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Effect of Drip Irrigation Frequency and N-Fertilization on Soil Physical Properties, Yield and Water Use Efficiency of Cucumber (Cucumis sativus L) in Ado Ekiti, Southwestern Nigeria

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Abstract
Soil water budgets are essential in determining the proper timing and amount of optimal irrigation for improving water and nutrient use efficiency in vegetable production A field experiment was therefore setup at the Teaching and Research Farm, Faculty of Agricultural Sciences, Ekiti State University, Ekiti State, Nigeria during 2015 dry season to evaluate the effect of drip irrigation frequency and N-fertilization on soil physical properties, yield and water use efficiency of cucumber (*Cucumis sativus*). The experiment was a 3x2 factorial in randomized complete block design, with split-plot arrangement in three replications. The main block consisted of three levels of drip irrigation frequency: daily water application (ID), twice weekly water application (I2W) and weekly water application (IW) while the sub-plots were nitrogen fertilization (No fertilizer (N0) and 80 kg N ha^{-1} (N80)). The results showed that soil bulk density (BD) and water content (SWC) of the 0-10 cm surface layer increased with time and was significantly highest from ID treatment compared with other treatments. N-fertilization had no influence on both BD and SWC whereas cucumber yield was significantly ($p<0.05$) increased. Reducing the frequency of water application increased cucumber water use efficiency (WUE) whereas N-fertilization had no significant effect on WUE. The different drip irrigation levels caused distinct spatial patterns of SWC and BD. The study showed that cucumber fruit yield will increase with more availability of water as well as good soil structural condition. However, for optimum yield, water saving strategy, reduced cost of pumping and lesser effect on soil structure, drip irrigation scheduling of twice weekly (I2W) combined with N-fertilization is recommended for cucumber cultivation.
Keywords: Drip irrigation frequency, soil physical properties, spatio-temporal variability, cucumber yield, water use efficiency

1. Introduction

Cucumber (*Cucumis sativus*) belongs to the family cucurbitaceae. It is a native of Asia and Africa, where it has been consumed for over 3,000 years. Its origin is traced to both Kalahari and Sahara deserts in Africa (Jarret *et al.* 1996) and these areas have been regarded as points of diversification to other parts of the world (Schippers 2000). According to Huh *et al.* (2008), cucumber is one of the most widely cultivated plants in the world. Its consumption is great, accounting for 60% of the world area devoted to vegetable production (Gunner & Wehner 2004; Goreta *et al.* 2003). In Africa, it has not been ranked important because of limitation in use (Eifediyi & Remison 2010). In Nigeria, cucumber production is confined to the drier savannah region of Nigeria where it thrives better (Anon 2006). As a result of its health and nutritional attributes, cucumber is now produced in other regions such as south-eastern and western regions. However, the demand for cucumber in Nigeria is still high while its production remains low, resulting in the fruit being quite expensive and affordable only by the rich. Therefore, efforts are now geared towards commercial production of the fruit in the country.

As a result of the need to boost food supply for the populace, emphasis has been placed on irrigated agriculture. Despite the simplicity of the surface irrigation systems, efficient use of water has become increasingly important, and alternative water application methods such as the drip irrigation system has been advocated for ensuring the best use of water for agriculture and improving irrigation efficiency. Thus, the trend has been towards conversion from surface to drip irrigation (Sezen *et al.* 2007). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation decreases yield, while insufficient irrigation causes water stress and reduces production. On the other hand, the intensity of the operation requires that the soil water supply be kept at the optimal level to maximize returns to the farmer (Sezen *et al.* 2007). Several experiments have shown positive responses in some crops to different drip irrigation frequency (Segal *et al.* 2000; Sharmasarkar *et al.* 2001), however, there seems inconsistency as to what frequency might be optimum for certain crops and under certain conditions. While Dalvi *et al.* (1999) found that the maximum yield was obtained at every second day frequency, Wang *et al.* (2006) found that reducing irrigation frequency from once a day to once a week resulted into significant reduction in potato yield while Pitts *et al.* (1991) reported that two drip irrigation frequencies (three times per day, one time per day) had no effect on tomato yield.

In order to sustain the quality and quantity of crop production system, maintaining and improving soil fertility is very important, and this can only be achieved by applying fertilizers either in inorganic or organic form (Efthimiadou *et al.* 2010). Adeniyan & Ojeniyi (2006) stated that the main purpose of fertilization in agriculture is to obtain a high yield and to enhance soil fertility. However, Amer *et al.* (2009) opined that soil nutrient status can be improved by fertilization but maximum plant growth could only be achieved when the nutrient availability coincides with water availability. Therefore, the development of water and fertilizer management technology that enhance efficient water use has become an important strategy to guarantee sustainable vegetable production. Thus, in the field of water and fertilizer management, several researchers have studied the effect of different irrigation regimes (Hashern *et al.* 2011; Mao *et al.* 2003; Song *et al.* 2010; Sun *et al.* 2008; Wei *et al.* 2010), different levels of fertilization (Eifediyi & Remison 2010; Yang *et al.* 2013) and irrigation coupled fertilization (Ahmet *et al.* 2006; Amer *et al.* 2009; Li *et al.* 2010) on cucumber growth, yield and water use efficiency. Mao *et al.* (2003) evaluated the effect of drip irrigation on cucumber (*Cucumis sativus*) and found that fresh fruit yield of cucumber were highly affected by total volume of irrigation water, with the least productive irrigation regimes were those that had water deficiencies during fruiting stages. Amer *et al.* (2009) reported that cucumber yield was not increased by surplus irrigation alone but maximum yield was obtained with adequate water applied within fertilizer treatment and with increasing amounts of N applied. They concluded that management of cucumber for maximum yield requires optimizing irrigation water supply in combination with N management.

The introduction of irrigation to the soil leads to fundamental changes in physical properties and processes, such as placing stresses upon soil structure which affects the pore space, availability of 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 with rainfed agriculture (Currie 2006). Evidence of soil structural decline, such as increased bulk density, under drip irrigation has been reported (Clark 2004). Moreover, drip irrigation whereby a certain portion of the soil is wetted also causes the spatial variability of soil physical and hydraulic properties. Therefore, the evaluation of the spatial variability of soil characteristics and digitization are very useful tool for the determination of fluctuations in soil behaviour. 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 production. Despite the great effort towards commercial production of cucumber in the country, little is known about the soil structural formation as well as the effect of combined water and nutrient management on its yield and water use pattern. Therefore the objective of this study was to evaluate the effect of drip irrigation frequency and N-fertilization on soil physical properties, yield and water use efficiency of cucumber (*Cucumis sativus*) in southwest Nigeria.

2. Materials and Methods

2.1 Description of Experimental Site

The field experiment was conducted between January-March 2015, at the Irrigation Teaching and Research Farm, Ekiti state university, Ado-Ekiti south-western Nigeria. The site was located at longitude 4^0 45' to 5^0 45'E and latitude 7^0 15 to 8^0 5'N at 434 m above sea mean level. It has a humid tropical climate characterized by distinct dry and wet seasons with moderate mean annual rainfall of about 1367.7 mm while temperature almost uniform throughout the year with little deviations from means 27˚C. The soil of the study site belongs to the broad group Alfisol (Soil Survey Staff 2010), with top sandy-loam to clay texture (Fasina *et al*. 2005). The results of the physico-chemical properties of 0-15 cm soil surface layer of the experimental area before the commencement of the study are shown in Table 1. According to the cropping history of the land; it has been used previously for the cultivation of water melon, okra, cucumber for 5 years prior to this study.

Table 1: Some soil physico-chemical properties of the 0-15 cm surface layer before the commencement of the experiment.

Chemical properties										
pH	OM	TN	Na	K	Ca	Mg	Av.P	H+Al	ECEC	BS
	------%-----		----------cmol kg^{-1}----------				mg kg^{-1}	-	cmol kg^{-1}	%
6.3	5.74	0.56	0.72	0.33	57.5	2.22	26.7	0.1	60.9	99.8
Physical properties										
Clay	Silt	Sand	texture							
----------%---------										
12.2	14.8	73.0	SL							

pH: alkalinity/acidity; OM: organic matter; TN: total nitrogen; Na: sodium; K: potassium; Ca: calcium; Mg: magnesium; Av. P: available phosphorus; H+Al: acidity, ECEC: effective cation exchange capacity; BS: base saturation; SL: sandy loam

2.2 Experimental Design and Treatments

The experiment was a two factorial laid out in a randomized complete block design (RCBD) in a split-plot arrangement and three replications. Irrigation constituted the main factor at 3 irrigation regimes namely: **ID** – Daily; **I2W** - Twice weekly and **IW** – weekly water application while the sub-plot was N-fertilization constituted by **N0** - Control (no fertilizer application) and **N80** – 80 kg Urea/ha, giving a total of six treatment combinations giving a total of 18 plots.

2.3 Land preparation, Field Layout and Installation of the Drip Irrigation System

The experimental site was prepared by ploughing followed by harrowing and unburied grasses were properly removed to ensure a clean field. In the field layout, there were 3 plots of 2 m x 5 m in each of the 6 blocks, giving a total field area of 180 m². The drip irrigation system consisted of a 3000 L tank, 25 mm diameter main pipe and sub mains, end plugs, T-joint plugs, rubber hose, gum, gate valves, laterals cum drippers, pipe nipples etc. The mainline delivered water from the tank to the sub mains and sub mains into the drip lines, while the emitters delivered water to the field at a rate of 4 L h^{-1}. The field and part of the drip irrigation set up are shown in Figure 1.

2.4 Planting and Field Management

Planting of cucumber was done on the 21st of January 2015, on the prepared plots. Two to three (2-3) seeds of cucumber (Ashley variety) were planted at a spacing of 60 cm x 60 cm using a planting depth of about 5 cm. A week after planting, excess seedlings were thinned to two plants per stand, giving a plant population of 55,555 plants/ha. 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 80 kg/ha urea (46 g N) was applied by hand method at two weeks (2 WAP) after planting. Weed control was done manually three times and other cultural practices including crop protection were conducted.

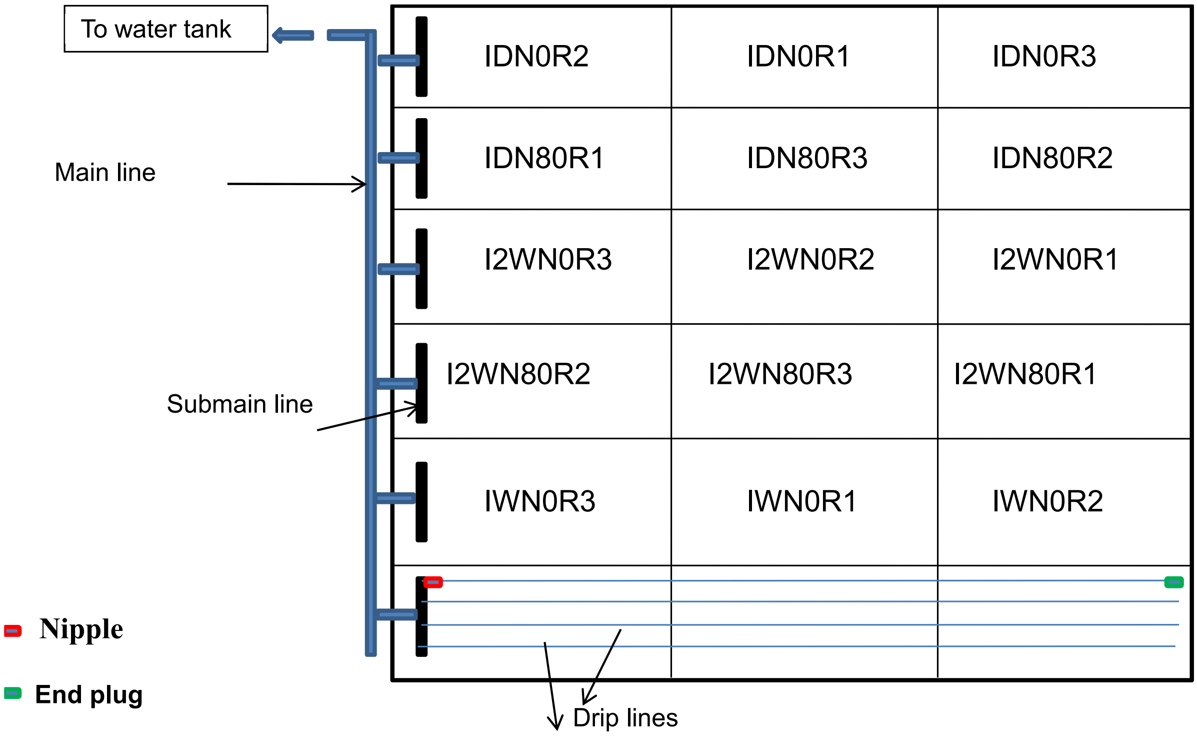

Figure 1. Installation of drip irrigation setup and field layout.

IDN0: daily water application + no fertilizer; IDN80: daily water application + 80 kg N-fertilization; I2WN0: twice weekly water application + no fertilizer; I2WN80: twice weekly water application + 80 kg N-fertilization; IWN0: weekly water application + no fertilizer; IWN80: weekly water application + 80 kg N-fertilization.

2.5 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 were air-dried, ground with mortar and passed through a 2-mm sieve for the determination of soil physical and chemical properties including soil pH, K, Na, Mg, Ca, ECEC (effective cation exchange capacity), base saturation, total organic carbon (TOC), total nitrogen (TN) and available phosphorus and soil texture. The soil pH was determined using the digital electrode pH meter. Bray-1 extractant was used to extract available P (Olsen & Sommers, 1982) while organic carbon and total N were determined by Walkey-Black (1934) oxidation and Kjeldahl digestion technique, respectively (Bremner & Mulvaney 1982). Exchangeable K, Ca, Mg and Na were extracted using normal ammonium acetate K, Ca and Na were determined using Flame Photometry while Mg was determined by the Atomic Absorption Spectrophotometry (AAS, Perkins Elmer 2280 model). Effective cation exchangeable capacity (ECEC) was obtained by the sum of exchangeable K, Ca, Mg and Na. Particle size distribution was determined by hydrometer method of soil mechanical analysis as outlined by Bouyoucous (1981).

Two representative profiles were also dug within the experimental field and undisturbed soil samples were collected at 0-10, 10-20 and 20-30 cm soil layers using core samplers made from metallic cylinders, 43.4 mm diameter and 40 mm high for the determination of bulk density saturated water content, saturated hydraulic conductivity and particle density as described below:

2.5.1 Saturated water content.

This was obtained by saturating the samples in a water bath for 48 hours and the weight was determined.

2.5.2 Bulk density.

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

$$BD = Ms/V \quad (1)$$

where BD= bulk density(g/cm3), Ms=weight of dry soil (g), V= volume of soil (cm^3)

2.5.3 Particle density.

It was determined by volumetric flask method according to Gubiani *et al.* (2006).

$$Dp = Ms/Vs \quad (2)$$

where Dp = Particle density (g/cm^3), Ms = weight of soil (g), and Vs = Volume of solid (cm^3)

2.5.4 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 hours. 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:

$$Ksat = \frac{Q * L}{A * H * t} \qquad (3)$$

where *Ks*at 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 Temporal variability of soil moisture content and bulk density

The soil moisture content and bulk density of the 0-10 cm surface layer was monitored weekly by oven-drying the soil samples at 105 °C for 48 hours. The soil moisture content was determined according to the equation:

$$\theta_g = \frac{W_{ws} - W_{ds}}{W_{ds}} \qquad (4)$$

where θ_g = gravimetric soil moisture cm^3 cm^{-3}; W_{ws} = Weight of wet soil (g), W_{ds} = Weight of oven-dried soil (g).

The soil volumetric moisture content was obtained by multiplying the gravimetric content by the respective bulk density (BD) determined for each measurement campaign.

2.7 Spatial Distribution of Moisture Content and Bulk Density

The spatial distribution of moisture content and bulk density was obtained at distances, 0, 10, 20, 30, 40 and 50 cm, from the drip emitters and from 0-10, 10-20, and 20-30 cm soil layers from each of the irrigation treatments. The data obtained were subjected to geostatistical analysis using the GS+ (Gamma Design Software, version 2005) to determine the spatial variability of the soil moisture content and bulk density. Block kriging procedure in the GS^+ was used to estimate soil variables at unsampled locations in the experimental field, and a 2-D map was generated for each variable.

2.8 Biomass, Fruit Yield and Water Use Efficiency (WUE)

Matured cucumber fruits were harvested from an area, 1 m x 1 m, from each plot periodically and the weight was measured with a sensitive scale. The yield component evaluated included number of fruits, fruit length and fruit diameter. The total fruit yield was obtained from the sum of the various harvests and total yield was thereafter converted to kg ha^{-1}. Fresh and dry biomass was determined when no fruit was found on the vines. Dry biomass was determined by oven drying the fresh biomass at 65 °C for 48 h.

Irrigation water use efficiency (IWUE) and total water use efficiency (TWUE), which combines rainfall received during the growing period were calculated according to equations 5 and 6 (FAO, 1982):

$$IWUE = \frac{Y}{I} \qquad (5)$$

$$TWUE = \frac{Y}{I + R} \qquad (6)$$

where $IWUE$, $TWUE$ is the irrigation and total water use efficiency, respectively (kg ha^{-1} mm^{-1}); *Y* is the total marketable fruit yield (kg); *I* is the amount of irrigation water, mm and *I* + *R* is the amount of irrigation water + rainfall, mm.

2.9 Statistical Analysis

Data collected were subjected to statistical analysis of variance (ANOVA) and means were separated by Fisher's Least Significant Different (LSD) test at 5% level of probability. Pearson correlation was carried out between soil physical properties and yield. Regression analysis was done to determine the relationship between WUE and water applied (irrigation and rainfall). All analyses were performed using SPSS software (IBM version 20).

3. Results and Discussion

3.1 Initial Soil physical and hydraulic properties of the study site

The physical and hydraulic properties of the 0-10, 10-20, 20-30, 30-40 and 40-60 cm soil layers of the field shortly after planting of cucumber are shown in Table 2. The soil bulk density increased with depth, with average values ranging between 1.48 and 1.74 g cm^{-3}, with the lowest and highest values from the 0-10 cm surface and 30-40 cm subsurface layers, respectively. The saturated soil moisture content was highest (0.4721 cm^3 cm^{-3}) in the 0-10 cm surface layer while the lowest value (0.3730 cm^3 cm^{-3}) was recorded from 30-40 cm layer. The highest (239.1 mm h^{-1}) value of soil saturated hydraulic conductivity was obtained from the 0-10 cm surface layer while the lowest value (89.0 mm h^{-1}) was obtained also from the 30-40 cm layer. The particle density ranged between 2.53 and 2.60 g cm^{-3}, with the highest value from the 0-10 cm surface layer. The lowest BD (1.48 g cm^{-3}) obtained in the 0-10 cm surface layer prior to the commencement of the experiment was as a result of soil mobilization by ploughing and harrowing. In the subsurface layers, the BD was highest, 1.74 g cm^{-3}, in the 30-40 cm layer, which is below the 1.75 g cm^{-3} considered as the threshold, above which is considered critical to limit root proliferation and growth for this type of soil (Reinert *et al.* 2008), which can have both positive and negative effects on vital soil properties such as water flow and gaseous exchange, porosity, water retention, soil temperature, among others. The

Table 2. Soil particle density, soil bulk density, saturated moisture content and hydraulic conductivity of the different soil layers of the field shortly after planting of cucumber.

Soil depth, cm	BD g cm^{-3}	θsat cm^3 cm^{-3}	Ksat mm h^{-1}	Dp g cm^{-3}
0-10	1.48	0.4721	239.1	2.60
10-20	1.56	0.4349	206.5	2.59
20-30	1.67	0.3852	154.9	2.58
30-40	1.74	0.3730	89.0	2.53
40-60	1.65	0.3922	129.0	2.53

BD: bulk density; θsat: saturated water content; Ksat: saturated hydraulic conductivity; Dp: particle density.

highest saturation water content of the surface layers is attributed to higher organic matter content and improved pore spaced caused by soil mobilization. Saturated hydraulic conductivity depends on water fluidity, which is proportional to its viscosity and soil bulk density as well asmacroporosity (Timm & Reichardt 2004) which is a function of soil texture and structure (Bormann & Klaassen 2008; Hu *et al*, 2009).

The highest saturated hydraulic conductivity (Ksat) in the 0-10 cm surface layer of this soil is attributed to soil mobilization by ploughing and harrowing prior to planting of cucumber. This recently tilled layer is characterized by low bulk density and larger pore volume. On the other hand, the low Ksat values in the surface layers were due to high BD obtained in these layers, which are antecedent soil conditions.

3.2 Evapotranspiration, Precipitation and Irrigation Quantity

The daily evaporative demand of the atmosphere (ETo) and rainfall values during the drip irrigated cucumber cultivation are shown in Figure 2. The daily rainfall amount was less than 5mm between

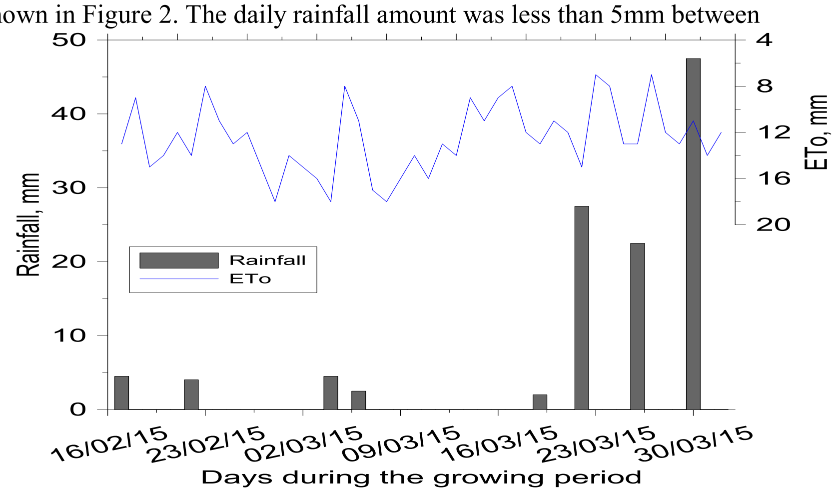

Figure 2: Temporal distribution of rainfall and evaporative demand of the atmosphere (ETo) during the cucumber growing period at the Irrigation Experimental Field, Ekiti State University, Ado Ekiti, Nigeria.

February and second week in March and towards the end of the experiment, rainfall was high with the amount of about 47.5 mm. The daily evapotranspiration ranged between 7 and 17 mm. A comparison between the amount of rainfall when it rained (between February and second week in March) and the ETo showed that the rainfall amount was not enough in meeting the evaporative demand of the atmosphere, hence the cucumber would be subjected to water and physiological stress without irrigation. In addition, the ETo trend strictly followed the course of rainfall as the evaporation rate goes down when it rains and when

Table 3. The total irrigation applied, and irrigation + rainfall amount received by each treatment combination during the drip irrigation period.

Treatment	I mm	I+R mm
IDN0	422.4	537.43
IDN80	422.4	537.43
I2WN0	128.0	243.03
I2WN80	128.0	243.03
IWN0	51.2	166.23
IWN80	51.2	166.23

I: irrigation; I+R: irrigation + rainfall IDN0: daily water application + no fertilizer; IDN80: daily water application + 80 kg N-fertilization; I2WN0: twice weekly water application + no fertilizer; I2WN80: twice weekly water application + 80 kg N-fertilization; IWN0: weekly water application + no fertilizer; IWN80: weekly water application + 80 kg N-fertilization.

there is no rain, it goes up.

The total amount of irrigation depth applied to the different irrigation treatments, including the total rainfall amount are presented in Table 3. The daily irrigation water application (ID) received 422 mm,the twice weekly water application received 122 mm while the weekly received 51 mm. Considering the combined irrigation applied and rainfall amount, the daily application (ID) treatment received 537.43 mm, twice weekly (I2W) treatment received 243 mm and weekly application (IW) treatment received 166.23 mm.

3.3 Temporal Variability of Soil Bulk Density and Water Content

The temporal variablity of soil bulk density (BD) of the 0-10 cm surface layer of the cucumber field under drip irrigation frequency and N-fertilization during the 2015 dry season is shown in Figure 3. Except at 3 weeks after planting (WAP) (3/3/3015) under 0 kg N/ha fertilizer treatment, there were significant differences ($p<0.05$) in the average values of BD among the different drip irrigation frequency with time, with the daily water application (ID) having the significantly highest BD, as high as about 1.75 g cm^{-3} (Figure 3a). A comparison between the fertilizer treatments showed that 80 kg N/ha application had lower bulk density (Figures 3 a and b). The increase in the BD from all treatments with time is an effect of aggregate coalescence, which is a soil hardening process whereby the cementing of aggregates leads to increase in soil BD. Another reason may be due to biophysical activities such as the cucumber roots 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 significantly highest BD from daily (ID) water application compared to other water application treatments is attributed to more alternate wetting and cycles, indicating that slaking and dispersion phenomenon are not necessarily at play (Lanyon *et al.* 2000). The introduction of irrigation leads to fundamental changes in soil hydrologic regimes because irrigated soils undergo a greater number of wetting and drying cycles compared to rainfed soils (Cockroft & Olsen 2000), leading to aggregate coalescence. This result also agrees with the findings of Currie (2006) who found that drip irrigation increased soil bulk density in grape vineyard. According to Cockroft & Olsen (2000), the consequences of increased BD include lower hydraulic conductivity within the soil profile, restricted root growth and reduced crop productivity.

The temporal variability of soil water content (SWC) of the 0-10 cm surface layer of the cucumber field under drip irrigation frequency and N-fertilization is presented in Figure 4. There were significant differences ($p<0.05$) in the average values of SWC due to irrigation frequency, with the daily (ID) and weekly (IW) water application treatments having the highest and lowest values of SWC. A comparison between the two fertilizer treatments also indicated that 80 kg N/ha had slightly higher SWC compared with 0 kg N/ha (Figures 4 a and b). The significantly highest soil water content from daily (ID) water application is attributed to higher frequency of soil wetting. Meshkat *et al.* (2000) also pointed out that an irrigation regime with excessively high frequency could cause the soil surface to remain wet. Due to the great changes in soil moisture distribution along the growth period, crop yields may be different when the same quantity of water is applied under different irrigation frequencies. Therefore, low irrigation frequency may cause unstable moisture conditions for water movement in soil, inhibits uptake by roots, and hence reduces crop productivity.

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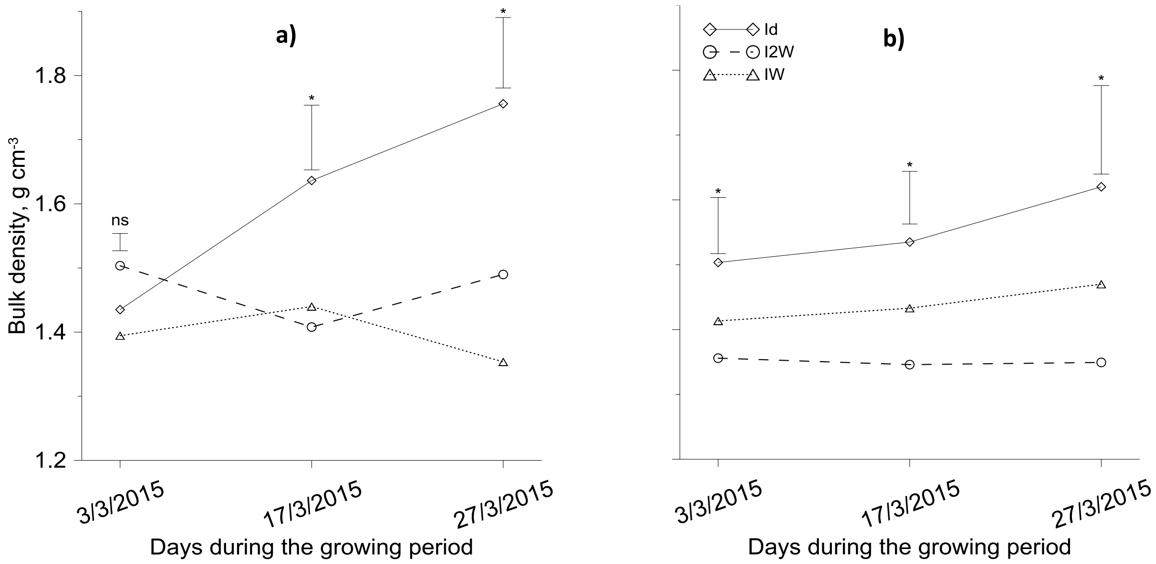

Figure 3. Temporal variability of soil bulk density of the 0-10 cm surface layer of the cucumber field under drip irrigation frequency and (a) 0 kg N/ha and (b) 80 kg N/ha fertilization during the 2015 dry season.

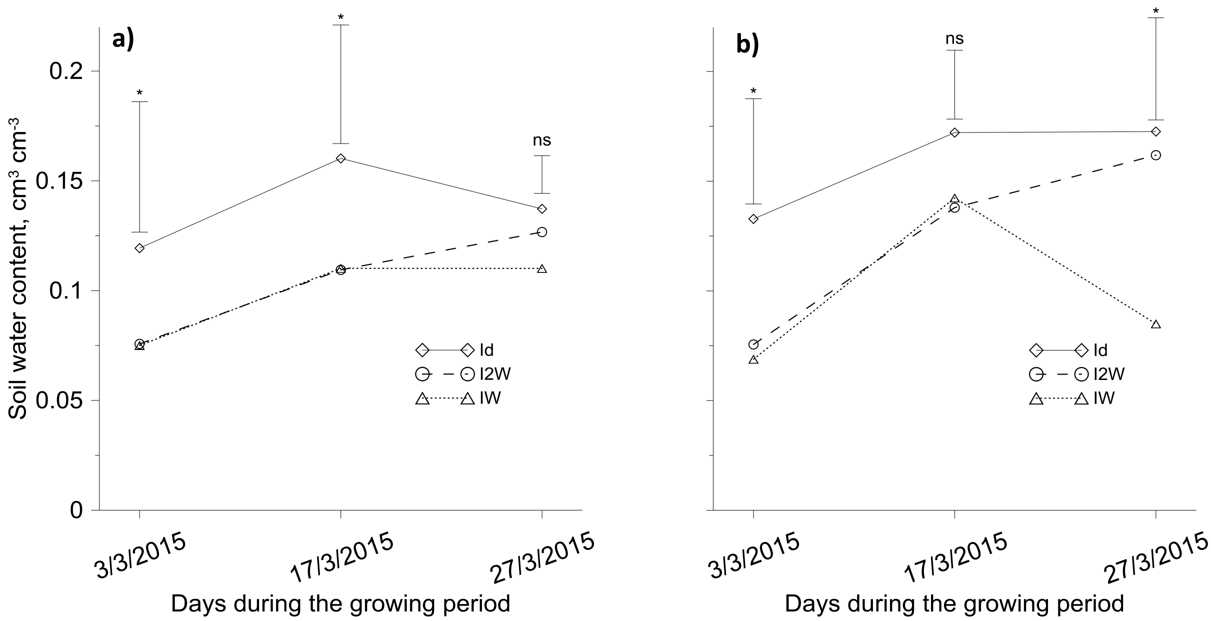

Figure 4. Temporal variability of soil water content of the 0-10 cm surface layer of the cucumber field under drip irrigation frequency and N-fertilization during the 2015 dry season.

3.4 Spatial Variability of Soil Bulk Density and Water Content

The spatial variability of soil bulk density (BD) of the cucumber field under daily (ID), twice weekly (I2W) and weekly (IW) water application is shown in Figure 5. For the ID treatment, the BD was low up to 20 cm from emitter discharge compared to 40 and 50 cm from emitter. Down the soil profile, there was an increase in the BD, with the high values from about 10 cm from the soil surface (Figure 5a). For the I2W and IW treatments, similar trend was observed, with the BD increasing with soil depth. A comparison of the spatial results between the three irrigation frequencies showed that the ID treatment gave

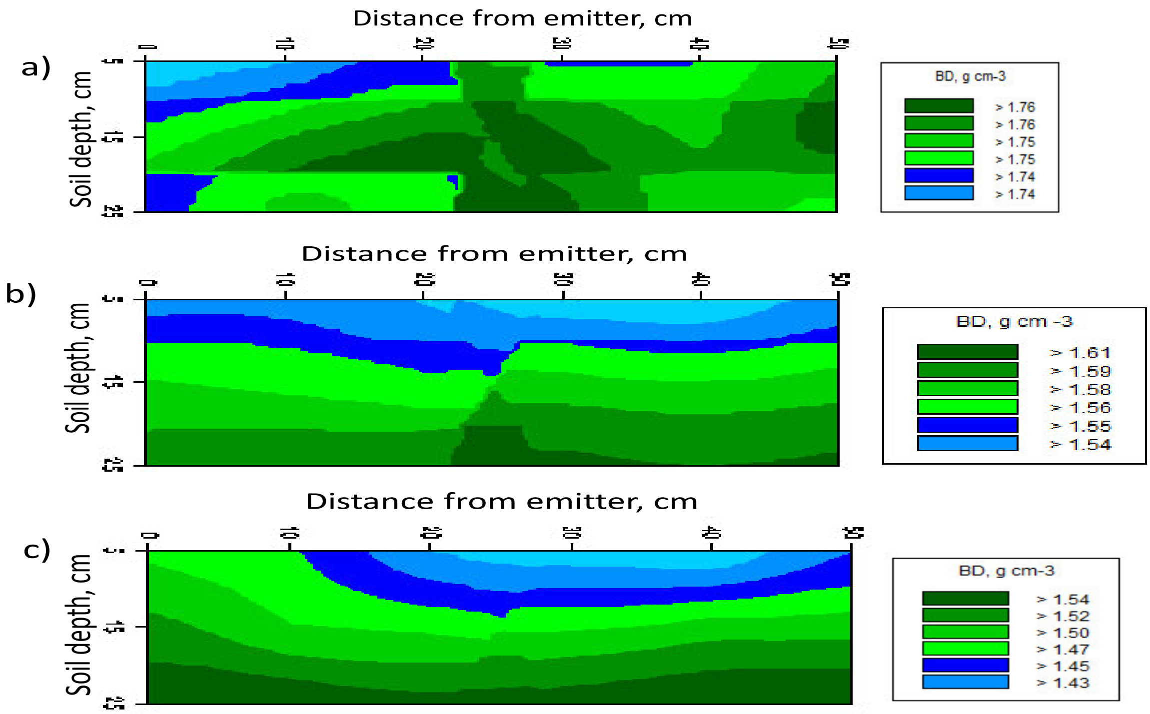

Figure 5. Spatial variability of soil bulk density under (a) daily water application, (b) twice weekly water application, and (c) weekly water application

the highest BD which agrees with the highest BD values already reported for this treatment under the temporal variability.

Figure 6 shows the spatial distribution of soil water content (SWC) of the cucumber field

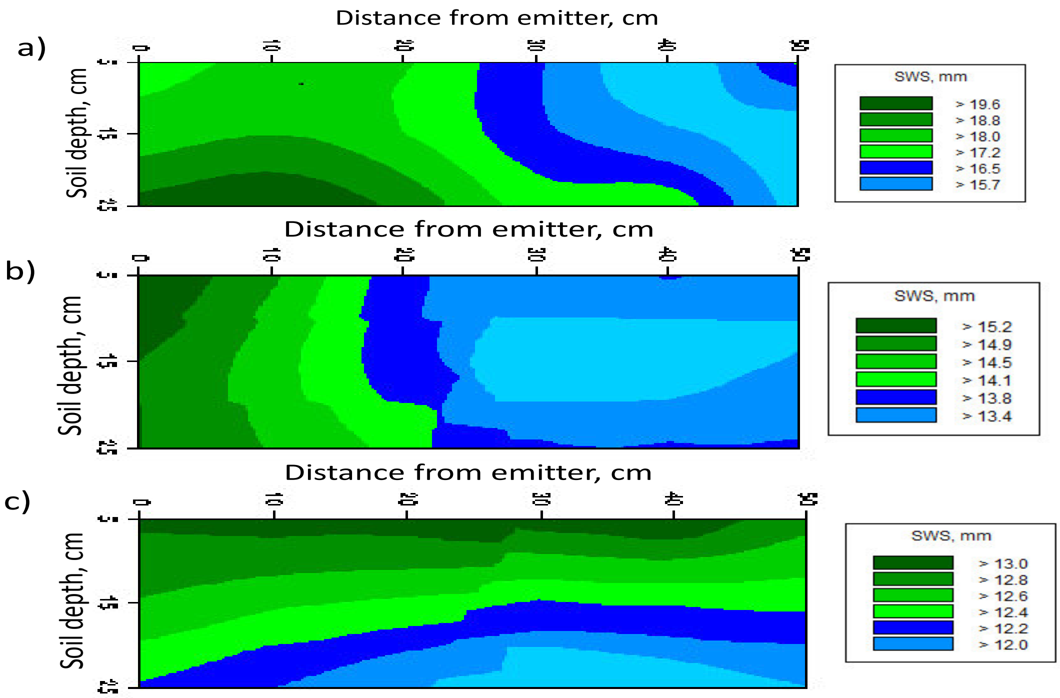

Figure 6. Spatial variability of soil water content under (a) daily water application, (b) twice weekly water application, and (c) weekly water application

subjected to different drip irrigation frequencies. Both the ID and I2W treatments showed similar trend, with the SWC decreasing with distance from the emitter (Figures 6 a and b). For the IW water application treatment, a different behavior was observed as the SWC was uniform with distance from emitter but decreased with soil depth (Figure 6c). Comparing the three irrigation treatments, the ID water application had the highest SWC values while the IW water application gave the lowest SWC values for all soil depths. These results agree with the observed SWC under the temporal monitoring. The appearance of distinct soil physical properties and soil fertility zones are indications of considerable spatial variability inherent to the soil (Wendroth *et al.* 2003), with the extent of soil spatial variability depending on the variations arising from soil forming factors as well as management practices such as drip irrigation frequency applied for a particular crop growth (McGraw 1994; Mulla & McBratney 2000). The heterogeneity of irrigation water application resulted into spatial variability of soil moisture content and bulk density. The greater wetted radius and depth resulting from ID treatment compared to I2W treatment was due to higher water application frequency, indicating that more soil volume will remain wet under more frequent water application (Figure 5 a and b). The different spatial behavior obtained from weekly water application (IW) (Figure 5 c) was due to limited amount of water to the soil surface due to low irrigation frequency in which part of the water would have been taken up by the plants and part evaporated thus making the subsoil layer remaining dry during the growing period. The bulk density also remained spatially higher in the subsoil layers of all treatments.

3.5 Effect of Drip Irrigation and N-Fertilization on Cucumber Biomass and Yield

The results of the effect of drip irrigation frequency and N-fertilizer on fresh and dry biomass and yield of cucumber are shown in Figure 7 while Table 4 shows the results of analysis of variance. Drip irrigation frequency and N-fertilization had no significant effect on fresh biomass yield, with the average

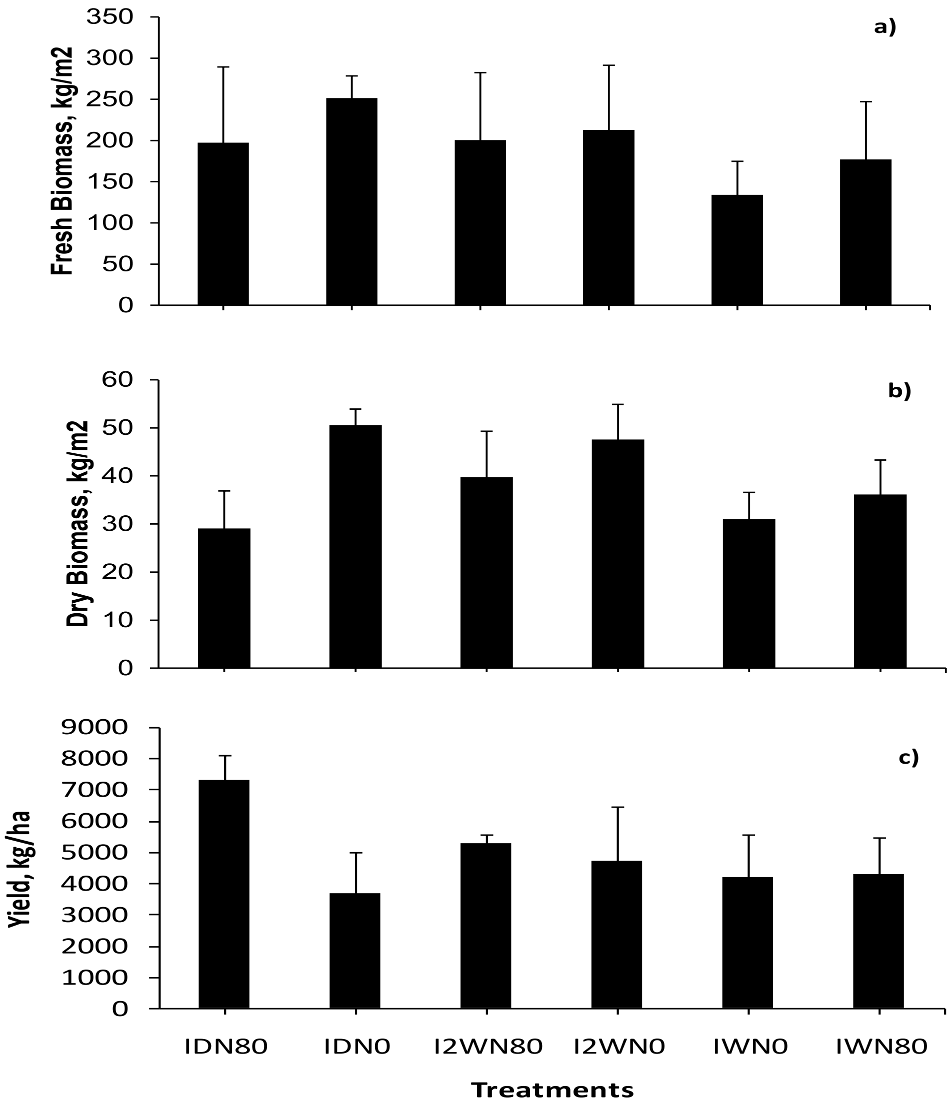

Figure 7. Interactive effect of drip irrigation frequency and N-fertilization on a) fresh biomass, b) dry biomass and c) yield of cucumber.

Table 4. Statistical results of the effect of drip irrigation frequency and N-fertilization on cucumber biomass, yield and water use efficiency.

Parameters	FrshBio ---------- kg m^{-2}-------	DryBio	Yield kg ha^{-1}	TWUE ----kg ha^{-1} mm^{-1}----	IWUE
I	1.62ns	3.11*	1.54ns	12.39*	31.62*
F	1.26ns	11.91*	5.66*	1.24ns	0.27ns
I x F	0.15ns	2.30ns	3.89*	0.67ns	0.17ns

TWUE: total water use efficiency; IWUE: irrigation water use efficiency; I: irrigation effect; F: fertilizer effect; I X F: interaction effect of irrigation and fertilizer
*significant and ns: not significant by Fisher's LSD test at 5% level of probability.

values ranging between 120 and 260 kg m^{-2}). On the other hand, both irrigation frequency and N-fertilizer had significant effect ($p<0.05$) on dry biomass yield, with the lowest (29 kg m^{-2}) and highest (52 kg m^{-2}) values from IDN0 and IDN80 treatments, respectively. Biomass was positively increased with the application of more quantity of irrigation water. Under nitrogen treatment, the total above ground biomass of cucumber was significantly higher than that of the contrast nitrogen treatment (N0). Water deficit had effect on the total aboveground biomass in all nitrogen treatments. The interaction between irrigation frequency and N-fertilization was not significant on both fresh and dry biomass. These results agree with the findings of Yuan *et al.* (2005) who found that irrigation water significantly affected plant growth and biomass increased with increase of irrigation water up to certain limit. Gallardo *et al.* (1996) reported that decreased water supply had a greater effect on the fresh weight than on the dry weight. Aujla *et al.* (2007) also found that biomass yield of a similar crop, eggplant, had a positive response to the increase of nitrogen fertilizer under different irrigation levels.

Drip irrigation frequency had no significant effect on cucumber fruit yield, although the highest yield (5481.62 kg ha^{-1}) was obtained from daily water application (ID), followed by 5001.15 kg ha^{-1} from I2W water application while weekly water application (IW) had the lowest yield (4253.47 kg ha^{-1}) (Figure 7), representing about 8% and 22% reduction, respectively, compared with daily irrigation. The results agree with the findings of Mao (2003) who found that fresh fruits yield were highly influenced by the total volume of irrigation water at every growth stage. However, our results contradicted that of El-Hady & Wanas (2006) who found increased cucumber yield with decreased irrigation amount. The IW irrigation had water saving potential of about 88%, however the relative high reduction in yield is an indication that the crop water need of cucumber is not met. Abdul Hakkim & Jisha Chand (2014) also reported the lowest cucumber yield when irrigation level was reduced by 50%. The low reduction in yield from I2W irrigation showed that this scheduling can be adopted considering factors such as water loss from excessive irrigation and cost of pumping. When water in the plant tissues is sufficient, the rate of photosynthesis and all other metabolic processes will be maximized and plant growth will increase, which at the end will be reflecting in all growth parameters e.g. plant height, number of leaves, biomass etc.

The statistical analysis showed that N- fertilization had a significant effect ($p<0.05$) on cucumber yield. Thus, the reduction, about 26%, in cucumber yield from N0 treatment compared with N80 treatment is an indication that although adequate moisture might be available in the soil, however, soil nutrients, such as nitrogen, may be limiting and thus the optimum soil condition is not met for crop growth and productivity. Also there was significant interaction of fertilizer and irrigation levels on the cucumber yield, with the lowest (3678.9 kg ha^{-1}) and highest (7284.3 kg ha^{-1}) values from IDN0 and IDN80 treatments, respectively.

3.6 Total water use efficiency (TWUE) and Irrigation water use efficiency (IWUE)

The water use efficiency (WUE) was determined to evaluate the productivity of irrigation in the treatments. The results of the effect of drip irrigation frequency and N-fertilization on total (TWUE) and irrigation water use efficiency (IWUE) of cucumber are presented in Figure 8. From Figure 8, both the TWUE and the IWUE increased when irrigation amount decreased. TWUE and IWUE were highest from IW treatment while ID treatment had the minimum value. Some researchers have reported highest IWUE values for cucumber under deficit irrigation conditions (Kirnak & Demirtas 2006; Hashem *et al.* 2011; Abdul Hakkim & Jisha Chandy 2014). These results also confirm that water productivity under water saving strategy was higher (about 88% from IW irrigation) than the full or excess water application.

The relationship between TWUE and IWUE versus water applied is presented in Figure 9, in which significant second degree polynomial relationships between WUE and water applied were found. The determination factor (R^2) of irrigation quantity to IWUE was high and significant, $R^2 = 0.8337$ and $R^2 = 0.629$ for TWUE and IWUE, respectively. The water use efficiency increased with decreasing amount of irrigation water. These results are in agreement with the results of Sezen *et al.* (2007) who also reported significant second degree polynomial relationship between irrigation water applied and water use of bell pepper. Using proper water quantity application allows plants to use water and nutrients from deep soil, thus increases water and nutrient use efficiency and reduces nitrogen leaching. These results suggest that WUE could be a good criterion for evaluating the effectiveness of irrigation.

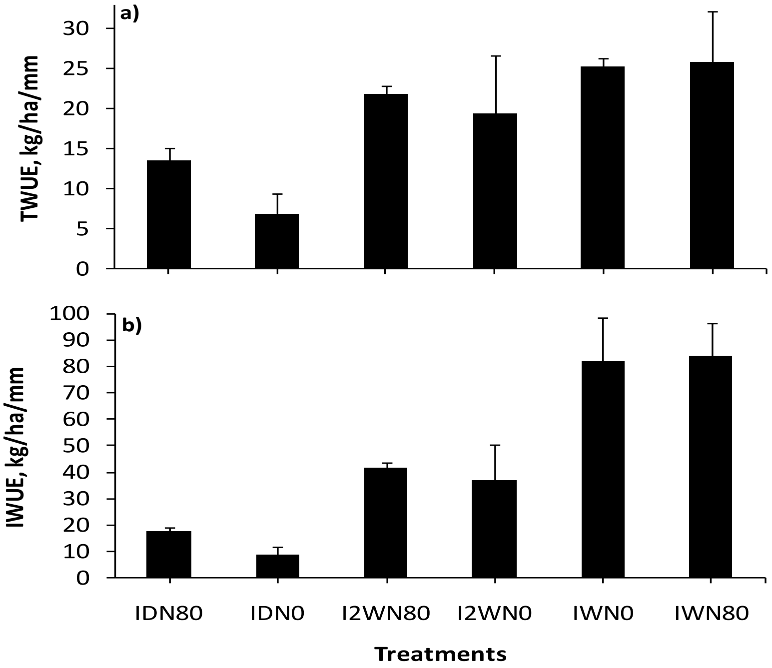

Figure 8. Interactive effect of drip irrigation frequency and N-fertilization on a) total water sue efficiency (TWUE) and b) irrigation water use efficiency (IWUE) of cucumber.

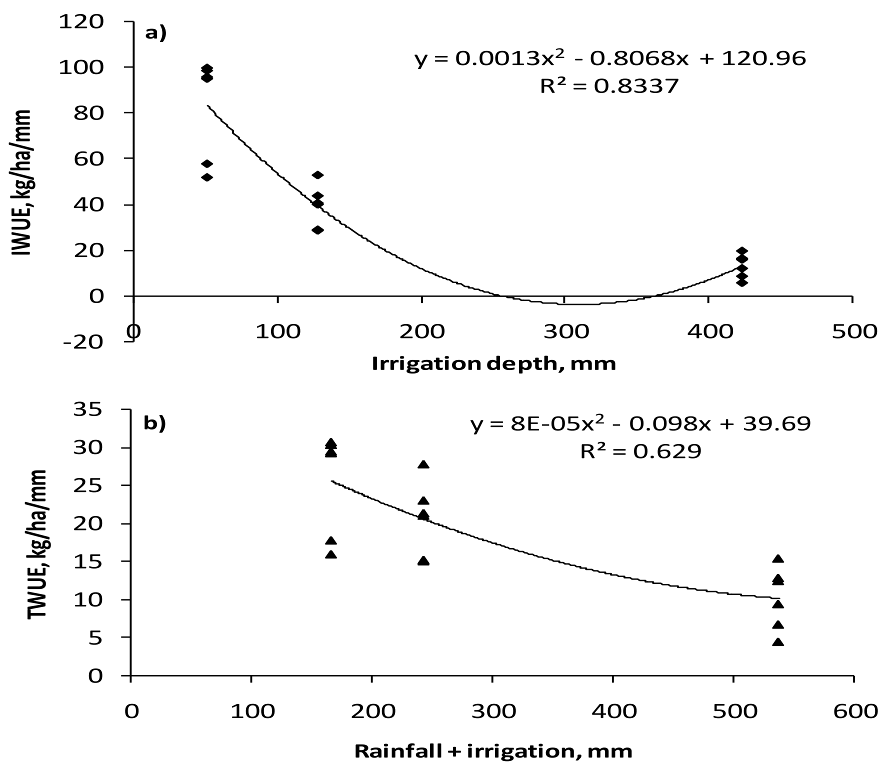

Figure 9. Relationship between total water use efficiency (TWUE) and irrigation water use efficiency (IWUE) versus water applied.

3.7 Correlation between cucumber yield components and soil physical properties

The results of Pearson correlation analysis between cucumber yield components and selected soil physical properties are shown in Table 4. There was positive correlation between cucumber fruit yield

Table 4 . Correlation between cucumber yield components and selected soil physical properties.

Variable	Yield	NoFrt	FrtLnt	FrtDia	FrshBio	DryBio	BD	SWC
Yield	1	0.379	0.454	0.694	-0.426	-0.318	-0.643*	0.754**
NoFrt		1	-0.054	0.356	-0.197	-0.270	-0.366**	0.334
FrtLnt			1	0.705**	-0.24	-0.343	0.182	0.100
FrtDia				1	-0.12	-0.124	-0.534*	0.096
FrshBio					1	0.800**	-0.456**	0.732*
DryBio						1	-0.387*	0.589**
BD							1	0.663*
SWC								1

NoFrt: number of fruit; FrtLnt: fruit length; FrtDia: fruit diameter, FrshBio: fresh biomass; DryBio: dry biomass; BD: bulk density; SWC: soil water content.

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).

versus number of fruit, fruit length and fruit diameter, with increase in fruit number that is the most important component influencing yield increase. Abdul Hakkim & Jisha Chand (2014) also reported significant positive correlation between cucumber yield and yield components. On the other hand, the correlation of the fruit yield versus fresh- and dry biomass was negative and also not significant, indicating that high vegetative growth does not necessarily mean high yield. The correlation between BD and cucumber yield and yield components was significant and negative, showing that elevated BD will negatively impact cucumber productivity. Cucumber yield had significant positive correlation with soil water content (SWC). Similarly, the correlation between the BD and SWC was significant and positive, indicating that under adequate water supply, dense soils store more water as more micropores were formed at the expense of macropores.

4. Conclusions

The effect of drip irrigation frequency and N-fertilization on soil physical properties, yield and water use efficiency of cucumber (*Cucumis sativus*) was investigated. The bulk density of the 0-10 cm surface layer increased over time and was the highest from Id treatment, with the elevated BD from Id treatment, indicating negative impact on soil structure. The lowest yield obtained from water saving strategy from weekly water application (IW) showed that cucumber crop water requirement was not met. N-fertilization had no influence on both BD and SWC whereas cucumber yield was significantly ($p<0.05$) increased. Reducing the frequency of water application increased cucumber water use efficiency. In this study, the different drip irrigation levels caused distinct spatial pattern of SWC and BD. The correlation analysis showed that cucumber fruit yield will increase with more availability of water as well as good soil structural condition. Therefore, for optimum yield, water saving strategy, reduced cost of pumping and lesser effect on soil structure, drip irrigation scheduling of twice weekly (I2W) combined with N-fertilization is recommended for cucumber cultivation.

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