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Irrigation and Nutrient Management for Crop Production: Maize (Zea mais) Performance, Resource Use Efficiency and Temporal Variability of Some Soil Properties

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Abstract
Information on soil health and nutrient management is crucial for recommending appropriate management practices for effective crop production and optimum yield. This study evaluated the effect of drip irrigation and fertilizer application on soil hydro-physical properties, performance and resource use of maize (*Zea mais*) in southwestern Nigeria. The experiment was a two factorial laid out in randomized complete block design (RCBD) and three replications. Irrigation treatment constituted the main factor namely: 100% (full irrigation), 75%, 50% and 35% of crop water requirement designated as $1.0I_E$; $0.75I_E$; $0.5I_E$ and $0.35I_E$, respectively while the sub-plot was N-fertilization as N_0 - no fertilizer application and N_{100} –100 kg Urea ha^{-1}. The highest evaporation from the soil surface was obtained from the treatment that received full irrigation. At harvest, irrigation regimes and fertilizer rates significantly increased bulk density (BD) and soil water content (SWC) while saturated hydraulic conductivity (Ksat) decreased. The highest grain yield (3.5 tons ha^{-1}) was obtained under full application of crop water requirement, about 28% greater than the yield obtained from water deficit ($0.35I_E$) treatment. Nitrogen application of N_{100} gave higher grain yield compared to no fertilizer application. The interaction between drip irrigation and N-fertilization was significant on growth parameters, yield and water use efficiency (WUE) of maize. The study showed that soil hydro-physical properties were significantly influenced by drip irrigation while the combination of full irrigation water application ($1.0I_E$) and adequate N-fertilization (100 kg N ha^{-1}) is the best option for optimum maize performance and resource use efficiency.
Keywords: Crop evapotranspiration, irrigation scheduling, soil hydro-physical properties, crop performance, resource use efficiency.

1. Introduction

Maize is an important cereal crop worldwide. In Nigeria, maize is a vital staple food, fodder and industrial crop grown both at subsistence level and commercially (Eleweanya *et al*. 2005). It is an important raw material for the production of both indigenous and commercial food products that are relished for their unique and distinctive flavours. It could be eaten fresh or milled into flour and serves as a valuable ingredient for infant food, cookies, livestock feed and a variety of beverages (Olaoye & Adegbesan 1991; Okoruwa 1998). Maize is consumed all year round however, its major production is during the rainy season which spans between April and October and very little is produced during the dry period (off season) from November to March, making the product very scarce and expensive during this period. Where maize is produced during the dry season, it is cultivated in wetlands and low land areas where residual soil moisture is relied upon. In most cases, artificial watering is carried out to minimize water stress. Therefore, there is the need to incorporate sustainable irrigation system into crop production program which will ensure all year supply of food to the populace. According to Ewemoje et al. (2006), irrigation assists in stabilizing food production in a number of countries by either supplementary or replacing the need for natural precipitation. It serves as crop insurance against drought and increases crop yield and quality when rainfall is insufficient.

Several methods of irrigation exist, however drip irrigation is often preferred over other irrigation methods because of high water application efficiency on the account of reduced losses, fertigation, limited surface evaporation and reduction in losses due to percolation (Rajput and Patel, 2005), with positive results from several drip irrigation trials (e.g. Assouline 2002; Candido *et al.* 2009; Awe and Ogedengbe 2011; Hussein and Pibars 2012; Abegunrin *et al.* 2013; Ningaraju & Joseph 2015; Sahin *et al.* 2015; Abegunrin *et al.* 2016; Awe *et al.* 2016).

Scheduling of water application is a very important aspect of drip irrigation system and it is very critical to make the most efficient use of water, as excessive irrigation decreases yield, while insufficient irrigation causes water stress and reduces crop productivity. According to Yuan et al. (2005), the optimal use of irrigation is the supply of sufficient water according to plant needs in the rooting area and, high-frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant, and maintains a high soil matric potential in the rhizosphere to reduce plant water stress.

The introduction of irrigation to the soil leads to fundamental changes in composition and functional soil properties and processes, such as bulk density, soil water content, porosity, saturated hydraulic conductivity and so on by placing stresses upon soil structure which affects the pore space, plant available water, nutrients and gaseous exchange (Hamblin 1985) because irrigated soils experience rapid wetting and undergo a greater number of alternate wetting and drying cycles compared to rainfed agriculture (Currie 2006). Evidence of soil structural decline, such as increased bulk density, under drip irrigation has been reported (Clark 2004). From the foregoing, the study on the impact of drip irrigation on soil physical properties and processes are imperative with a view to ensuring sustainable crop production.

Attempts aimed at improving crop performance and obtaining high crop yield necessitate the augmentation of the nutrient status of the soil. Increasing the nutrient status of the soil can be achieved by boosting the soil nutrient contents either with the use of mineral fertilizers such as NPK and urea or through the use of organic materials such as poultry manure, farm yard manure (FYM) or compost. Mineral fertilizers play a vital role in improving crop yields but the major challenge is to ensure adequate balance between the different nutrients and support optimal yield (Hussien & Alva, 2014). Among different nutrients applied to the soil, nitrogen (N) fertilizer is the principal nutrient, associated with high photosynthetic activity, vigorous vegetative growth and a dark green coloration of the leaves (Dauda *et al.* 2008; John *et al.* 2004). For crops that are heavy feeder of nitrogen, adequate supply of nitrogen can be a limiting factor closely related to high yield. At the other end, excessive supply of nitrogen may result in leaching and contamination of water bodies as well as luxury consumption and the production of vegetative growth at the expense of high grain yield (Akongwubel *et al.* 2012).

Integrated water and nitrogen management is now an important issue in most cropping systems. Under water deficit condition, nitrogen is less available to the plant and, in this case, the symptoms of water stress are the consequence of the interaction between the water and nitrogen deficits (Frederik & Camberato 1995; Perniola *et al.* 1996; Miccolis *et al.* 2002). On the other hand, insufficient nitrogen input can reduce the efficiency of water use by the crop (Hsiao 1993). Therefore, excessive or inadequate use of water and nitrogen fertilization (with respect to the real needs of the plant) should be avoided because of possible losses due to leaching and negative consequences for the environment (Zhu *et al.* 2005; De Pascale *et al.* 2006; Gercek *et al.* 2009). Thus, proper irrigation and nutrient management of is very important to increase the fertilizer use efficiency and decrease the loss of water. Elsewhere, studies have been conducted to investigate the interaction effect of irrigation and N-fertilization on maize production, water and nitrogen use efficiency (Al-Kaisi & Yin 2003; Ghulam *et al.* 2005; Singh *et al.* 2007; Hussaini *et al.* 2008; Shirazi *et al.* 2011; Hussein & Pibars 2012; Shirazi *et al.* 2014). In most of these studies, increase in moisture enhances maize yield response to N-fertilization, especially when high rates are applied. In this context, the response of corn yield to N-fertilization may probably relate to drip irrigation. In southwest Nigeria, little is known on the effect of integrated water and nutrient management on soil physical properties and performance of maize grown under drip irrigation and N-fertilization. We hypothesized that water application significantly influences soil hydro-physical properties and that the combination of irrigation and N-fertilization significantly influence maize performance. Therefore the objectives of this study were to evaluate (i) the effect of drip irrigation regimes on soil hydro-physical properties, and (ii) the interaction effect of irrigation and N-fertilization on maize growth, yield and resource use efficiency.

2.0 Materials and Methods

2.1 Description of experimental site

The field experiment was conducted between December 2015 - April 2016, at the Irrigation Unit of Teaching and Research Farm, Ekiti State University, Ado-Ekiti southwestern Nigeria. The site is located on latitude 7^0 42' 48.29" N and longitude 5^0 14' 45.80" E at 407 m above sea mean level. The location is a humid tropical climate characterized by distinct dry and wet seasons with moderate mean annual rainfall of about 1367.7 mm while the minimum and maximum daily temperatures are 17 and 34 ^oC, respectively. The soil of the study site belongs to the broad group Alfisol (Soil Survey Staff 2010), sandy-loam in the superficial layer and clayey in the subsurface layer (Fasina 2005). According to the cropping history of the land, the place has been under irrigation since 2009 prior to this study. The results of some physico-chemical properties of 0-15 cm soil surface layer of the experimental site before the commencement of the study showed that the pH was 5.64 indicating that the soil is slightly acidic, soil organic carbon was 1.00% while the total nitrogen was 0.086%. The soil particle analysis of the surface layer showed that the clay, silt, and sand content are 17.76, 8.00 and 74.24%, respectively, giving sandy loam texture using USDA textural triangle. The BD of the surface layer was high (1.72 g cm^{-3}) although it is less than threshold BD (1.75 g cm^{-3}) above which the soil is considered compacted (Reichert *et al.* 2009).

2.2 Experimental design and treatments

The experiment was a two factorial laid out in a randomized complete block design (RCBD) and three replications. Irrigation constituted the main factor at 4 irrigation regimes namely: 100% (full irrigation), 75%, 50% and 35% of crop water requirement designated as $1.0I_E$; $0.75I_E$; $0.5I_E$ and $0.35I_E$, respectively while the sub-plot was N-fertilization constituted by N_0 - Control (no fertilizer application) and N_{100} –100 kg Urea/ha, giving eight treatment combinations namely: $1.0I_EN_0$: 100% crop water requirement + no fertilizer; $1.0I_EN_{100}$: 100% crop water requirement + 100 kg N-fertilization; $0.75I_EN_0$: 75% crop water requirement + no fertilizer; $0.75I_EN_{100}$: 75% crop water requirement + 100 kg N-fertilization; $0.5I_EN_0$: 50% crop water requirement + no fertilizer; $0.5I_EN_{100}$: 50% crop water requirement + 100 kg N-fertilization, $0.35I_EN_{100}$: 35% crop water requirement +100kg N-fertilization, $0.35I_EN_0$ crop water requirement + No fertilizer. The respective total irrigation water received was 2800, 2100, 1440 and 1032 mm for $1.0I_E$, $0.75I_E$, $0.5I_E$ and $0.35I_E$ treatments.

2.3 Land preparation, field layout, installation of drip irrigation system, planting and field management

The experimental site was prepared by ploughing followed by harrowing to about 20 cm deep and unburied grasses were properly removed to ensure a clean field. Based on the experimental design, there were 24 plots, each plot 2.1 m x 8 m, with 1 m spacing between plots. The drip irrigation system consisted of a 3000 L water supply tank, 25 mm diameter main pipe and sub mains, end plugs, T-joint plugs, rubber hose, gum, gate valves, laterals cum drippers (drip lines), pipe nipples etc. The mainline delivered water from the water supply tank to the sub mains and the sub mains to the drip lines, while the emitters delivered water to the field at a rate of 4 L h^{-1}. The field layout is shown in Figure 1.

Planting of maize was done on 14th December, 2015, on the prepared plots. Two to three (2-3) seeds of maize were planted at a spacing of 70 cm x 50 cm using a planting depth of about 5 cm. A week after planting, excess seedlings was thinned to two plants per stand, giving a plant population of about 57,200 plants ha^{-1}. The field was adequately irrigated for crop emergence and establishment. After crop establishment, both irrigation and nitrogen fertilizer treatments were imposed. The fertilizer treatment of 100 kg/ha urea (46 g N) was applied by band method at two weeks (2 WAP) after planting. Weed control was done manually three times and cypermethrin was applied to control infestation of stem borers.

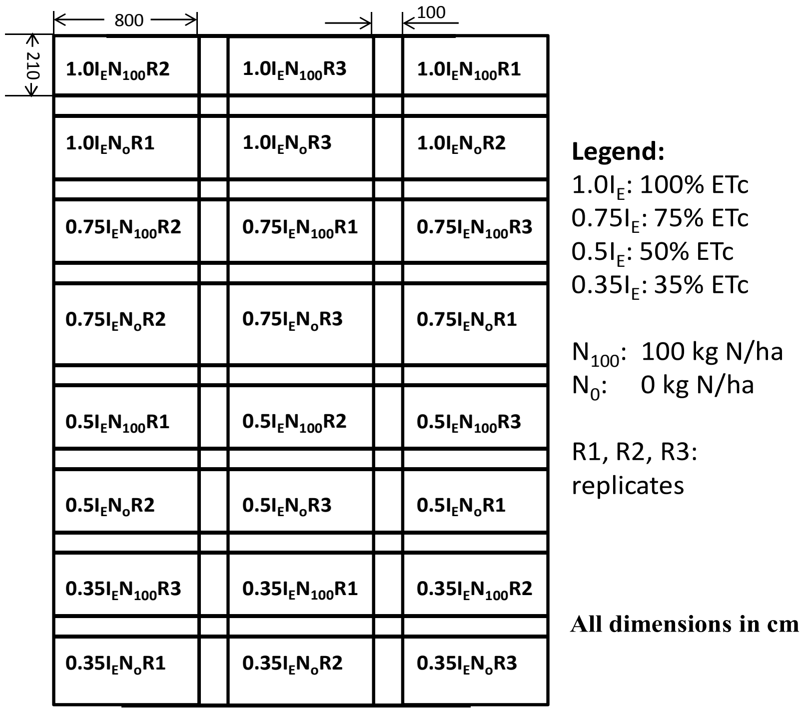

Figure 1. Field layout showing the different treatment combinations.

2.4 Soil sampling and analysis

Prior to planting, soil samples were randomly collected from 0-15 cm soil depth from three representative locations and were mixed to obtain a composite sample, which was air-dried, ground with mortar and pestle, passed through a 2-mm sieve for the determination of soil physical and chemical properties including soil pH, K, Na, Mg, Ca, total organic carbon (TOC), total nitrogen (TN) and available phosphorus (av.P) and soil texture using standard laboratory procedures.

2.5 Temporal variability of soil moisture content, bulk density and Ksat

During the maize growing season, gravimetric soil moisture content, BD and Ksat were evaluated periodically to study the effect of the different irrigation regimes on soil structure as described below:

Soil water content

The soil moisture content was determined according to the equation:

$$\theta_g = \frac{W_{ws} - W_{ds}}{W_{ds}}$$

where θ_g = gravimetric soil moisture g g^{-1}; W_{ws} = Weight of wet soil (g), W_{ds} = Weight of oven dried soil(g).

Bulk density

After obtaining the saturation weight, the undisturbed samples were oven-dried at 105°C for 48 h and the weight of dry soil was determined (Blake & Hartge 1986).

$$BD = \frac{M_s}{V_s}$$

where BD = bulk density(g cm^{-3}), M_s = weight of dry soil (g), V_s = volume of soil (cm^3)

*Saturated hydraulic conductivity, (*Ksat*).*

Soil saturated hydraulic conductivity was determined by the constant-head permeameter (Klute & Dirksen 1986) on undisturbed soil samples collected in metal cylinders (of known volume) after saturation by capillarity in a water bath for 48 h. The determination of Ksat was performed by collecting and measuring the amount of water that percolates through the soil sample under a constant hydraulic head of about 3 cm in the water column, according to the methodology described by EMBRAPA (2011). From the data, soil Ksat was calculated using the following equation:

$$\text{Ksat} = \frac{Q*L}{A*H*t}$$

where Ksat is saturated hydraulic conductivity, mm hr^{-1}; Q is volume of water that flow through the soil column in a given time, cm^3; L is length of the soil column, cm; H is length of soil column + water head above the soil column, cm; A is area the soil column, cm^2; t is time, h.

2.6 Evaporation from soil surface

Twelve (12) PVC pipes, 15.24 cm diameter and 60 cm long, were cut, with one side covered with perforated lid making mini-lysimeters. The mini-lysimeters were filled with soil from 0-15 cm layer of the irrigated plots and installed into the pits where soil was already removed. The space between the lysimeters and the soil wall was gently covered. Before irrigation, each lysimeter was removed and weighed on daily basis and the difference between two consecutive days give the amount of water loss by evaporation.

2.7 Growth parameters, yield and yield components

At four (4) weeks after planting (WAP), plant growth parameters of number of green leaves, plant height and leaf area were measured at ten (10) weeks after planting. At physiological maturity, maize was harvested from an area, 1 m x 1 m, from each plot. Yield components of ear length and diameter, ear length, 100 grain weight, number of row per ear, number of kernels/row and grain yield were determined. Grain yield was corrected to 13% moisture content and converted to tons/ha.

2.8 Water and nitrogen use efficiency

Water use efficiency (WUE) was calculated according to Israelson and Hansen (1962) as the ratio of crop yield (Y) to the amount of water applied (IR) in the field as:

$$WUE = \frac{Y}{IR}$$

where WUE is the water use efficiency (kg ha^{-1} mm^{-1}); Y is the crop yield (kg) and IR is the amount of seasonal irrigation water (mm).

Nitrogen use efficiency (NUE) was calculated as the ratio between grain yields and amount of nitrogen applied according to Israelson and Hansen (1962) as:

$$NUE = \frac{Y}{F}$$

where Y is the grain yield (kg ha^{-1}); and F is the amount of N applied (kg N ha^{-1}).

2.9 Weather data and evaporative demand of the atmosphere

Daily minimum and maximum temperature, solar radiation, wind speed and relative humidity were obtained from a weather station located about 500 m from the experimental field while daily rainfall was measured using a rain gauge installed at the center of the field. The daily reference evapotranspiration or evaporative demand of the atmosphere (ETo) was obtained using $FAO - ET_o$Calculator software and Thornthwaite (1948) equation was adopted.

2.10 Statistical analysis

Data collected were subjected to descriptive statistics and analysis of variance (ANOVA) and means were separated by Fisher's LSD test at 5% level of probability. Regression analysis was carried out between soil water content versus bulk density and saturated hydraulic conductivity. All statistics were performed using SPSS (IBM v. 20).

3.0 Results and Discussion

3.1 Rainfall, evaporative demand of the atmosphere and evaporation from soil surface

The temporal distribution of evaporative demand of the atmosphere and rainfall received during the growing period is presented in Figure 2. No rainfall was received between December 2015 and February 2015, thus there was total irrigation during this period while supplemental irrigation was applied in the months of March and April when there was rainfall. Evaporative demand of the atmosphere (ETo) was low during the relative cold months of December 2015 and January 2016. With any rainfall event, the ETo decreased because of the cooling effect produced by rain.

The distribution of soil evaporation from the different drip irrigation regimes is shown in Figure 3. Evaporation was high at the initial growth stage of maize simply because the percent of land covered by plant canopy was very low and therefore large surface available for evaporation. There was significantly highest evaporation from the plot receiving 100% crop water requirement (CWR), $1.0I_E$ while the lowest was obtained from the plot receiving 35% CWR, $0.35I_E$. The high evaporation from treatment 1.0IE compared to other treatments is attributed to the fact more water is available for evaporation. There was decrease in evaporation along the growing season and from 60 days after planting, there was no significant difference in evaporation. The decrease in evaporation from the soil surface over time is attributed to increase in canopy cover which reduces the energy from the sun from reaching the soil surface. The increase in canopy cover also decreases the surface area available for evaporation. Thus, the degree of shading by crop canopy and amount of water available within evaporative layer are the major factors affecting the evaporation process.

3.2 Soil hydro-physical properties

The temporal distribution of BD of the 0-10 cm surface layer of the maize field showed that irrigation water application rates significantly affected the BD (Figure 4). At each evaluation campaign, the BD was highest from treatment $0.75I_E$ and over time, the BD increased showing the soil is reverting back to its pre-preparation state. At harvest, that is 115 days after planting, the BD of this surface layer has become high (about 1.70 g cm^{-3}), almost equal the pre-plant BD, representing an increase of 14.3% when compared to the BD value (1.51 g cm^{-3}) shortly after planting. This elevated BD is an indication of compaction process and degradation of soil structure however the values were still below the BD of 1.92 g cm^{-3} considered as critical and poor structural formation for this type of soil (Reinert *et al.* 2008). The increased BD at harvest is attributed to the continuous process of soil reconsolidation and rearrangement of soil particles caused by alternate wetting and drying cycles caused by irrigation. According to Cockroft & Olsen (2000), the introduction of irrigation led to fundamental changes in soil hydrologic regimes because irrigated soil undergo a greater number of wetting and drying cycles compared to rainfed soils, leading to aggregate coalescence, which is a soil hardening process whereby the cementing of aggregate leads to increase in soil BD. Another reason may be due to biophysical activities such as the maize roots which tend to enmesh and compress groups of soil aggregates into larger aggregates. Moreover, water uptake by plant roots promotes differential dehydration, with an increase in BD near the root zone as a result of soil adhesion (Young 1998). The BD of this surface layer could increase and surpass the critical level (1.92 g cm^{-3}) before the next growing season if adequate soil conservation practices such as planting of cover crop are not put into place. Reichert et al. (2009) stated that any soil layer with BD greater than 1.92 g cm^{-3} is fully compacted, posing both positive and negative effects on vital soil properties and processes such as inadequate gaseous exchange, low porosity, increased water retention, high soil temperature, low hydraulic conductivity within the soil profile, restricted root growth and reduced crop productivity. This result agrees with the findings of Currie (2006) who found that drip irrigation increased soil bulk density in grape vineyard.

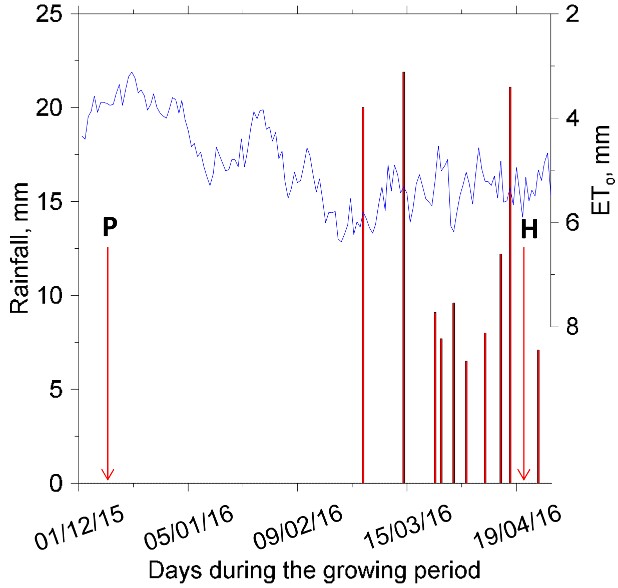

Figure 2. Distribution of rainfall and evaporative demand of the atmosphere (ETo) during the growing period of the drip-irrigated maize crop.
P: Planting date; H: Harvest date

Saturated hydraulic conductivity depends on water fluidity, which is proportional to its viscosity and soil bulk density as well as macroporosity (Reichardt and Timm, 2004) which is a function of soil texture and structure (Bormman & Klaassen 2008; Hu *et al.* 2009). Except at harvest (115 days after planting), there were significant differences in the average values of Ksat due to irrigation water application during the growing season (Figure 5), with treatments $1.0I_E$ and $0.75I_E$ having the highest values of Ksat up to 61 days after planting. At 29 days after planting, Ksat slightly increased in three treatments, $1.0I_E$, $0.75I_E$ and $0.35I_E$. This increased might be as a result of special cases during sampling as sampling points could have special features presence of cracks or biopores created by plant roots, earthworms and other microorganisms, hence water percolates these pores at high rate. At harvest, there was drastic reduction in the average values of Ksat. The low Ksat value at harvest is attributed to the direct effect of elevated BD. When the BD is increased, the volume of macropores responsible for conducting water within the soil matrix is reduced, thus decreased Ksat.

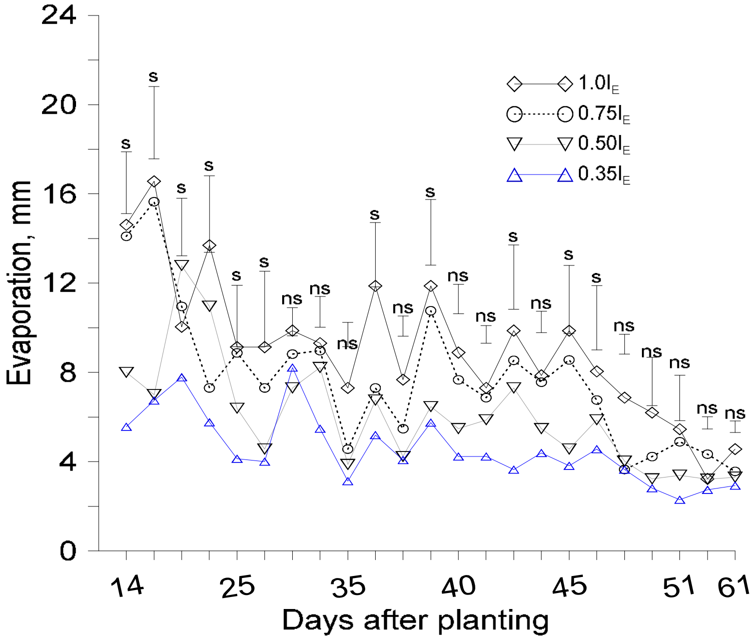

Figure 3. Temporal distribution of evaporation of water from the soil surface during the maize growing season.
$1.0I_E$: 100% crop water requirement; $0.75I_E$: 75% crop water requirement; $0.5I_E$: 50% crop water requirement; $0.35I_E$: 35% crop water requirement.
The vertical bars are the standard error of means.
s: significant ns: not significant

Under drip irrigation, the ponding zone that develops around the emitter is strongly related to either irrigation frequency or water application rate (Wang *et al.* 2006), which therefore play a key role in determining the soil water content around the emitter, the amount of water percolation under the root zone

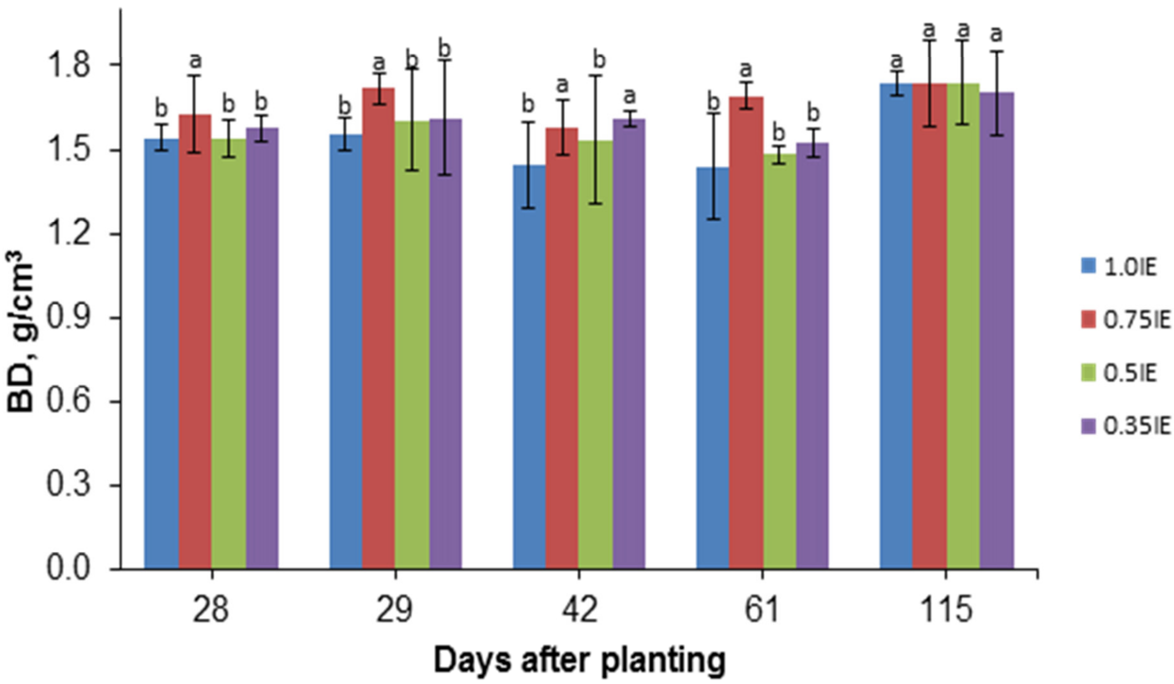

Figure 4. Temporal variability of soil bulk density (BD) of the maize field under drip irrigation frequency.
$1.0I_E$: 100% crop water requirement; $0.75I_E$: 75% crop water requirement; $0.5I_E$: 50% crop water requirement; $0.35I_E$: 35% crop water requirement
The vertical bars are the standard error of means.
s: significant ns: not significant

and the water uptake pattern (El-Hendawy *et al.* 2008). Water application rates significantly ($p<0.05$) influenced the soil water content (SWC) of the 0-10 cm layer of the maize field (Figure 6). As expected, treatment $1.0I_E$ had the significantly highest SWC values while treatment $0.35I_E$ had the lowest SWC values. The SWC was low in all treatments when there was no water application as shown at 28 and 42 days after planting while the SWC increased when water was applied (for example, 29 days after planting). The significantly highest SWC obtained from full ($1.0I_E$) and relatively full ($0.75I_E$) water application is attributed to high rate of soil wetting. Meshkat *et al.* (2000) also pointed out that an irrigation regime with excessively high rate or frequency could cause the soil surface to remain wet. The results of the regression analysis between SWC versus BD and logarithm transformed Ksat are shown in Figure 7. The coefficient of determination, R^2, was low in both cases.

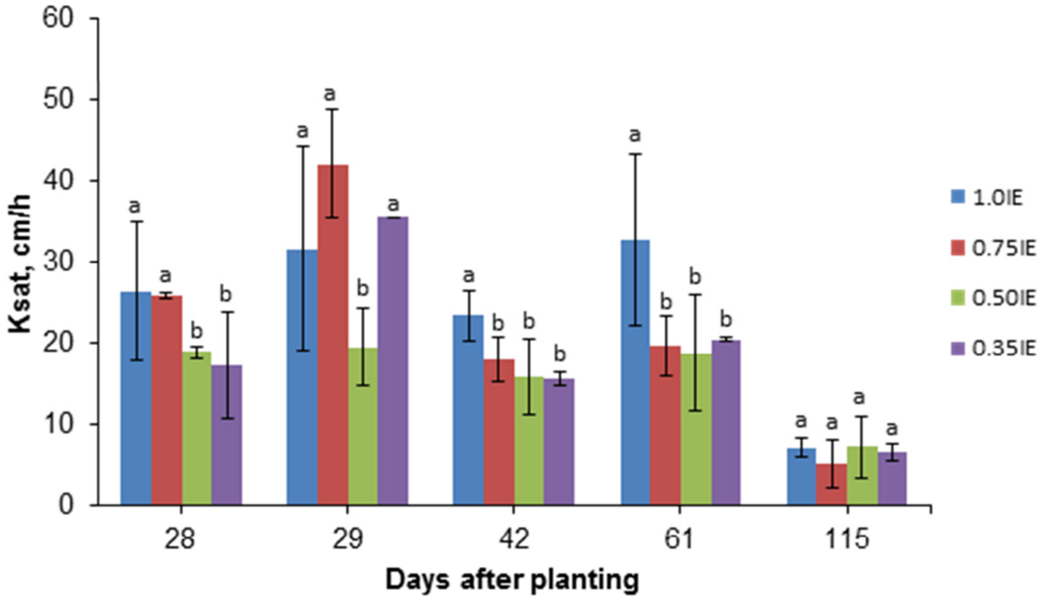

Figure 5. Saturated hydraulic conductivity of the soil in the field during the maize growing season.
Ksat: Saturated hydraulic conductivity; $1.0I_E$: 100% irrigation water requirement; $0.75I_E$: 75% irrigation water requirement; $0.5I_E$: 50% irrigation water requirement; $0.35I_E$: 35% irrigation water requirement
The vertical bars are the standard error of means
s: significant ns: not significant

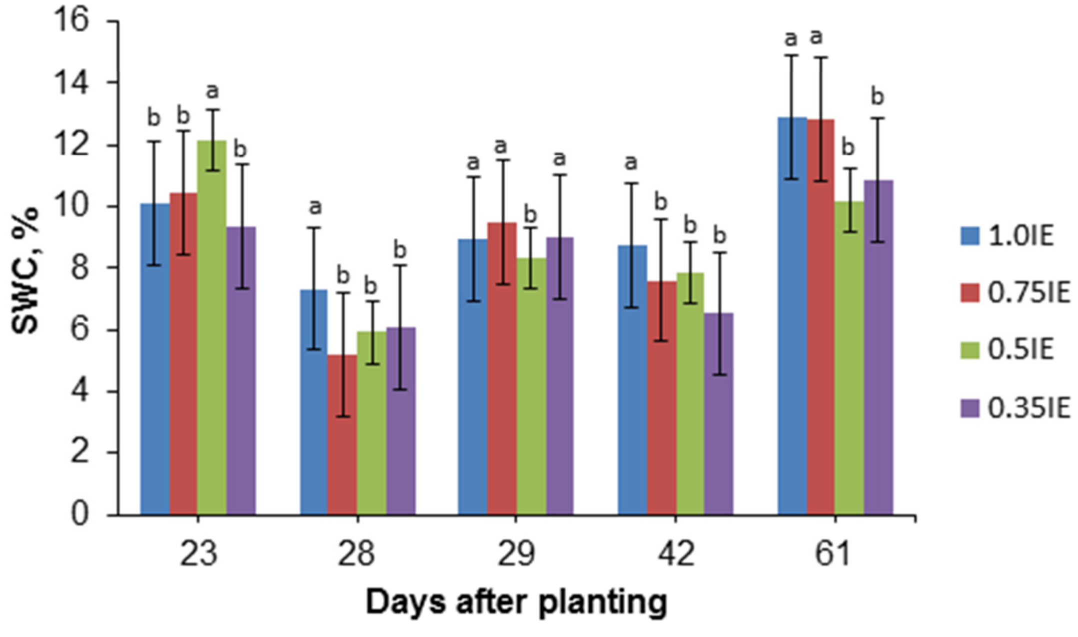

Figure 6. Temporal distribution of soil water content (SWC) of the field during the maize growing season.
$1.0I_E$: 100% irrigation water requirement; $0.75I_E$: 75% irrigation water requirement; $0.5I_E$: 50% irrigation water requirement; $0.35I_E$: 35% irrigation water requirement
The vertical bars represent the standard error of means.
s: significant ns: not significant

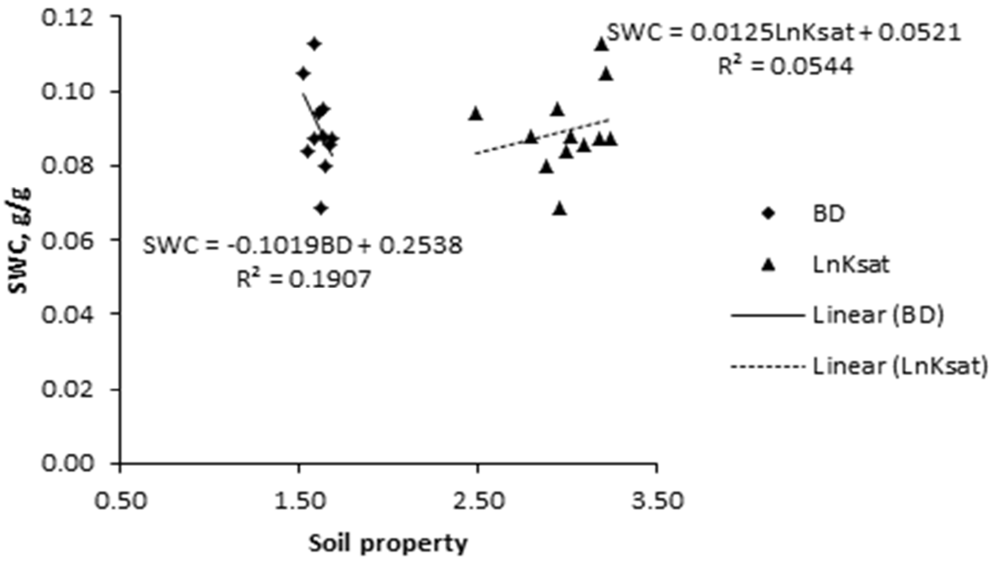

Figure 7: Relationship between SWC versus Ksat and BD.
SWC: Soil water content; Ksat: Saturated hydraulic conductivity; BD: Bulk density
R^2: Coefficient of determination

3.3 Maize performance: Growth parameters, yield and yield components

Drip irrigation regimes significantly ($p<0.05$) influenced plant height of maize at 10WAP (Table 1), the highest plant height recorded from $1.0I_E$ irrigation treatment while the lowest value was recorded from $0.35I_E$ irrigation treatment. Availability of well distribution soil moisture at different growth stages due to irrigation, enhanced the growth of plant. Similar effect of irrigation on plant height has also been reported (Gordon *et al.* 1995; Shirazi *et al.* 2011). The higher N dose (N_{100}) (Table 1) resulted in taller plant which was significantly different from that obtained from control (no fertilizer) treatment. Grazia et al. (2003) reported that plant height can be increased with N application. This observation is also in conformity with the findings of Babatola *et al.* (2002) and Babatola (2006) who reported that increasing level of fertilizer application led to increase in growth and yield of crops.

Number of leaves (NOL) was significantly influenced by irrigation and N-fertilization (Table 1). Water application at 100% of crop water requirement ($1.0I_E$) gave the highest NOL which is 24.5% greater than deficit irrigation treatment of $0.35I_E$. This is in agreement with the findings of Roe and Cornfort (2000) who reported that irrigation at 100% gave a significant higher number of leaves. Similarly, maize plants that received 100 kg N/ha (N_{100}) gave the significantly ($p<0.05$) higher number of leaves than the control (no fertilizer). Shirazi et al. (2011) also recorded the highest NOL from 100 kg N ha^{-1}. The significantly

Table 1. Effect of irrigation regimes and N-fertilization on growth parameters, yield and yield components of maize.

Trmts.	PH cm	NOL -	LA cm^2	Ear L. --------cm--------	Ear Dia.	Kernels/row -	Rows/ear -	100 GW g	Grain Yld, ton/ha
Irrigation									
$1.0I_E$	190.06a	27.83a	593.44a	20.52a	3.53	25.74a	13.11	239.07a	3.57a
$0.75I_E$	180.56ab	27.66a	463.24b	11.93b	3.66	21.11b	13.86	204.45b	3.24b
$0.50I_E$	161.16c	25.44ab	474.79b	11.83b	3.66	19.50b	14.00	197.43b	3.06b
$0.35I_E$	157.95d	20.99b	462.55b	12.75b	3.51	19.52b	13.21	208.58b	2.58c
Fertilizer									
N_0	153.83b	22.66b	435.66b	15.95a	3.44	18.58b	13.12	205.95b	2.70b
N_{100}	186.03a	24.30a	561.36a	12.58b	3.74	22.35a	13.97	218.81a	3.42a

Trmts: treatments; $1.0I_E$: 100% crop water requirement; $0.75I_E$: 75% crop water requirement; $0.5I_E$: 50% crop water requirement; $0.35I_E$: 35% crop water requirement
PH: plant height; NOL: number of leaves; LA: leave area; Ear L.: ear length; Ear Dia.: ear diameter; GW: grain weight; Yld: yield
Values followed by different letters in same column differed significantly at 5% level of probability by Fisher's LSD test.

($p<0.05$) highest leaf area (LA) was obtained from $1.0I_E$ irrigation treatment while those of other treatments were statistically similar. The application of 100 kg N ha^{-1} resulted in significantly ($p<0.05$) higher plant LA compared to control treatment.

Due to irrigation, ear length was significantly ($p<0.05$) increased (Table 1). Irrigation water treatment of $1.0I_E$ gave the highest ear length while the results from deficit water treatments ($0.75I_E$, $0.50I_E$ and $0.35I_E$) were statistically the same. In contrast, maize plants that did not receive fertilizer (control) had the higher ear length. Both irrigation water application and N-fertilization did not significantly ($p<0.05$) affect ear diameter. The number of kernels per row reduced significantly ($p<0.05$) due to deficit irrigation, the highest kernels per row obtained from $1.0I_E$ irrigation treatment. The application of N-fertilizer (N100) gave the significantly ($p<0.05$) higher number of kernels per row compared to control. Number of rows per ear was not significantly ($p<0.05$) affected by both irrigation water application and N-fertilization, with the average number of rows per ear about 14. Irrigation water application and N-fertilization significantly ($p<0.05$) influenced 100-grain weight. The highest 100-grain weight was obtained at full application of crop water requirement ($1.0I_E$) while the average value was almost at par for other deficit irrigation treatments.

According to Hussein & Pibars (2012), variation in drip irrigation system scheduling is useful for determining whether maximum yield can be obtained under sufficient or limited water applications. In this study, grain yield significantly increased due to irrigation water application. Under the different irrigation regimes, full application of crop water requirement ($1.0I_E$) had the highest grain yield, about 28% greater than the yield obtained from highest water deficit ($0.35I_E$) treatment, while the grain yield values from 75 and 50% water deficit were statistically at par Table 1). A quadratic relationship was obtained between grain yield and water applied (Figure 8). The implication is that if the amount of water applied is increased further without replenishing the soil with nitrogen, maize yield will reduce and may become zero at certain water level. El-Hendawi & Hokam (2007) also reported quadratic relationship between irrigation water applied and yield components. N-fertilization of 100 kg N ha^{-1} had significantly higher grain yield compare to the control (N_0) treatment. The higher grain yield and yield components from $1.0I_E$ and N_{100} treatments is due to the fact that a very humid region and good distribution of water within the root zone which aided the translocation of applied nitrogen and other nutrients to the maize plant. Since kernel numbers and weight determines the potential yield of maize (Jacobs & Pearson 1991), it therefore follows that shortage of N or water stress reduces grain yield by reducing kernels per ear (Sticker *et al.* 1995).

The interaction effect of drip irrigation and N-fertilization was significant on maize growth parameters, yield and yield components (Table 2). The significant interaction between irrigation and N-fertilization is attributed to the significant and positive impact of nitrogen on yield components response to soil moisture. Other researchers (Al-Kaisi & Yin 2003; El-Hendawi & Hokam 2007; Shirazi *et al.* 2011) have also reported significant interaction between irrigation and N-fertilization on maize performance. The combination of $0.75I_E$ and N_{100} treatments gave the significantly highest growth parameters of PH, NOL and LA while the combination of $1.0I_E$ and N_{100} gave the significantly highest grain yield while the combination of $0.35I_E$ and N_0 treatments gave the lowest yield. High water application ensures optimum soil moisture within the crop root zone which may have resulted in a better utilization of applied nitrogen and subsequently promotes various physiological processes in plants. On the other hand, high water deficit, such as the $0.35I_E$ treatment in this study, leads to drying up of surface soil over time between irrigations which reduces the availability of nitrogen and hence negatively impacts crop performance and yield.

3.4 Water and nitrogen use efficiency

The interactive effect of drip irrigation regimes and N-fertilization was significant ($p<0.05$) on water use efficiency (WUE) of maize (Figure 9). The WUE values ranged from 0.19 to 3.07 kg/ha/mm with treatment combination of $0.35I_EN_{100}$ giving the highest WUE while treatment combination of $1.0I_EN_0$ gave the lowest WUE. Similar results of highest water use efficiency at the lowest irrigation regime have being reported by various researchers (Şimşek *et al.* 2005; Kirnak & Demirtas 2006; Hashem *et al.* 2011). In contrast, Rahimi *et al.* (2013) reported that seed water use efficiency (WUE) of isabgol plant decreased with the increasing drought stress (lower irrigation water application), even with nitrogen level, showing both water and nitrogen are yield limiting factors under arid and semi-arid conditions. In our study, increasing the applied amount of irrigation water to plant decreased the water use efficiency, it follows that for this humid region, WUE may not be a good parameter for evaluating irrigation systems as the minimum value of irrigation water amounted to the minimum yield production.

Dupont *et al*. (2006) noted that improving nitrogen use efficiency (NUE) is of great economic and environmental importance which directly affects grain protein content. The results of NUE under the different irrigation regimes are presented in Figure 10. The significantly ($p<0.05$) highest NUE was observed from $1.0I_E$ irrigation regime while the lowest NUE was obtained from $0.35I_E$ treatment. This result also conformed to the findings of Ashraf *et al*. (2016) who found higher NUE from high irrigation water applied in a study on maize growth, yield formation and water-nitrogen usage in response to varied irrigation and nitrogen supply under semi-arid climate.

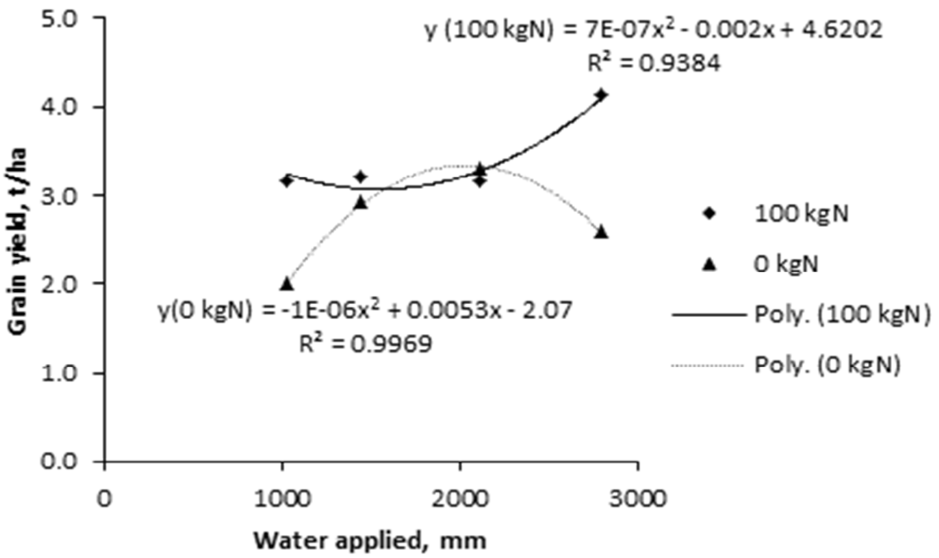

Figure 8. Relationship between grain yield and irrigation water applied with and without N-fertilization.

NUE increased with increase in water application which favors nitrogen uptake and higher rate of photosynthesis. Therefore, applying proper quantity of water allows crops makes better use of water and nutrient from deep soil layers, thus increases water and nutrient use efficiency although care must be taken as regards the quantity of nitrogen applied, a highly mobile nutrient prone to leaching.

Table 2. Interactive effect of irrigation regimes and N-fertilization on growth parameter yield and yield components of maize.

Treatments	PH cm	NOL -	LA cm^2	Ear L. --------cm--------	Ear Dia.	Kernels/row -	Rows/ear -	100 GW g	Grain Yld, ton/ha
$1.0I_EN_{100}$	184.9b	25.2b	516.6c	13.1b	3.57	24.5a	13.3	226.6a	4.12a
$1.0I_E N_0$	164.6d	20.1c	437.0d	27.9a	3.50	18.7c	12.9	218.4	2.59e
$0.75I_EN_{100}$	191.3a	28.9a	570.6a	12.6b	3.66	21.9ab	14.1	212.9b	3.19c
$0.75I_E N_0$	149.8e	26.8ab	355.9f	11.3b	3.67	20.3b	13.7	196.0c	3.30b
$0.50I_EN_{100}$	175.0c	25.6b	551.2b	12.3b	4.00	21.7b	14.7	200.9bc	3.22bc
$0.50I_E N_0$	167.3d	21.3c	398.3ef	11.3b	3.33	17.3c	13.3	193.9c	2.92d
$0.35I_EN_{100}$	182.2b	17.6d	507.0c	12.3b	3.74	21.1b	13.8	201.7bc	3.17c
$0.35I_E N_0$	133.7f	22.4c	418.1e	13.3b	3.29	18.0c	12.6	215.5b	2.00f

$1.0I_EN_{100}$: 100% crop water requirement + 100 kg N-fertilization; $1.0I_EN_0$: 100% crop water requirement + no fertilizer; $0.75I_EN_{100}$: 75% crop water requirement + 100 kg N-fertilization; $0.75I_EN_0$: 75% crop water requirement + no fertilizer; $0.5I_EN_{100}$: 50% crop water requirement + 100 kg N-fertilization, $0.5I_EN_0$: 50% crop water requirement + no fertilizer; $0.35I_EN_{100}$: 35% crop water requirement +100kg N-fertilization, $0.35I_EN_0$ crop water requirement + No fertilizer.

PH: plant height; NOL: number of leaves; LA: leave area; Ear L.: ear length; Ear Dia.: ear diameter; GW: grain weight; Yld: yield

Values followed by different letters in same column differed significantly at 5% level of probability by Fisher's LSD test.

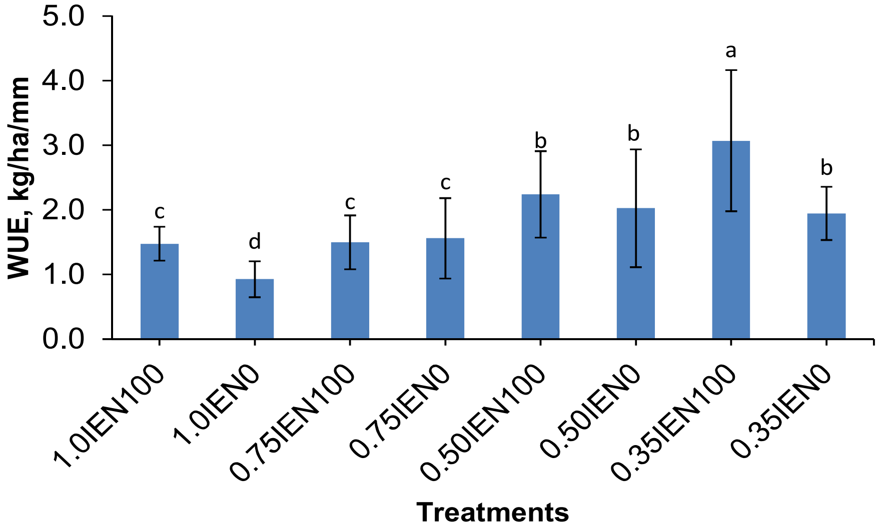

Figure 9. Interactive effect of drip irrigation and N-fertilization on water use efficiency (WUE).
$1.0I_EN_0$: 100% crop water requirement + no fertilizer; $1.0I_EN_{100}$: 100% crop water requirement + 100 kg N-fertilization; $0.75I_EN_0$: 75% crop water requirement + no fertilizer; $0.75I_EN_{100}$: 75% crop water requirement + 100 kg N-fertilization; $0.5I_EN_0$: 50% crop water requirement + no fertilizer; $0.5I_EN_{100}$: 50% crop water requirement + 100 kg N-fertilization, $0.35I_EN_{100}$: 35% crop water requirement +100kg N-fertilization, $0.35I_EN_0$ crop water requirement + No fertilizer.

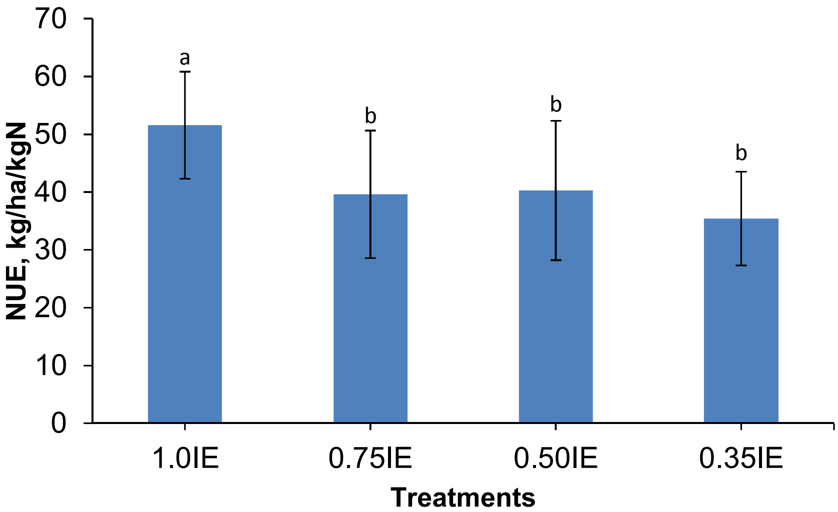

Figure 10. Effect of drip irrigation on nitrogen use efficiency (NUE).
$1.0I_E$: 100% irrigation water requirement; $0.75I_E$: 75% irrigation water requirement; $0.5I_E$: 50% irrigation water requirement; $0.35I_E$: 35% irrigation water requirement

4. Conclusions

The highest evaporation from the soil surface was obtained from full irrigation and the rate decreased during the growing season as a result of canopy expansion and decreased evaporative surface.

At harvest, bulk density (BD) and soil water content (SWC) significantly increased while saturated hydraulic conductivity (Ksat) decreased significantly.

The interactive effect of drip irrigation and N-fertilization was significant on maize growth parameters, yield and yield components and resource use efficiency.

The study showed that irrigation water application significantly influenced soil properties and the data obtained could be useful for soil management and modeling.

The combination of full irrigation water application and adequate N-fertilization is the best for optimum maize performance and resource use efficiency.

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