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Effect of Different Nitrogen Fertilizer Rates and Plant Density on Growth of Water Efficient Maize Variety under Different Field Conditions

A.R. Adebayo, F.R. Kutu[1], E.T. Sebetha

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ABSTRACT

Background: In most areas where maize is planted, the growth is usually affected by low nitrogen and high plant density. An experiment was carried out during the 2015/16 and 2016/17 planting seasons to investigate the effect of different nitrogen fertilizer rates and plant densities on growth of water efficient maize under different field conditions.

Methods: The experiment was laid out in split plot arrangement fitted into randomized complete block design (RCBD) with four replicates. Measured growth parameters were plant height, chlorophyll content, leaf area, number of leaves and stem diameter.

Result: Maize planted at Molelwane had tallest plant height (269.63 cm) than Taung. Maize sown at 33,333 plants/ha produced highest number of leaves (15.83) and highest chlorophyll content (59. 63 SPAD - units) was obtained in the plots fertilized with 240 kg N/ha. In this study, the plant density of 55,555 plants/ha and 240 kg N/ha can be recommended for cultivation of WEMA maize variety.

Key words: Fertilizer, Nitrogen, Plant density, Plant height, WEMA maize.

INTRODUCTION

Maize is widely grown throughout the South Africa and under different environmental conditions (FAO 2018; Haarhoff *et al*., 2020). 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 for more than six hundred years (Tollenaar, 1992; Testa *et al*., 2016). Therefore, nitrogen fertilizer application and plant destiny have been continuously studing in maize cultivation (Testa *et al*., 2016).

Nitrogen is considered to be the most important and limiting nutrient for profitable maize production in most African soils (Baloyi, 2012). Nitrogen increases the protoplasm content, cell size, leaf area and photosynthetic activity (Sen *et al*., 2012). Nitrogen represents the presence of constituents such as protein and nucleic acids (Eivazi and Habibi., 2013). Mu *et al*. (2016) reported that nitrogen prolonging the appearance of leaves. Mu *et al*. (2016) explained further that at low and high nitrogen fertilizer rates, the number of leaves of maize plant was similar.

Plant density is one of the major agronomic management factors that intensely and repeatedly affect resource availability in maize production (Brekke *et al*., 2011). Testa *et al*. (2016) explained that plant density has a great influence on maize growth 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 nutrient assimilation.

Maize has been known as a cereal crop that grow well in subtropical regions but not thrives well where summer growing season at latittude greater than 30^{o} from the equator (Ahmad *et al*., 2012; Fischer *et al*., 2014). Ahmad *et al*. (2012) revealed that maize adapted to the areas where rainfall is less than 250 mm per annum without irrigation due to its higher biological efficiency.The subtropical regions were characterized by shallow and nutient poor soils. Therefore, the major contraints to maize production are nutrient deficiencies and poor soil fertility.

The information on the optimum N fertilizer requirement and appropriate plant density for this newly released Water Efficient Maize for Africa (WEMA) variety in South Africa is till scanty. Yet, soil types and environmental conditions significantly constraint maize prduction in South Africa. The hypothesis for the study is that growth parameters of this new maize variety will respond differently to varying N

Food Security and Safety Niche Area Research Group, Faculty of Natural and Agricultural Sciences, North-West University Mafikeng Campus, Private Bag x 2046, Mmabatho-2735, South Africa.
[1]School of Agricultural Sciences, University of Mpumalanga, P/Bag X11283, Mbombela-1200, South Africa.

Corresponding Author: A.R. Adebayo, Food Security and Safety Niche Area Research Group, Faculty of Natural and Agricultural Sciences, North-West University Mafikeng Campus, Private Bag x 2046, Mmabatho-2735, South Africa. Email: adebayoruth101@gmail.com

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fertilizer rates and plant densities.This study aims to investigate the effect of different N rates fertilizer and plant density on growth parameters of water efficint maize variety in two different field conditions in North West Province of South Africa.

MATERIALS AND METHODS

The experiment was carried out in 2015/16 and 2016/17 planting seasons at the Molelwane, North-West University (NWU) Research Farm (25°48′ S, 45°38′ E.; 1,012 m asl) and Taung Experimental Station (27°30′ S, 24°30′ E; 1,111 m asl). Both sites are located in the North West Province of South Africa. The climatic condition and physico- chemical properties of sites were presented in Table 1 and 2. The layout of experiments at each location was in split plot arranged in randomized complete block design with four replicates. The main-plots were assigned to plant densities (33,333; 44,444 and 55,555 plants/ha) and the five N fertilizer rates (0.60, 120,180 and 240 kg N/ha) constituted the sub-plots. Each sub-plot measured 6 m x 4 m with a total experimental plot size of 30 m x 76 m (0.228 ha) at each site. The distance of 1 m and 2 m were maintained between plots and replicates respectively. Each block had 15 experimental plots. Maize (WE 3127) seed sowing was done at inter and intra row spacing of 1 m x 0.3 m, 0.75 m x 0.3 m and 0.9 m x 0.2 m to achieve the density of 33,333, 44,4444 and 55,555, respectively. Basal fertilizer application of 30% of the each rate using NPK 20:7:3 was done at planting while 40% and 30% 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.

Five plants in the middle row of harvested area were tagged in each plot from both sites for growth data measurements at the tasseling stage (84 days after planting (DAP) and at physiological maturity (115 DAP) from both sites. The data collected included plant height with the aid of a steel measuring tape, number of leaves per plant by counting and stem diameter with the aid of a vernier caliper. Non-destructive chlorophyll measurements were determined using a chlorophyll meter (SPAD - 502 PLUS) and leaf area was estimated as described by (Bertin and Gallais 2000). All data were 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.

RESULTS AND DISCUSSION

Effect of treatment factors on plant height

The location, plant density and nitrogen rates had significant ($p \leq 0.05$) effect on maize plant height during the 2015/16 and 2016/17 planting seasons (Table 3). During the 2015/16 planting season, WEMA maize planted in Molelwane had taller plant height (217.23 cm) than Taung. This may possibly relate to variations in soil texture and in the rainfall. 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. Maize sown at 44,444 plants/ha had tallest plant height (221.61 cm) than maize planted under other plant densities. This conforms to the findings of Murányi and Pepó (2013) who reported that the plants become taller as the plant density increases. The application of 60 kg N/ha had tallest plant height (222.14 cm) and shortest plant height was recorded in the plots applied with 240 kg N/ha at 84 days after planting. At 115 days after planting, taller plant height (257.83 cm) was recorded in Taung than Molelwane. The tallest plant height (246.55 cm) was obtained in the plots under 55,555 plants/ha than 33,333 plants/ha. This conforms to the findings of Muranyi and Pepo (2013) who reported that the plants become taller as the plant density increases. The plots treated with 240 kg N/ha had tallest plant height (247.02 cm) and shortest plant height (232.17) was recorded in the unfertilized plots. During the 2016/17 planting season, higher plant height (269.63 cm) was observed in Molelwane at 84 days after planting while higher plant height (254.10 cm) was recorded in Taung at 115 days after plating. The plant density of 55,555 plants/ha had tallest plant height (271.51 cm) than rest plant densities at 115 days after planting. The tallest plant height (273.56 and 248.21 cm) was obtained in the plot fertilized with 240 kg N/ha than unfertilized plots at 84 and 115 days after planting respectively. This is in consonance with the results of Sebetha and Modi (2016), showed that maize plants use nitrogen during their active cell division process to form building blocks of protein that are essential for cell development. The interactions of location, plant density and nitrogen rates had significant ($p \leq 0.05$) on plant height. However, the interactions effect was non- significant ($p \geq 0.05$) at 115 days after planting during the 2016/17 planting season.

Effect of treatment factors on number of leaves

The number of leaf was significantly ($p \leq 0.05$) affected by treatment factors during the 2015/16 and 2016/17 planting seasons (Table 3). Maize sown in Molelwane had higher number of leaves (14.11) at 84 days after planting while Taung showed higher number of leaves (15. 87) at 115 days after planting during the 2015/16 planting season. This can possibly be attributed to the favourable environmental conditions. Highest number of leaves (14.12 and 13.70) were observed in the plots under 44,444 and 55, 5555 plants/ha than 33,333 plants/ha at 84 and 115 days after planting respectively. This agreed with the finding of Yada (2011) who reported that low plant density produce the highest number of leaves. The application of 180 kg N/ha had highest number of leaves (14.37) and least number of leaves (13.48) was recorded with the application of 60 kg N/ha at 84 days after planting. At 115 days after planting, the plots treated with 60 kg N/ha had significantly highest number of leaves (13. 40) than unfertilized plots. During the 2016/17 planting season, highest number of leaves (16.33) was attained at Molelwane at 84 days after planting and Taung had higher number of leaves (13.63) at 115 days after planting. Maize planted under the plant density of 33,333 plants/ha showed highest number of leaves (15.83) at 84 days after planting and shortest number of leaves (13.81) was observed under plant density of 44,444 plants/ha. The plant density of 44,444 plants/ha produced higest number of leaves (13.80) than plant density of 33,333 plants/ha at 115 days after planting. The plots applied with 240 kg N/ha had highest number of leaves (15.95) and at 84 than 0 kg N/ha. Similarly, at 115 days after planting application 240 kg N/ha had highest number of leaves (14. 02) than the application of 60 kg N/ha. Amin (2011) obtained highest number of leaves per plant to the application of 180 kg N/ha to increase the number of nodes.

Table 1: 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).

The interaction between location x plant density x N rates had non-significant effect ($p \geq 0.05$) on number of leaves at 84 days after planting and significant ($p \leq 0.05$) at 115 days after planting during the 2015/16 and 2016/17 planting seasons.

Effect of treatment factors on chlorophyll content

The analysis of variance showed that the treatment factors had significant effect ($p \leq 0.05$) on chlorophyll content of WEMA maize (Table 3). Taung had higher chlorophyll content (41.71 SPAD - units) at 84 days after planting while Molelwane showed higher chlorophyll content (28.02 SPAD - units) during 115 days after planting during the 2015/16 planting season. This may relates to the application of nitrogen fertilizer and favourable environmental conditions. Highest chlorophyll content (55.23 and 28.07 SPAD-units) was recorded under the plant density of 33,333 and 55,555 plants/ha at 84 and 115 days after planting respectively. This result is corroborrated by the findings of Capici *et al*. (2010) who stated that the chlorophyll content decreases significantly with increasing plant density levels.The plots fertilized with 180 N kg/ha had highest chlorophyll content (50.87 and 24.89 SPAD - units) at 84 and 115 days after planting than other fertilizer rates.During the 2016/17 planting season, the higher chlorophyll content (57.39 SPAD - units) was attained at Taung at 84 days after planting whereas higher chlorophyll content (28.82 SPAD-units) was recorded in Molelwane at 115 days after planting. WEMA planted in the plots under 33,333 and 44,444 plants/ha had highest chlorophyll content (57.86 and 30.68 SPAD - units) at 84 and 115 days after planting respectively. The application of 240 kg N/ha showed highest chlorophyll content (59.63 and 29.47 SPAD - units) at 84 and 115 days after planting respectively. This agreed the earlier findings (Tajul *et al*. 2013), who reported an increase in the chlorophyll content index as the rate of nitrogen fertilizer increases. Chlorophyll content was significantly affected by interaction between location x plant density x nitrogen rates during 2015/16 and 2016/17 planting season and non- significant ($p \geq 0.05$) at 84 days after planting during the 2016/17 planting season.

Effect of treatment factors on stem diameter

The stem diameter was significantly ($p \leq 0.05$) affected by location, plant density and N rates (Table 4). During the 2015/16

Table 2: Physico-chemical properties of experimental sites during 2015/16 and 2016/17 planting seasons.

Physico-chemical Properties	2015/16 trial		2016/2017 trial	
	Molelwane	Taung	Molelwane	Taung
Sand (%)	82.00	85.00	82.00	85.00
Silt (%)	1.00	1.00	1.00	1
Clay (%)	18.00	14.00	18.00	14.00
Texture	Sandy Loam	Loam sandy	Sandy Loam	Loam sandy
Total N %	0.08	0.12	0.17	0.19
Available P mg/kg	6.00	5.00	80.00	49.00
K mg/kg	279.00	366.00	238.00	180.00
pH (H_2O)	4.31	6.45	4.50	4.30
Soil classification (WRB, 2016)	Ferric Luvisol	Rhodic Ferralsol	Ferric Luvisol	Rhodic Ferralsol

Table 3: Effect of treatment factors on plant height, mumber of leaves and chlorophyll content.

Treatment factors	2015/16 Plant height (cm) 84 DAP	2015/16 Plant height (cm) 115 DAP	2015/16 Number of leaves 84 DAP	2015/16 Number of leaves 115 DAP	2015/16 Chlorophyll content (SPAD-units) 84 DAP	2015/16 Chlorophyll content (SPAD-units) 115 DAP	2016/17 Plant height (cm) 84 DAP	2016/17 Plant height (cm) 115 DAP	2016/17 Number of leaves 84 DAP	2016/17 Number of leaves 115 DAP	2016/17 Chlorophyll content (SPAD-units) 84 DAP	2016/17 Chlorophyll content (SPAD-units) 115 DAP
Location												
Molelwane	217.23a	223.71b	14.11a	12.58b	41.71b	28.02a	269.63a	239.40b	16.33a	13.50a	55.14b	28.82a
Taung	213.26b	257.83a	13.64b	15.87a	52.28a	18.28b	250.29b	254.10a	15.03b	13.63a	57.39a	25.04b
$LSD_{(0.05)}$	0.82	0.20	0.30	0.15	0.67	0.48	1.27	2.41	0.40	0.38	1.90	2.67
Plant density (plants/ha)												
33,333	211.80b	235.48c	13.51b	12.53c	53.27a	21.26b	252.73b	246.40b	15.83a	13.20b	57.86a	24.50b
44,444	221.61a	240.28b	14.12a	13.45b	44.64b	20.13c	255.65b	241.10c	15.51a	13.81a	54.18b	30.68a
55,555	212.32b	246.55a	14.00a	13.70a	43.07c	28.07a	271.51a	252.70a	15.71a	13.70a	56.15a	25.61b
$LSD_{(0.05)}$	1.01	0.24	0.36	0.17	0.82	0.59	1.56	2.95	0.49	0.48	2.33	3.27
N rates (kg/ha)												
0	220.54b	232.17e	13.59bc	12.99c	44.94c	21.11c	247.72d	246.30a	15.40a	13.92a	56.16bc	29.30a
60	222.14a	238.27d	13.48c	13.40a	48.24b	22.14b	257.13c	248.10a	15.69a	13.02b	54.67c	25.99a
120	202.77e	247.02a	13.90abc	13.35a	44.32c	23.04c	257.46c	248.20a	15.63a	13.50ab	53.28bc	25.05a
180	217.17c	243.55b	14.37a	13.20b	50.87a	24.89a	263.94b	243.00b	15.73a	13.38ab	57.56ab	24.84b
240	213.59d	242.83c	14.04ab	13.20b	46.60c	24.56b	273.56a	248.21a	15.95a	14.02a	59.63a	29.47a
$LSD_{(0.05)}$	1.30	0.31	0.47	0.21	1.06	0.76	2.01	3.08	0.63	0.61	3.02	4.22
Grand Mean	215.24	240.77	13.87	13.23	46.99	23.15	259.96	246.80	15.68	15.57	56.26	26.93
F test												
N x PD x L	**	**	ns	**	**	**	**	ns	ns	**	ns	**

N=N rates, PD=Plant Density, L= Location, DAP = Days After Planting. Notes: Means with the same letter on the same column and treatment are not significantly different at P ≤0.05 using Duncans Multiple Range Test (DMRT). ** significant at 5% probability

Table 4: Effect of treatment factors on stem diameter and leaf area.

Treatment factors	2015/16				2016/17			
	84 DAP	115 DAP	84 DAP	115 DAS	84 DAP	115 DAP	84 DAP	115 DAP
	Stem diameter		Leaf area		Stem diameter		Leaf area	
Location								
Molelwane	1.86b	2.45b	647.85a	632.30b	3.20b	2.72b	809.63a	660. 00b
Taung	1.98a	2.92a	593.46b	712.86a	3.38a	2.91a	671.36b	694.20a
LSD	0.01	0.11	0.63	0.52	0.10	0.18	0.64	18.60
Plant density (plants/ha)								
33,333	1.89c	2.47b	590.84c	676.70b	3.43a	2.84a	767.41a	703.30a
44,444	1.91b	2.58b	627.56b	661.62c	3.23b	2.70b	720.52c	656.20b
55,555	1.97a	2.88a	643.55a	679.41a	3.21b	2.92a	733.55b	671.80b
LSD	0.01	0.14	0.78	0.64	0.12	0.22	0.74	22.78
N rates (kg/ha)								
0	1.90c	2.46b	623.08d	637.38e	3.16d	2.84a	742.44d	670.20a
60	1.96a	2.75a	632.05a	698.73a	3.24c	2.62b	733.95c	683.00a
120	1.97a	2.57ab	629.39b	684.67c	3.26b	2.93a	702.33e	692.30a
180	1.91ab	2.76a	620.05c	697.30b	3.52a	2.69b	749.71b	679.00a
240	1.89c	2.62ab	598.70e	644.81d	3.26b	2.99a	774.06a	661.10b
LSD	0.02	0.83	1.00	0.82	0.15	0.30	0.96	29.40
Grand Mean	1.92	2.63	620.65	672.58	3.29	2.81	740.50	677.10
F test								
N x PD x L	ns	**	**	**	**	ns	**	**

N=N rates, PD=Plant Density, L= Location, DAP = Days After Planting. Notes: Means with the same letter on the same column and treatment are not significantly different at P ≤0.05. using Duncans Multiple Range Test (DMRT). ** significant at 5% probability.

planting season, thicker stem diameter (1.98 and 2.92 mm) was recorded in Taung at 84 and 115 days after planting respectively. This may possibly due to variations in the environmental conditions and the soil factor. The plant density of 55,555 produced thickest stem diameter (1.98 and 2.92 mm) at 84 and 115 days respectively. The plot treated with 120 kg N/ha had thickest stem diameter (1.97 mm) than plot applied with 240 kg N/ha at 84 days after planting. At 115 days after planting, application of 180 kg N/ha showed thickest stem diameter (2.76 mm) and the thinnest stem diameter (2.46 mm) was recorded in unfertilized plots. The Taung location had thickest stem diameter (3.38 and 2.91 mm) at 84 and 115 days after planting during the 2016/17 planting season. The thickest stem diameter (3.43 mm) was recorded under the plant density of 33,333 than 55,555 plants/ha at 84 days after planting. However, the plant density of 55,555 plants/ha had thickest stem diameter (2.94 mm) than 44,444 plants/ha at 115 days after planting. At 84 days after planting, the application of 180 had thickest stem diameter (3.43 mm) than 0 kg N/ha. The plots treated with 120 kg N/ha showed thickest stem diameter (2.99 mm) than unfertilized plots at 115 kg N/ha. This is disagreed with the finding of Mandi *et al*. (2015), who revealed that high plant density reduce photosynthesis and cause reductions in the stem diameter. Opoku (2017) pointed that an increase in the nitrogen fertilizer supply enhanced the growth of diameters of cells and stems. The interactions of location, plant density and nitrogen fertilizer rates had significant (p≤ 0.05) effect on stem diameter.

Effect of treatment factors on leaf area

The leaf area of WEMA maize was significantly (p≤ 0.05) affected by location, plant density and N rates during the 2015/16 and 2016/17 planting seasons (Table 4). Each locations had higher leaf area (647.78 and 712.86 cm^2) at 84 days after planting and (809.63 and 694.20 cm^2) at 115 days after planting during the 2015/16 and 2016/17 planting seasons respectively. This can be attributed to the favourable environmental conditions, in tandem with the adequate fertilization rates. During the 2015/16 planting seasons, the plant density of 55,555 plants/ha had highest leaf area (643.55 and 679.41 cm^2) at 84 and 115 days after planting respectively. Hokmalipour and Darbandi (2011) indicated that plant density affects leaf area. The plots fertilized with 60 kg N/ha had highest leaf areas (632.05 and 698.73 cm^2) than unfertilized plots at 84 and 115 days after planting respectivel. During the 2016/17 planting season, the highest leaf area (767.41 and 703.30 cm^2) was obtained in the plots under 33,333 plants/ha at 84 and 115 days after planting. The highest leaf area (774.06 cm^2) was obtained in the plot treated with 240 kg N/ha at 84 days after planting. The plots fertilized with 60 kg N/ha showed highest leaf area (678.60 cm^2) at 115 days after planting. Amanullah *et al*. (2009) and Amin (2011) revealed that high fertilizer rates enhance cell division, which in its turn significantly promotes cell expansion, leaf development and expansion of the leaf area. The interactions between location x plant density x nitrogen rates had significant (p≤ 0.05) effect on leaf area.

CONCLUSION

The results of this study show that the WEMA growth parameters grow better with the application of 240 kg N/ha. The plant height, stem diameter and leaf area of WEMA maize developed better under the plant densisy of 55,555 plants/ha than other plant densities.The growth parameters of WEMA maize performed better across the two locations. However, Molelwane location improved the plant height, number of leaves, chlorophyll content and stem diameter of WEMA maize. Therefore, WEMA maize should grow under plant density of 55,555 plants/ha with application of 240 kg N/ha in the two locations.

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