number of crown root at the tasseling stage. At this stage, the number of crown root produced was significantly influenced by N rates at the physiological maturity stage, with significant highest number (22.10) when fertilized with 60 kg N/ha (Figure 4.12).

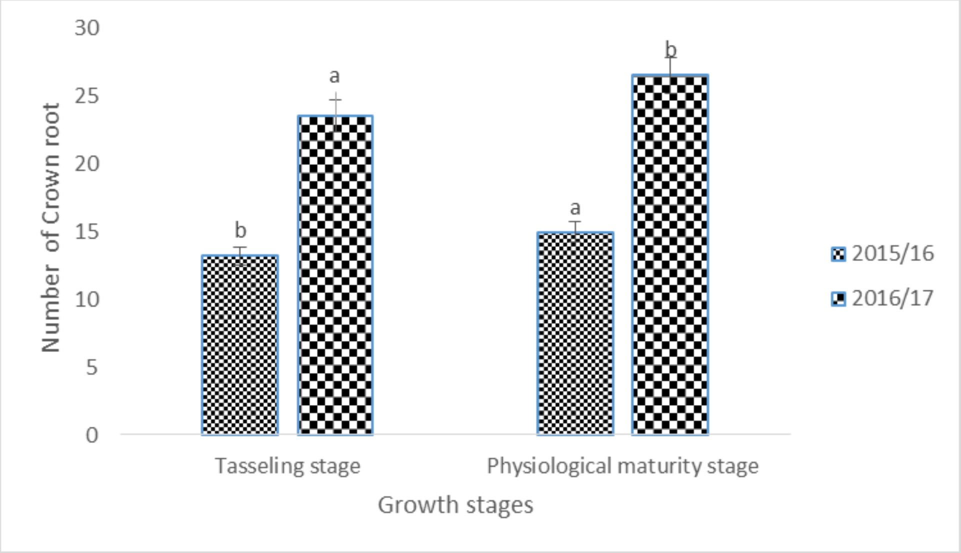

Figure 4.9: Effect of planting season on number of crown root

Notes: Means with the same letter(s) are not significantly different at $p\leq 0.05$ according to Least significant difference (LSD).

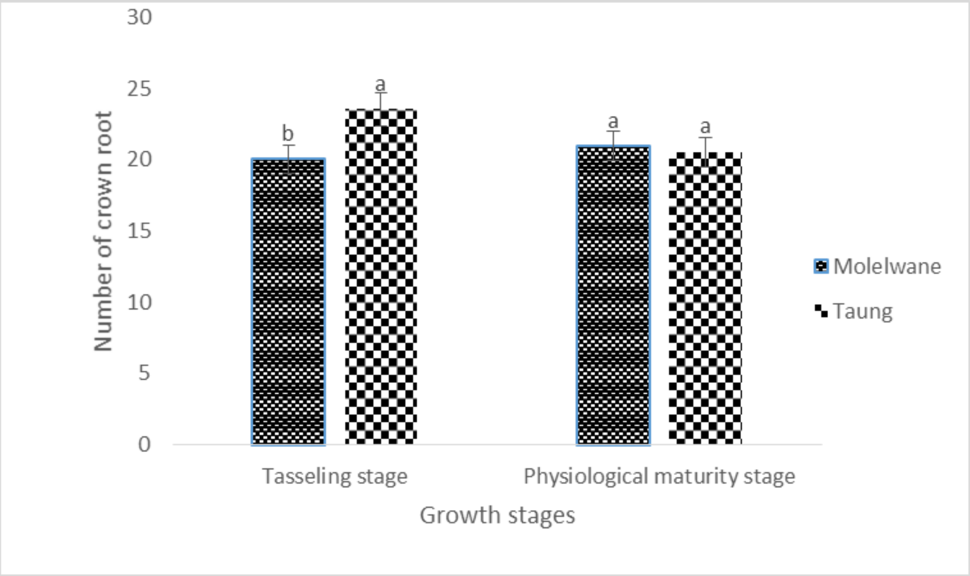

Figure 4.10: Effect of location on number of crown root

Notes: Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD).

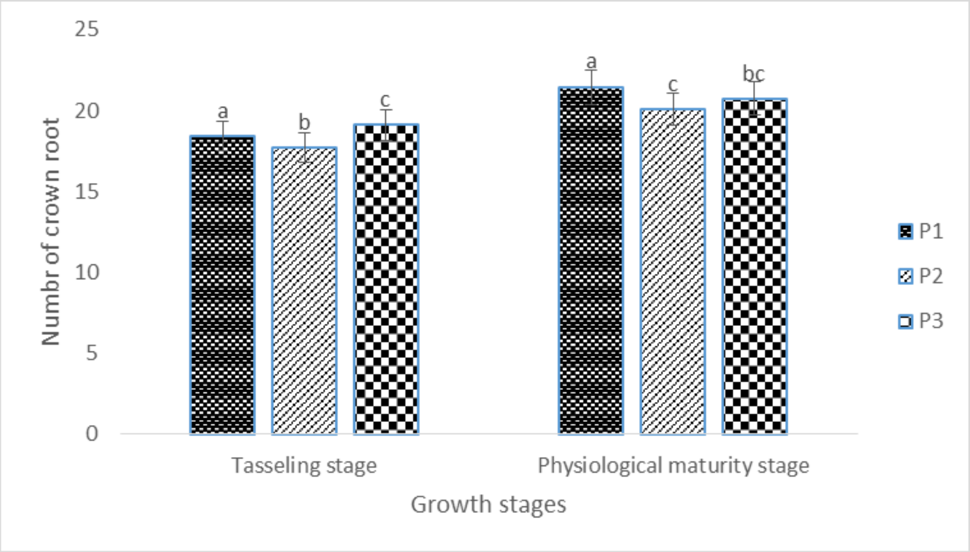

Figure 4.11: Effect of plant density on number of crown roots

Notes: Means with the same letter(s) are not significantly different at p≤ 0.05 according to Duncan's multiple range test; P1 – 33,333 plants/ha, P2 – 44,444plants/ha and P3 – 55,555 plants/ha

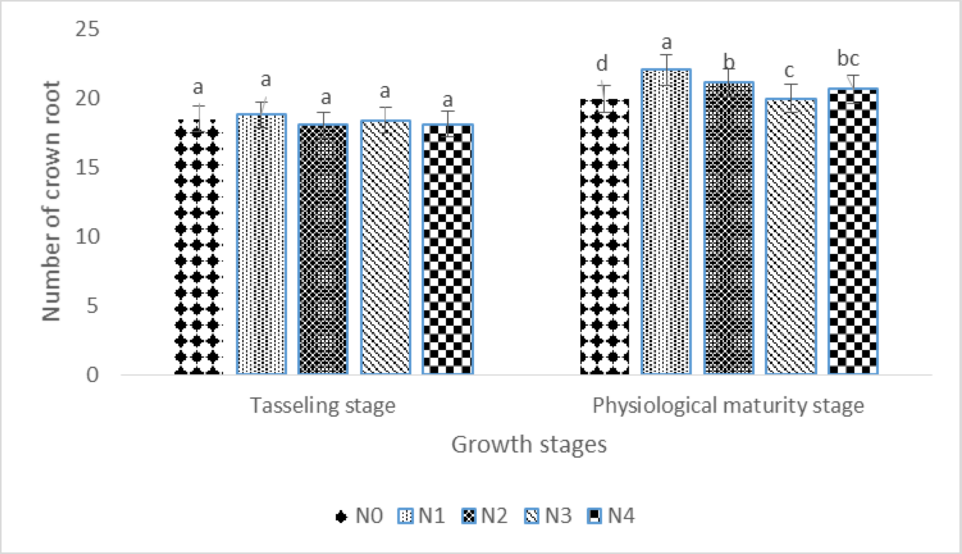

Figure 4.12: Effect of N fertilizer rates on crown root number

Notes: Means with the same letter(s) are not significantly different at p≤ 0.05 according to Least significant difference (LSD). N0 – 0 kg N/ha, N1 – 60 kg N/ha, N2 – 120 kg N/ha, N3 – 180 kg N/ha and N4 –240 kg N

4.3.7: Treatment interaction effect on number of crown root

The interaction among planting season x location x plant density x N fertilizer rates significantly (p<0.05) affected number of crown root (Table 4.8). At the tasseling stage, the number of crown roots was highest (38.25) significantly during the 2016/17 planting season at Molelwane on plots at a density of 44 444 plants/ha treated with 180 kg N/ha (Table 5.9). However, at the physiological maturity stage, the number of crown root was significantly highest (36.00) in plots that had 33,333 plant/ha and fertilized with 60 kg N/ha.

Table 4.8: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on crown root number at tasseling and physiological stages

Location	N fertilizer (kg/ha)	Plant density	Crown root number			
			Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	12.25	14.25	26.25	27.26
		44,444	12.75	13.25	26.25	26.50
		55,555	11.50	13.50	33.25	26.25
	60	33,333	11.75	15.25	22.25	36.00
		44,444	12.00	15.75	22.50	31.00
		55,555	12.25	12.00	36.00	26.25
	120	33,333	13.25	13.75	28.00	26.75
		44,444	14.25	15.75	28.75	32.00
		55,555	12.50	13.25	24.25	16.25
	180	33,333	13.25	16.25	24.50	28.75
		44,444	12.25	12.25	38.25	32.25
		55,555	11.00	15.50	24.50	19.75
	240	33,333	11.75	13.50	24.75	33.50
		44,444	12.25	12.75	25.75	25.25
		55,555	13.00	13.25	26.25	30.76
Taung	0	33,333	14.75	13.50	24.75	24.50
		44,444	13.75	14.50	24.75	29.25
		55,555	15.75	14.00	18.00	23.00
	60	33,333	13.75	20.75	18.50	23.50
		44,444	12.50	17.00	21.50	23.50
		55,555	12.75	15.75	16.50	28.50
	120	33,333	14.75	15.75	21.00	24.50
		44,444	12.75	13.00	23.75	29.00
		55,555	15.50	23.25	17.75	30.60
	180	33,333	13.50	12.75	17.25	21.75
		44,444	14.00	16.25	19.50	30.75
		55,555	13.00	14.75	21.75	19.25
	240	33,333	14.00	13.75	17.50	18.75
		44,444	13.25	15.75	15.75	23.50
		55,555	14.75	18.00	21.00	28.25
	LSD $_{(0.05)}$		4.02	2.61	4.02	2.61

4.3.8: Effect of main treatment factors on crown root branching depth (cm)

Planting season had significant effect on crown root branching depth of WEMA (Table 4.9). The depth of crown root branch of WEMA was significantly higher both at tasseling and physiological maturity during the second year (2016/2017) planting cycle compared to the values obtained during the first year planting cycle (2015/2016). Nevertheless, the depth of crown root branching was not significantly affected by location (12.21 and 12.08 cm) respectively at both locations throughout the growth stages. The plant density had no significant effect on the depth of crown root branching at the tasseling stage but the depth of the crown root branch was significantly highest (12.38 cm) under 55,555 plant/ha compared to other plant densities.

Different nitrogen fertilizer rates significantly ($p<0.05$) affected the depth of the WEMA crown root branch. The WEMA with shallowest crown root branching was observed on the control plots where no nitrogen fertilizer was applied. The depth of crown root branching was not significantly affected by the different rates of N fertilizers applied. However, plots supplied with 120 kg N/ha had deepest crown root branch at the tasseling (12.40 cm) and the physiological maturity (12.50 cm) stages.

4.3.9: Treatment interaction effect on crown root branching depth (cm)

The crown root branching depth of WEMA was significantly affected through the interactions among , plant density x location x plant density x N fertilizer rates (Table 4:10). All of the treatment factors had a significant effect on the deepest crown root branching depth varied from 13.75 cm – 15.00 cm during the 2016/17 planting season and across the two locations and growth phases, compared to the range of 7.50 cm to 10.00 cm reached during the 2015/16 planting season.

Table 4.9: Effect of treatment factors on crown root branch depth (cm) of WEMA

Treatment factors	Tasseling stage	Physiological maturity stage
Planting season		
2015/2016	9.50b	9.42b
2016/2017	14.83a	14.75a
$LSD_{(0.05)}$	0.31	0.33
Location		
Molelwane trial	12.21a	12.08a
Taung trial	12.21a	12.08a
$LSD_{(0.05)}$	0.31	0.33
Plant density (plants/ha)		
33 333	12.06a	11.94b
44 444	12.20a	11.94b
55 555	12.38a	12.38a
$LSD_{(0.05)}$	0.38	0.41
Nitrogen rates kg/ha		
0	11.77b	11.25b
60	12.30a	12.29a
120	12.40a	12.50a
180	12.30a	12.40a
240	12.30a	11.98ab
$LSD_{(0.05)}$	0.50	0.53

Table 4.10: Location x N fertilizer rates x plant density interaction effect across planting seasons on crown root branch depth (cm) at tasseling and physiological maturity stage

Location	N fertilizer (kg/ha)	Plant density	Crown root branch depth (cm)			
			Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	10.00	8.75	15.00	15.00
		44,444	8.75	8.75	13.75	12.50
		55,555	10.00	7.50	13.75	13.75
	60	33,333	10.00	8.75	15.00	15.00
		44,444	10.00	10.00	15.00	15.00
		55,555	10.00	10.00	15.50	15.00
	120	33,333	10.00	10.00	15.00	15.00
		44,444	10.00	10.00	15.00	15.00
		55,555	10.00	10.00	15.00	15.00
	180	33,333	10.00	10.00	15.00	15.00
		44,444	10.00	10.00	15.00	15.00
		55,555	8.75	10.00	15.00	15.00
	240	33,333	8.75	8.75	15.00	15.00
		44,444	10.00	10.0	15.00	15.00
		55,555	7.50	7.50	15.00	15.00
Taung	0	33,333	10.00	10.00	15.00	15.00
		44,444	8.75	8.75	13.75	12.50
		55,555	10.00	8.75	13.75	13.75
	60	33,333	8.75	10.00	15.00	15.00
		44,444	10.00	8.75	15.00	15.00
		55,555	8.75	8.75	15.50	15.00
	120	33,333	10.00	10.00	15.00	15.00
		44,444	8.75	10.00	15.00	15.00
		55,555	10.00	10.00	15.00	15.00
	180	33,333	10.00	10.00	15.00	15.00
		44,444	8.75	10.00	15.00	15.00
		55,555	10.00	10.00	15.00	15.00
	240	33,333	10.00	10.00	15.00	15.00
		44,444	7.50	7.50	15.00	15.00
		55,555	8.75	8.75	15.00	15.00
	LSD $_{(0.05)}$		1.28	1.83	1.28	1.83

4.3.10: Effect of treatment factors on number of lateral root of WEMA

The number of lateral root was significantly ($p<0.05$) affected by the planting season (Table 4.11). The WEMA had significantly higher number of lateral root during the 2016/2017 planting season than during the 2015/2016 planting season at the tasseling (3.94), as well as the physiological maturity stages (4.00).

Location had significant effect ($p<0.05$) on the number of lateral roots formed by the WEMA plants. The crop had significantly higher number of lateral root (4.75) during the tasseling stage at the Molelwane trial whereas significantly higher number of lateral roots (5.70) was recorded at the Taung site during the physiological maturity stage .

Plant density had significant effect on the number of lateral roots produced by the WEMA During both of the planting seasons and growth phases considered, the WEMA variety produced significantly highest number of root under 44,444 plants/ha compared to other plant densities (Table 4.11).

Different N fertilizer rates had significant ($p<0.05$) effect on the number of lateral root on the WEMA plant. Those plots supplied with 180 kg N/ha showed significant highest number of lateral root (4.73) at the tasseling stage than at any of the other fertilizer rates. However, the number of lateral roots formed at physiological maturity phase was significantly highest (4.25) in plot fertilized with 120 kg N/ha compared with the plots supplied with 180 kg N/ha or the unfertilized plots (Table 4.11).

4.3.11: Effect of planting season, location, plant density and nitrogen fertilizer rates on number of lateral root of WEMA at different growth stages

The interactioneffec of planting season x location x plant density x N fertilizer rates had significant effect on number of lateral roots of WEMA (Table 4.12). During tasseling stage, significant and highest number of lateral root (8.00) was recorded during 2016/17 at Molewane under 55,555 plants/ha in plots treated with 180 kg N/ha than other treatments. However, at the physiological maturity stage, the number of lateral roots number was highest (7.00) during the 2016/17 planting season at plots at the Molelwane field under 44,444 plants/ha treated with 120 kg N/ha compared to other treatments.

Table 4.11: Number of lateral root of WEMA maize as influenced by planting season, experimental location plant density and nitrogen fertilizer rates at different growth stages

Treatment factors	Tasseling stage	Physiological maturity stage
Planting Season		
2015/2016	2.48b	4.00a
2016/2017	3.94a	3.94a
LSD $_{(0.05)}$	0.24	0.22
Location		
Molelwane	4.75a	2.24b
Taung	3.94b	5.70a
LSD $_{(0.05)}$	0.24	0.22
Plant density (plants/ha)		
33 333	4.33b	3.90b
44 444	4.60a	4.21a
55 555	4.13b	3.81b
LSD $_{(0.05)}$	0.29	0.27
N rates (kg/ha)		
0	4.31bc	3.83bc
60	4.15bc	4.04ab
120	4.48ab	4.25a
180	4.73a	3.67c
240	4.06c	4.06ab
LSD $_{(0.05)}$	0.38	0.34

Notes: Means with the same letter(s) in the same column are not significantly different at $P \leq 0.05$ according to Least significant difference.

Table 4.12: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on number of lateral root at tasseling and physiological maturity stages

Location	N fertilizer (kg/ha)	Plant density	Number of Lateral roots Tasseling	Maturity	Tasseling	Maturity
			2015/16		2016/17	
Molelwane	0	33,333	2.25	2.25	7.50	6.00
		44,444	2.75	2.25	7.50	5.00
		55,555	1.50	2.50	5.00	5.00
	60	33,333	4.00	2.25	7.00	6.00
		44,444	3.00	1.50	6.50	6.50
		55,555	2.25	1.75	6.00	6.50
	120	33,333	2.00	2.50	5.50	5.50
		44,444	5.50	3.00	6.50	7.00
		55,555	1.75	3.00	6.50	5.00
	180	33,333	2.25	1.75	7.50	5.00
		44,444	2.00	2.25	7.50	5.00
		55,555	4.50	2.00	8.00	6.50
	240	33,333	2.50	2.25	7.00	5.50
		44,444	4.00	2.50	6.00	5.50
		55,555	2.25	2.25	6.00	6.00
Taung	0	33,333	2.50	1.75	5.50	5.50
		44,444	2.50	2.50	5.50	7.00
		55,555	1.75	1.25	7.50	5.00
	60	33,333	1.50	2.25	5.00	5.50
		44,444	2.00	2.00	5.50	6.00
		55,555	2.50	2.25	4.50	6.00
	120	33,333	2.25	3.00	7.00	6.50
		44,444	2.00	2.50	6.00	5.50
		55,555	2.25	1.50	6.50	6.00
	180	33,333	3.25	1.50	6.00	4.50
		44,444	1.25	3.25	7.50	6.00
		55,555	2.00	1.25	5.00	5.00
	240	33,333	3.00	3.75	3.00	4.50
		44,444	1.25	2.00	7.00	7.00
		55,555	1.75	2.50	5.00	5.00
	LSD $_{(0.05)}$		1.13	1.19	1.13	1.19

Table 4.12: Relationship between root system architectural traits and grain yield at tasseling and physiological stages

Root architecture system had positive and significant association with grain yield at tasseling and physiological stages as shown in Table 13a and b. Nevertheless, the relationship between brace root branch depth ($R^2 = 0.37$) , crown number ($R^2 = 0.34$) and lateral roots ($R^2 = 0.30$) during tasseling stages was not significant. Hitherto, during physiological maturity the root architecture system exhibited positive and significant with grain yield. The co-efficeint of regrssion of relationship between root **root** system architectural traits and grain yield during physiological maturity range between 0.87 – 1.00. (Table 13b).

Table 4. 13a: Relationship between root system architectural traits and grain yield at tasseling stage

Parameters	N rates equation	Plant density equation	R^2 N rate	R^2 Plant density
Brace angle (◦)	$y = 0.013x^2 – 0.94x + 48.51$	$y = -3.94 \ln (x) + 50.83$	0.99**	0.69**
Brace number	$y = 0.021x^2 – 0.31x + 16.37$	$y = -14.84 \ln (x) + 33.50$	0.95**	0.70**
Brace root branch depth(cm)	$y = 0.08x^2 – 0.43x + 11.06$	$y = -14 \ln (x) + 33.50$	0.37^{ns}	0.97**
Crown angle (◦)	$y = - 0.060x^2 + 0.523x + 3.61$	$y = - 0.93 \ln x + 60.34$	0.95**	0.83**
Crown number	$y = 0.001x^2 – 0.068x +18.69$	$y = -2.31 \ln (x) + 22.15$	0.34^{ns}	1.00**
Crown root branch depth (cm)	$y = 0.020x^2 – 0.32x+ 13.16$	$y = -0.63 \ln (x) + 13.07$	1.00**	1.00**
Number of lateral roots	$y = 0.080x^2 +0.480x$	$y = -0.92 \ln (x) + 5.61$	0.30^{ns}	1.00**

Table 4.13b: Relationship between root system architectural traits and grain yield at physiological maturity

Parameters	N rates equation	Plant density equation	R^2 N rate	R^2 Plant density
Brace angle (◦)	$y = 0.020x^2 + 0.900x +49.57$	$y = -1.92 \ln (x) + 48.92$	0.99**	0.96**
Brace number	$y = 0.006x^2 – 0.292x + 17.70$	$y = 1. 83 \ln (x) + 19.50$	0.92**	0.90**
Brace root branch depth (cm)	$y = 0.006x^2 – 0.292x + 17.70$	$y = -0.37 \ln (x) + 11.85$	0.92**	1.00**
Crown angle (◦)	$y = 0.025x^2 – 0.345x + 61.79$	$y = 0.57 \ln x + 61.63$	1.00**	1.00**
Crown number	$y = 0.112x^2 -1.246x + 23.21$	$y = -0.893\ln(x) + 13.31$	0.99**	0.87**
Crown root branch depth (cm)	$y = -0.104x^2 + 0.337x + 12.23$	$y = -0.63 \ln (x) + 13.07$	0.99**	0.81**
Number of lateral roots	$y = -0.001x^2 – 0.080x + 4.32$	$y = -0.59 \ln (x) + 14.60$	0.97**	0.96**

4.4: Discussion

The root system of the WEMA variety included all of the elements of root system architecture such as the brace root, crown root and lateral root traits or properties, with all their accessory components such as angle, number and branching depth. According to Traschel et al. 2011, these traits are collectively referred to as root architectural system in maize production

The brace and crown rootstraits had deeper and steeper during the 2016/17 planting season. This could be attributed to variations in the total precipitation between the 2015/16 (257.40 and 231.20 mm) and 2016/17 (646.40 and 598.80 mm) planting seasons. These observations are in consonance with the findings of Nafziger (2012), who reported that when rain wets the soil sufficently, it allows the brace roots to penetrate and grow downward and at a steep angle. This finding is also in agreement with those from the earlier study of Dathe et al. (2016), who observed that precipitation influences the root system architecture of maize. However, Mi et al. (2016) further reported that the root systems of maize plants grown in the field are affected by different environmental stimuli.

Many studies have discovered that roots grow best on loamy soil and that significantly longer root lengths and root density areobtained on sandy loam (Zhang 2011; Mi et al., 2016). Brace root traits had deeper and steeper in Taung, while crown root at the Molelwane site were deeper and steeper across both of the growth stages. This could be attributed to the soil types and properties in the respective locations. These findings agree with those of (Wang et al. 2018) who revealed that the root system architecture of the maize plant is related to the properties of the soil.

The deepest and steepest properties of brace and crown root traits were observed at plant density levels of 44,444 and 55,555 plants/ha respectively. These may be attributed to intra-plant competition and the particular variety of maize. These results conform with the findings of Mi et al. (2016), who revealed that root angle could be associated with varietal specificity and also be slightly affected by plant density. Dai et al. (2014) suggested that an increased plant density level could enhance the root depth in deep soils, thereby improving the uptake of nitrogen from the leached nutrients retained there. Nevertheless, these findings are in contradiction of those of York et al. (2015), who reported that the brace root has a shallower angle at plant density levels of 20,000 plants/ha compared to 80,000 plants/ha.

Brace and crown roots were found to penetrate deeper and steeper in plots that had applications of 120 kg /ha than other fertilizer rates. This could be attributed to environmental factors, soil factors and the particular maize variety. These results are corroborrated by the findings of Chen et al. (2018), who reported that root system architecture with steep brace root angles was considered advantageous when water and solubilized nutrients can be found in deeper soil layer, in soil with long nutrient retention capacity. Meanwhile, these observations do not support the findings of York et al. (2015) who reported that the number of crown roots decreases as the nitrogen content diminishes (i.e. from high nitrogen fertilizer ratess to lower rates). York et al. (2015) further explained that the number of crown roots decreases from old maize varieties to the most recently developed varieties.

Lateral roots are one of the basic components that control the root system architecture (Nibau et al., 2008). An higher number of lateral roots were observed during the 2016/17 planting season compared to 2015/16 planting season. This might be attributed to the environmental conditions, and are supported by the findings of Sun et al. (2017) who reported that lateral roots are highly sensitive to changing environmental conditions.

Postma et al. (2014) discovered that an optimum number of lateral roots were greatly influenced by the balance between the marginal cost of root production and the marginal utility of acquiring the soil resource. The Molewane trial crop had a larger higher number of lateral roots which could be attributed to the soil propertiesof the site.

An optimal plant density of 44,444 plants/ha showed highest number of lateral roots than other plant densities. This could be attributed to intra- plant competition. These results are in line with those of other studies that reported that under high plant density root system architecture change which result to increased number of lateral roots (York et al., 2015; Mi et al., 2016).

Many studies have revealed that in maize production the lateral roots grow dynamically in those areas rich in nitrogen(Zhu et al ., 2011: Li et al., 2012; Ma et al., 2013). However, those plots that were supplied with 180 and 120 kg N/ha had highest number of lateral roots during the tasseling and physiological maturity stages respectively. This could be attributed to the availability of nitrogen during the growth stage. Shahzad and Amtmann (2017) found that the availability of nitrogen and its variability have a significant effect on lateral root growth and development. Moreover, it was observed that as WEMA maize increased in growth stages, there was a positive relationship between the WEMA maize with grain yield. This revealed the root architecture system greatly enhanced grain yield of WEMA variety. The grain yield increased directly with increasing root traits (Liu et al., 2019). According to Hammer et al. (2009) and Liu et al. (2019), the modern maize had a steeper root angle which improved water and nutrient uptake at deep depth and enhanced grain yield. Similarly, the results are in line with the findings of many scholars that crown was significantly correlated with nitrogen efficiency and grain yield under both low and high nitrogen availability (Liu et al., 2015: Liu et al., 2017: Liu et al., 2019). Liu et al. (2019) reported that maize variety with a vaster crown root number acquired more grain yield.

Conclusion

The results from the investigation showed that WEMA has steep, cheap and deep ideotype root system architecture. This enhanced the performance of WEMA under semi-arid conditions. WEMA can be grown under moderate and high plant densities with application of 120 kg N/ha. Therefore, WEMA can be cultivated either under 44,444 plants/ha or 55,555 plants/ha with application of 120 kg N/ha in Northwest Province of South Africa.

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CHAPTER FIVE

YIELD AND YIELD COMPONENTS OF WEMA MAIZE AS INFLUENCED BY DIFFERENT RATES OF NITROGEN FERTILIZER AND PLANT DENSITIES IN TWO LOCALITIES OF NORTH WEST PROVINCE OF SOUTH AFRICA

ABSTRACT

Field study was conducted during the 2015/16 and 2016/17 planting seasons in two localities of North-West Province of Republic of South Africa to evaluate the influence of N fertilizer rates and plant density on grain yield and yield components of WEMA. The experiment was laid out in split plot fitted into a randomized complete block design with four replicates in each trial site. The main plot effect was plant density (33,333, 44,444 and 55,555 plants/ha) and nitrogen rates (0, 60, 120, 180 and 240 kg N ha^{-1}) constituted the subplot. The parameters measured were grain yield and grain yield components. Data were analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences in the treatment means were tested by Least significant difference (LSD) at 5% level of probability.

The relationships among grain yield, N rates, plant density and grain yield components were evaluated using regression, correlation and path analyses. Interaction of season x location x N fertilizer rates x plant densities had significant ($p \leq 0.05$) effect on yield and yield component of WEMA. During the 2016 /17 planting season, WEMA maize planted at Molelwane had significant and highest grain yield (7.78 t/ha) in plots with 55,555 plants/ha and supplied with 120 kg N/ha fertilizer. The total biological yield had significant and strong correlation with grain yield (r=0.97) and stover yield (r=0.98). Path analyses indicated that the total biological yield had highest positive direct effect (30.50) on grain yield, this was followed by shelling percentage (3.95) while stover yield (-29.83) and harvest index (-4.66) showed negative but direct effect on the grain yield. Generally, the results of the experiment showed that maximum yield and yield components of WEMA were obtained from plots at the two research sites that were supplied with 120 kg /ha and at a plant density of 55,555 plants/ha.

Keywords: Total biological yield, grain yield, harvest index, plant density, N rate

5.1 Introduction

As opposed to other cereal crops, maize has the greatest grain yield potential (Ion *et al.,* 2015). The main cultural practices that affect maize yield are the selection of suitable cultivars, fertilization and plant density (Ion et al., 2015; Ayman et al., 2015). However, plant density and applications of nitrogen fertilizer have been documented as the major crop management practices to improve maize yield (Yan et al., 2017). Ion et al. (2015) reported that when the nitrogen supply by the soil is low, the application of nitrogen fertilizer improves the maize yield. Nitrogen fertilization causes 43 to 68% and 25 to 42% increases in grain yield and biological yield respectively (Zaman and Khan, 2016). Bakht et al. (2007) revealed that a significant increase in grain and stover yield was obtained with the application of 240 kgN/ha. Many researchers have reported the highest harvest index was observed under high nitrogen fertilizer rates (Alizede et al., 2007 and Maral et al., 2012).

Numerous researchers have reported that modern maize hybrids produce higher yields under high plant density than the older hybrids, which is due to the tolerance of the more recent hybrids to various biotic and abiotic stresses (Chen et al., 2014; Yan et al., 2017). Chen et al. (2014) further revealed that the modern maize hybrids are the best in efficiently responding to .unfavourable..environmental conditions in terms of precipitation and solar radiation on account of the climate change that is being and has been experienced over the past years.

Amnuallah (2011) reported that high plant density improved maize yield per unit area compared to low density, which caused by higher crop growth and higher light interception. Yan et al. (2017) showed that plant density increases both the grain and the biological yields of maize. Plant density is one of agronomic practices that has significant effect on harvest index. Amnuallah et al. (2009) observed that high plant density increase the stover yield. Shah et al. (2008) reported that insufficient nitrogen application, alongside inadequate plant density in maize production caused low maize yield. Dawadi and Sah (2012) observed higher grain yields under high plant density and nitrogen fertilizer Rates.The harvest index is also greatly affected by plant densities and nitrogen rates.

Water Efficient Maize for Africa (WEMA) is a modern maize hybrid with little information on its agronomic practices under which its potentials could be optimized. There is limited information on the effect of nitrogen rates and plant density on yield and yield component of

WEMA maize in North West province of South Africa. It is assumed that WEMA yield and yield components will respond differently to different nitrogen fertilizer rates and plant densities. This study was conducted to evaluate the effect of nitrogen fertilizer rates and plant densities on yield and yield component of WEMA maize.

5.2.0 Materials and Methods

5.2.1 Description of study area

The NWU research farm is located in a semi-arid tropical savanna region that receives mean annual summer rainfall of 571 mm while the Taung trial site receives a mean annual rainfall of 318 mm (Kasirivu et al., 2011; Saexplorer 2019). Approximately 68% of the annual precipitation at the NWU farm falls between November and January in a few relatively heavy downpours, with a pronounced dry season from April to September. The mean maximum temperature is 37°C and the mean minimum temperatures range from 7°C -11°C.). The Taung Experimental Station had average maximum temperature of 35 °C and the mean minimum temperature ranged between 5°C– 18.5°C. The annual average pan evaporation of North-West is 1023 mm (Kasirivu et al., 2011) . The annual average pan evaporation of North-West is 1023 mm (Kasirivu et al., 2011).The soil at the two sites is deep, fine and freely drained, and is dominated by yellow and red sands and sandy loams texture, eutrophic with Aeolian deposits(Staff, 1999) belong to Hutton series, according to South Africa soil classification (Molope, 1987; Kasirivu et al., 2011). .According to WRB (2016), the soil at NWU Research Farm is classified as Ferric Luvisol while that of Taung is classified as Rhodic Ferrasol.

5.2.2 Soil Sampling and Analysis

The soil samples from each trial site were collected from depths of 0 15 and 0 30 cm. The samples were then analyzed for physical and chemical properties. Soil pH (KCl extraction), total nitrogen (Kjedahl method) available P (Bray I-P), exchangeable K (Ammonium acetate) and particle analysis (Hydrometer method) as described by SASS (1990).

During 2015/16 planting season, the soil chemical properties at Molelwane were pH (4.31 and 4.18), total nitrogen, (0.08 and0.01%) available P (6 and 10 mg/kg), exchangeable K (279 and 322 mg/ kg).and Taung were Soil pH (6.45 4.30), total nitrogen (0.12 and 0.10 %), available P (5 and 3 mg/kg), exchangeable K (366 and 304 mg/ kg). whereas at Molelwane during 2016/17 planting season the following soil chemical properties were pH (4.50 and 4.50), total nitrogen

(0.17 and 0.18 %), available P (80 and 11 mg/kg) exchangeable K (49 and 203 mg/ kg) whilst Taung had Soil pH (4.30 and 5.00), total nitrogen (0.19 and 0.15%) available P (49 and 8 mg/kg), exchangeable K (180 and 185 mg/ kg).

The soil at the Molelwane site is sandy loam whereas that at the Taung site is loamy sand.

5.2.3 Weather conditions during experimental period

The planting of the trial took place during December, 2015 to July, 2016 at both Molelwane, NWU farm and Taung experimental station. Likewise in 2016/17, Sowing of the trial took place between December, 2016 and June, 2017 in both locations. The summary of climatic condition at the sites during the experimental periods was obtained from South Africa Weather Service is presented in Table 5.1. On account of the much lower rainfall experienced during the 2015/16 planting season at both trial sites, supplementary irrigation was porvided from the seed planting stage right through to the early vegetative stage in order to guarantee good crop establishment. On the other hand, no supplementary irrigation was necessary during the 2016/17 planting season owing to the adequate rainfall throughout the growing period.The total amount of supplementary irrigation applied was not quantified due to resource constraint.

Table 5.1: The meteorological data of experimental locations

Climate data	**Molelwane**	**Taung**
2015/16 summer planting season		
Temperature (°C)		
Minimum	15.24	13.77
Maximum	27.00	31.32
Mean daily	22.17	22.47
Total Rainfall (mm)	257.40	231.20
Relative humidity (%)		
Minimum	13.77	22.57
Maximum	74.86	74.00
Mean	50.29	48.86
2016/17 summer planting season		
Temperature (°C)		
Minimum	13.16	11.57
Maximum	27.23	29.09
Mean daily	20.16	20.42
Total Rainfall (mm)	646.40	598.80
Relative humidity (%)		
Minimum	34.14	24.29
Maximum	86.43	82.89
Mean	61.86	54.14

Source: South African Weather Services (2018)

5.2.4 Experimental Design and Treatments

The experiment at each location was laid out in split plot arrangement fitted into a randomized complete block design with four replicates. The main plot effect was the three plant densities (33,333, 44,444 and 55,555 plants/ha) while the five N fertilizer rates (0, 60, 120,180 and 240 kg N/ha) served as the sub-plot effect. Each sub-plot measured 6 m x 4 m with a total experimental plot size of 30 m x 76 m at each site. Planting was done at inter and intra row spacing of 1m x 0.3m, 0.75 m x 0.3m and 0.9 m x 0.2 m to achieve the density of 33,333, 44,4444, and 55,555, respectively. The water efficient maize variety used was, WEMA3127.

5.2.5 Agronomic Practices

The fertilizer application treatment was carried out by applying a third of the each rate as basal treatment at planting using NPK 20:7:3 while two-third and a third of the remaining quantity from each rate was applied as top dressing at 3 and 5 weeks after planting (WAP) using lime ammonium nitrate (LAN, 28%).Weeding was done manually at 3 and 7 weeks after sowing.

5.2.6 Data collection

Maize plants were harvested within the middle row from each plot with harvested area of 8 m^2.The ears were air dried for 6 weeks after harvesting until uniform moisture content of 12% was attained. The ears were removed manually and threshed with aid of manual sheller. Data on yield and its components were evaluated as follows:

Yield = $\frac{Dry\ yield}{100 - moisture\ content/100}$ (CIMMYT, 2013; Abebe and Feyisa, 2017)

Stover yield = $\frac{Stover\ yield\ obtained\ from\ harvested\ area}{Harvested\ area}\ x\ actual\ plot\ area$

To obtained stover yield / ha = stover yield of plot area x 10 000 m^2

Total biological yield = grain yield + stover yield (Yada, 2011)

Harvest Index = $\frac{Economic\ yield\ (kg)}{Total\ biological\ yield\ (kg)}$ (CIMMYT, 2013)

Shelling percentage = $\frac{Grain\ weight\ of\ shelled\ ears}{Weight\ of\ unshelled\ ears}$x100

5.2.7. Statistical Analysis

All data obtained were analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences in the treatment means were tested by Least significant difference (LSD) at 5% level of probability. Relationship between plant density, nitrogen rates and yield and its component was evaluated using regression and correlation with the aid of Excel program. The sets of correlation coefficients were subjected to path coefficient analysis and the direct and indirect effects were estimated according to the method of Dalkani et al., (2011). Regression was used to predict optimum grain yield with N rate and plant densities interaction .

$y = b + b_{1x1} + b_{2x2} + \xi$

Y = maize grain yield

b_0 = intercept

b_1 = co-efficient of nitrogen rate

b_2 = co-efficient of plant densities

x_1 = N fertilizer rates

x_2 = plant densities

ξ = constant

5.3 Results

5.3.1 Effect of treatment factors on grain yield

WEMA maize grain yield was significantly ($p<0.05$) affected by planting season. Maize grain yield (6.70 t/ha) was significantly higher during 2016/2017 planting season than 2015/2016 planting season (Table 5.2). Similarly, location also had significant effect on grain yield. Maize planted at Taung showed significantly higher grain yield (5.11 t/ha) than those grown in Molelwane. The WEMA grain yield was also significantly ($p<0.05$) affected by plant density. Maize planted at a plant density of 55,555 plants/ha produced highest grain yield (4.56 t/ha), but this was not significantly different from WEMA grown at a plant density of 33,333 plants/ha. The least grain yield was recorded from plots sown at a density of 44,444 plant/ha. The different N fertilizer rate, also had significant effect on WEMA grain yield. The plots treated with 180 kg N/ha had significant and highest grain yield (4.73 t/ha) but not stastistically difference from 120 and 240 kg N/ha fertilizer rates.

Table 5.2: Effect of treatments factors on grain yield of WEMA

Treatment factors	Yield (t/ha)
Planting season	
2015/16	2.31a
2016/17	6.70b
LSD $_{(0.05)}$	0.06
Location	
Molelwane	3.92b
Taung	5.11a
LSD $_{(0.05)}$	0.06
Plant density (Plants/ha)	
33 333	4.50a
44 444	4.48b

55 555	4.56a
LSD $_{(0.05)}$	0.07
N rates (kg/ha)	
0	4.11c
60	4.32b
120	4.71a
180	4.73a
240	4.70a
LSD $_{(0.05)}$	0.09

.Notes: Means with the same letter on the same column and treatment are not significantly different at $P \leq 0.05$. using least different significant difference (LSD).

5.3.2 Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on grain yield

The effect of varying rates of N fertilizer on grain yield of WEMA variety sown at three plant densities at two locations during the 2015/16 and 2016/17 planting seasons, are shown in Table 5.3.

During the 2016/17 planting season, the Molelwane trial produced highest grain yield (7.78 t/ha) for the WEMA variety from plots with a plant density of 55,555 plants/ha and fertilized with 120 kg N/ha . These statistics stand in contrast to the results obtained for the 2015/16 planting season at the same location and plant density. but from plots that had received no nitrogen fertilizer whatsoever.

5.3.3: Effects of planting season, location, plant density and nitrogen fertilization rates on the biological yield of maize

Different planting seasons affected biological production of WEMA significantly. The maize had higher biological yield, stover yield and harvest index during the 2016/2017 planting season than during the 2015/2016 planting season (Table 5.4). As indicated in Table 5.4, the biological production, stover accumulation and harvest index by WEMA differed statistically across Molelwane trial and Taung experimental station . The biological yield (8.27 kg/ha), stover yield (3.17 kg/ha) and harvest index (0.60) were higher at Taung than Molelwane. Similarly highest biological yield, stover yield and harvest index were recorded under 44,444 plant density than the other plant plnat density investigated. Application of 120 kg N/ha promoted greater biological production and stover yield significantly relative to the other fertilizer rates. Nevertheless, the plots treated with 180 kg N/ha had significantly highest harvest index (0.55) than other nitrogen fertilizer rates.

5.3.4. Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on biological yield

There was significant ($p<0.05$) interaction among planting season x location x plant density x N fertilizer rates (Table 5.5). A significant and highest biological yield (13.14 kg/ha) was recorded during 2016/17 planting season in Taung in plots with 55,555 plants/ha and supplied with 120 kg N/ha relative to other treatments across different seasons and locations.

Table 5.3: Interaction effect of treatment factors rates on grain yield (t/ha) maize

Location	N fertilizer (kg /ha)	Plant density	Grain yield (t/ha)	
			2015/16	2016/17
Molelwane	0	33,333	0. 90	6.85
		44,444	0.69	5.20
		55,555	0.64	6.50
	60	33,333	0. 84	7.18
		44,444	1.11	5.54
		55,555	0.92	5.95
	120	33,333	0.96	6.91
		44,444	0.86	7.72
		55,555	0.80	7.78
	180	33,333	1.63	7.33
		44,444	0.97	7.25
		55,555	0.77	6.78
	240	33,333	0.88	7 .23
		44,444	0.92	7.69
		55,555	1.58	7.25
Taung	0	33,333	3.52	5.24
		44,444	3.71	6.60
		55,555	3.75	5.73
	60	33,333	3.53	6.32
		44,444	3.38	6.69
	120	33,333	3.48	6.40
		44,444	3.40	7.38
		55,555	3.82	7.06

180	33,333	4.03	6.83
	44,444	4.11	7.34
	55,555	3.92	5.77
240	33,333	4.53	6.64
	44,444	2.80	6.33
	55,555	3.66	6.83
LSD $_{(0.05)}$		0.03	

Table 5.4: Effect of planting season, location, plant density and N fertilizer rates on biological yield, stover yield and harvest index of WEMA

	Biological yield (t/ha)	**Stover yield (t/ha)**	**Harvest index**
Planting Season			
2015/16	5.19b	2.88b	0.43b
2016/17	10.01a	3.31a	0.62a
LSD $_{(0.05)}$	0.09	0.07	0.02
Location			
Molelwane	6.93b	3.01b	0.44b
Taung	8.27a	3.17a	0.60a
LSD$_{(0.05)}$	0.09	0.07	0.02
Plant density (plants/ha)			
33,333	7.43c	2.87c	0.53a
44,444	7.74a	3.26a	0.50b
55,555	7.63b	3.14b	0.54a
LSD $_{(0.05)}$	0.11	0.08	0.02
N (kg/ha)			
0	6.80d	2.70d	0.54a
60	7.19c	2.87c	0.51c
120	8.24a	3.53a	0.47d
180	7.94b	3.23b	0.55a
240	7.83b	3.14b	0.53b
LSD $_{(0.05)}$	0.14	0.11	0.02

Notes: Means with the same letter(s) on the same column and treatment are not significantly different at $P \leq 0.05$.

Table 5.5: Interaction effect of planting season x location x plant density x nitrogen fertilizer rates on biological yield (t/ha)

Location	N fertilizer (kg/ha)	Plant density	Biological yield (t/ha)	
			2015/16	2016/17
Molelwane	0	33,333	4.17	8.44
		44,444	3.57	7.41
		55,555	3.59	8.73
	60	33,333	4.08	9.40
		44,444	4.70	7.44
		55,555	4.12	8.16
	120	33,333	5.72	9.58
		44,444	4.30	10.88
		55,555	4.40	12.24
	180	33,333	6.06	10.08
		44,444	5.02	9.95
		55,555	4.22	9.65
	240	33,333	3.45	9.42
		44,444	3.31	10.80
		55,555	5.59	9.48
Taung	0	33,333	5.40	8.10
		44,444	6.10	11.15
		55,555	5.13	9.02
	60	33,333	6.81	9.99
		44,444	4.97	10.98
	120	33,333	5.12	10.56
		44,444	5.78	9.49
		55,555	6.38	11.86
	180	33,333	5.85	13.14
		44,444	6.75	10.41
		55,555	5.83	12.27
	240	33,333	6.98	9.16
		44,444	6.04	11.18
		55,555	6.35	10.43
$LSD_{(0.05)}$			0.25	

5.3.5: Interaction effect of planting season x location x plant density x nitrogen fertilizer rates on stover yield of WEMA

The stover yield was significantly ($p<0.05$) affected by the interaction of planting season x location x plant density x N fertilizer rates (Table 5.6). The stover yield was significantly highest (6.08 t/ha) during the 2016/17 season under 55,555 plants/ha in plots supplied 120 kg N/ha at Taung field when compared to the stover yield recorded during 2016/17 planting season in plots sown at 33,333 plants/ha at Molelwane without fertilizer application .

5.3.6: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on harvest index of WEMA

There was significant ($P\leq0.05$) interaction among planting season, location, plant density and N fertilizer rates (Table 5.7). The WEMA showed highest harvest index (0.81) during 2016/17 planting season at Molelwane under 33,333 plants/ha in unfertilized plot compared to plots treated with 60 kg N/ha under the same plant density and location during 2015/16 planting density.

5.3.7: Effect of treatment factors on shelling percentage

Planting season had significant effect ($P\leq0.05$) on WEMA shelling percentage. The WEMA variety had significantly higher shelling percentage (75.9%) during the 2016/2017 planting season than during the 2015/2016 planting season (Table 5.8). The shelling percentage of WEMA grain was significantly ($p<0.05$) affected by location. Maize planted at Molelwane had significantly higher shelling percentage (78.2%) than maize planted in Taung.

Plant density had significant ($p<0.05$) effect on WEMA shelling percentage. The highest shelling percentage (75.7%) was obtained under 55,555 plants/ha compared to the other plant density treatments. Different N fertilizer rates had significant ($p<0.05$) effect on shelling percentage of WEMA variety. Significant and highest shelling percentage (77.9%) was obtained in the unfertilized plots compared to other fertilizer rates.

Table 5.6: Interaction effect of planting season x location x plant density x nitrogen fertilizer rates on stover yield of WEMA

Location	N fertilizer (kg/ha)	Plant density	Stover yield (t/ha)	
			2015/16	2016/17
Molelwane	0	33,333	3.26	1.59
		44,444	2.90	2.21
		55,555	2.95	2.24
	60	33,333	3.24	2.21
		44,444	3.59	1.89
		55,555	3.19	2.21
	120	33,333	4.77	2.67
		44,444	3.45	3.17
		55,555	3.60	4.46
	180	33,333	4.43	2.75
		44,444	4.05	2.70
		55,555	3.45	2.87
	240	33,333	2.57	2.20
		44,444	2.39	3.10
		55,555	4.01	2.23
Taung	0	33,333	2.45	2.86
		44,444	1.69	4.57
		55,555	2.35	3.29
	60	33,333	1. 60	3.68
		44,444	3.43	4.29
	120	33,333	1.36	3.74
		44,444	1.64	3.10
		55,555	2.40	4.48
	180	33,333	2.56	6.08
		44,444	1.82	3.58
		55,555	2.64	4.93
	240	33,333	2.10	3.38
		44,444	2.45.	4.54
		55,555	3.25	4.10
LSD $_{(0.05)}$			0.004	

Table 5.7: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates on harvest index

Location	N fertilizer (kg /ha)	Plant density	Harvest index	
			2015/16	2016/17
Molelwane	0	33,333	0.22	0.81
		44,444	0.20	0.70
		55,555	0.18	0.75
	60	33,333	0.21	0.24
		44,444	0.37	0.75
		55,555	0.23	0.73
	120	33,333	0.17	0.72
		44,444	0.21	0.29
		55,555	0.18	0.56
	180	33,333	0.27	0.71
		44,444	0.19	0.71
		55,555	0.18	0.70
	240	33,333	0.26	0.77
		44,444	0.28	0.72
		55,555	0.28	0.63
Taung	0	33,333	0.59	0.65
		44,444	0.69	0.48
		55,555	0.61	0.64
	60	33,333	0.69	0.37
		44,444	0.51	0.61
	120	33,333	0.73	0.65
		44,444	0.68	0.68
		55,555	0.58	0.38
	180	33,333	0.60	0.54
		44,444	0.69	0.66
		55,555	0.61	0.60
	240	33,333	0.67	0.64
		44,444	0.65	0.55
		55,555	0.47	0.61
LSD ($_{0.05}$)			0.08	

Table 5.8: Effect of treatment factors on shelling percentage of WEMA

Treatment factors	**Shelling %**
Planting Season	
2015/16	72.4b
2016/17	75.9a
LSD $_{(0.05)}$	0.6
Location	
Molelwane	78.2a
Taung	70.0b
LSD $_{(0.05)}$	0.6
Plant density (Plants/ha)	
33,333	73.4b
44,444	73.3a
55,555	75.7a
LSD $_{(0.05)}$	0.7
N rates (kg/ha)	
0	77.9a
60	72.5c
120	74.3b
180	72.9c
240	73.1c
LSD $_{(0.05)}$	1.00

Notes: Means with the same letter(s) in the same column and treatment are not significantly different at $P \leq 0.05$.

5.3.8: Interaction effect of planting season x location x plant density x nitrogen fertilizer rates on shelling percentage of WEMA

There was a significant ($p<0.05$) interaction effect of planting season x location x plant density x N fertilizer rates on shelling percentage (Table 5.8). In the 2016/17 planting season, WEMA planted at Molelwane under 55,555 plants/ha on unfertilized plots had highest shelling percentage (98.3%) compared to shelling percentage obtained at Taung in the same year in plots with 33,333 plants/ha fertilized with 60 kg N/ha (Table 5.8).

5.3.9: Relationship between nitrogen rates and grain yield and plant density

As reflected by the quadratic function between the two variables, The nitrogen rate is directly related to grain yield of WEMA as reflected by the quadratic function between the two variables (Figure 5.1a).The result indicated that the optimum rates of N fertilizer could be predicted up to 95%. Using the quadratic function $y = -2E\text{-}05x^2 + 0.0067x + 4.0746$, the highest grain yield of 4.63 t/ha was obtained at 180 kg N/ha. Hence, this N rate appeared optimum for high grain yield in WEMA variety in North West Province of South Africa.

Similarly, the relationship between grain yield and plant density showed a significant ($p \leq 0.05$) and inverse association ($R^2 = 0.67$). Using the logarithm model $y = -0.061\ln(x) + 4.5499$, the highest grain yield of 4.54 was obtained at a plant density of 33,333 plants/ha (Figure 5.1b).

The optimum N rate and plan density interaction was determined using Multiple quadratic model $y = -0.0475x^2 + 0.4625x + 3.6675$and $y = 0.05x^2 - 0.27x + 4.84$ respectively while ($R^2 = 0.95$ and 1) correspondingly (Figure 5.2). The N rates and plant densities interaction suggested that optimum N rate of 148 kg N/ha and plant density (44,444 plants /ha). However, highest grain yield of 4.5 t/ha was obtained at estimated optimum N rate and plant density interaction.

Table 5.9: Interaction effect of planting season x location x plant density x nitrogen fertilizer rates on shelling percentage

Location	N fertilizer (kg N/ha)	Plant density	Shelling percentage (%)	
			2015/16	2016/17
Molelwane	0	33,333	90.28	77.64
		44,444	70.15	73.37
		55,555	89.25	98.25
	60	33,333	85.62	78.55
		44,444	87.70	69.45
		55,555	74.55	81.65
	120	33,333	73.75	79.01
		44,444	65.92	80.08
		55,555	77.88	80.30
	180	33,333	73.62	61.35
		44,444	89.30	80.89
		55,555	71.67	79.38
	240	33,333	75.70	79.00

		44,444	74.73	77.88
		55,555	75.10	74.05
Taung	0	33,333	66.66	73.27
		44,444	69.10	71.43
		55,555	65.77	89.13
	60	33,333	66.62	56.06
		44,444	59.72	73.62
		55,555	79.01	75.35
	120	33,333	62.20	74.73
		44,444	70.07	75.35
		55,555	69.80	76.37
	180	33,333	67.30	75.18
		44,444	69.02	68.00
		55,555	67.40	70.93
	240	33,333	66.67	75.00
		44,444	63.92	75.06
		55,555	64.62	74.78
LSD $_{(0.05)}$			4.66	

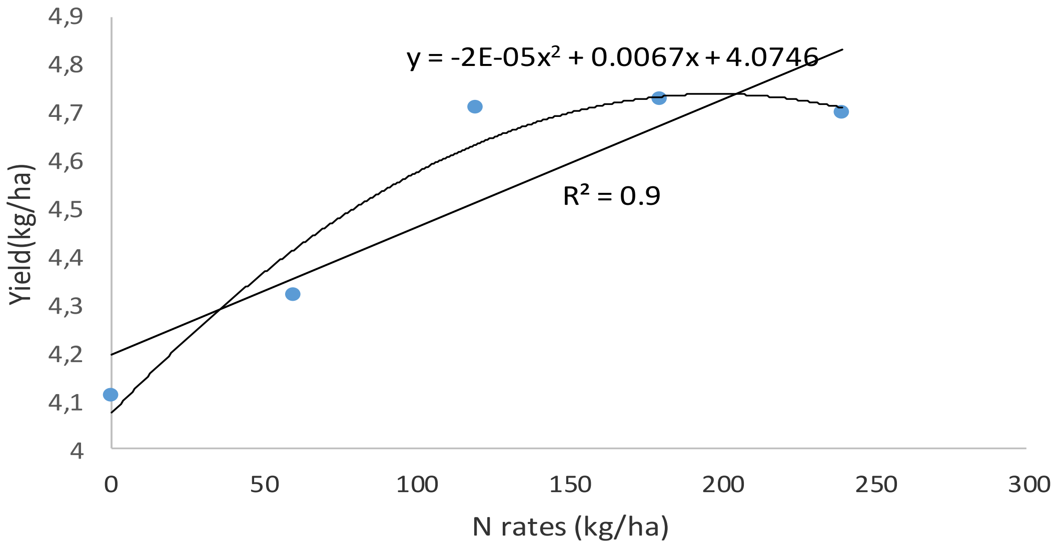

Figure 5.1a: Relationship between grain yield and nitrogen rates

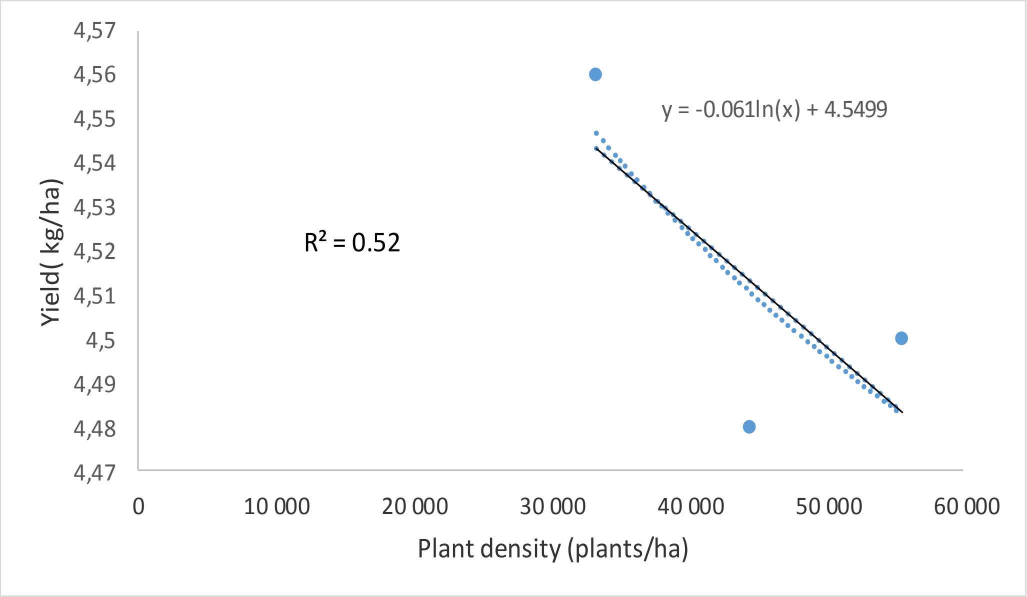

Figure 5.1b: Relationship between grain yield and plant density

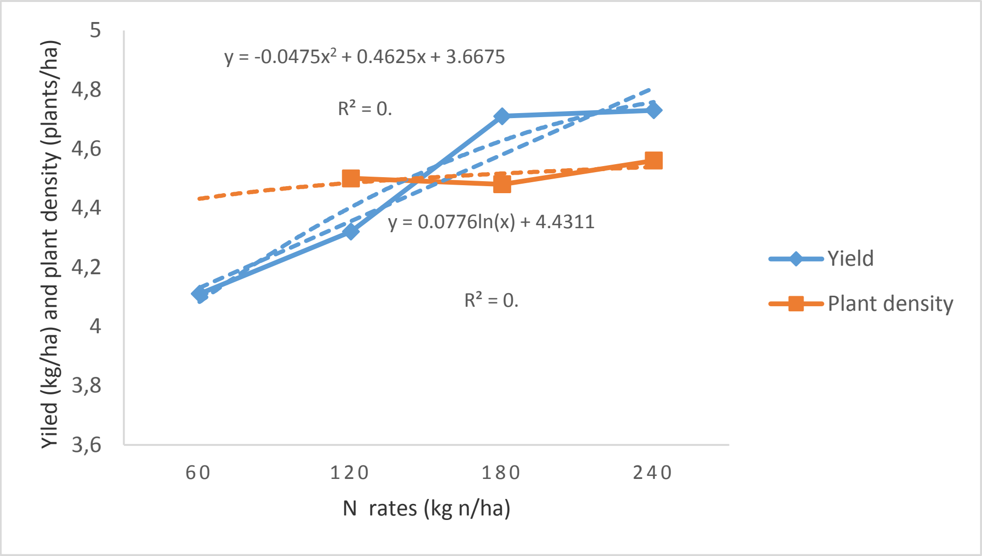

Figure 5.2: Grain yield x N rates x plant densities interaction

5.3.10: Correlation relationship between yield and yield components of WEMA

The total biological yield had a significant ($p \leq 0.01$) and positive correlation with biological yield ($r=0.97$) and stover yield ($r=0.89$). Also, shelling percentage was significantly ($p \leq 0.01$) and negatively correlated with grain yield. Nevertheless, harvest index had no significant correlation with yield. Biological yield showed significant ($p \leq 0.01$) and positive association with stover yield and negative correlated with shelling percentage. The biological yield displayed no significant correlation with harvest index, however.. The stover yield indicated a significant and positive correlation with biological yield and a negative association with harvest index, but no significant association with shelling percentage. Harvest index showed no significant association with any of the other components expect with stover yield.

Table 5.10: Correlation relationship between biomass yield and other parameters

Parameters	Total biological yield	Grain Yield	Stover yield	Shelling %	Harvest index
Total biological yield	1				
Grain yield	0.97**	1			
Stover yield	0.98**	0.89**	1		
Shelling%	-0.57**	-0.66**	-0.45^{ns}	1	
Harvest index	-0.42^{ns}	-0.21^{ns}	-0.56**	0.14^{ns}	1

5.3.12: Path analysis of grain yield and yield components

Path analysis revealed that total biological yield had the largest , most positive and direct effect (30.50) on grain yield. This was followed by shelling percentage (3.95). The stover yield showed the largest, most negative and direct effect (-29.83) on grain yield and was followed by harvest index (-4.66). The indirect effect of stover yield (29.90) and harvest index (1.96) - through total biological yield - had a positive effect on grain yield and a negative effect on shelling percentage (-2.25). Similarly, both total biological yield (29.90) and harvest index (2.61) had a positive but indirect effect on grain yield, whereas shelling percentage (-1.78) had an indirect effect through the stover yield on grain yield. Nevertheless, the indirect effects of total biological yield (-17.38) and harvest index (-0.65) on grain yield through shelling percentage were negative . The indirect effects of stover yield (16.70) and shelling percentage (0.55) through harvest index -on grain yield were positive. The total biological yield (-12.81) had an indirect but negative effect -through harvest index -on grain yield(Table 5.11).

Table 5:11: Path analysis of grain yield and yield components

	Total biological yield (kg/ha)	Stover yield (kg/ha)	Shelling (%)	Harvest index	Sum Effect
Total biological yield	**30.50**	-29.23	-2.25	1.96	0.97
Stover yield	29.90	**-29.83**	-1.78	2.61	0.89
Shelling%	-17.38	13.42	**3.95**	-0.65	-0.66
Harvest index	-12.81	16.70	0.55	**-4.66**	-0.21
Residual					-0.40

5.4. Discussion

5.4.1 Influence of planting seasons and trial locations on maize yield and yield component

The WEMA grain yields and yield components were better during the 2016/17 planting season than during the 2015/2016 season. The better yield recorded in the second season of planting could probably be linked to the higher rainfall during this season as opposed to that which fell during the first year of planting. In 2016/17, the rainfall for Molelwane was 60.2% higher than the rainfall that it received during 2015/16; while similarly, the rainfall at Taung was 61.4% higher than the rainfall that it received during 2015/16.

Although, WEMA is a drought tolerant variety but under adequate moisture availability, it is expected to perform well in terms of growth and yield as it has propensity for efficient water use. This agrees with the findings of Waddington et al. (2007) and Sebetha et al.(2014) whoreported separately that rainfall significantly affects crop yields and yield components whether fertilizer has been applied or not. This observation confirms that when water is available in adequate quantities, the WEMA variety tends to respond better than it does under water deficit conditions. A superior performance was observed at the Taung experimental station with respect to maize yield and its yield components as opposed to what was recorded at the Molelwane farm. WEMA grain yield and yield components had superior performance in the Taung experimental field than Molelwane research field.

The better performance obtained in Taung station could be attributed directly to favourable edaphic factors such as an abundance of the necessary nutrients and a better soil-moisture-holding capacity. These factors in this location where higher than what was recorded in Molelewane site.

Nutrients, especially nitrogen, are known to enhance crop growth and development. These results are in consonance with the findings of Ion et al. (2015), who showed that nitrogen fertilization improves maize yield when the nitrogen content of the soil is low.

5.4.2: Maize yield and yield component as influenced by plant densities

The better performance in terms of yield and its components from plots sown at a plant density of 33,333 plants/ha could be attributed to less competition among the crops for the basic crop growth factors compared to other plant density with high plant population per unit area. When competition for resources is minimal, crops are likely to demonstrate superior performance levels in terms of the appropriate partitioning of their assimilates into useful products such as grains. On the other hand, competition stimulates the crop to use whatever it has synthesized for its own maintenance rather than to partition the product and use it to intensify its own economic yield. This could explain why under high plant density such as 55,555 plants/ha, the maize yield and its components were found to be lower than what was obtained at lower plant density.

The observations in this study do not agree with those of Maral et al. (2017), who reported that the highest stover yield was obtained under low plant density conditions. Nonetheless, the findings of Al-Naggar et al. (2015) and Hashemi et al. (2005), who reported that as the plant density per unit area increases, so the maize grain yield per plant decreases, agree with the results that we what we obtained during this trial. Similar results obtained by Plensicer and Kustor (2005) and Sharifi and Namvar (2016), that high plant density amplify the biological yield, are in line with the results of this study.

5.4.3: Maize yield and yield component as influenced by N fertilizer rates

The application of 120 kg N/ha fertilizer resulted in improved grain yield. On the other hand, the application of 180 kg N/ha enhanced the yield components of the WEMA variety. This suggests that grain yield and its components would be appreciably improved when marginal soil is supplied with quantities of nitrogen fertilizer ranging from 120 kg - 180 kg/ha. This shows that the availability of nutrients enhances the uptake of essential nutrients especially nitrogen, phosphorus and potassium, into the plant. These minerals are necessary for the production of meristematic tissue and the physiological activities of the leaves, roots and shoots, which in their turn promote the efficient translocation of water and nutrients so necessary in many of the metabolic processes, especially photosynthate accumulation.

Improved grain yield result was in line with the findings of Ahmad et al. (2018) who obtained highest grain yield with application of 180 kg N/ha. These findings disagreed with findings of Bakht et al., (2007)who reported that highest stover yield and harvest index were obtained with application of 200 and 160 kg N /ha. Also, unfertilized plots had highest shelling percentage. This indicates that the availability of nutrients in these quantities enhances the growth of the plant but these quantities are not sufficient to boost the plant in the reproductive stage. Our observation was disagreed with the findings of Ahmad et al., (2018) who reported that the shelling percentage increases as the nitrogen fertilizer increases.

5.4.4: Regression relationship between N fertilizer rates, plant densities maize yield and yield component

A significant and positive relationship was observed between nitrogen fertilizer rates and maize grain yield. This implies that as the nitrogen fertilizer rates increases, so the maize grain yield also increases. This underscores the importance of nitrogen in maize production and this result also corroborrates the findings of Yihenew (2015) who indicated that the maize grain yield increases in the same proportion as the nitrogen fertilizer rate increases.

The relationship between plant density level and maize grain yield indicates that as the plant density decrease, so the maize grain yield increases. These findings are similar to report of Tokatlidis (2012) who showed that each environments required an optimum plant density and failure to meet that actual planting density causing failure in yield potential.

5.4.5: Correlation between maize yield and yield components

The grain yield of the WEMA variety was significant and strongly correlated with total biological yield and stover yield. This indicates that as the maize grain yield increases, so the biological yield also increases. The biological yield had linear relationship with stover yield. This study revealed that an increased stover yield results in an increased biomass yield. This is in line with result of Yihenew (2015) who indicated that there was significant and positive relationship between maize grain yield and stover yield. Total biological yield showed no significant and negative correlation with harvest index and shelling percentage. This means that as the total biological yield increases, so both the harvest index and the shelling percentage decrease. The relationship between biological yield and harvest index could mean that in order to increase the harvest index, factors such as agronomical practices (e.g. fertilization, minimizing intra crop competition in terms of adequate plant population per unit area should be ensured.

5.4.6: Predicted optimum N fertilizer rate and plant density

The nitrogen fertilizer rates required to produce highest grain yield of 4.63 t/ha in WEMA was 180 kg N/ha using the quadratic model $y = -2E\text{-}05x^2 + 0.0067x + 4.0746$. This rate at which WEMA variety performed best was in tandem with the optimum nitrogen fertilizer rates recommended for growing corn in South Africa. Our result is in line with the findings of Nel and Bolem (2006) who reported that optimum nitrogen rates for maize production in Republic of South Africa varied from less than 10 to 252 kg N/ha. Furthermore, the plant density of 33,333 plants/ha required to produced highest yield of 4. 53 t/ha. This is agrees with the findings of Haarhoff and Swanepoel, (2018) who reported that in order to avoid crop failure, maize growers in semi-arid areas generally plant at low plant density between 14,000 and 18,000 plants/ha during years of unfavourable rainfall. Similarly, the interaction between the estimated optimum nitrogen fertilizer rates and plant densities needed to produce a maximum grain yield of 4. 5 t/ha amounted to 146 kg N/ha and 44,444 plants/ha.

Our finding is in line with the findings of African Agricultural Technology Foundation (2010) and African Centre Biodiversity (2017), who reported that a grain yield of 4.5 t/ha of WEMA maize grain yield was harvested. In the same manner, ideal plant density for WEMA is 44,444 plants/ha. This indicated that WEMA tolerated high plant density. This finding is in conformity with the findings of Tokatlidis (2012) who recommended that maize planted under dry conditions should not be beyond 4.5 plants/m^2. Haarhoff and Swanepoel (2018) further explained that there was no statistically difference between low plant density of 30,0000 and 120,000 plants/ha in semi-arid areas.

5.4.6: Path analysis

This is indicate that total biological yield and shelling percentage had great contribution to grain yield compared to stover yield and harvest index. This result is in concordance with the finding of Fellahi et al., (2013) that biological yield showed the greatest positive effect on grain yield of wheat. Furthermore, Golparvar and Karimi (2012) revealed that harvest index had negative effect on seed yield of canolaseed. By improving total biological yield and shelling percentage, the grain yield can be improved.

Conclusion

It was concluded that WEMA maize cannot tolerate severe drought which is the reason why yield was poor when rainfall volume was lower during the 2015/16 planting season. Greater improvements were experienced in the yields and its components, during the 2016//17 planting season, when the rainfall at the Molelwane was higher relative to the rainfall at the Taung . Appreciable quantities of grain were harvested from plots supplied with 180 kg N/ha relative to other N fertilizer rates especially under the native nutrients. However, components of yield were better at lower N fertilizer rate of 120 kg N/ha. Maize grain yield and yield were greatly influenced by plant density ranged from 44,444 plants/ha. However, the predicted optimum nitrogen fertilizer rate and plant density for WEMA grain yield are 148 kg N/ha and 44,444 plants/ha for Molelwane and Taung localities of North West province of Republic of South Africa.

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CHAPTER SIX

NUTRITIONAL COMPOSITION OF WATER EFFICIENT MAIZE (*Zea mays L.)* KERNELS AS INFLUENCED BY NITROGEN RATES AND PLANT DENSITY IN MOLELWANE AND TAUNG, SOUTH AFRICA

ABSTRACT

The nutritional quality of maize is usually affected by environmental conditions and cultural management practices. This study was conducted during the 2015/16 and 2016/17 planting seasons at Taung and Molelwane to investigate the effect of different nitrogen fertilizer rates and plant densities on nutritional attributes of grain of Water Efficient Maize (WEMA).

In each trial site, the experiment was laid out in split plot arrangement fitted into randomized complete block design with four replicates. The main plot effect at each trial site was plant density (33,333 44,444 and 55,555 plants/ ha) while nitrogen rates (0, 60, 120, 180 and 240 kg N/ ha) constitutes the sub-plot. The nutritional qualities determined are oil yield, protein yield, starch yield, grain nitrogen uptake and ethanol production. Data were analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences in the treatment means were tested by Least significant difference (LSD) at $p \leq 0.05$. The relationships among nutrient composition of the kernel, N rates and plant density were evaluated using regression and correlation analyses. Season x location x nitrogen N fertilizer rates x plant densities had significant ($p \leq 0.05$) effect on the nutritional attributes of WEMA. In fact, during the 2016/17 planting season WEMA variety had significantly highest oil yield (486 kg/ha) in plots with 55,555 plant density and fertilized with 180 kg N/ha .Furthermore, also at the same location, and during the same planting season, higher starch yield (5,166 kg/ha) was recorded under the same plant density of 55,555 plants/ha from plots fertilized with 180 kg N/ha. The predicted interaction between optimum nitrogen fertilizer rate and plant density interaction for starch yield is 120 kg N/ha and 44,444 plants/ha to produce 2,700 kg/ha. However, other nutritional components were better at higher density of 55,555 plant/ha and 240 kg N/ha.

Keywords: Oil yield, grain nitrogen uptake, ethanol production optimum nitrogen, optimum density

6.1: Introduction

Owing to its nutritional qualities, maize has the reputation of being the most important dietary crop in Africa (Mandigora, 2018). According to IITA (2009) and Mandigora (2018), maize is South Africa’s staple food with more than 85% of the white maize produced being used for human consumption. Maize is used as a raw material in the production of many commodities such as starch, flour, ethanol and cooking oil (Koca et al., 2015). The quality of the maize kernel determines the grain quality, which in turn is directly related to the nutritional quality or chemical composition of the maize grain (Zilic et al., 2011).

South Africa is ranked as the 10th largest maize producer in the world and the largest maize producer in Africa (International Biotechnology Outreach, 2017; Mandigora, 2018). According to a study in China (Ahoulete et al., 2011; Zhao et al., 2009), many researchers have reported that the maize grain is richer in starch than grain of sweet sorghum with production levels of 39% to 48% respectively. Maize grain has so many other valuable commodities as by-products, such as ethanol, that can be used as a biofuel (DAFF, 2015, ;Ndokwana, 2016).

Nitrogen is a major element that is essential for the synthesis of amino acids, nucleic acids, hormon and some organic acids that are important for plant growth and development (Neuman et al., 2017). The application of nitrogen fertilizer is one of the most important agronomic practices that influences grain yield and the nutritional quality of maize (Anther et al., 2009). Da Silva (2013) reported that increased in nitrogen fertilizer significantly affect composition of maize kernel. Rafiq et al. (2010) observed a linear relationship between the nitrogen fertilizer rates and grain’s protein content.

Nitrogen fertilizer enhanced the nutritive value by increasing protein content (Anther et al., 2009). Grain nitrogen accumulation increased drastically as nitrogen fertilizer increased (Yang et al., 2004). Although, Ahouelete et al. (2011) indicated that the oil content of the maize grain is not affected by the quantity of nitrogen applied, the oil yield was nevertheless found to decline as the nitrogen fertilizer rate declined.

It has also been reported in another study that applications of nitrogen fertilizer reduce the starch content of the maize grain (Ahouelete et al., 2011), thus increasing the proportion of protein in the grain. In another report by Sebetha (2015), the highest starch content was recorded on a plot where a zero nitrogen fertilizer rate was applied.

Ensuring an adequate plant population density is also a significant cultural practice that affects maize production. Munamava et al., (2006) and Koca et al. (2017) reported that as opposed to the older maize varieties, the newer maize breeds are responding extremely well to .higher.plant density. Infante et al. (2018) reported that high plant density enhance the production of oil in maize kernels than is the case with lower plant density. According to Koca et al. (2017), kernels with the highest oil and protein content were harvested from fields sown at a plant density of 59 524 plants/ha. Zhang et al. (2016) showed that kernel protein proportions increase with an increase in the plant density from 120 -180 plants/m^2.

However, information on the effect of nitrogen fertilizer and plant density on nutritional quality of Water Efficiency Maize for Africa (WEMA), a newly released drought tolerant maize variety is inconsistent. Thus, this study was conducted to assess the effects of different nitrogen fertilizer rates and plant densities on nutritional composition of kernels of WEMA variety in two localities of North West Province of South Africa.

6.2.0 Materials and Methods

6.2.1 Description of study area

The experiment was carried out during the 2015/2016 and 2016/2017 planting seasons at the Molelwane North-West University (NWU) Research Farm (25° 48^{1}S, 45° 38′E and 1,012 m asl.) and Taung Experimental Station (27 30′S, 24 30′E; 1,111 m asl)of the Provincial Department of Agriculture Research Station during 2015/2016 and 2016/2017 planting seasons. Both sites are located in the North West Province of South Africa.

The NWU research farm is located in a semi-arid tropical savanna region that receives a mean annual summer rainfall of 571 mm while the Taung trial site receives a mean annual rainfall of 318 mm (Kasirivu et al., 2011; Saexplorer 2019). The Taung Experimental Station had average maximum temperature of 35 °C and the mean minimum temperature ranged between 5°C–18.5°C. The annual average pan evaporation of North-West is 1023 mm (Kasirivu et al., 2011). Approximately, 68% of the annual precipitation at the NWU farm falls between November and January in a few relatively heavy downpours, with a pronounced dry season from April to September.

North West Province experiences a mean maximum temperature of 37°C while the mean minimum temperature ranges from 7°C – 11°C. The annual average pan evaporation level for North West is 1 023 mm (Kasirivu et al., 2011).

The soil at the two sites is deep, fine and freely drained. It is dominated by yellow and red soils, which are eutrophic with aeolian deposits (Staff, 1999). The soils belong to the Hutton series, according to South Africa soil classification (Molope, 1987; Kasirivu et al.,2011). The classification of the soil as NWU Research Farm is Ferric luvisol while that of Taung is Rhodic Ferrasol (WRB, 2016).

6.2.2 Soil Sampling and Analysis

The pre-plant soil samples collected (0-15 and 15-30 cm soil depth) from the trial sites were subjected to laboratory analysis following standard procedures. The results, as presented in Table 6.1, suggest that the soils at both sites are low in total N and phosphorus (P). The soil at Molelwane is sandy loam while that of Taung is loamy sand.

Table 6.1 1: Physico-chemical properties of experimental sites during 2015/16 and 2016/17

Physio-chemical Properties	**2015/2016 trial**				**2016/2017trial**			
	0-15 cm		**0-30 cm**		**0.15 cm**		**0-30 cm**	
	Molelwane	**Taung**	**Molelwane**	**Taung**	**Molelwane**	**Taung**	**Molelwane**	**Taung**
Sand (%)	82	85	82	85	82	85	82	85
Silt (%)	1	1	1	1	1	1	1	1
Clay (%)	18	14	18	14	18	14	18	14
Texture	Sandy Loam	Loam sandy	Sandy loam	Loam sandy	Sandy Loam	Loam sandy	Sandy Loam	Loam sandy
Total N %	0.08	0.12	0.03	0.1	0.17	0.19	0.18	0.15
Avail P mg/kg	6	5	10	3	80	49	11	8
K mg/kg	279	366	322	304	238	180	203	185
pH (H_2O)	4.31	6.45	4.18	4.50	4.50	4.30	4.30	5

6.2.3 Weather conditions during experimental period

Planting of the trial took place between December, 2015 and July, 2016 at both Molelwane, the NWU farm, and the Taung experimental station, under the auspices of the Department of Agriculture. Likewise in 2016/17, the sowing of the trial took place between December, 2016 and June, 2017 at both locations. A summary of the climatic conditions at the sites during the experimental planting seasons was obtained from the South African Weather Services and is presented in Table 2. During the 2015/16 planting season, the amount of rainfall received was insufficient to sustain the growth of the crop in both locations. Hence, supplementary irrigation was provided from the emergence stage through to the early vegetative stage to guarantee good crop establishment. However, during the 2016/17 planting season, the trial crop at both locations was purely rainfed. The total amount of supplementary irrigation applied was not quantified.

Table 6.2: Rainfall, temperature and relative humidity data of experimental locations

Climate data	**Molelwane**	**Taung**
2015/16 summer planting season		
Temperature (°C)		
Minimum	15.24	13.77
Maximum	27.00	31.32
Mean daily	22.17	22.47
Total Rainfall (mm)	257.40	231.20
Relative humidity (%)		
Minimum	13.77	22.57
Maximum	74.86	74.00
Mean	50.29	48.86
2016/17 summer planting season		
Temperature (°C)		
Minimum	13.16	11.57
Maximum	27.23	29.09
Mean daily	20.16	20.42
Total Rainfall (mm)	646.40	598.80
Relative humidity (%)		
Minimum	34.14	24.29
Maximum	86.43	82.89
Mean	61.86	54.14

Source: South African Weather Services (2018)

6.2.4 Experimental Design and Treatments

The layout of experiment at each location was in split plot arrangement fitted into a randomized complete block design with four replicates. The main plot effect was the three plant densities (33,333, 44,444 and 55,555 plants/ha) while the five N fertilizer rates (0.60, 120,180 and 240 kg N/ha) constituted the sub plot effect. Each subplot measured 6 m x 4 m with a total experimental plot size of 30 m x 76 m at each site. Maize (WE 3127) seed sowing was done at inter and intra row spacing of 1m x 0.3m, 0.75 m x 0.3m and 0.9 m x 0.2 m to achieve the density of 33,333, 44,4444, and 55,555, respectively.

6.2.5 Cultural Practices

Basal fertilizer application of a third of the each rate using NPK 20:7:3 was done at planting while two-third and a third of the remaining amount from each rate was applied as top dressing at 3 and 5 weeks after seedling emergence (WAE) using lime ammonium nitrate (LAN, 28%). Manual weeding was done at 3 and 7 weeks after seed sowing to maintain a weed-free condition.

6.2.6. Data collection

The maize grains were analysed using the Near Infrared Reflectance (NIR) Grain Analyser (NIR) at the Agricultural Reseach Council's GCI food quality laboratory. The maize grains were analysed for their oil, protein and starch content. The oil, protein and starch yields were calculated according to the procedures described by Ahouelete et al. (2011):

Oil yield (kg/ha) = $\frac{oil\ content\ \%\ x\ grain\ yield}{100}$

Protein yield (kg/ha) = $\frac{Protein\ content\ \%\ x\ grain\ yield}{100}$

Starch yield (kg/ha) = $\frac{Starch\ content\ \%\ x\ grain\ yield}{100}$

The nitrogen content of the grain was obtained according to the methods of AOAC (2000)

Grain nitrogen content = $\frac{Protein\ content\ \%}{6.25}$

Grain nitrogen uptake = $\frac{Grain\ nitrogen\ \%\ x\ grain\ yield}{100}$

Ethanol was obtained from starch yield as described by Thomas et al. (1996) and Ahouelete et al., (2011) as follows: Ethanol = Starch yield x 1.11 x 0.51

6.2.7 Statistical Analysis

All data obtained were analyzed using analysis of variance (ANOVA) of GenStat 11th edition. Differences in the treatment means were tested by Least significant difference (LSD) at 5% level of probability. Regression analysis was calculated manually using Excel programme.

6.3: Results

6.3.1: Nutritional attributes of WEMA as influenced by planting season, location, different N rates and plant densities

6.3.1.1. Oil and protein yield

The analysis of variance revealed that oil and protein yield were significantly affected ($p \leq 0.05$) by planting season (Figures 1- 4). Higher oil yield (312.20 kg /ha) and protein yield (411.16 kg/ha) were recorded during the 2016/17 than during the 2015/16 planting season (Figure 6.1).

Location also had significant effect on the oil and protein yields. Maize grains obtained from the Molelwane farm produced higher oil (245.70 kg /ha) and protein (396 kg/ha) yield than those obtained from Taung field (Figure 6.2). Although the plant density had no significant effect on the protein production, the highest oil (254.80 kg/ha) and protein (448 kg/ha) yields were obtained from those plots with a plant density of 33,333 plants/ha (Figure 6.3). Instead, the nitrogen fertilizer had significant effect on the oil and protein yield. The plots supplied with 240 kg/ha of nitrogen fertilizer produced highest oil yields (361.50 kg/ha). Similarly, the highest protein yields (571.00 kg/ha) were recorded from those plots that were supplied with 240 kg N/ha. Nevertheless, there was no significant difference in the case of the plots supplied with 180 kg N/ha (Figure 6.4).

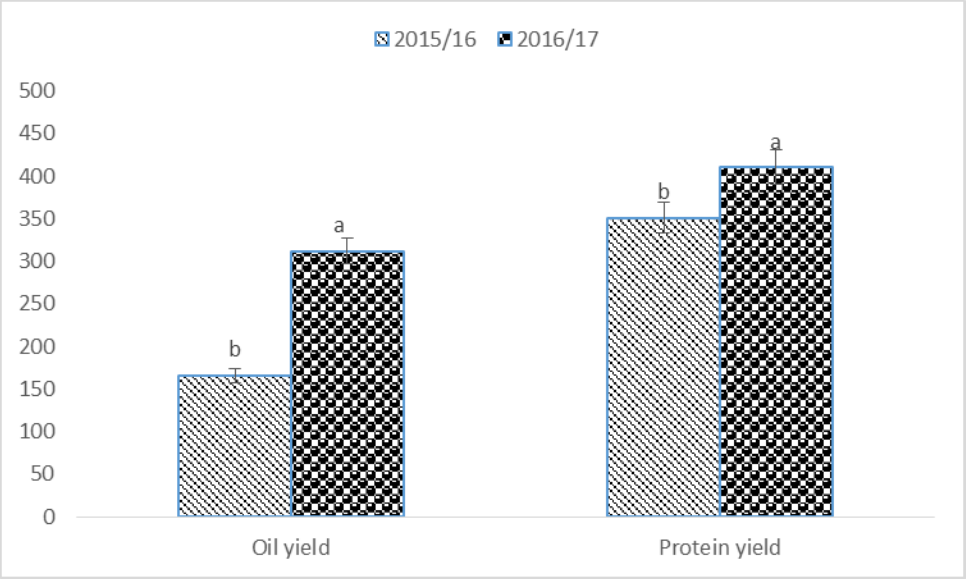

Figure 6.1: Effect of planting season on oil and protein yield of WEMA

Notes: Means with the same letter(s) in the same column are not significantly different at P ≤0.05 according to Least significant difference.

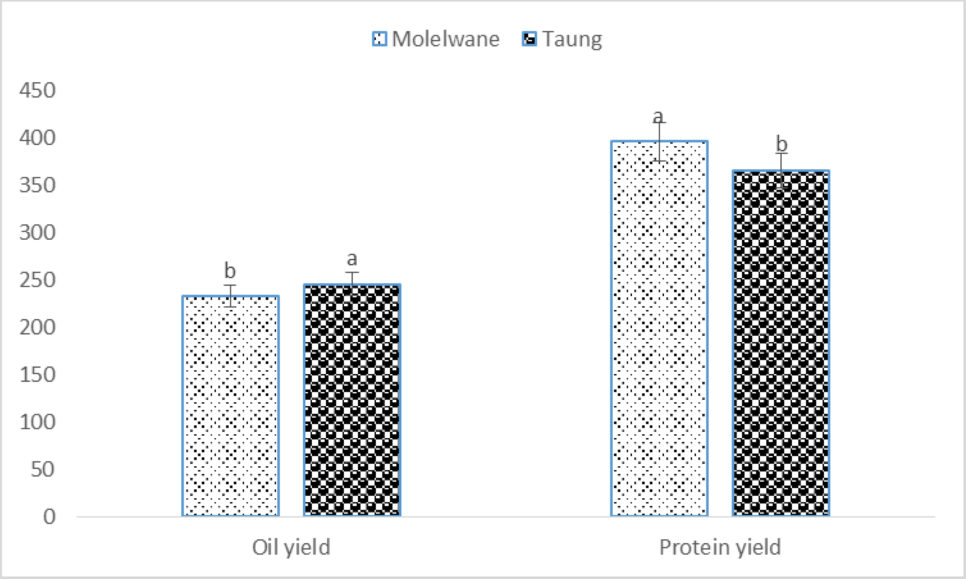

Figure 6.2: Effect of location on oil and protein yield of WEMA

Notes: Means with the same letter(s) in the same column are not significantly different at P ≤0.05 according to Least significant difference.

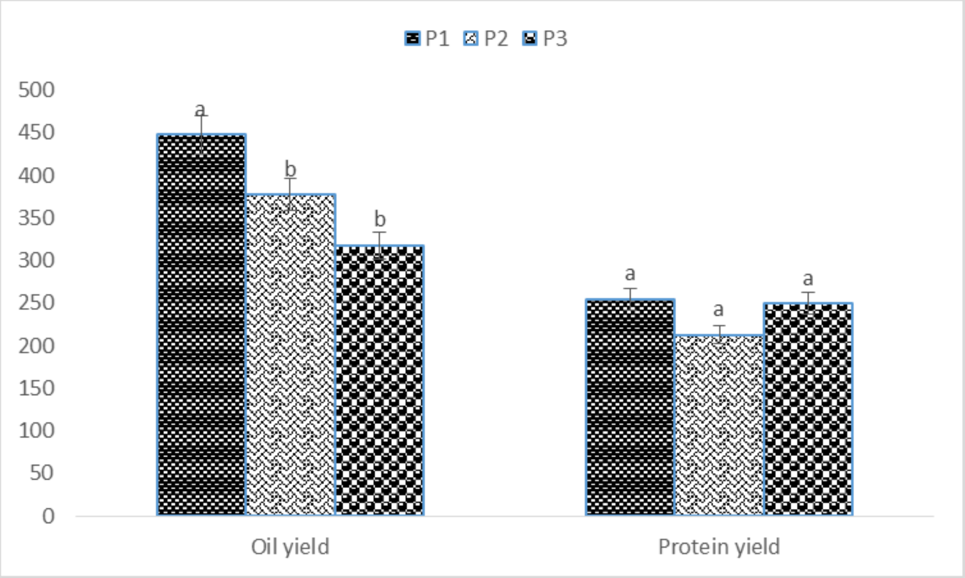

Figure 6.3: Effect of planting density on oil and protein yield of WEMA

Notes: Means with the same letter(s) in the same column are not significantly different at P ≤0.05 according to Least significant difference

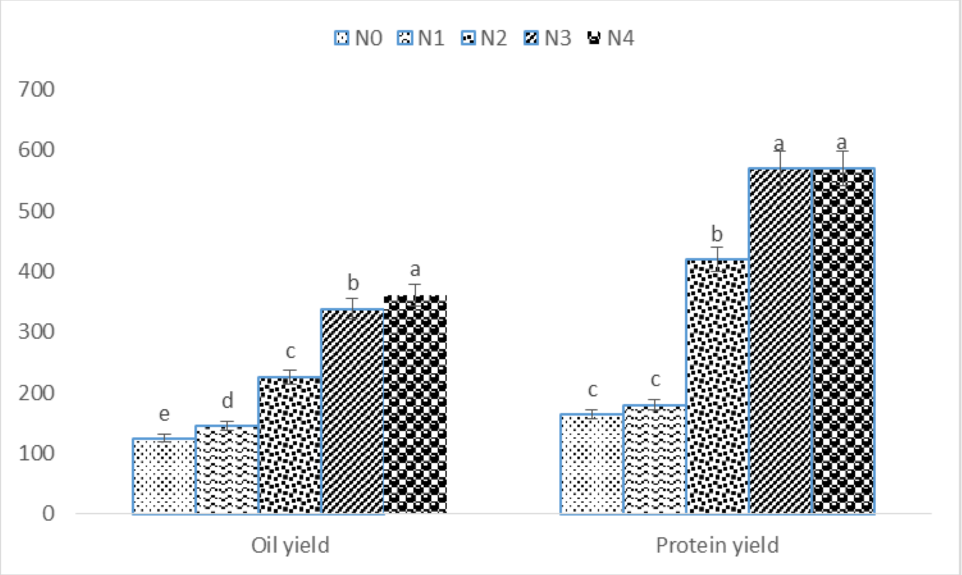

Figure 6.4: Effect of nitrogen fertilizer rates on oil and protein yield of WEMA

Notes: Means with the same letter(s) in the same column are not significantly different at P ≤0.05 according to Least significant difference

6 3.1.2. Starch yield and ethanol production of WEMA variety as influenced by plant density and different N fertilizer rates

Maize starch and ethanol production was significantly ($p \leq 0.05$) affected by the planting season (Table 6.3). Higher starch yield (3,465 kg/ha) was recorded during the 2016/17 planting season than during the 2015/16 planting season.

Location had no significant ($p \geq 0.05$) effect on starch production. A higher starch yield (3,011 kg/ha) was produced at the Taung trial than at the Molelwane trial. The planting season and the location had no significant ($p \geq 0.05$) effect on the production of ethanol but higher ethanol production (1,964 kg/ha) was observed during the 2016/17 planting season.

Starch yield and ethanol production were significantly ($p \leq 0.05$) affected by different plant densities. A plant density of 33,333 plants/ha produced the highest starch yield (3,278 kg/ha), while the highest ethanol production (2,034 kg/ha) was obtained under 55,555 plants/ha.

Variable nitrogen fertilizer rates significantly ($p \leq 0.05$) affected starch yield and ethanol production. The yields of starch produced from plots fertilized with 240 kg N/ha were higher (4,478 kg N/ha) than those produced from other fertilizer rates. Applications of 240 kg N/ha resulted in highest ethanol production (3,090 kg /ha), but there was no significant difference in the production arising from applications of 180 kg N/ha (Table 6.3).

6.3.1.3. Grain nitrogen uptake

The grain nitrogen uptake was not significantly ($p \geq 0.05$) affected by planting season (Figure 6.5-6.8). Higher grain nitrogen uptake (58.65 kg/ha) was obtained during the 2016/17 planting season. On the other hand, the grain nitrogen uptake was significantly ($p \leq 0.05$) affected by location. The Taung had higher grain nitrogen uptake (60.53 kg/ha). Significant and highest grain nitrogen uptake (64.28 kg /ha) was recorded under 33,333 plants/ha. Different N fertilizer rates had significant ($p \leq 0.05$) effect on grain nitrogen uptake. Application of 240 kg N/ha resulted in highest nitrogen uptake but not significantly difference from 180 kg N/ha.

Table 6.3: Starch yield and ethanol production of WEMA variety as influenced by plant density and different N fertilizer rates at two localities during 2015/16 and 2016/17 planting seasons

Treatment factors	Total starch (kg/ha)	Ethanol production (kg/ha)
Planting season		
2015/16	2454b	1615.00b
2016/17	3465a	1964.00a
$LSD_{(0.05)}$	66.70	147.20
Location		
Molelwane	2908b	1651.00b
Taung	3011a	1927.00a
$LSD_{(0.05)}$	66.70	147.20
Planting Density (plants/ha)		
33333	3278a	1473.00c
44444	2555c	2034.00a
55555	3044b	1860.00b
$LSD_{(0.05)}$	81.60	180.30
N rates (kg/ha)		
0	1506c	852.00d
60	1559c	890.00d
120	2785b	1584.00c
180	4467a	2529.00b
240	4478a	3090.00a
$LSD_{(0.05)}$	105.4	232.70

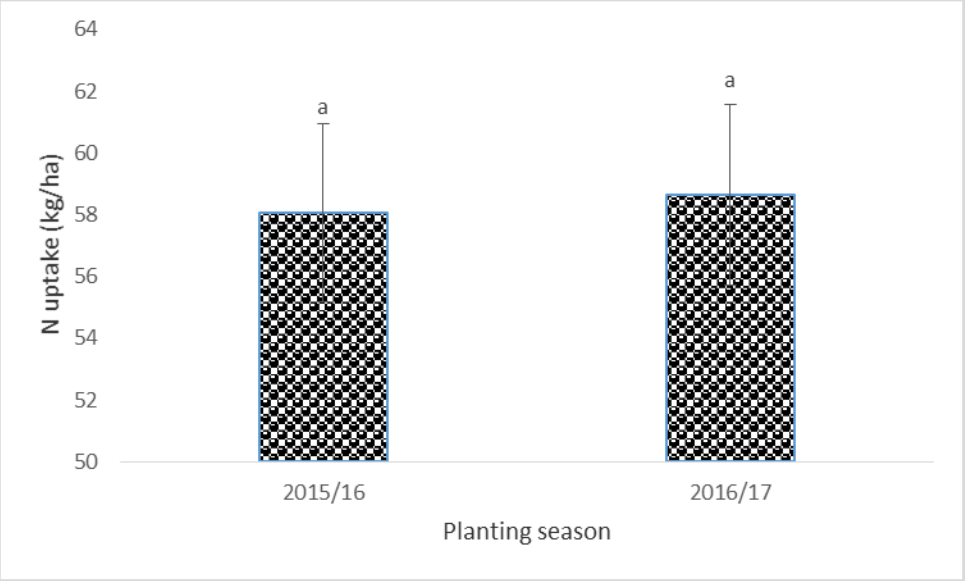

Figure 6.5: Effect of planting season on grain N uptake by WEMA kernel

Notes: Means with the same letter(s) in the same column are not significantly different at P≤0.05 according to Least significant difference

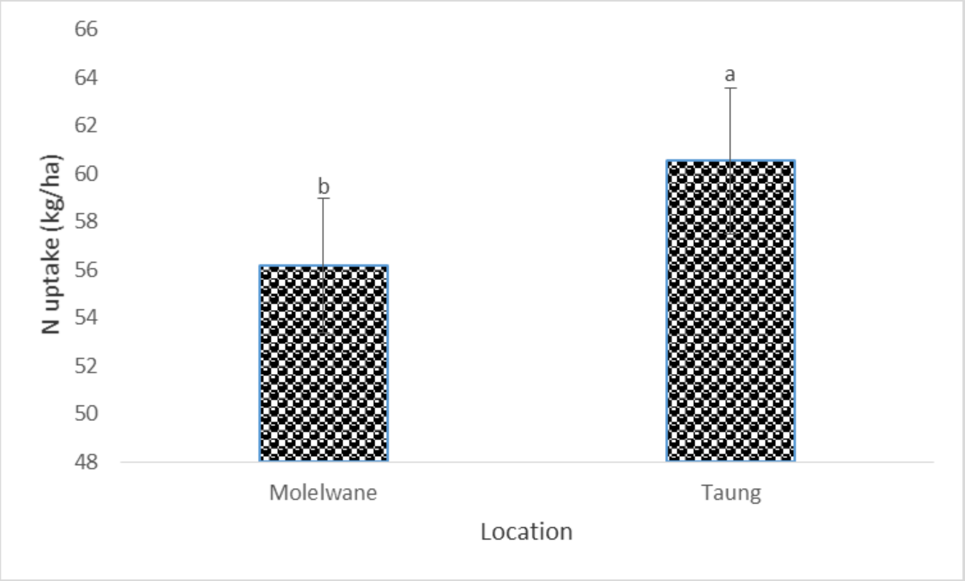

Figure 6.6: Effect of location on grain N uptake by WEMA kernel

Notes: Means with the same letter(s) in the same column are not significantly different at P≤0.05 according to Least significant difference.

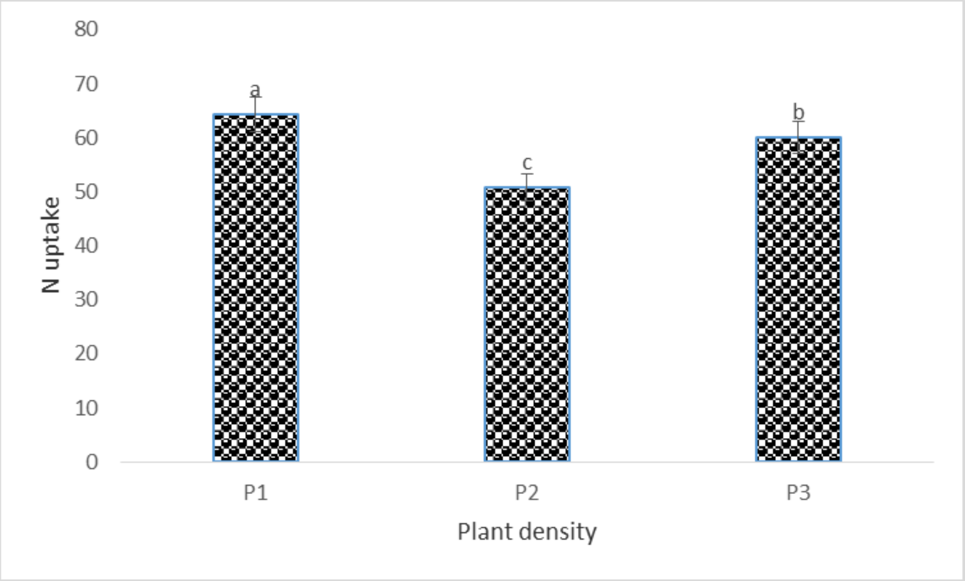

Figure 6.7: Effect of planting density grain N uptake byWEMA Kernel

Notes: Means with the same letter(s) in the same column are not significantly different at P≤0.05 according to Least significant difference.

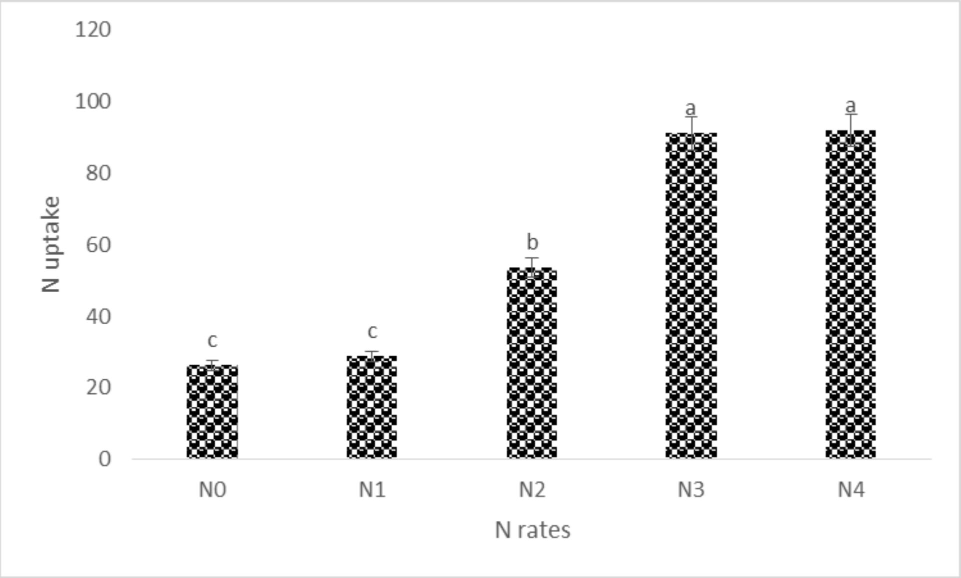

Figure 6.8: Effect of nitrogen fertilizer rates grain N uptake of WEMA

Notes: Means with the same letter(s) in the same column are not significantly different at P≤0.05 according to Least significant difference

6.3.2: Interaction effect of planting season, location, plant density and nitrogen fertilizer rates nutritional composition of WEMA

6.3.2.1. Oil and protein yields

Interaction among planting season, location, plant density and N fertilizer rates significantly (p<0.05) influenced nutritional composition of WEMA variety (Table 6.4). Total oil yield was highest (486 kg N/ha) statistically, during the 2016/17 plant season at Taung field under 55,555 plants/ha with the application of 180 kg N/ha relative to plots with 0 kg N/ha at Molelwane under 44,444 plant/ha during the 2015/16 planting season. Higher protein yield was produced at Taung field under 33,333 plants/ha in the plots fertilized with 120 kg N/ha compared to the protein yield recorded during the 2016/17 planting season in plots sown at 44,444 plants/ha at the same locations without fertilizer application.

6.3.2.2. Starch yield and ethanol production

Starch and ethanol production were statistically affected by interaction of planting season x location x plant density x nitrogen fertilizer rates (Table 6.5). The starch had higher yield (5,166.00 kg/ha) during 2016/17 in Molelwane and Taung fields under the same density of 55,555 plants/ha in plots fertilized with 180 kg N/ha compared to starch yield (405 kg/ha) obtained during 2016/17 and 2015/16 planting seasons in Taung field under 44,444 plants/ha in the unfertilized plots, respectively. Higher ethanol production (8,893.00 kg/ha) was obtained during the 2015/16 planting season from the Taung plots at a plant density of 55,555 plants/ha with applications of nitrogen fertilizer of 240 kg/ha than was the case with the ethanol produced from unfertilized plots at the same location and during the same planting season and at a plant density of 44,444 plants/ha.

6.3.2.3. Grain nitrogen uptake

The grain nitrogen uptake of WEMA was significantly affected by the interactions among season x plant density x location x nitrogen fertilizer rate (Table 6.6). Highest grain nitrogen uptake (119.80 kg/ha) was obtained from plots at the Molelwane during the 2015/16 planting season that were fertilized with 240 kg N/ha under plant density of 55,555 plants/ha compared with other treatments investigated.

Table 6.4: Effect of planting density, location, plant density and nitrogen fertilizer rates on oil and protein yield

Season	Location	N rate	Plant density	Oil Yield	Protein yield
201516	Molelwane	0	33,333	36.30	77.00
			44,444	23.40	56.00
			55,555	37.90	81.00
		60	33,333	32.20	76.00
			44,444	38.60	81.00
			55,555	40.10	98.00
		120	33,333	288.70	618.00
			44,444	34.20	89.00
			55,555	35.90	94.00
		180	33,333	318.90	671.00
			44,444	216.50	552.00
			55,555	312.30	722.00
		240	33,333	305.20	743.00
			44,444	320.20	709.00
			55,555	305.20	751.00
	Taung	0	33,333	35.10	68.00
			44,444	24.90	55.00
			55,555	48.70	95.00
		60	33,333	93.20	131.00
			44,444	31.10	69.00
			55,555	41.90	82.00
		120	33,333	277.50	1592.00
			44,444	63.10	135.00
			55,555	218.20	466.00
		180	33,333	310.90	671.00
			44,444	245.50	566.00
			55,555	349.60	650.00

		240	33,333	269.60	631.00
			44,444	300.30	584.00
			55,555	326.40	667.00
	Molelwane	0	33,333	227.70	241.00
			44,444	253.60	247.00
			55,555	219.30	239.00
		60	33,333	227.60	287.00
			44,444	224.40	214.00
			55,555	232.20	198.00
		120	33,333	333.70	359.00
			44,444	185.60	202.00
			55,555	273.10	326.00
		180	33,333	440.70	484.00
			44,444	355.30	509.00
			55,555	363.80	426.00
		240	33,333	366.20	391.00
			44,444	450.50	481.00
			55,555	475.10	522.00
2016/17	Taung	0	33,333	195.10	290.00
			44,444	209.80	277.00
			55,555	179.40	241.00
		60	33,333	252.40	301.00
			44,444	257.20	312.00
			55,555	270.70	313.00
		120	33,333	346.00	364.00
			44,444	232.10	276.00
			55,555	424.70	520.00
		180	33,333	371.80	530.00
			44,444	426.30	492.00
			55,555	486.20	570.00
		240	33,333	366.50	441.00
			44,444	362.10	451.00
			55,555	355.40	484.00
LSD $_{(0.05)}$				59.04	179.60

Table 6.5: Effect of planting season, location, plant density and nitrogen fertilizer rates on starch and ethanol production

Season	Location	N rate	Plant density	Starch yield (kg/ha)	Ethanol production (kg/ha)
2015/16	Molelwane	0	33,333	579.00	328.00
			44,444	437.00	247.00
			55,555	570.00	322.00
		60	33,333	481.00	273.00
			44,444	543.00	307.00
			55,555	606.00	345.00
		120	33,333	4079.00	2309.00
			44,444	582.00	344.00
			55,555	556.00	385.00
		180	33,333	4079.00	2764.00
			44,444	3485.00	1973.00
			55,555	4976.00	2817.00
		240	33,333	4569.00	2587.00
			44,444	4567.00	2586.00
			55,555	4609.00	2609.00
	Taung	0	33,333	536.00	304.00
			44,444	405.00	229.00
			55,555	704.00	399.00
		60	33,333	1038.00	588.00
			44,444	504.00	285.00
			55,555	611.00	346.00
		120	33,333	4309.00	2439.00
			44,444	1000.00	566.00
			55,555	3267.00	1850.00
		180	33,333	4309.00	2473.00
			44,444	3742.00	2118.00
			55,555	4858.00	2750.00
		240	33,333	4580.00	2593.00
			44,444	3321.00	2411.00
			55,555	4841.00	8893.00
2016/17	Molelwane	0	33,333	2215.00	1254.00
			44,444	2812.00	1592.00
			55,555	2445.00	1384.00
		60	33,333	2642.00	1585.00
			44,444	2261.00	1280.00
			55,555	2720.00	1540.00
		120	33,333	3769.00	2134.00
			44,444	1856.00	1051.00
			55,555	3169.00	1794.00
		180	33,333	3769.00	2855.00
			44,444	4344.00	2459.00
			55,555	3906.00	2211.00
		240	33,333	4962.00	2809.00
			44,444	4862.00	2738.00
			55,555	4698.00	2659.00
	Taung	0	33,333	2102.00	1190.00
			44,444	2731.00	1546.00

		55,555	2532.00	1433.00
	60	33,333	2808.00	1590.00
		44,444	2451.00	1387.00
		55,555	2047.00	1159.00
	120	33,333	3943.00	2232.00
		44,444	2541.00	1438.00
		55,555	4352.00	2464.00
	180	33,333	3943.00	2262.00
		44,444	4842.00	2741.00
		55,555	5166.00	2925.00
	240	33,333	4660.00	2638.00
		44,444	3818.00	2161.00
		55,555	4242.00	2402.00
$LSD_{(0.05)}$			365.10	140.10

Table 6.6: Effect of planting season, location, plant density and nitrogen fertilizer rates on nitrogen grain uptake

Season	Location	N rate	Plant density	Nitrogen grain uptake
2015/16	Molelwane	0	33,333	12.14
			44,444	8.95
			55,555	12.89
		60	33,333	12.14
			44,444	12.98
			55,555	15.63
		120	33,333	98.69
			44,444	14.31
			55,555	14.99
		180	33,333	107.31
			44,444	88.28
			55,555	115.49
		240	33,333	118.74
			44,444	113.15
			55,555	119.80
	Taung	0	33,333	10.87
			44,444	8.74
			55,555	15.19
		60	33,333	20.91
			44,444	10.99
			55,555	13.09
		120	33,333	97.09
			44,444	21.68
			55,555	74.48
		180	33,333	107.42
			44,444	90.50
			55,555	104.18
		240	33,333	100.97
			44,444	93.57
			55,555	106.75
2016/17	Molelwane	0	33,333	38.63
			44,444	39.56
			55,555	38.27
		60	33,333	45.82
			44,444	34.26
			55,555	31.62
		120	33,333	58.69
			44,444	32.31
			55,555	52.11
		180	33,333	77.82
			44,444	80.35
			55,555	68.23
		240	33,333	62.53
			44,444	76.90
			55,555	82.69
	Taung	0	33,333	46.39
			44,444	44.34

		55,555	38.45
	60	33,333	48.19
		44,444	49.97
		55,555	50.15
	120	33,333	58.25
		44,444	44.21
		55,555	77.62
	180	33,333	84.79
		44,444	78.67
		55,555	91.03
	240	33,333	78.20
		44,444	72.01
		55,555	77.33
LSD $_{(0.05)}$			11.09

6.3.3: Relationship between N uptake, starch yield and N fertilizer rates

The regression analysis indicates that there was significant and direct relationship between nitrogen fertilizer rate and grain nitrogen uptake with $R^2 = 0.91$ (Figure 6.9). There was a linear relationship between nitrogen fertilizer rate and starch yield (Figure 6.10).

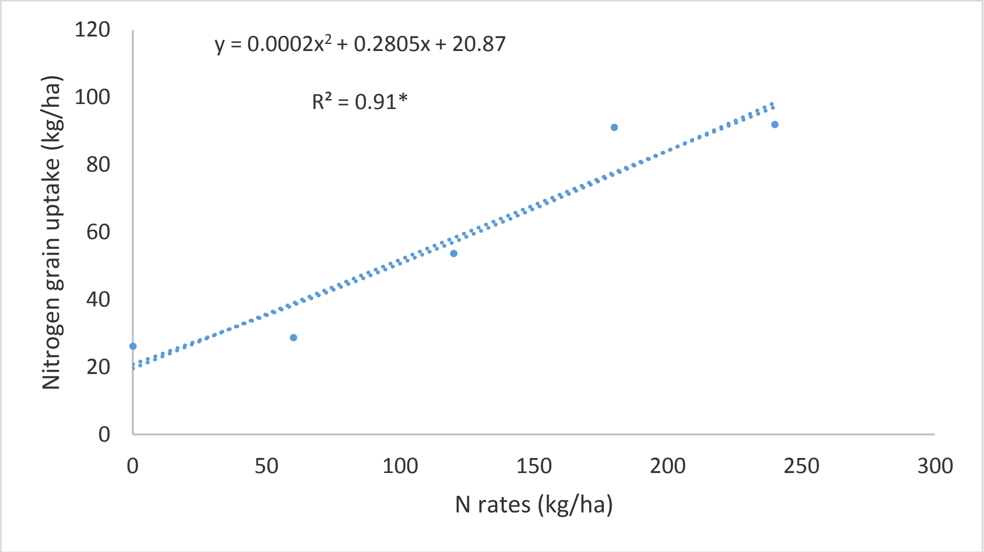

Figure 6.9: Relationship between N grain uptake and N fertilizer rates

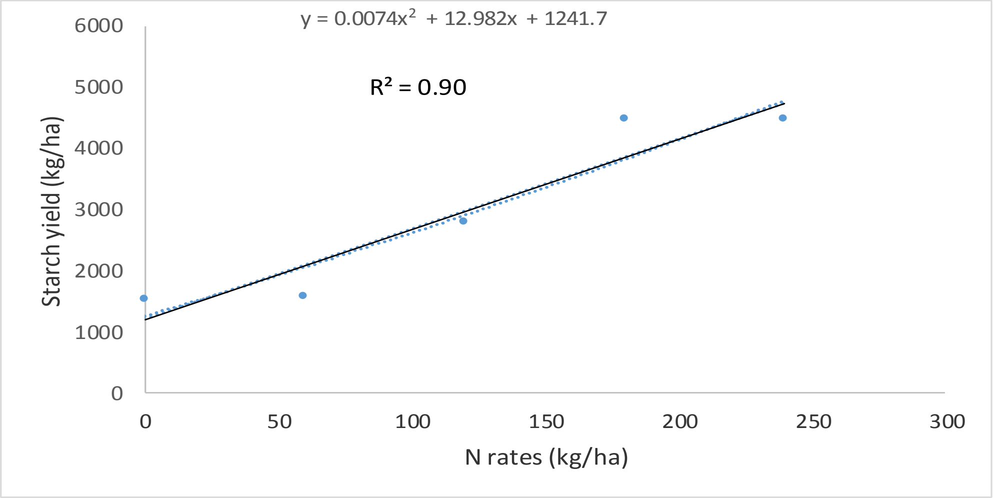

Figure 6.10: Relationship between starch yield and N fertilizer rates

6.3.4: Relationships between nitrogen fertilization rate and starch yields and plant density respectively

The optimum interaction between nitrogen fertilizer rate and plant density was determined using quadratic model y = -303.75x^2 + 2562.6x - 806.25 and y = -127.5x^2 + 1126.5x + 812 respectively, while correspondingly R^2 = 0.96 and 1 (Figure 6.11). The nitrogen fertilizer rate and plant density interaction indicated that the fertilizer rate at 120 kg N/ha and plant density (44 444 plants /ha) enhanced the optimum nutritional composition of the WEMA kernel and therefore its production in North West Province. The highest starch yield (2,700 kg/ha) was obtained at the predicted optimum interaction between nitrogen fertilizer rate and plant density.

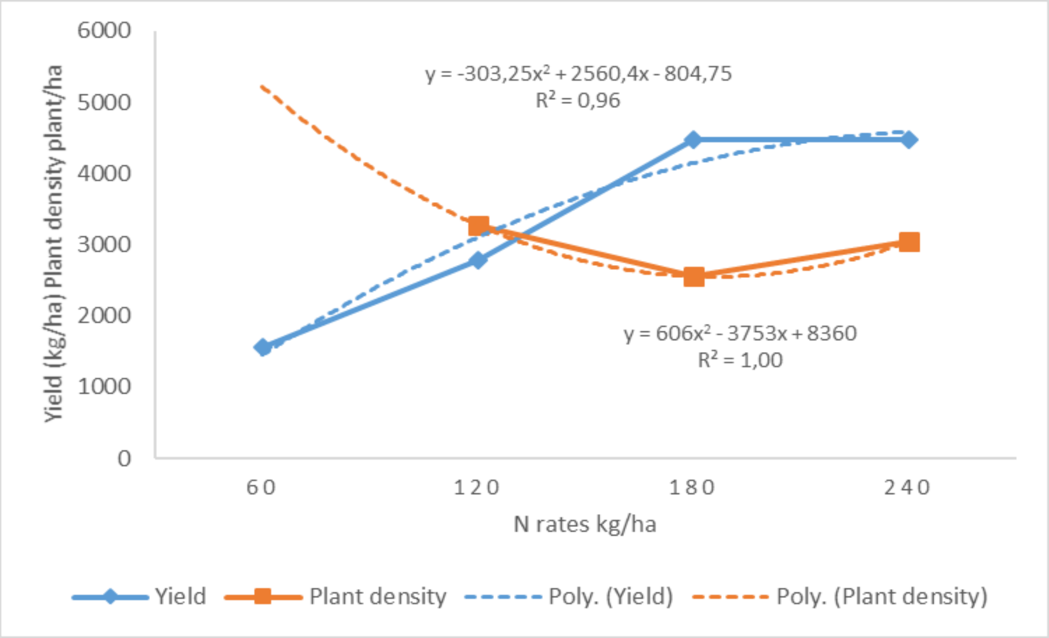

Figure 6.11: Starch yield x N rates x plant density interaction

6. 4: Discussion

The highly nutritional qualities of Water Efficiency Maize (WEMA) grain were demonstrated during the 2016/17 planting season, which outclassed the 2015/16 planting season. This could be attributed to the more favourable conditions of the 2016/2017 planting season. More rainfall was received during the 2016/17 season which would have contributed to the availability of nutrients in the soil ,which could then have been efficiently utilized to improve the nutritional quality of the WEMA variety. The importance of favourable weather conditions, especially in terms of rainfall in enhancing the developmental processes in the maize crop's life cycle cannot be overemphasized.

The observations made in this study agree with the findings of Kejicirious et al. (2007) and Buresova et al. (2010) who reported that the protein yield is affected by climatic conditions. The variation in the cropping seasons drastically affected the starch quality of the grain which is probably associated with rainy weather (Lango et al., 2017). De Geus et al. (2008) also observed that the protein yield for a particular genotype differs significantly between two planting seasons. Haegele (2008) showed that environmental stresss, such as deficits of water and nutrients limit kernel development.

Maximum nutritional attributes were obtained in Taung field compared to Molewane Farm. These could be linked to the environmental conditions and soil types and selected maize variety. For instance, the Taung trial soil had higher nitrogen content than that of the Molelwane field as revealed by the results of the pre-planting soil analysis.

This observation is in agreement with the findings of Zhao et al. (2007) that the concentration of proteins in plants is largely dependent on the availability of nitrogen, whereas the supply of nitrogen to a crop is linked to the quantity of available nitrogen in the soil during the planting stage. These findings have been corroborrated by Sebetha et al. (2015) who reported that the differences in the oil and starch content of the maize harvested in the environments of Potchefstroom and Rustenburg, in North West Provinceof South Africa are caused by the soil types of these locations. Similarly, De Geus et al. (2008) reported that differences in the oil seed yield are affected by location and genotype. Wilkes et al. (2010) further revealed that the soil type had great influence on both protein and starch content, with the grains from the grey vertisol soils in having higher protein content both insoluble and soluble, and lower starch content.

Many studies have indicated that on account of variations in the climate, soil fertility, and other agronomic factors, a hybrid producing the highest ethanol yields in one production environment may not perform as well in another environment (Singh and Graeber 2005; Haegele 2008; Sharma et al., 2016;). Nevertheless, Sebetha et al. (2015) concluded in their findings that maize grains collected from soils at locations with a high clay content had higher oil and starch content than maize grains collected from locations with a high sand content. Nevertheless, maize grains collected at locations with high sand showed higher protein content (Sebetha et al., 2015).

The plant densities 44,444 indicated better quality grains with a superior nutritional composition. This could be attributed to plant spacing. Ciampitti and Vyn (2011) observed high nitrogen uptake in fields where the crops are arranged in narrow rows and at high plant density. In the case of wheat, plant density also exert a marked influence on the protein content and quality traits of the grain and should be considered an important factor contributing to the yield and quality of the grain. Geleta et al. (2002) and Zhang et al. (2016) reported that the concentration of protein in grain (GPC) declines with an increasing seeding rate. Zhang et al. (2016) also revealed in their study that the quality of wheat was found to increase from 120 to 240 plant/m$^{2.}$

The nutritional composition of WEMA was affected by different nitrogen rates. Furthermore, The highest nitrogen rates (240 kg N/ha) impact significantly on the nutritional quality of the WEMA variety. This reveals the importance of nitrogen in the metabolic and physiological activities of maize growth and development .

Amanullah et al. (2015) and Khan (2016) reported that the efficient use of nitrogen is one of the most important inputs needed for intensifying the concentration of protein in the grain kernel. Zhang et al. (2016) stated that fertilizer applied to the soil at a rate of 240 kg/ha would boost the nutritional quality of wheat.

The results of our regression analysis indicated linear relationships between nitrogen fertilization rate and both starch yield and nitrogen uptake by the maize grain respectively. Thus, as the rate of nitrogen supply increases, so the accumulation of nitrogen in the maize grain also increases. The higher rate of nitrogen in the kernel is subsequently reflected in the improved nutritional quality of the kernel.

Ahoulete at al. (2011) and Uhart and Andrew (1995) stated that without nitrogen, the cornkernel cannot develop well, while Hao et al. (2007) found that nitrogenfertilization fosters the accumulation of protein in the rice grain. In their study in Pakistan, Khan (2016) and Amanullah and Shah (2010) found that the highest grain protein concentration (93 g/kg) were obtained in the plots fertilized with highest rate of nitrogen (180 kg N/ha) and lowest grain protein concentration (82 g/kg) were recorded in plots received the lowest rate of N (60 kg N /ha).

Regression analysis estimated that optimum nitrogen fertilizer rate and plant density interaction to produced highest starch yield could be 120 kg N/ha and 44,444 plants/ha to produce 2,700 kg/ha starch yield. This indicated that WEMA starch yield production required adequate nitrogen fertilizer rate and under optimal plant density for better nutritional quality.

Conclusion

The results showed that WEMA nutritional yield production had better composition with application of 240 kg N/ha. This indicates that nutritional yield requires more N rate. The plant density of 44,444plants/ha improved nutritional qualities with superior nutritional composition. Higher nutritional composition was obtained in Taung compared to Molelwane. Therefore, for nutritional purpose WEMA should cultivated under plant density of 44,444 plants/ha with application of 240 kg N/ha in North West province of South Africa.

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CHAPTER SEVEN

EFFECTS OF NITROGEN FERTILIZER AND SOIL MOISTURE LEVELS ON THE PERFORMANCE OF WEMA MAIZE (*Zea mays* L.) ON FERRIC LUVISOL AND RHODIC FERRALSOL SOILS

ABSTRACT

A greenhouse experiment was carried out to investigate the effect of different N fertilizer and soil moisture levels on the growth, yields and water-use efficiency of the WEMA variety on two distinct soils. The experiment was laid out in 5 x 2 x 2 factorial experiment fitted into acompletely randomized design with three replications. Treatments comprised five N fertilizer rates (0, 60, 120, 180 and 240 kg N/ha), two soil moisture levels [45 and 100% field capacity (FC)], and two soil types (Ferric Luvisols and RhodicFerralsol). The growth, grain and water-use efficiency parameters were determined. Data were analyzed using ANOVA of GenStat, edition 11 and differences in the treatment means were tested with the Least Significant Difference (LSD) test at a 5% level of probability. The relationships between the measured parameters were analyzed using regression, correlation and path analyses. The growth parameters were better in Rhodic Ferralsol treated with 240 kg N/ha at 100% FC, while the plants grown on Ferric Luvisol and fertilized with 180 kg N/ha at 100% field capacity produced the highest grain yield of 3.49 t/ha. Water-use efficiency (41.73%) of the WEMA variety under water stress condition (45% FC) was highest in the Rhodic Ferralsol treated with 180 kg N/ha. The relationship between N fertilizer rates and the grain yield was linear ($R^2 = 0.91$). Total dry matter similarly showed linear effect ($R^2 = 0.51$) on the grain. Base on path analysis, harvest index exerted positive direct effect (0.67) on the water-use efficiency of WEMA. The results showed that WEMA had better growth and water use efficiency on Rhodic Ferralsol.

Keywords: Water-use efficiency, field capacity, grain yield, harvest index, WEMA variety

7.1 Introduction

Water stress and nitrogen (N) deficiency are among the two most important factors that limit the growth and yields of many cereal and leguminous crops across diverse semi-arid and arid regions (Fageria et al., 2006, Wang and Shangguan, 2010). Water stress negatively affects crop growth and yields, and thus reduces the consistency of production (Song et al., 2010). The effects of

water stress on the phonological development of maize cannot be overemphasized. It is widely reported that water shortage causes reductions in leaf area, biomass, and grain yield and total crop failure (Song et al., 2010). Water stress condition affects the anatomical, morphological, physiological and biochemical process in plants, especially at the tasseling and pollination stages (Koca et al., 2015). Moreover, the condition of low soil moisture content can reduce water and nutrient uptake by plant roots leading to dehydration of the leaves, which consequently results in stomatal closure. The stomata closure causes a reduction in the photosynthetic activities, which may lead to reduced growth and reductions in the accumulation of biomass (Shaxson and Barber, 2003; Farooq et al. ,2009). Similarly, an insufficient supply of water to crops during the active vegetative phase, often has a negative effect on the elongation of the stems (Farooq et al., 2009)
Nitrogen deficiency affects maize yield (Alvereza and Grigera, 2005; Rimski-Korsakov, 2009). Nitrogen deficiency is an abiotic stressor that causes significant reductions in leaf expansion and the photosynthetic rate. Nitrogen deficiency reduces maize yields as a result of the ensuing low rates it causes to the physiological and biochemical activities of the plant (Rimski-Korsakov, 2009). Low soil nitrogen can restrict the ability of the leaf area to intercept light, and the capacity of plants to fix carbon dioxide (Wang and Shangguan, 2010).

Limited water supply impedes nutrients availability to plants. When water supply to the crop-growing environment is inadequate, the soil structure may be adversely affected, and soil aeration and the soil water content altered (Gurian –Sherman, 2012). In a semi-arid environment, where water availability is a challenge, it would be appropriate to adopt the cultivation of a maize cultivar that would efficiently exploit the available resources, especially water and nitrogen, for the production of biomass and to benefit the yield components. The manifestation of improved water-use efficiency in any crop is an indication of an adaptation made by the plants to survive under the minimal availability of water, especially under arid/semi-arid conditions. A crop or cultivar hybrid that use water more efficiently would improve yields and productivity even under limited soil moisture conditions.

Mashingaidze (2012) reported that as opposed to the other maize varieties, WEMA provides at least a 20% yield benefit under moderate drought conditions. Although the WEMA variety is drought-tolerant, the information on degree of tolerance of WEMA to different soil types particularly in North West province of South Africa is limited. Paterson et al. (2015) reported that the degree to which drought exert influence on the growth and yield of crops in the arid regions will be vary from one soil to another based on the prevailing conditions including soil. According to Rengasamy (2010) crop growth responses to different soil inherent characteristics such as texture, pH, and many others, vary greatly. The information on the degree of tolerance of WEMA variety to water stress and varying N fertilizer rates on soils with different inherent characteristics is scarce. Therefore, this study was carried out to examine growth, grain yield and water use efficiency of WEMA maize on Ferric Luvisol and Rhodic Ferralsol soils at different soil moisture levels and nitrogen rates.

7.2 Materials and Methods

7.2.1 Description of the study site

A greenhouse experiment was carried out at North-West University Research Farm (25° 48′S, 45°38′E. 1012 m above sea level, located in North West Province. Soil samples were collected at a depth of 0 to 15 cm from the North-West University (NWU) Research Farm and the Taung Experimental Station (25^0 48^1S, 45^0 38^1 E.; 1,012 m and 27° 30′S, 24° 30′E; 1,111 m above sea level respectively) of the Provincial Department of Agriculture. The soil was colleted from 0-15 cm and used for greenhouse experiment. The temperature of greenhouse ramged between 24°C and 33°C while the relative humidity varied from 63 - 74%. The soils used for the trial were obtained from uncultivated section of the Molelwane NWU farm with sandy loam textural characteristics and classified as a Ferric Luvisol (A) while a second soil was obtained from the Taung experimental site with loamy sand texture and classified as Rhodic Ferralsol (B). Surface soil sample (0 to 15 cm) was collected for the trial with sub-samples taken and analyzed following the standard procedures of the South African Soil Science Guidelines (1990) while the field capacity for the respective fields was determined according to the procedures of Kebede et al. (2014). Table 7.1 shows the results of pre-planting analysis of the soils.

Table 7.1: Physicochemical properties of the soil types

Physio-chemical properties	Sample A	Sample B
Sand %	82	85
Silt %	1	1
Clay %	18	14
Texture	Sandy loam	Loamy sand
Total N (%)	0.14	0.22
Phosphorus (mg/kg)	7.00	10.00
Potassium (mg/kg)	235	240
pH (H_2O)	4.13	5.60
Bulk density (g/cm^3)	1.80	1.60
Soil water content (g/g)	0.093	0.097
Volumetric water content (g/cm^3)	0.17	0.16
Soil porosity (%)	68	60
Effective saturation (%)	25	27
Field water-holding capacity (%)	49.5	50.7
Soil classification (WRB, 2016)	Ferric Luvisol	Rhodic Ferralsol

7.2.2 Experimental design and treatments

The experiment was laid out in a 5 x 2 x 2 factorial fitted into a completely randomized design block with three replications. The treatment factors comprised of five nitrogen fertilization rates (0, 60, 120, 180, and 240 kg N/ha), two soil moisture levels (45% and 100% field capacity (FC), and two soil types (Ferric Luvisol and Rhodic Ferralsol). Soil sieved using 6 mm mesh sieve in order to remove the plant debris and stone. Plastic pots of 475 mm x 270.70 mm x 339.65 mm dimensions, with perforations at the bottom, and covered with plumber cellotape to prevent soil loss and leaching, were filled with 18 kg of soil. A total of 180 pots (3 pots/treatment factor) were used. The pots were watered to field capacity and allowed to equilibrate for eight hours, after which two seeds of WEMA, variety WE3127, were sown in each pot. The seedlings were thinned to one plant per pot at 10 days after emergence. Half of each of the quantities of the nitrogen fertilizer (NPK 20:7:3) were applied at 10 days after seedling emergence, and at four weeks after emergence; with the remaining half applied in the form of lime ammonium nitrate (28% N). Watering treatment done at two days interval resulting in bewteen 1.22 and 2.72 litres of water application in the Ferric Luvisol and between 1.26 and 2.81 litres in the Rhodic Ferralsol depending on the frequency of irrigation.

7.2.3 Data collection

Data were collected at six, eight and twelve-weeks after sowing (WAS). The data collected related to plant height, measured with the aid of a measuring tape; number of leaves per plant, by counting; chlorophyll content, measured with the aid of a hand-held chlorophyll meter (model CCM-200 plus); and stem diameter, with the aid of a vernier caliper. At harvesting, one ear per plant per pot was harvested and shelled. The yield/ha was calculated at a 12% moisture content, with the assumption that the plant density would be 55,555 plants/ha.

Water-use efficiency was calculated as follows:

$$\text{Water-use efficiency (\%)} = \frac{Grain\ yield\ \ kg/ha}{Quantity\ of\ water\ applied\,(L)}$$

7.2.4 Statistical Analysis

All data collected were analyzed using the analysis of variance (ANOVA) of GenStat, 11th edition. Differences in the mean values of the treatment means were tested by means of the Least Significance Difference (LSD) measure at a 5% level of probability. The relationships between the treatment factors and the measured parameters were analyzed using regression and correlation analyses. The sets of correlation coefficients were subjected to path coefficient analysis and the direct and indirect effects were estimated according to the method of Dalkani et al., (2011).

7.3: Results

7.3.1 Analysis of vvariance of the different treatment effects on performance of the WEMA variety

The results showed that varying rates of nitrogen rates, as well as different levels of irrigation supply to the two soil types significantly ($p \leq 0.01$) affected the growth, yield and dry matter parameters of the WEMA variety (Table7.2). However, none of the single treatment factors had significant ($p \geq 0.05$) effect on the number of leaves produced. Also, the grain yield, its components, and the water-use efficiency level of the WEMA variety were significantly ($p \leq 0.01$) affected by all of the treatment factors and their interactions.

7.3.3: Treatment interaction effects on the growth parameters

7.3.3.1 Plant height

The height of the plants was significantly ($p \leq 0.05$) affected by the interactions among the soil moisture levels, nitrogen fertilizer rates and soil types (Table 7.3). The tallest significant plant height (108.cm) was recorded in the Rhodic Ferralsol fertilized with 240 kg N/ha under 100% water-holding capacity (FC) level, as opposed to the shorter plants grown in the unfertilized Ferric Luvisol with the soil being watered to a 45 % field capacity level at six weeks after sowing stage. At eight weeks after sowing stage , significantly the tallest plant (279.33 cm) was observed on the Ferric Luvisol supplied with 240 kg of nitrogen fertilizer/ha at a 100 % field capacity level. A similar trend was observed at 8 and 12 weeks after sowing. However, the shortest plant was recorded in this same soil type, but with it being treated with 180 kg N /ha and at a 45 % field capacity level. However, the shortest plant height was recorded in the same soil type treated 180 kg N/ha at 45 % FC. Although this was not significantly difference from height obtained with 60 kg N/ha.

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Table 7.2: Mean square values of growth and yield parameters of WEMA variety as influence by nitrogen rates, moisture levels on two soil types

Parameters	N rates (N)	Moisture (WR)	Soil types (ST)	N x WR	N x ST	WR x ST	N x WR x ST
Plant height	6669**	2408**	32045**	763**	885**	2846**	429**
Number of leaves	1.63	5.51	0.001**	2.03**	2.26**	0.11**	0.80**
Chlorophyll content	319.60**	0.46**	3.02**	0.26**	0.13**	0.09**	0.25**
Dry shoot weight (kg)	3.96**	2.67**	8.76**	3.75**	8.72**	0.68**	1.27**
Dry root weight (kg)	0.25**	0.16**	0.19**	0.21**	0.20**	0.21**	0.06**
Total dry matter (kg)	22.65**	4.13**	11.25**	19.30**	4.26**	139.00**	5.22**
Grain yield (t/ha)	51,261.73**	49,931**	579.86**	17,162.51**	4,091.12**	1,003.13**	3,11.50**
Biological yield (t/ha)	132,2222**	1,169,800**	18,324**	2,872**	635,640**	3,3793**	28,716**
Harvest index	0.085**	0.0235**	0.0928**	0.0006**	0.0052**	0.0060**	0.0181**
Water use efficiency (%)	0.022**	0.062**	0.0014**	0.0018**	0.364**	0.052**	0.023**
Df	4	1	1	4	4	1	4

Note: N = N rates, WR = Water regime, ST = Soil type and df = degrees of freedom $^{**}p\leq0.01$, $^{*}p\leq0.05$, ns = no significant.

Table 7.3: Effects of soil moisture level, soil type and nitrogen fertilizer level on the plant height (in cm) of the WEMA

Soil moisture levels % (FC)	Soil type	N rates (kg/ha)	Weeks after sowing		
			6	8	12
45	Ferric Luvisol	0	62.17	175.33	210.67
		60	60.67	219.67	208.17
		120	69.33	216.33	210.07
		180	79.00	206.67	204.87
		240	77.33	201.17	210.00
	Rhodic Ferrasol	0	57.60	169.33	232.83
		60	61.17	228.50	229.00
		120	73.83	227.33	243.00
		180	86.33	256.00	211.67
		240	80.00	246.33	237.50
100	Ferric Luvisol	0	82.33	199.67	277.50
		60	92.33	236.33	248.17
		120	84.33	271.67	256.33
		180	85.67	252.33	232.50
		240	95.50	279.33	283.33
	Rhodic Ferrasol	0	38.67	224.33	249.33
		60	58.00	221.33	244.00
		120	95.60	269.33	252.33
		180	100.50	260.00	270.33
		240	108.00	270.00	259.67
LSD $_{(0.05)}$			5.94	3.80	3.36

7.3.3.2 Number of leaves

Interaction among the three factors had significant effect on the number of leaves of the WEMA variety as indicated in Table 7.4. At the earlier growth stage, WEMA had significantly the hightest number of leaves on the Rhodic Ferralsol watered to a field capacity of 100%, but without any fertilizer application (Table 4). At eight weeks after sowing, the number of leaves formed by the WEMA variety was significantly higherr on the Ferric Luvisol fertilized with 240 of nitrogen/ha and irrigated up to a 45% soil moisture level, as opposed to those plants in pots containing Ferric Luvisol fertilized with 180 kg N/ha and watered to a field capacity of 100%. Also at 12 weeks after sowing, the higher number of leaves was recorded in the Ferric Luvisol (14.67), supplied with 240 kg N /ha at a 45% soil moisture level and which differed significantly from the number of leaves obtained from the Rhodic Ferralsol fertilized with 180 kg N /ha and watered to a 100% field capacity level.

7.3.3.3 Stem diameter

The interaction among soil moisture levels, soil types and nitrogen fertilizer rates had significant effect on the stem diameter of the maize plants (Table 7.5). At 6 weeks after sowing, WEMA had significantly highest stem diameter (2.37) on Rhodic Ferralsol supplied with 240 kg N/ha at 100 % F compared to the results observed on Rhodic Ferralsol supplied with 60 kg N/ha at 100% FC. The stem diameter was highest (2.53 mm) in Ferric Luvisol that received 240 kg N/ha at 100% FC which was statistically different from other treatments. Similarly, WEMA, had highest stem diameter (2.57 mm) on Ferric Luvisol supplied 240 kg N/ha at 100% at 12 WAS and was least in all the unfertilized treatments in both soil types.

Table 7.4: Interaction effect of soil moisture level, soil type and nitrogen fertilizer level on the number of leaves of the WEMA variety

Soil moisture levels % (FC)	Soil type	N rates (kg/ha)	Weeks after sowing		
			6	8	12
45	Ferric Luvisol	0	11.00	13.00	14.33
		60	11.67	12.33	14.33
		120	12.00	13.67	14.67
		180	11.00	14.33	13.33
		240	11.00	15.33	14.67
	RhodicFerralsol	0	12.67	15.00	12.67
		60	10.67	12.67	13.67
		120	12.67	13.33	13.33
		180	13.00	15.00	12.67
		240	11.00	12.00	12.67
100	Ferric Luvisol	0	13.67	12.67	14.00
		60	12.67	14.00	14.00
		120	11.33	11.50	13.67
		180	12.33	10.67	13.67
		240	12.00	13.67	14.00
	RhodicFerralsol	0	10.33	13.00	13.00
		60	10.33	12.00	13.33
		120	12.33	11.67	13.67
		180	12.00	13.00	11.67
		240	11.67	13.67	14.00
LSD (0.05)			1.28	1.88	1.52

Table 7.5: Interaction effect of soil moisture levels, soil types and nitrogen fertilizer level on the stem diameter (mm) of the WEMA variety

Soil moisture levels (%FC)	Soil type	N rates (kg/ha)	Weeks after sowing		
			6WAS	8 WAS	12WAS
45	Ferric Luvisol	0	1.43	0.43	1.97
		60	1.27	0.67	2.13
		120	1.50	1.37	1.97
		180	1.67	1.80	1.93
		240	1.50	1.43	2.03
	RhodicFerralsol	0	1.67	1.27	1.77
		60	2.10	1.47	2.27
		120	1.93	2.13	2.00
		180	1.93	2.20	1.93
		240	2.00	2.10	2.00
100	Ferric Luvisol	0	1.10	1.83	1.90
		60	1.46	2.27	2.23
		120	1.70	2.33	2.57
		180	2.03	2.17	2.03
		240	2.03	2.53	2.20
	RhodicFerralsol	0	1.10	1.83	2.03
		60	1.03	1.90	2.17
		120	1.63	2.17	2.23
		180	2.17	2.23	1.87
		240	2.37	2.47	2.20
$LSD_{(0.05)}$			0.24	0.07	0.26

7.3.3.4 Chlorophyll content

At the six weeks after sowing, the Rhodic Ferralsol fertilized with 240 kg N/ha produced plants with the highest chlorophyll content. This chlorophyll content level was not significantly different, however, from that recorded in the same soil type fertilized with 120 kg N/ha and irrigated to a field capacity of 100%. The least chlorophyll content was obtained in unfertilized soils, belonging to both soil types at a 45% soil moisture level (Table 7.6).

The chlorophyll content of the WEMA variety was highest in the Rhodic Ferralsol supplied with 120 kg N/ha and watered to a 100% field capacity, but not significantly different from other treatments on the same soil type. The lowest chlorophyll content at eight weeks after sowing was obtained in the Ferric Luvisol supplied with 60 kg N/ha (17.63 SPAD-units), which was statistically comparable to the Ferric Luvisol and Rhodic Ferralsol supplied with different rates of nitrogen fertilizer and watered to a 45% field capacity. However, at 12 weeks after sowing, the WEMA variety had the highest chlorophyll content (2.13 SPAD-units) on the Rhodic Ferralsol fertilized with 120 kg N/ha and irrigated to a 45% soil moisture level.

7. 3.3.5 Shoot dry weight

The interactional effect of soil moisture levels, soil types and N fertilizer rates had significant ($p \leq 0.05$) effect on the dry shoot weight of the WEMA variety (Table 7.7). Under the 100% field capacity level, the WEMA grown on the Rhodic Ferralsol fertilized with 180 kg of N/ha had significantly highest dry shoot weight (30.19 g) relative to the same soil type, but without fertilizer, and irrigated to 45% soil moisture level (12.14 g) at six weeks after sowing. The Ferric Luvisol supplied with 240 kg N/ha at 100 % soil moisture level had significantly highest shoot dry weight at 8 and 12 weeks after sowing (Table 7.7). The least dry shoot weights were recorded in an unfertilized Rhodic Ferralsol and Ferric Luvisol supplied with 45% soil moisture level.

Table 7.6: Interaction effect of soil moisture level, soil type and nitrogen fertilizer rates on the chlorophyll content (SPAD-units) of the WEMA variety

Soil moisture levels % (FC)	Soil type	N rates (kg/ha)	Weeks after sowing		
			6	8	12
45	Ferric Luvisol	0	9.33	3.23	1.40
		60	12.03	7.57	1.47
		120	14.43	9.03	1.50
		180	14.60	10.93	1.40
		240	14.40	12.93	1.40
	Rhodic Ferralsol	0	9.27	5.60	2.13
		60	12.43	7.40	1.27
		120	20.17	11.57	1.40
		180	23.90	14.00	1.73
		240	25.43	11.87	1.73
100	Ferric Luvisol	0	6.67	2.93	1.45
		60	11.30	4.13	1.43
		120	16.33	6.50	1.33
		180	19.60	11.10	1.30
		240	19.07	15.87	1.40
	RhodicFerralsol	0	15.20	6.70	1.33
		60	14.87	9.67	1.40
		120	22.43	7.83	1.40
		180	28.23	8.53	1.47
		240	33.03	14.05	1.47
LSD $_{(0.05)}$		6.32	1.75	1.78	0.25

Table 7.7: Interaction effect of nitrogen rate, water regime and soil type on the dry shoot weight of the WEMA variety

Watering regime (%FC)	Soil type	N rates (kg/ha)	Weeks after sowing		
			6	8	12
45	Ferric Luvisol	0	14.02	102.00	91.17
		60	13 48	128.67	127.61
		120	22.55	173.33	122.14
		180	21.58	147.00	129.39
		240	19.94	180.67	125.34
	RhodicFerralsol	0	20.70	48.67	108.65
		60	17.61	166.00	137.68
		120	16.56	206.67	120.60
		180	13.38	154.00	126.21
		240	13.61	184.67	136.81
100	Ferric Luvisol	0	15.93	80.00	114.14
		60	15.04	151.00	131.30
		120	21.90	236.00	163.84
		180	24.68	261.33	169.90
		240	21.46	348.00	200.96
	RhodicFerralsol	0	12.14	68.67	126.41
		60	15.15	131.00	142.42
		120	21.33	252.00	151.51
		180	30.19	298.00	181.82
		240	25.38	304.33	175.73
$LSD_{(0.05)}$			9.63	2.61	3.86

7.3.3.6 Root dry weight

There was significant ($p \leq 0.05$) interactional effect of soil moisture level, soil types and nitrogen fertilizer rates on the dry root weight of the WEMA variety (Table 7.8). The significant and highest dry root weight (31.24 g) was recorded on the Rhodic Ferralsol fertilized with 180 kg N/ha under a 100% field capacity, while the lowest dry root weight (1.02 g) was found in an unfertilized Ferric Luvisol at a 45% soil moisture level at the six weeks after the sowing. At 8 weeks after sowing, Rhodic Ferralsol supplied with 240 kg N/ha under 100 % FC moisture level had highest dry root weight (36.67 g) which was significantly different from dry root weight obtained in pots containing both soil types at either 45% or 100% FC moisture level. Ferric Luvisol enhanced highest accumulation of dry matter into root when fertilized with 240 kg N/ha at 100% FC moisture level which was not significantly different from Rhodic Ferralsol supplied 180 or 240 kg N/ha at 12 WAS sowing.

Table 7.8: Interactional effects ofnitrogen rates, water regimes and soil types on the dry root weight (g)

Soil moisture levels (% FC)	Soil type	N rates (kg /ha)	Weeks after sowing		
			6	8	12
45	Ferric Luvisol	0	1.02	7.33	13.51
		60	4.81	16.00	20.92
		120	9.57	18.00	25.18
		180	8.58	13.67	19.10
		240	7.62	16.67	20.03
	RhodicFerralsol	0	1.33	2.67	13.19
		60	12.28	6.00	21.29
		120	3.56	14.67	11.84
		180	7.03	17.00	18.44
		240	4.94	16.67	14.59
100	Ferric Luvisol	0	2.93	4.00	13.67
		60	2.14	8.33	19.82
		120	8.90	13.67	28.50
		180	6.57	28.00	26.36
		240	8.61	30.00	32.01
	RhodicFerralsol	0	3.82	3.67	19.42
		60	2.15	7.33	16.56
		120	8.33	30.67	27.05
		180	31.24	21.67	31.96
		240	15.69	36.67	30.40
$LSD_{(0.05)}$			1.22	1.05	1.93

7.3.3.7 Dry matter yield

As indicated in Table7.9, the interaction among soil moisture level, soil types and nitrogen fertilizer rates had significant effect on the accumulation of dry matter by the WEMA variety. During the early growth stage, the Rhodic Ferralsol supplied with 180 kg N/ha under a 100 % soil moisture level had the highest dry matter weight (71 g) relative to the unfertilized Ferric Luvisol at a 45% soil moisture level. The largest amount of dry matter (278.70 g) was accumulated on the Rhodic Ferralsol fertilized with 180 kg N/ha and irrigated to a 45% field capacity at eight weeks after sowing. The highest dry matter weight (232.97 g) was recorded on a Ferric Luvisol treated with 240 kg N/ha under a 45% soil moisture level and the lowest dry matter weight (104.69 g) was obtained on an untreated Ferric Luvisol at a soil moisture of 45 % during the late growth stage.

Table 7.9: Interaction effect ofnitrogen rate, water regime and soil type on dry matter (g)

Soil moisture levels (%FC)	Soil type	N rates	Weeks after sowing		
			6	8	12
		0	15.04	253.3	104.69
		60	18.29	204.0	148.53
		120	32.12	215.70	147.33
		180	30.17	248.0	148.49
		240	27.56	138.7	145.37
	Ferric Luvisol				
		0	22.03	258.30	121.84
		60	29.89	220.70	158.97
		120	20.11	209.70	132.45
		180	20.41	278.70	144.65
		240	18.55	201.30	151.40
45	RhodicFerralsol				
		0	18.87	203.00	127.82
		60	17.17	203.70	151.11
		120	30.81	211.70	192.33
100		180	31.25	261.70	196.26
		240	30.07	226.70	232.97
	Ferric Luvisol	0	15.96	203.30	145.83
		60	17.30	252.70	158.97
		120	29.66	205.30	178.56
		180	71.44	181.00	213.78
	RhodicFerralsol	240	41.07	275.00	206.13
$LSD_{(0.05)}$			9.90	39.95	20.23

7.3.3: Interaction effect of nitrogen rate , water regime and soil type on yield, yield components, and water-use efficiency of the WEMA variety

The interactions among soil moisture level, soil type and nitrogen fertilizer rates had significant effect on the maize yield and its components (Table 7.10). The WEMA variety had significantly higher grain yield (3.49 t/ha) on Ferric Luvisols fertilized with 180 kg N/ha at a 100 % field capacity level than the same soil type fertilized with 60 kg N/ha and irrigated up to a 45 % field capacity level. Such conditions resulted in the lowest grain yield. The stover yield was highest (11.16 t/ha) on the Ferric Luvisol supplied with 240 kg N/ha at 100% soil moisture level. The stover yield differed statistically from the stover yield obtained on a Ferric Luvisol supplied with 60 kg N/ha or from an unfertilized soil irrigated at a 45% field capacity level. Similarly, the biological yield (14.43 t/ha) was significantly the highest on a Ferric Luvisol treated with 240 kg N/ha at a 100% soil moisture level, while the lowest biological yield was observed on the same soil type fertilized with 120 kg N/ha at 45% soil moisture level. The harvest index was significantly highest (0.30) on a Rhodic Ferralsol treated with 180 N/ha and watered to a field capacity of 45% than on the same soil type that received 60 kg N/ha at the same moisture level. The water-use efficiency of WEMA was statistically significant and higher (41.73 %) on the Ferric Luvisol supplied with 180 kg N/ha at a field capacity level of 45 %. On the other hand, the lowest water-efficiency use was obtained on an unfertilized Ferric Luvisol soil at a 100% field capacity level.

7.3.4 Regression analysis of relationship between nitrogen fertilizer rate and grain yield and water-use efficiency

The regression results showed that the grain yield is directly related to the nitrogen fertilizer rates, thus suggesting that the higher the nitrogen fertilizer rate, the higher the grain yield per hectare (Figure 7.1). Similarly, water-use efficiency is statistically significantly related to the quantity of fertilizer applied. The result showed that 88% of the water-use efficiency is predictable on considering the relationship between the amount of the nitrogen fertilizer applied and the water-use efficiency (Figure 7.2).

Table 7.10: Effects of water regime, soil type and nitrogen fertilizer rate on yield, yield components and water-use efficiency of the WEMA

Soil moisture levels % (FC)	Soil type	N rates (kg/ha)	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index	Water use efficiency (%)
45	Ferric Luvisol	0	0.62	5..07	5.68	0.11	9.14
		60	0.56	7.09	7.64	0.07	8.19
		120	1.55	6.78	8.33	0.19	22.80
		180	1.34	7.20	8.53	0.16	19.80
		240	1.20	6.96	8.16	0.15	17.60
	Rhodic Ferralsol	0	1.28	6.22	7.50	0.17	18.31
		60	1.64	7.83	9.47	0.17	23.40
		120	2.72	6.70	9.42	0.29	38.91
		180	2.92	7.01	9.93	0.30	41.73
		240	2.36	7.60	9.96	0.24	33.68
100	Ferric Luvisol	0	0.91	6.34	7.25	0.13	5.99
		60	1.15	7.48	8.63	0.14	7.64
		120	2.48	9.10	11.58	0.21	16.42
		180	3.49	9.64	13.13	0.27	23.08
		240	3.27	10.96	14.23	0.23	21.62
	RhodicFerralsol	0	2.09	7.02	9.11	0.23	13.43
		60	2.70	8.01	10.70	0.25	17.30
		120	3.22	8.42	11.63	0.28	20.68
		180	3.30	10.08	13.37	0.25	21.15
		240	3.40	9.74	13.13	0.26	21.79
LSD $_{(0.05)}$			0.0006	0.043	0.043	0.001	0.07

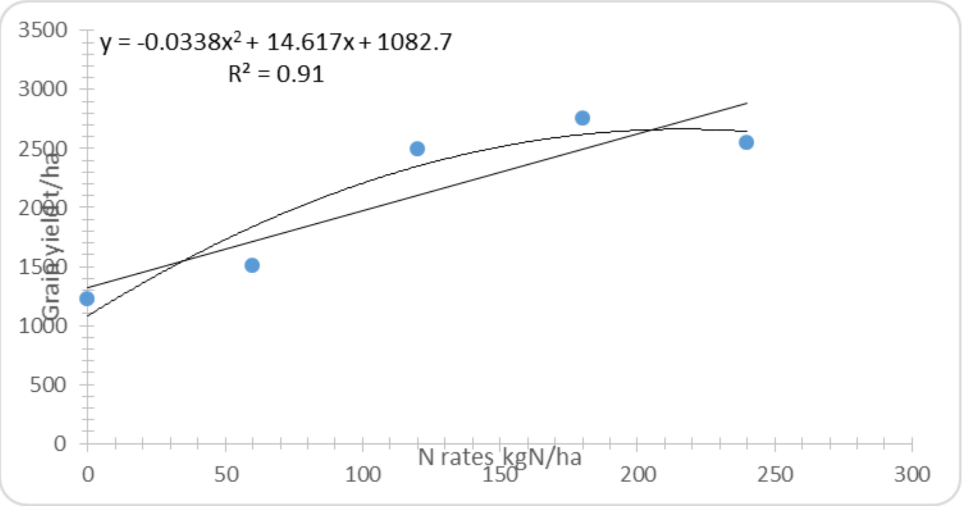

Figure 7.1: Relationship between nitrogen fertilizer level and grain yield

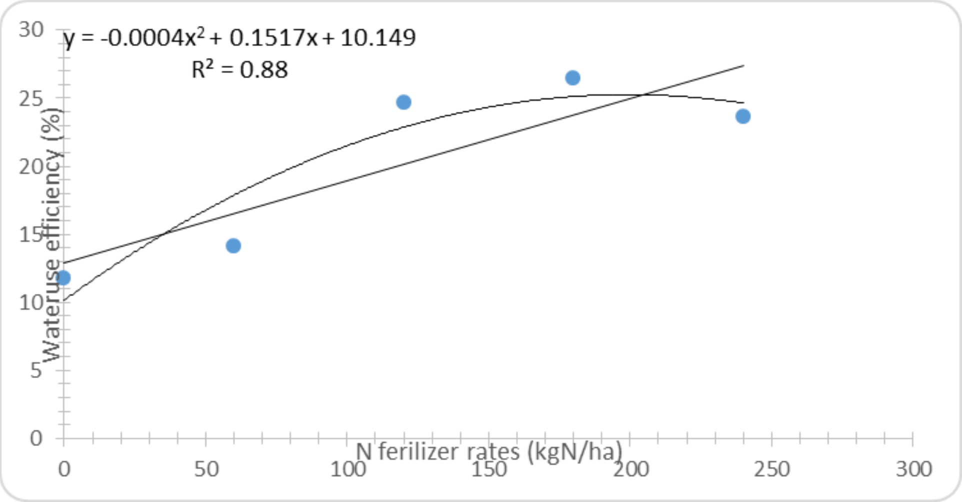

Figure 7.2: Relationship between nitrogen fertilizer level and water-use efficiency

7.3.5: Correlations among grain yield, growth, dry matter, yield components and water-use efficiency

The results of this research indicated that grain and growth are significantly ($p \leq 0.001$) and positively correlated with plant height, number of leaves, stem diameter, chlorophyll content , dry shoot weight, dry root weight, total dry matter, biological yield, stover yield, harvest index and water-use efficiency (Table7. 11). The respective correlations among plant height and other growth variables, dry matter accumulation, yield components, and water-use efficiency were also positive and largely significant ($p \leq 0.001$). Similarly, the number of leaves also showed a significant ($p \leq 0.001$) and positive correlation with other growth variables, dry matter accumulation, yield components and water-use efficiency. The chlorophyll content was found to be significantly ($p \leq 0.01$) associated with other growth variables, dry matter accumulation, yield components and water-use efficiency. The dry shoot and root weight, as well as the total dry matter, showed positive and vastly significant ($p \leq 0.001$) correlations with other growth variables, yield components and water-use efficiency. The biological yield correlated significantly ($p \leq 0.001$) and positively with growth, dry matter accumulation, other yield components, and water-use efficiency. The stover yield showed a significant ($p \leq 0.001$) and positive correlation with growth, dry matter accumulation, yield components and water use efficiency. Also, harvest index had significant ($p \leq 0.001$) and positive association with growth, dry matter accumulation, other yield components and water-use efficiency. Water-use efficiency was found to be significantly ($p \leq 0.001$) and positively correlated with grain yield, plant height, number of leaves, stem diameter, chlorophyll content , dry shoot weight, dry root weight, total dry matter, biological yield , stover yield and harvest index .

7.3.6 Path analysis

The path analysis showed that total dry matter had the greatest and most positive, direct effect (0.51) on grain yield as opposed to the direct effect exerted on grain yield by the number of leaves (0.11). Plant height revealed the greatest but most negative direct effect (-0.70) on grain yield, while chlorophyll content had the least direct effect (-0.140) on grain yield. Except for plant height and chlorophyll content index, all of the other parameters exerted a positive indirect effect on grain yield (Table 7.12). Stem diameter (0.85) and harvest index (0.67) had positive direct effect on water use efficiency and the least direct effect (0.14) was obtained via root dry weight (Table 7.13). Plant height, number of leaves and shoot dry weight indicated negative direct effect on water use efficiency. Similarly, the plant height, number of leaves and shoot dry weight revealed negative indirect effect on water use efficiency whereas the rest of the parameters had a positive indirect effect on water use efficiency (Table 7.13).

Table 7.11: Correlations between grain yield, growth parameters and dry matter accumulation

	GY	PH	NOL	STD	CCL	SW	RW	TDM	BY	SY	H1	WUE
GY	1.00											
PH	0.93**	1.00										
NOL	0.73**	0.73**	1.00									
STD	0.95**	0.99**	0.68**	1.00								
CCL	0.94**	0.95**	0.81**	0.96**	1.00							
SW	0.95**	0.98**	0.67**	1.00**	0.96**	1.00						
RW	0.99**	0.97**	0.75**	0.98**	0.97**	0.98**	1.00					
TDM	0.95**	0.99**	0.72**	1.00**	0.98**	1.00**	0.99**	1.00				
BY	0.95**	0.96**	0.67**	0.99**	0.97**	0.99**	0.98**	0.99**	1.00			
SY	0.87**	0.93**	0.59*	0.96**	0.95**	0.97**	0.92**	0.96**	0.98**	1.00		
H1	0.96**	0.85**	0.69**	0.86**	0.82**	0.84**	0.92**	0.85**	0.84**	0.71**	1.00	
WUE	0.99**	0.90**	0.69**	0.93**	0.89**	0.92**	0.97**	0.92**	0.92**	0.82**	0.98**	1.00

PH – plant height, NOL – number of leaves, STD, stem diameter, CCL – chlorophyll content, SW- shoot dry weight, RW- root dry weight, TDM – total dry matter, BY-Biological yield, SY-Stover yield, HI- Harvest index, WUE –Water-use efficiency $^{**}p\leq0.01$, $^{*}p\leq0.05$.

Table 7.12: Path analysis of grain yield, growth parameters and dry matter accumulation

	PH	NOL	STD	CCL	SW	RW	TDM	H1	Grain yield
PH	**-0.70**	0.08	0.42	-0.13	0.19	0.17	0.50	0.39	0.93
NOL	-0.51	**0.11**	0.29	-0.11	0.13	0.13	0.37	0.32	0.73
STD	-0.70	0.08	**0.43**	-0.13	0.20	0.17	0.51	0.40	0.95
CCL	-0.67	0.09	0.41	**-0.14**	0.19	0.17	0.50	0.38	0.94
SW	-0.69	0.08	0.43	-0.13	**0.20**	0.17	0.51	0.39	0.95
RW	-0.68	0.09	0.42	-0.13	0.19	**0.17**	0.50	0.42	0.99
TDM	-0.69	0.08	0.43	-0.13	0.20	0.17	**0.51**	0.39	0.95
H1	-0.59	0.08	0.37	-0.11	0.17	0.16	0.44	**0.46**	0.96
Residual									0.00

PH – plant height, NOL – number of leaves, STD, stem diameter, CCL – chlorophyll content, SW- shoot dry weight, RW- root dry weight, TDM – total dry matter, HI – harvest index

Table 7.13: Path analysis of water use efficiency, growth parameters and dry matter accumulation

	PH	NOL	STD	CCL	SW	RW	TDM	H1	WUE
PH	**-0.45**	-0.07	0.84	0.16	-0.62	0.14	0.33	0.57	0.90
NOL	-0.33	**-0.09**	0.58	0.14	-0.42	0.11	0.24	0.47	0.69
STD	-0.45	-0.06	**0.85**	0.16	-0.63	0.14	0.34	0.58	0.93
CCL	-0.43	-0.07	0.82	**0.17**	-0.61	0.14	0.33	0.55	0.89
SW	-0.44	-0.06	0.85	0.16	**-0.63**	0.14	0.34	0.57	0.92
RW	-0.44	-0.07	0.83	0.17	-0.62	**0.14**	0.33	0.62	0.97
TDM	-0.44	-0.06	0.85	0.17	-0.63	0.14	**0.34**	0.58	0.92
H1	-0.38	-0.06	0.73	0.14	-0.53	0.13	0.29	**0.67**	0.98
Residual									0.00

PH – plant height, NOL – number of leaves, STD, stem diameter, CCL – chlorophyll content, SW- shoot dry weight, RW- root dry weight, TDM – total dry matter, HI – harvest index, WUE – yield water use efficiency.

7.4 Discussion

The WEMA variety performed better on a Rhodic Ferralsol fertilized with 240 kg N/ha and irrigated up to a 100 % field capacity. The Rhodic Ferralsol is a soil type that is generally low in fertility (WRB 2014). As such, there is perhaps the need to apply high levels of nitrogen fertilizer in order to upgrade the soil's fertility status and improve the growth performance of the crop.

Although this soil type is characteristically excellent in terms of its porosity, it is also good in terms of its permeability and promotes favourable infiltration levels. However, its low fertility requires improved fertility management strategies based on external resources inputs to upscale its productivity. Similar views have been shared by Bationo et al. (2012). The soil pH was found to enhance the growth performnace of WEMA on Rhodic Ferralsol soil when compared with Ferric Luvisol. This may be due to the high acidity levels in the Ferric Luvisol (pH of 3.5) when compared with Rhodic Ferralsol (pH of 5.5). High acidity levels (low soil pH) in soils have been found to generally impede the growth of crops. This is agrred with findings of Fertilizer Society of South Africa (FSSA) 2000 the society indicated that maize performed better on soil types with soil pH range between 5.5 – 7.5. Miller (2016) reported that effective uptake of nitrate by plants is preeminent in the soil types with soil pH acidic in nature.

Under supplementary inputs through irrigation that would promote adequate soil moisture conditions (100% FC level), the performance of the WEMA variety has been greatly enhanced, and strikingly so, if compared to its status when limited by inadequate moisture levels. This shows that when moisture is supplied to the plant in adequate quantities, the performance of the WEMA variety is optimally enhanced. On the other hand, if the moisture level proves to be too low, it could result in impaired growth of the maize plant, poor dry matter formation and low yields.

Wang et al. (2012) further showed that owing to a reduction in leaf biomass and leaf area, the most important effects of a water deficit include impaired shoot growth. The observation here is in agreement with the findings of earlier studies by Jaleel et al. (2008), Jaleel et al. (2009), and Farooq et al. (2009), who reported that water deficits inhibit plant growth and impairs various physiological and biochemical processes such as photosynthesis, respiration, translocation, ion uptake, carbohydrate synthesis, and nutrient metabolism.

Kusaka et al (2005) and Shao et al (2008) have reported the deleterious effect of water deficits on the growth and development of maize. While Wu et al. (2008) affirmed reductions of up to 25% in plant height in citrus seedlings exposed to water stress, Wang et al. (2012) reported that the major physiological consequence of water deficits is the inhibition of photosynthesis. This could be the reason behind the low chlorophyll content recorded in a water-deficient environment and a limited native fertility. Similar observations were reported by Farooq et al.

(2009) that chlorophyll content is highly susceptible to soil drying, while Ebrahimia et al. (2014) indicated that the chlorophyll content in sunflower plants declines to a significant level when the water deficiency intensifies. According to Habtegebrial et al. (2007) and Khan et al. (2017), nitrogen fertilizer improves vegetative growth, maize biomass and the production of dry matter which together ultimately lead to higher crop productivity levels.

The dry shoot and root weights are more developed in the Ferric Luvisol at a field capacity level of 100%, and in conjunction with the largest application rates of nitrogen fertilizer. This soil type is known for its better porosity and excellent aeration properties. These attributes are beneficial to nutrient uptake and root growth and development. The type of soil had good fertilizer use efficiency compared to the soil types which lack such beneficial properties. Maize thrives well under a well-aerated soil environment, and good fertility conditions and the availability of water. The better performance of the WEMA variety on a Ferric Luvisol is an attestation to the fact that the soil type will support WEMA cultivation under good irrigation practices, as well as adequate fertilization levels. According to Nsanzabaganwa et al. (2014) and Phefadu and Kutu (2016), maize is a heavy nutrient feeder that requires huge quantities of fertilizer, especially in the form of nitrogen-based fertilizers.

In terms of total dry matter produced, the WEMA variety performed better on the Ferric Luvisol than on the Rhodic Ferralsol, and under a field capacity of 45 %, with applications of 240 kg N/ha. This is in line with Kolawole et al. (2018), who reported that the dry shoot weight obtained on a Ferric Luvisol is much higher than that obtained on a Rhodic Ferralsol. In all likelihood, this could be due to the good absorptivity and permeability of the Ferric Luvisol which together improve its response to fertilization, the last-mentioned enhancing the absorption, assimilation and accumulation of nutrients. These findings are supported by those of ElZubair et al. (2015), who reported on maximum dry matter yields was obtained at high nitrogen fertilizer levels 180 kg N/ha. WRB (2014) reported that contrary to the Rhodic Ferralsol, the Ferric Luvisol has a higher percentage of organic matter in terms of its C:N ratio. Muller et al. (2005), report that loam and clay soils are more prone to water deficits because of their low level of drainable porosity after durable wetting. Ogola et al. (2002) indicated that limited quantities of soil water restrict maize crop yields more than the level of nitrogen fertilizer does.

These results are in line with the findings of Chiludo (2017) who revealed that maize is more likely to produce high yields when the uptake of nitrogen fertilizer is increased by relatively moderate to high soil moisture levels. Water deficits leading to water stress are associated with a reduction in yield of 30% to 50% (Cakir, 2004). Moneux et al. (2006) and Kamara et al. (2008) showed that water stress greatly reduces the grain yield, which is largely affected by the high level of defoliation resulting from water deficits.

The highest level of water-use efficiency was recorded on a Rhodic Ferralsol treated with 180 kg N/ha at a field capacity of 45%. Water-use efficiency can vary on account of the soil conditions and the quantities of fertilizer applied to the soil (Nwachukwu and Ikeadigh 2012). The major factors that affect water-use efficiency are soil structure and texture. These findings are in conformity with the findings of other investigators such as Blum (2009) Long and Ort (2010) and Gurian-Sherman (2012) who in their reports indicate that drought-tolerant plants typically benefit from a higher level of water-use efficiency. This WEMA variety showed a more limited water-use efficiency level than was expected, and this is in accordance with the findings of Gurian-Sherman (2012) who reported that drought-tolerant plants may not show improved water-use efficiency levels. Therefore, this maize variety may require more irrigation than plants that are not drought-tolerant.

The linear relationship between nitrogen fertilization rates and grain yield may be linked to the importance of nitrogen in maize growth, development and yields. These results are in consonance with the findings of Ogola et al. (2002), who showed that the effects of nitrogen on crop water use are expected to vary with the availability of soil moisture. Hammad et al. (2015) and Nilahyane et al. (2018) reported that both water and nitrogen are the most yield-limiting factors in semi-arid areas.

The respective relationships between grain yield and its components water-use efficiency, growth parameters, and dry matter accumulation were investigated in this research study. The significant and positive associations between grain yield and its components, growth, dry matter accumulation, and water-use efficiency respectively revealed that these parameters are the main determinants of the scope of the grain yield. This is in line with the findings of other scholars that grain yield is positively and significantly correlated with plant height, number of leaves per plant, and total amount of dry matter (Sharifai et al., 2006: Adesoji et al., 2015). These researchers further revealed that increased levels in the growth parameters, particularly in terms of plant height and number of leaves per plant, might help the photosynthetic apparatus of the plant to synthesize more assimilates and therefore produce larger yields. The relationships revealed that as the grain yield components increases, so the yield also increases. This indicates that by improving the yield components, the grain yield could be increased. The same result was observed by Maral et al. (2012) who reported that grain yield and the yield components are positively and significantly correlated.

Path analysis indicated that the total dry matter had a large and direct effect on the grain yield and the harvest index, as well on water-use efficiency. This implies that any improvements in the total dry matter and the harvest index will improve the yields and water-use efficiency of the WEMA variety. This result agrees with the findings of Mohankumar et al. (2011) that the amount of total dry matter has a positive effect on the grain yields of rice. Eivazi and Habibi (2013) showed that harvest index has a positive effect on the water-use efficiency of wheat.

Conclusion

The Rhodic Ferralsol improved growth performance of the WEMA variety with applications of 240 kg N/ha while the Ferric Luvisol fertilized with 180 kg N/ha enhanced the grain yield at the full field capacity level (100%). The WEMA variety performed better under adequate soil moisture conditions. However, it could also possibly perform well under a moderate soil moisture deficit. This maize variety can be cultivated on a Ferric Luvisol. However, its baseline grain yield could compare with that of the Rhodic Ferralsol.

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CHAPTER 8

GENERAL SUMMARY, CONCLUSION AND RECOMMENDATIONS

8.1 Research overview

Maize is a basic staple crop that is valued by a great number of the citizens of South Africa. However, its cultivation and productivity is constrained by several factors such as low soil fertility, drought, inappropriate planting density and biotic factors such as weeds, insects, pests and diseases. In order, to combat these constraints affecting maize production, a conventional hybrid known as Water Efficient Maize for Africa (WEMA) was bred in 2008. Project implementation and achievement was through a public-private partnership (PPP) consortium and funded by Bill and Melinda Gates Foundation (BMGF), the Howard G. Buffet Foundation, and the United States of Agency for Development (USAID).

The WEMA variety is a drought-tolerant and insect-pest resistance maize hybrid. However, the information regarding the performance of this newly-released hybrid maize, especially the WEMA 3127 variety, in South Africa, is limited. The performance of WEMA 3127 variety subjected to different plant population densities, N fertilizer rate in different locations of North West Province of South Africa is unknown. Therefore, this research investigated the effects of different N fertilizer rates and plant densities on WEMA 3127 variety at two localities of North West Province, South Africa.

It is hypothesized that N fertilizer, plant density, location, and their interactions would have significant influence on growth and yield of WEMA 3127 variety. This study aimed at determining the optimum agronomic practices in the form of N rate and plant population density that would enhance growth, development and yield of this maize variety. Similarly, the study aimed at providing explanation for the impact of variations in edapho-climatic conditions of the studied environments on performance of the WEMA 3127 variety in the two locations.

The research comprised of five experiments focusing on the following:

1. Effect of N rates and plant density on morphological and growth analysis of WEMA 3127 variety under contrasting field conditions.

2. Influence of different N fertilizer rates and plant density on root system architecture of WEMA 3127 variety, grown under different field conditions.
3. Yield and yield components of WEMA 3127 variety as influenced by different rates of nitrogen fertilizer and plant densities in two localities of North West province, South Africa.
4. Nutritional attributes of WEMA 3127 grains as influenced by different N rates and plant densities in two locations of North West Province, South Africa.
5. A greenhouse study investigating water-use efficiency of WEMA 3127 variety under different N rates, soil moisture levels and soil types.

8.2 Research organisation

A 2-year field experiment conducted under two distinct agro-ecological conditions during 2015/16 and 2016/17 planting seasons was at Mafikeng and Taung both in the North West Province. The trial assessed the effect of different N fertilizer rates and plant density on morphology, root architectural system, yield and nutritional attributes of WEMA 3127 variety under different conditions. A 5x2x2 factorial greenhouse trial carried out during the 2017/18 planting season examined water-use efficiency and yield of WEMA 3127 variety under different soil moisture levels and two soil types fertilized with different nitrogen rates.

8.3 Main findings from the study

These are the main findings from this study:

i. The variety had tallest plant (309.35 cm) under closer plant density of 55,555/ha supplied with 240 kg N fertilizer in 2016/17 when rainfall was much at Molelwane compared with other treatments.

ii. At closer spacing or higher plant density (55,555 plants/ha) and 120 kg N fertilizer, WEMA variety had wider leaf area index (3.93) at Molelwane during the 2016/17 compared to 2015/2016 planting season.

iii. Wider spacing or lower plant density (33,333 plants/ha) supplied with 240 kg N fertilizer had highest net assimilation rate (1.180 g/g/day) in Molelwane during the 2015/16 when the volume of rainfall received was lesser compared to that of 2016/2017 season.

iv. The variety had maximum relative growth rate (2.963 g/g/day) under lower plant density of 33,333 plants/ha and supplied with 180 kg N/ha during the 2015/16 planting season at Molelwane.

v. WEMA 3127 had the best root architecture system with steep, cheap and deep ideotype root in field sown at 44,444 plants/ha and fertilized with 120 kg N/ha at Molelwane during the 2016/17 planting season.

vi. Highest grain yield of 7.78 t/ha was obtained under field condition with plant density 44,444 plants/ha fertilized at 120 kg N/ha during the 2016/17 planting season in Molewane.

vii. WEMA 3127 kernel had highest nitrogen uptake (119.80 kg/ha) with plant population of 55,555 plants/ha and fertilized with 240 kg N/ha during the 2015/16 planting season at Molewane.

viii. Application of 180 kg N/ha enhanced the formation of highest starch content (5166.00 kg/ha) under 55,555 plants/ha during the 2016/17 planting season in Taung. On the other hand, WEMA 3127 had highest protein yield (1592.00 kg/ha) in the plot with low density of 33,333 plants/ha supplied with 120 kg N/ha during the 2015/16 in Taung.

ix. From the greenhouse trial, growth and development of WEMA 3127 was superior in Ferric Luvisol fertilized with 240 kg N/ ha at 100 % field capacity relative to Ferric Luvisol soil. However, highest grain yield of 3.45 t/ha was obtained in Ferric Luvisol soil fertilized with 180 kg N/ha under 100% field capacity.

x. The variety had highest water use efficiency (41.73%) in Ferric Luvisol soil fertilized with 180 kg N/ha at 45% field capacity.

8.4 Conclusion and recommendations

Conclusions from the studies are as follows:

i. WEMA 3127 grew better at density of 44,444 plants/ha and fertilized with 120 kg N/ha across the two locations.

ii. The performance of WEMA 3127 was better under moderate drought condition as there was decline in performance of the variety during 2015/16 when drought was more severe compared to 2016/2017 planting season when there rainfall was much. Similarly, the variety revealed differential and significant responses to location effect with better performance recorded at Molelwane than at Taung.

iii. Rhodic Ferrasol soil enhanced growth and development of WEMA maize better than Ferric Luvisol soil.

iv. WEMA maize was tolerance of drought with better water use efficiency in Rhodic soil than in Ferric Luvisol soil.

The following are recommended for future investigations:

1. There is the need to investigate the irrigation requirement of this maize variety considering variability in weather conditions especially volume of rainfall across different provinces of South Africa.
2. The high starch content observed in WEMA 3217 variety suggests the need to research into pattern of photosynthate partitioning into economic yield as influenced by different fertilizer types. The high starch content in this WEMA variety informs the need to research into its fortification with some micronutrients to improve its nutritional quality.
3. There is the need to investigate WEMA–weed interaction in order to understand the critical period of weed interference and evolve effective weed management strategies for this hybrid maize.
4. Investigation on relationship between field to store pest as influenced by plant density and N fertilizer is very germane considering the current prevalence of toxigenic fungi on maize grain.
5. It is also important to examine the response of WEMA maize to organic fertilizer when applied singly or in combination with inorganic fertilizers under different plant densities.