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Effect of Nitrogen Fertilizer and Soil Moisture Levels on the Performance of Drought-Tolerant Maize on Ferric Luvisol and Rhodic Ferralsol Soils

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Abstract

Globally, water and nitrogen have been known as the most important resources that significantly impact crop productivity. This study assessed the response of Water Efficient Maize for Africa, WEMA3127 variety to different soil moisture levels, and nitrogen fertilizer rates on Ferric Luvisol and Rhodic Ferralsol soils. A greenhouse experiment was conducted to investigate the effect of different N fertilizer and soil moisture levels on the growth, yields and water-use efficiency of the water-efficient maize for Africa (WEMA) variety on two distinct soils. The experiment was designed as a completely randomized design with three replicates and used a factorial design with a 5 x 2 x 2 design. Treatments comprised five N fertilizer rates (0, 60, 120, 180 and 240 kg N/ha), two soil moisture levels (45 and 100% field capacity), and two soil types (Ferric Luvisol and Rhodic Ferralsol). Plant height, chlorophyll content and total dry matter weight as growth attributes, grain yield, total biological yield and water-use efficiency parameters were determined. The tallest plant height (283.33 cm) was recorded in Ferric Luvisol supplied with 240 kg N/ha at 100% field capacity. The highest grain yield (136.8 g /pot) and water-use efficiency (1.94%) were obtained in Rhodic Ferralsol treated with 180 kg N/ha at 100% and 45% field capacity (FC), respectively. A linear relationship was obtained between N fertilizer rates and the grain yield (R^2 = 0.91) and between total dry matter and grain yield (R^2 = 0.51). The results showed that the growth and water-use efficiency of WE3127 maize variety was better on Rhodic Ferralsol than in Ferric Luvisol.
Keywords: Water-use efficiency; Grain yield; WEMA variety; N fertilizer rates.

1. Introduction

Water stress and nitrogen (N) deficiency are among the two most important factors that reduce the growth and yield of many cereal and leguminous crops in various semi-arid and arid regions [1-3]. Water stress adversely affects crop growth and yields and thus reduces productivity [4]. Water stress significantly impacts maize development, which cannot be overemphasized. It is widely that dehydration leads to general crop failure and decreased leaf area, biomass, and crop yield [4]. The state of water stress affects the anatomical, morphological, physiological, and biochemical processes in plants, especially at the tasseling and pollination stages [5, 6]. In addition, low soil moisture content can reduce the absorption of water and nutrients by plant roots, leading to the dehydration of the leaves, consequently resulting in stomatal cessation. Water stress causes reduced photosynthetic activities, leading to reduced growth and biomass accumulation [4, 7]. Similarly, adequate water supply to crops during the active vegetative phase often has a detrimental effect on stem growth [7, 8].

Limited water supply prevents nutrients uptake by plants [3, 9, 10]. When the water supply to the crop-growing environment is inadequate, the soil structure may be disrupted, and soil aeration and water content change [11]. In a semi-arid environment, where access to water is a challenge, it would be good to plant a variety of maize that will make good use of available resources, especially water and nitrogen, to produce biomass and benefit parts of the crop [12]. Improved water-use efficiency in any crop indicates plants' adaptation to survive under low water availability, especially under arid/semi-arid conditions [13]. A crop or cultivar hybrid that uses water more efficiently can improve yields and productivity even under limited soil moisture conditions [13].

Nitrogen deficiency affects maize yield and is an abiotic stressor that causes a significant decrease in leaf growth and the photosynthetic rate [14, 15]. Nitrogen deficiency reduces maize yields, and as a result of the ensuing low rates, it affects the physiological and biochemical activities of the plant [14, 16]. Low soil nitrogen may reduce the ability of the leaf area to intercept light and the facility of plants to fix carbon dioxide [3].

Mashingaidze and James [17] reported that, unlike other varieties, the WEMA variety provides at least a 20% yield benefit under moderate drought conditions. Although the WEMA variety is drought-tolerant, the information on the degree of tolerance to different soil types, particularly in the North West Province of South Africa, is limited.

According to Paterson, *et al.* [18], the extent to which drought influences crop growth and yield in arid regions varies from soil to soil depending on existing conditions such as soil moisture. Rengasamy [19] also confirmed that plant growth response of crops to different soil inherent characteristics such as texture, pH, and many others, vary greatly. The **i**nformation on the degree of tolerance of WEMA variety to water stress and varying N fertilizer rates on soils with different inherent characteristics is scarce. We hypothesize that the growth parameters and yield of the WEMA variety will perform differently under varying N regimes and soil conditions. Therefore, this study was conducted to evaluate the performance of WEMA maize on Ferric Luvisol and Rhodic Ferralsol soils at different soil moisture levels and nitrogen rates.

2. Materials and Methods

A greenhouse experiment was carried out between February and July 2018 at North-West University (NWU) Research Farm, located at Molelwane (25° 48′S, 45°38′E). 1012 m above sea level, located in North West Province. The greenhouse temperature ranged between 24 – 33°C, and relative humidity ranged between 63 – 74%. Soil samples were collected at a depth of 0 to 15 cm from the NWU Research Farm and the North West Provincial Department of Agriculture Taung Experimental Station (27° 30′S, 24° 30′E; 1 111 m above sea level). The soil in Molelwane farm is sandy loam and classified as a Ferric Luvisol, while the soil at the Taung experimental site is a loamy sand soil classified as a Rhodic Ferralsol. Soil samples collected at depths of 0 to 15 cm were analyzed following the standard procedures of the South African Soil Science Guidelines [20], while the field capacity for the respective fields was determined according to the procedures of Kebede, *et al.* [21]. The results of the Physico-chemical properties are presented in Table1.

The experiment was a factorial experiment with a 5 x 2 x 2 design and was designed as a completely randomized design with three replicates. 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% FC, and two soil types (Ferric Luvisol and Rhodic Ferralsol). The soil was sieved using a 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 sellotape to prevent soil loss and leaching, were filled with 18 kg of soil. A total of 180 pots (3 pots/treatment factor) were used (Figure 1). The soil-filled pots were irrigated to field capacity and allowed to drain for eight hours, after which two seeds of the WEMA3127 variety were planted in each pot. The seedlings are thinned out with one plant per pot 10 days after germination. Half of the quantities of the inorganic nitrogen fertilizer (NPK 20:7:3) required per pot were applied at 10 days weeks after emergence, and the remaining half was applied (at four weeks after emergence) in the form of limestone ammonium nitrate, LAN (28% N). The pots were irrigated every two days depending on the treatment. The Ferric Luvisol was irrigated with 1.22 and 2.72 litres, while the RhodicFerralsol was irrigated with 1.26 and 2.81 litres, thus ensuring that their respective field capacities could be accommodated (45 % and 100% water-holding capacity levels, respectively).

Data were collected at six, eight and twelve weeks after sowing (WAS). The data collected related to plant height, measured with a measuring tape; the number of leaves per plant by counting; chlorophyll content measured with a portable chlorophyll meter (model CCM200 plus); and stem diameter, with the aid of a vernier calliper. At harvesting, one ear per plant per pot was harvested and shelled. The yield/ha was calculated at a 12% moisture content.

Yield = $\frac{Dry\ yield\ /pot}{100-moisture\ content/100}$ [22, 23]

Total biological yield = grain yield + stover yield [24]

Harvest Index = $\frac{Economic\ yield\ (g)}{Total\ biological\ yield\ (g)}$ [23]

Water-use efficiency was calculated as follows:

Water-use efficiency (%) = $\frac{Grain\ yield\ \ g/pot}{Quantity\ of\ water\ applied(L)}$

2.1. Statistical Analysis

All data collected were analyzed using Analysis of Variance (ANOVA) GenStat, 11th Edition. Differences in treatment mean values were tested using the least significant difference (LSD) measure with a probability level of 5%. The relationships between the treatment factors and the measured parameters were analyzed using regression and correlation analyses.

3. Results

3.1. Analysis of Variance of the Different Treatment Effects on the Performance of the Wema Variety

The results showed that varying N rates and the different levels of irrigation supplied to the two soil types significantly ($p \leq 0.01$) affected the growth, yield and dry matter parameters of the WEMA maize variety (Table 2).

However, none of the single treatment factors had a 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.

3.2. Treatment Interaction Effects on the Growth Parameters

3.2.1. 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 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. Eight weeks after the sowing stage, the tallest plant (279.33 cm) was significantly observed on the Ferric Luvisol supplied with 240 kg N/ha at a 100 % field capacity level. A similar trend was observed at 12 weeks after sowing. However, the shortest plant was recorded in this same soil type but 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. However, this was not significantly different from the height obtained with 60 kg N/ha.

3.2.2. Number of Leaves

Interaction among the three factors significantly affected the number of leaves of the WEMA variety, as indicated in Table 4. At the earlier growth stage, WEMA had significantly the highest number of leaves on the Rhodic Ferralsol watered to a field capacity of 100%, but without any fertilizer application. At eight weeks after sowing, the number of leaves formed by the WEMA variety was significantly higher 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.

3.2.3. Stem Diameter

The interaction among soil moisture levels, soil types, and nitrogen fertilizer rates significantly affected the maize plants' stem diameter (Table 5).

At 6 weeks after sowing, WEMA had the significantly thickest stem diameter (2.37 mm) 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 thickest (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 the thickest 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.

3.2.4. Chlorophyll Content

The chlorophyll content was significantly influenced by the interaction between soil moisture levels, soil types and nitrogen fertilizer rates. At six weeks after sowing, the Rhodic Ferralsol fertilized with 240 kg N/ha produced plants with the highest chlorophyll content. However, this chlorophyll content level was not significantly different 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 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. Eight weeks after sowing, the lowest chlorophyll content 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.

3.2.5. Shoot Dry Weight

The interaction effect of soil moisture levels, soil types and N fertilizer rates had a significant ($p \leq 0.05$) effect on the dry shoot weight of the WEMA variety (Table 7). Under the 100% field capacity level, the WEMA grown on the Rhodic Ferralsol fertilized with 180 kg of N/ha significantly had the 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 significantly had the highest shoot dry weight at 8 and 12 weeks after sowing (Table 7). The least dry shoot weights were recorded in an unfertilized Rhodic Ferralsol, and Ferric Luvisol was supplied with a 45% soil moisture level.

3.2.6. Root Dry Weight

There was a significant ($p \leq 0.05$) interaction effect of soil moisture level, soil types and nitrogen fertilizer rates on the dry root weight of the WEMA variety (Table 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 the highest dry root weight (36.67 g), significantly different from dry root weight obtained in pots containing both soil types at either 45% or 100% FC moisture level. Ferric Luvisol enhanced the 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.

3.2.7. Dry Matter Yield

As indicated in Table 9, the interaction among soil moisture level, soil types and nitrogen fertilizer rates significantly affected 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 soil moisture of 45% during the late growth stage.

3.3. Interaction Effect of Nitrogen Rate, Water Regime and Soil Type on Grain Yield, Yield Components, and Water-Use Efficiency of the Wema Variety

The interactions among soil moisture level, soil type and nitrogen fertilizer rates significantly affected the maize yield and its components (Table 10). The WEMA variety had a significantly higher grain yield (136.8 g/pot) on Rhodic Ferrasol fertilized with 180 kg N/ha at a 100 % field capacity level than Ferric Luvisol fertilized with 60 kg N/ha and irrigated up to a 45 % field capacity level. The stover yield was highest (201,2 g/pot) 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 from an unfertilized soil irrigated at a 45% soil moisture level. The biological yield (324.39 g/pot) was significantly 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 two soil types fertilized with 0 kg N/ha at a 45% soil moisture level. The harvest index was significantly highest (0.50) 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 (1.94% /pot) on the Rhodic Ferralsol 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.

3.4. Regression Analysis of the 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 2a and 2b). Similarly, water-use efficiency is statistically and significantly related to the quantity of fertilizer applied. The result showed that (60 and 83%) at a 45% field capacity and (91 and 84)% in the pots watered with 100% field capacity of the water-use efficiency were predictable on considering the relationship between the amount of the nitrogen fertilizer applied and the water-use efficiency under Rhodic Ferralsol and Ferric Luvisol soil respectively (Figure 3a and 3b).

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 (Table 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 and 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, the harvest index had a 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.

4. Discussion

The WEMA variety had better growth attributes 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 [25]. As such, there is perhaps the need to apply high levels of nitrogen fertilizer 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 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.* [26]; the soil pH was found to enhance the growth performance 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) compared with Rhodic Ferralsol (pH of 5.5). High acidity levels (low soil pH) in soils have been generally found to impede the growth of crops. This is agreed with the findings of the Fertilizer Society of South Africa (FSSA) [27]; the society indicated that maize performed better on soil types with soil pH ranges between 5.5 – 7.5. Miller [28] reported that effective uptake of nitrate by plants is preeminent in the soil types with soil pH acidic in nature.

When supplemental irrigation was used to promote acceptable soil moisture conditions (100 % FC level), the WEMA variety performance was considerably improved, and this was especially noticeable when contrasted to its status when moisture levels were inadequate. This demonstrates that the WEMA variety performance is ideally increased when appropriate moisture is applied to the plant. On the other hand, if the moisture level is too low, the maize plant's growth will be hampered, dry matter accumulation will be poor, and yields will be low.

According to Wang and Shangguan [3], the most notable effects of a water deficit are poor shoot growth due to a loss in leaf biomass and leaf area. Water deficits inhibit plant growth and impair various physiological and biochemical processes such as photosynthesis, respiration, translocation, ion uptake, carbohydrate synthesis, and nutrient metabolism. This is consistent with studies by Jaleel, *et al.* [29], Jaleel, *et al.* [30], and Farooq, *et al.* [7], who reported that water deficits inhibit plant growth and impair various physiological and biochemical processes such as photosynthesis, respiration, and translocation.

Kusaka, *et al.* [31] and Shao, *et al.* [32] have reported the deleterious effect of water deficits on the growth and development of maize. While Wu, *et al.* [33] affirmed reductions of up to 25% in plant height in citrus seedlings exposed to water stress, Wang and Shangguan [3] reported that the main physiological consequence of water deprivation is inhibition of photosynthesis. This could be why the low chlorophyll content was recorded in a water-deficient environment and limited native fertility. Similar observations were reported by Farooq, *et al.* [7] that chlorophyll content is highly susceptible to soil drying, while Ebrahimia, *et al.* [34] indicated that the chlorophyll content in sunflower plants declines to a significant level when the water deficiency intensifies. Consistent with Habtegebrial, *et al.* [35] and Khan, *et al.* [36], nitrogen fertilizer improves vegetative growth, maize biomass, and dry matter production, leading 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%, in conjunction with the largest nitrogen fertilizer application rates. This soil type is known for its better porosity and excellent aeration properties. These properties are beneficial for nutrient absorption, root growth and development. The soil type showed better fertilizer use efficiency than those without these beneficial properties. Maize thrives well under a well-aerated soil environment, good fertility conditions, and water availability. 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 and adequate fertilization levels. According to Nsanzabaganwa, *et al.* [37] and Phefadu and Kutu [38], 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.* [39], 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 El Zubair, *et al.* [40], who reported on maximum dry matter yields was obtained at high nitrogen fertilizer levels 180 kg N/ha. World Reference Base for Soil Resources [25] reported that contrary to the Rhodic Ferralsol, the Ferric Luvisol has a higher percentage of organic matter in terms of its C: N ratio. Muelle, *et al.* [28] report that loam and clay soils are more prone to water deficits because of their low level of drainable porosity after durable wetting. Li, *et al.* [41], indicated that limited quantities of soil water restrict maize crop yields more than the level of nitrogen fertilizer doses.

These results are in line with the findings of Chilundo [42], 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. Monneveux, *et al.* [43] and Kamara, *et al.* [44] showed that water stress greatly reduces the grain yield, which is largely affected by the high level of defoliation resulting from water deficits. The harvest index and dry matte of maize were reduced under water deficit [5, 45].

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 based on the soil conditions and the quantities of fertilizer applied to the soil [46]. The major factors that affect water-use efficiency are soil structure and texture. These findings conform with the findings of other investigators such as Blum [47], Long and Ort [48] and Gurian-Sherman [11], 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 per the findings of

Gurian-Sherman [11], who reported that drought-tolerant plants might 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 agree with Li, *et al.* [41], who showed that the effects of nitrogen on crop water use are expected to vary with the availability of soil moisture. Hammad, *et al.* [49] and Nilahyane, *et al.* [50] reported that water and nitrogen are the most yield-limiting factors in semi-arid areas.

This research study investigated the relationships between grain yield and its components' water-use efficiency, growth parameters, and dry matter accumulation. 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 the total amount of dry matter [51, 52]. These researchers further revealed that increased levels in the growth parameters, particularly in terms of plant height and the number of leaves per plant, might help the plant's photosynthetic apparatus to synthesize more assimilates and, therefore, produce larger yields. The relationships revealed that as the grain yield components increase, the yield also increases. This indicates that the grain yield could be increased by improving the yield components. Maral, *et al.* [53], observed the same result and reported that grain yield and the yield components are positively and significantly correlated.

5. Conclusion

The application of 240 kg/ha to Rhodic Ferralsol improved the growth performance of WEMA maize, while the Ferric Luvisol fertilized with 180 kg N/ha increased grain production at full field capacity (100%). The WEMA variety showed better water-use efficiency under 45% field capacity. This indicated that WEMA maize could also possibly perform well under a moderate soil moisture deficit. This maize variety can be cultivated on a Ferric Luvisol, but its baseline grain yield could compare with that of the Rhodic Ferralsol.

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Table-1. Physico-chemical properties of the soil types

Physico-chemical properties	Ferric Luvisol	Rhodic Ferralsol
Sand %	82	85
Silt %	1	1
Clay %	18	14
Texture	Sandy loam	Loamy sand
pH (H_2O)	4.13	5.60
Total N (%)	0.14	0.22
Phosphorus (mg/kg)	7.00	10.00
Potassium (mg/kg)	235	240
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

Table-2. Mean square value of growth and yield parameters of WEMA variety as influence by nitrogen rates, soil moisture levels and soil types

	Parameters										
Treatments	Plant height (cm)	Number of leaves	Chlorophyll content (SPAD - units)	Dry shoot weight (g)	Dry root weight (g)	Total dry matter (g)	Grain yield (g/pot)	Stover yield (g/pot)	Biological yield (g/pot)	Harvest index	Water-use efficiency
ST	3205.00**	0.001**	3.02**	8.76**	0.19**	11.25**	28,354.28**	218.86 **	30,189.16**	0.2377**	3.7261**
SML	2408.00**	5.51	0.46**	2.67**	0.16**	4.13**	10,733.27**	14,440.00**	54,381.82**	0.0195**	2.3636**
N rates (kg/ha)	6669.00**	1.63	319.60**	3.96**	0.25**	22.65**	6,298**	4264.37**	20, 3356.79**	0.0283**	0.7749**
N rates X ST	885.00**	2.24**	0.13**	8.72**	0.20**	4.26**	767.05**	266.86**	1,362.92**	0.0053**	0.085**
N rates X SML	767.00**	2.03**	0.20**	3.75**	0.21**	19.30**	1762.31**	1469.43	4,090.71**	0.0007**	0.2062**
ST X SML	2846.00**	0.11**	0.09**	0.68**	0.21**	139.00**	67.84**	391.30 **	1402.43**	0.0030**	0.6556**
N rates X ST XSML	429.00**	0.80**	0.25**	1.27**	0.06**	5.20**	577.50**	195.92**	661.44**	0.033**	101.31**

Note: N = N rates, SML = Soil moisture level, ST = Soil types ** $p \leq 0.01$, * $p \leq 0.05$, ns = no significant

Table-3. Effects of soil moisture level, soil type and nitrogen fertilizer level on the mean plant height (cm) of the WEMA

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	6	WAS 8	12
		0	62.17	175.33	210.67
		60	60.67	219.67	208.17
	Ferric Luvisol	120	69.33	216.33	210.07
		180	79.00	206.67	204.87
		240	77.37	201.17	210.08
45					
	Rhodic Feralsol	0	57.60	169.83	232.83
		60	62.17	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
	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	252.38	232.50
100		240	92.50	279.33	283.33
	Rhodic Feralsol				
		0	48.67	224.33	249.33
		60	50.00	221.33	244.00
		120	93.60	269.33	252.33
		180	100.00	260.00	270.33
		240	108.00	270.00	259.67
LSD $_{(0.05)}$			5.94	3.80	3.36

WAS = Weeks after sowing

Table-4. Interaction effect of soil moisture level, soil type and nitrogen fertilizer level on number of leaves of WE3127 maize plant variety

Soil moisture level (% FC)	**Soil type**	**N rates (kg/ha)**	**6**	**WAS**	**12**
				8	
		0	11.00	13.00	14.33
		60	11.67	12.33	14.33
	Ferric Luvisol	120	12.00	13.67	14.67
		180	11.00	14.33	13.33
		240	11.00	15.33	14.67
45					
	Rhodic Feralsol	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
	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
100		240	12.00	13.67	14.00
	Rhodic Feralsol				
		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

WAS = Weeks after sowing

Table-5. Interaction effect of soil moisture level, soil types and nitrogen fertilizer level on stem diameter (mm) of the WE3127 maize plant variety

Soil moisture level (% FC)	**Soil type**	**N rates (kg/ha)**	**6**	**WAS**	**12**
				8	
		0	1.43	0.43	1.90
		60	1.27	0.67	2.13
	Ferric Luvisol	120	1.50	1.37	1.97
		180	1.67	1.80	1.93
		240	1.50	1.43	2.03
45					
	Rhodic Feralsol	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	2.03	2.10	2.00
	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
100		240	2.03	2.53	2.20
	Rhodic Feralsol				
		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

WAS = Weeks after sowing

Table-6. Interaction effect of soil moisture level, soil type and nitrogen fertilizer rates on chlorophyll content (SPAD-units) of the WE3127 maize plant variety

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	6	WAS 8	12
		0	9.33	3.23	1.40
		60	12.03	7.57	1.47
	Ferric Luvisol	120	14.43	9.08	1.50
		180	14.60	10.93	1.40
		240	14.40	12.98	1.40
45					
	Rhodic Feralsol	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
	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
100		240	19.07	15.87	1.40
	Rhodic Feralsol				
		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 $_{(0.05)}$			1.75	1.78	0.25

WAS = Weeks after sowing

Table-7. Interaction effect of nitrogen rate, soil moisture level and soil type on the dry shoot weight of the WE3127 maize plant variety

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	6	WAS 8	12
		0	14.02	102.00	91.17
		60	13.48	128.67	127.61
	Ferric Luvisol	120	22.55	173.33	122.14
		180	21.58	147.00	129.39
		240	19.94	180.67	125.34
45					
	Rhodic Feralsol	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	176.81
	Ferric Luvisol	0	15.93	80.00	114.14
		60	15.04	151.00	131.30
		120	31,90	236.00	163.84
		180	24.68	261.33	169.90
100		240	21.66	348.00	200.96
	Rhodic Feralsol				
		0	12.14	68.67	126.41
		60	15.15	131.00	140.42
		120	121.33	252.00	151.51
		180	30.19	298.00	181.82
		240	25.28	304.13	175.73
LSD $_{(0.05)}$			9.63	2.61	3.36

WAS = Weeks after sowing

Table-8. Interaction effect of nitrogen rates, soil moisture level and soil types on the dry root weight (g) of WE3127 maize plant

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	6	WAS 8	12
		0	1.02	7.33	13.51
		60	4.81	16.00	20.92
	Ferric Luvisol	120	9.57	18.00	25.18
		180	8.58	13.67	19.10
		240	7.62	16.67	20.03
45					
	Rhodic Feralsol	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
	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	26.26
100		240	8.61	30.00	32.01
	Rhodic Feralsol				
		0	3.82	3.67	19.42
		60	2.15	7.33	16.56
		120	8.33	30.63	27.05
		180	31.24	21.67	31.96
		240	15.89	36.67	30.40
LSD $_{(0.05)}$			1.22	1.05	1.93

WAS = Weeks after sowing

Table-9. Interaction effect of nitrogen rate, soil moisture level and soil type on dry matter (g) production of WE3127 maize variety

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	6	WAS 8	12
		0	15.04	253.30	104.69
		60	18.29	204.00	148.53
	Ferric Luvisol	120	32.12	215.00	147.33
		180	30.17	248.00	148.49
		240	27.53	138.70	145.37
45					
	Rhodic Feralsol	0	22.03	238.30	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
	Ferric Luvisol	0	18.87	203.00	127.82
		60	17.17	203.70	151.11
		120	30.81	211.70	192.33
		180	31.25	261.70	196.26
100		240	30.07	226.70	232.97
	Rhodic Feralsol				
		0	15.96	203.03	145.33
		60	17.30	252.70	158.97
		120	29.66	205.30	178.56
		180	31.44	181.00	213.78
		240	41.07	275.00	206.13
LSD $_{(0.05)}$			9.87	39.95	20.22

WAS = Weeks after sowing

Table-10. Effects of soil moisture level, soil type and nitrogen fertilizer rate on yield, yield components and water-use efficiency of the WE3127 maize plant

Soil moisture level (% FC)	Soil type	N rates (kg/ha)	Grain yield/pot (g)	Stover yield/pot (g)	Above biological yield/pot (g)	Harvest index/pot	Water- use efficiency/pot (%)
		0	27.00	91.17	118.17	0.23	0.46
		60	21.60	130.94	152.56	0.14	0.37
	Ferric Luvisol	120	64.40	122.14	186.57	0.34	1.10
		180	58.90	128.06	179.96	0.29	0.89
		240	52.30	125.67	177.95	0.30	0.90
45							
	Rhodic Feralsol	0	59.50	111.99	171.49	0.36	0.97
		60	74.90	141.01	215.87	0.35	1.22
		120	105.30	120.60	225.92	0.47	1.71
		180	119.10	132,21	251.28	0.50	1.94
		240	86.00	136.81	223.27	0.39	1.41
	Ferric Luvisol	0	35.00	114.14	149.11	0.24	0.27
		60	45.10	136.30	181.44	0.25	0.35
		120	48.80	157.03	230.16	0.32	0.37
		180	109.60	169.90	279.48	0.40	0.84
100		240	123.10	201.29	324.39	0.38	0.94
	Rhodic Feralsol						
		0	75.20	126.41	201.58	0.37	0.56
		60	117.30	137.42	254.70	0.46	0.89
		120	109.00	157.51	261.00	0.42	0.81
		180	136.80	181.16	317.97	0.43	1.02
		240	129.60	175.73	305.31	0.42	0.96
LSD $_{(0.05)}$			16.40	5.45	7.50	0.02	0.13

Table-11. Correlationsbetween grain yield, growth parameters and dry matter accumulation of WE3127 maize plant variety

	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≤0.01, *p≤0.05

Figure-1. Ferric Luvisol A Rhodic Ferralsol B

Fig-2. Relationship between N rates and grain yield under (A) Rhodic Ferralsol soil and (B) Ferric Luvisol soil

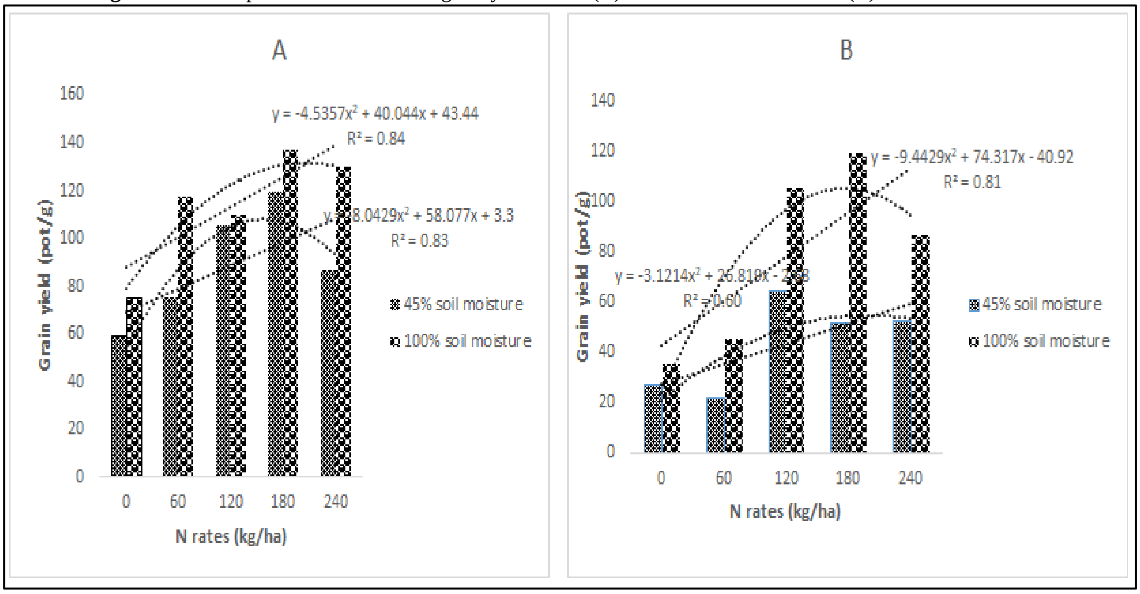

Fig-3. Relationship between N rate and water-use efficiency under (A) Rodic Ferralsol soil and (B) Ferric Luvisol soil