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Effect of Deficit Irrigation and Biochar Application on Growth, Yield Components , Water Use Efficiency and Water Productivity of Banana (*Musa sapientum*) Grown in Sandy Soil Under Drip Irrigation

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El Namas, A. E.*

Department of Soil and Water Science, Faculty of Agric., Alexandria University

ABSTRACT

A two-season field experiment was conducted investigate the effect of deficit irrigation treatments: 100% (D_1), 80% (D_2) and 60% (D_3) of the crop evapotranspiration (ET_c) and biochar application: 0.2 wt.% (B_1) and 0.4 wt.% (B_2) on the growth , water use efficiency (WUE) and Water Productivity (WP) of banana plant grown in sandy soil under drip irrigation. Results indicated that all bananas' vegetative growth parameters, and the fruit yield and its measured quality parameters were significantly impacted ($P<0.05$) by treatments. Results showed that the highest yield of banana (36.20 and 36.38 ton/fed.) was recorded with D_1B_2 treatment in both seasons, while the lowest yield (21.23 and 21.73 ton/fed.) was recorded due to D_3B_1 treatment (60 % of ET_c + 0.2 wt.% biochar) in both seasons. The total soluble solids, total sugars, and starch contents of banana fruit exhibited significant differences between all treatments of deficit irrigation and biochar application while its total acidity was not significantly impacted in both seasons. The maximum values of WUE (4.65 and 4.90 kg / m^3) were as associated with D_2B_2 treatment (80 % of ET_c + 0.4 wt. % biochar) in both seasons. The highest values of WP were associated with D_2B_2 treatment (9.57 LE/m^3), followed by D_1B_2 treatment (8.15 LE/m^3) while the lowest value of WP was due to D_3B_1 treatment in both seasons. This data indicates that combination of 80% of ET_c and 0.4 wt. % biochar has saved a significant amount of irrigation water (20% reduction in irrigation water) without a compromise over neither the banana yield nor its fruits quality.

Keywords: Banana, Deficit irrigation, Biochar, Drip Irrigation, Water use efficiency, Water productivity.

INTRODUCTION

There is a growing demand worldwide for food and agricultural products and is expected to increase by more than 50% between 2012 and 2050 (FAO, 2017). This can be achieved through an increase in cultivation of agricultural crops that require increased demand for irrigation water.

Egyptian Authorities estimated around 570 cubic meters of water per person per year since hydrologists considered a country is facing water poverty if water supplies drop below 1000 cubic meters per person annually. Egypt's figure is expected to drop down to 500 cubic meters by 2025 (Drainage Research Institute, 2010 and FAOSTAT, 2013). Taking into account the impact of the Grand Ethiopian Renaissance Dam, this will lower water levels, for Egypt and Sudan. As a result, Egypt is urging farmers to use more efficient irrigation techniques and plant species and varieties with shorter life spans that consume less water.

Banana (Musa spp.) is one of the most important fruit crops, which is the fifteenth of the world's imported commodities and the fourth most important food crop after rice, wheat and maize in many developing countries (Heslop-Harrison and Schwarzacher, 2007; FAOSTAT, 2010). Banana is grown in subtropical areas such as Western Australia, South Queensland, South Africa, Israel, Taiwan, Spain (The Canary Islands), Egypt, Morocco and parts of Brazil and Turkey (Galán Saúco *et al*., 2004), many of which are situated between the latitudes 20 and 30°N (Stover and Simmonds, 1987. , FAO, 2016 and Panis and Thinh, 2001). In Egypt, banana is one of the oldest cultivated plants. It is well known that banana requires large amounts of potassium and nitrogen fertilizers. Thus, banana growers are the high costs of excessive manufactured fertilizers needs for banana plants.

An official report issued by the Egyptian Ministry of Agriculture and Land Reclamation (MALR), represented by the Central Administration of Horticulture, revealed a report on banana cultivation in Egypt, explaining that the total area is 84205 feddan producing one million and 487 thousand tons, with an average productivity of 20 tons per fed. The areas planted with bananas in the desert areas exceed 20000 fed. representing about 25% of the total area of bananas in Egypt. According to the official report, the largest area of bananas outside the delta and the Nile Valley is limited to El-Nubaria area in Beheira Governorate, located to the west of Cairo-Alexandria Desert Road, with a total area of 20,113 fed. , while the remaining small areas are distributed between the governorates of Matrouh, the New Valley and South Sinai depending on irrigation by groundwater facilities, indicating that 5 governorates acquire the most expensive land planted with bananas with a total area of 54 thousand and 657 fed. in Beheira Governorate, Menoufia,

* **Corresponding author.**
E-mail address: elnamasashraf@gmail.com
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Luxor, Qena and Qalyubia, with a percentage up to 64% of the total for Egypt.

Water deficit is one of the most important factors that limits banana productivity in the world, especially in arid and semiarid areas where large fluctuation in the amount and distribution of the rain fall (Zhu, 2002; Van Asten *et al*. ,2004; Nyombi, 2013 and Almeselmani *et al*., 2011) . Araya *et al*., (1998) mentioned that banana root system can greatly assist for irrigation scheduling. Robinson, (1995) showed that the effective rooting depth together with the water holding capacity of the soil, percentage of depletion of total available water allowed before irrigation, and the crop coefficient are essential for irrigation purposes.

Vegetative growth of banana is associated with yield. More girth of the stem, height and leaf area are desired characters because they correlate positively with the banana bunch size. Hidoto (2018) showed that banana yield per hectare was associated positively and highly significantly with growth parameters including pseudo stem girth and number of effective leaves . Leaf area is an important component that is closely related to the physiological processes controlling dry matter production and yield. Turner ,(1998) reported that water stress resulted in reduced leaf area leading to decreasing leaf area index in banana.

Biochar is defined as a pyrolysis of biomass derived from organic waste, manure and crop residues which exposed to oxygen-limited conditions (Lehmann and Joseph, 2009). It can reduce ground rays reflection, absorb more solar energy, and then rapidly raise soil temperature, due to the black color. In addition, application of biochar to soil may also increase the efficiency of nutrients use and soil fertility, resulting in a significant increase in agricultural productivity (Hagner *et al.* 2016; Laird *et al.* 2010). It has become a simple technology that can provide multiple environmental benefits when added to the soil, including long-term carbon sequestration (C) and increased P use efficiency in soil (Arif *et al.* 2017; Woolf *et al.* 2010 ; Verheijen *et al*.2014 ; Lehmann *et al.* 2011). The potential effect of biochar application to improve soil physical properties have been reported in several studies (Busscher *et al.* 2010; Sun and Lu 2014 ; Karhu *et al.* 2011 ; He *et al.* 2016).

The aim of this study therefore, was to investigate the effect of deficit irrigation and biochar application on growth, yield, fruit quality, water use efficiency and water productivity of banana crop cv. Grand Naine grown in sandy Soil under drip irrigation.

MATERIALS AND METHODS

Two field experiments were carried out in a private orchard at El-Nubaria Province, El-Behira Governorate, Egypt, (latitude 30º 30\ 1.4\\N, and longitude 30 º 19 \ 10.9\\ E, and mean altitude 21 m above sea level) during 2016/2017 and 2017/ 2018 growing seasons .Banana (*MUSA SAPIENTUM*) cv. Grand Naine grown under drip irrigation in sandy soil. The physical, chemical, properties of the experimental soil and irrigation water composition were analyzed according to the methods described by Black (1965), Jackson, (1973) and Page et. al., (1982) and the results obtained are shown in Tables 1- 3. The mean monthly weather conditions at the experimental location were obtained from the following website: https://power.larc.nasa.gov/ data-access-viewer during 2016/2017 and 2017/2018 growth seasons and this data are shown in Figs. 1-5.

Table 1. The mean values of some physical properties of experimental soil.

Soil depth (cm)	FC (%)	WP (%)	ASM (%)	D_b (Mg / m^3)	K_h (cm/hr.)	Particle size distribution , %				
						Coarse Sand	Fine Sand	Silt	Clay	Texture Class
0-20	11.2	4.9	6.3	1.65	19.5	40.5	45.6	11.6	2.3	Loamy Sand
20-40	11.8	5.3	6.5	1.67	18.1	39.4	51.3	6.2	2.1	Sand
20-60	10.6	4.8	5.8	1.70	18.4	39.2	52.7	3.1	5.0	Sand
60-80	10.9	5.1	5.8	1.70	17.3	42.3	49.5	4.4	3.8	Sand
Average	11.1	5.0	6.1	1.70	18.3	40.4	49.8	6.3	3.5	Sand

Where, F.C. (Field capacity, %) W.P. (Wilting Point, %) D_b (Bulk density, Mg.m^{-3}) ASM (Available soil Moisture , %) K_h (Hydraulic conductivity, cm.h^{-1})

Table 2. The mean values of some chemical properties of experimental soil

Soil depth, cm.	EC dS/m	pH (1:2.5)	O.M %	$CaCO_3$ %	Soluble cations (meq/L)				Soluble anions (meq/L)			
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0-20	0.52	8.60	0.62	6.81	1.42	0.82	2.03	0.93	0.12	1.31	2.62	1.15
20-40	0.57	8.51	0.53	5.21	1.41	0.74	1.93	1.62	0.10	1.95	2.71	0.94
20-60	0.73	8.82	0.33	4.03	1.56	0.86	2.55	2.33	0.14	2.68	3.79	0.69
60-80	0.87	8.52	0.25	2.55	1.87	0.98	2.89	2.96	0.09	2.88	3.99	1.74
Average	0.67	8.61	0.43	4.65	1.57	0.85	2.35	1.96	0.11	2.21	3.28	1.13

Table 3. The mean values of chemical composition of irrigation water (well water)

EC_w dS/m	pH	Soluble cations (meq/L)				Soluble anions (meq/L)				SAR
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	$CO3^{--}$	HCO_3^{-}	Cl^{-}	SO_4^{--}	
0.72	7.82	2.52	1.31	2.95	0.42	n.d.*	3.20	1.89	1.86	1.73

*** n.d. means (not detected)**

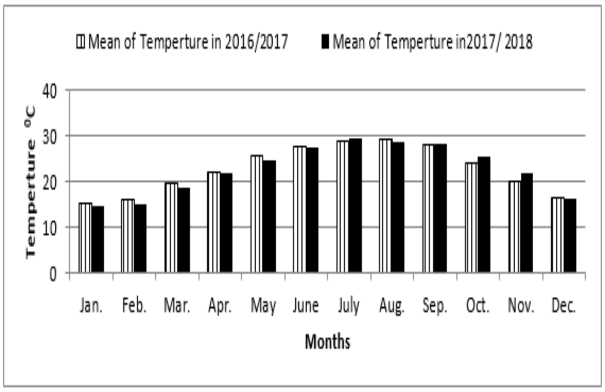

Fig .1. The mean monthly of temperature (C^0) of 2016 /2017 and 2017 / 2018 growing seasons.

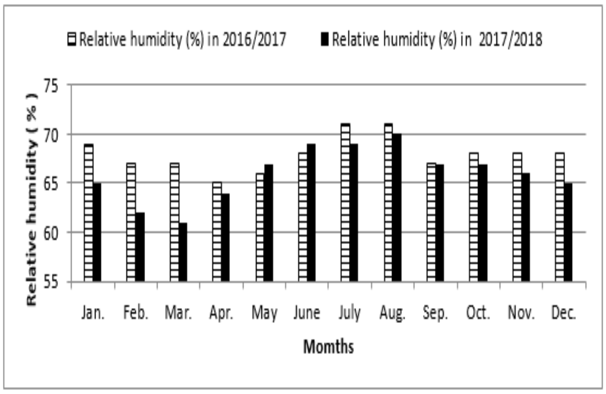

Fig .2. Monthly relative humidity (%) in 2016/2017 and 2017/2018 growing seasons.

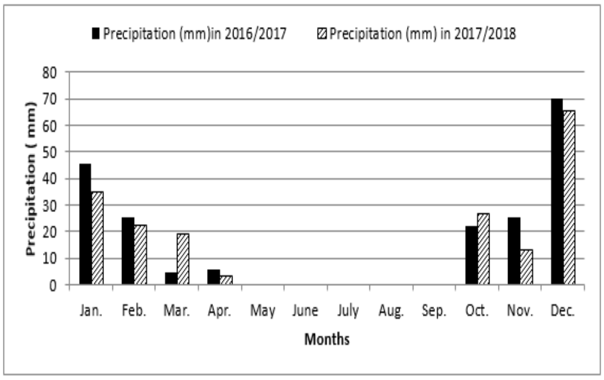

Fig .3. Monthly precipitation (mm) in2016/ 2017 and 2017/ 2018 growing seasons.

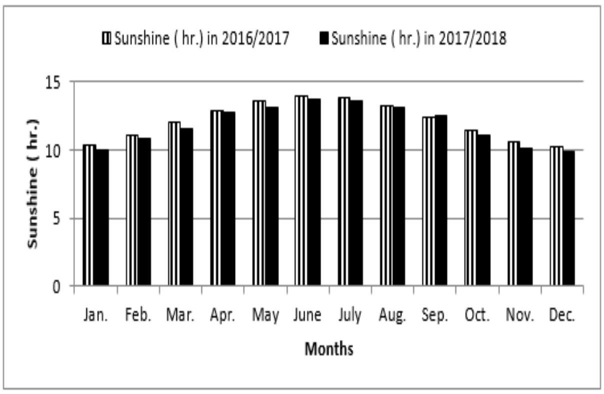

Fig .4. Mean monthly sunshine (hr.) in 2016/2017 and 2017/2018 growing seasons.

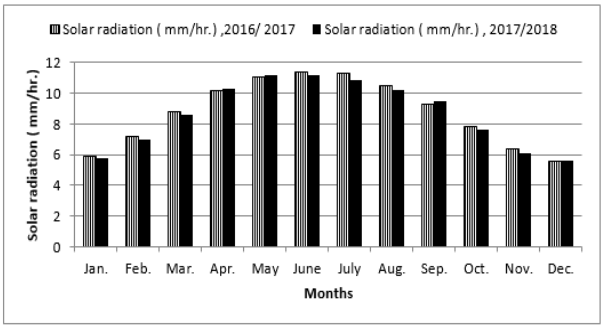

Fig .5. Mean monthly solar radiation (mm/hr.) in 2016/ 2017 and 2017/ 2018 growing seasons.

Preparation of Biochar :

The biochar used in this study was produced by pyrolysis of corn cob (as a feed stock) at a temperature of 450 C^0 with a retention time of 2 hour (Lehmann and Joseph , 2009) . The biochar was ground and sieved (< 0.5 mm) prior to use. Some physical and chemical properties of the biocbar were analyzed (Lehmann and Joseph , 2009) and the results obtained are shown in Table 4.The distribution and mixing with the amount of biochar required for the experimental of treatments were carried out around the plant during the preparation of the soil for cultivation in February 2016.

Table 4. Analytical results of the main physical and chemical properties of the used biochar.

SSA,m^2/g	O.C,%	H, %	N,%	P,%	K,%	C/N
7.79	77.84	2.95	0.86	0.5	1.2	90.5

Where, **SSA (Specific surface area, $m^2.g^{-1}$) O.C (Organic carbon, %)**

Banana cultivation:

The banana *(MUSA SAPIENTUM)* cultivar ; Grand Naine (Seedlings from tissue culture) was planted at spacing 3.5 m × 3.0 m apart in sandy soil (400 plant/fed.) .The suckers were planted in March 2016 (The offshoot / mother plant). The experiment started on the first ratoon and its suckers were chosen on the 1^{st} week of July 2016, as well as, on the second ratoon and its suckers were chosen at the same date in 2017. The stools were thinned, and three suckers were left for fruiting in the following season. In addition, three plants were left for cropping in the current season. The recommended agricultural practices for growing banana in El-Nobaria region were applied. Superphosphate fertilizer (15.5 % P_2O_5) at the rate of 1.25 kg. Plant^{-1}, ammonium nitrate (33.5 % N) at the rate of 3 kg. Plant^{-1} and potassium sulfate (48.52 % K_2O) at the rate of 4 kg. plant^{-1} were applied during the growing seasons.

Experimental Layout:

The field experiment was laid out in a randomized complete block design using three irrigation regime (D) : 100, 80 , 60 % of the crop evapotranspiration (ET_c) and two application rates of biochar (B) :0.2 wt.% (3.5 kg.plant^{-1}) and 0.4 wt.% (7.0 kg.plant^{-1}) in three replicates (Table 5) .

Table 5. Summary of the field experimental treatments.

i.	**D_1B_0**	**100 % of ET_c (The control)**
ii.	D_1B_1	100 % of ET_c+ 0.2 wt.% (3.5 kg.plant^{-1}) biochar
iii.	D_1B_2	100 % of ET_c + 0.4 wt.% (7.0 kg.plant^{-1}) biochar
iv.	D_2B_1	80 % of ET_c + 0.2 wt.% (3.5 kg.plant^{-1}) biochar
v.	D_2B_2	80 % of ET_c + 0.4 wt.% (7.0 kg.plant^{-1}) biochar
vi.	D_3B_1	60 % of ET_c + 0.2 wt.% (3.5 kg.plant^{-1}) biochar
vii.	D_3B_2	60 % of ET_c + 0.4 wt.% (7.0 kg.plant^{-1}) biochar

The drip irrigation system, used in the orchard farm included, an irrigation pump connected to sand and screen filters, and a hydraulic fertilizer injection pump. The main line is made of a PVC pipe of 63 mm diameter. Laterals of 16 mm diameter are connected to sub main line. Each lateral is 50 m long with standard drippers of 4 l/h discharge rate, spaced at 0.5m apart. Two laterals served each row of banana plant. The consumptive use (CU) of water by the plant was estimated using the water balance equation:

$$CU = ET_c = I + P \pm \Delta S \pm R \pm D \qquad (1)$$

Where:

ET_c = actual evapotranspiration in mm; I = amount of irrigation water (mm); P = effective rainfall (mm); ΔS = change in soil water storage (mm); R = surface runoff (mm) and D = amount of drainage water (mm).

Class A pan was used to determine the potential evapotranspiration (ETp) values which were obtained from class A pan method as follows :

$$ET_p = E_{pan} \times K_{pan} \text{ (Doorenbos and Pruitt , 1984)} \qquad (2)$$

Where :

E_{pan} : is pan evaporation (mm/day) K_{pan} : is pan coefficient .

The K_{pan} value of 0.75 was used at the experimental site according to the weather condition.

Crop irrigation requirements were scheduled weekly according to daily ET_o. Penman Monteith method was used to calculate ET_{crop} for banana grown in this district during three studied seasons using CROPWAT model (Smith 1991) .

Applied irrigation water (AIW) :

The amounts of irrigation water were calculated according to the equation given by Vermeiren and Jopling, 1981 as follows:

$$AIW = \frac{ET0 \times Kc \times Kr}{Ea} + LR \qquad (3)$$

Where:

AIW = Applied irrigation water depth (mm).
ET_0 = Reference crop evapotranspiration (mm/day) values obtained by Class A pan evaporation method.
K_c = Crop coefficient (0.75).
K_r = Reduction factor that depends on ground cover. It equals 0.7 for mature plants.
E_a = Irrigation efficiency of the drip system. Average value of 0.8 was used as determined at the beginning of each season (Ismail, 2002)
LR = Leaching requirements = 10 % of the total amount of water applied.

Water use efficiency (WUE) :

It was calculated according to the following equation (Vites, 1962 ; Stanhill,1986).

$$WUE = \frac{Ya}{AIW} \qquad (4)$$

Where:

WUE is the water use efficiency (kg/m^3). Y_a is the actual yield (kg/ fed.) AIW is the amount of applied irrigation water (m^3/fed)

Vegetative growth parameters, Yield , Yield component and chemical quality analy*sis:*

vegetative parameters :

Pseudostem plant height (cm), pseudostem girth (cm) , number of leaves, days taken to shooting, days to harvesting were measured. Leaf area (m^2) was calculated according to Murry (1960) as follows:

$$\text{Leaf area (m}^2\text{)} = \text{length} \times \text{width} \times 0.8 \qquad (5)$$

Yield and Yield component :

Bunch weight (kg) according to Dadzie and Orchard (1997), bunch length (cm), bunch girth (cm), number of hands per bunch, number of fingers per bunch, finger length(cm), finger girth(cm) finger weight (g) and yield
(ton/ fed.) were measured .

Chemical quality analysis :

Total soluble solids (TSS %), Total acidity (TA %), Total sugar (%) and Starch (%) were estimated from samples of ripened fruits taken from the middle portion (5th and 6th) of two hands for each bunch. Total sugar and titratable acidity were determined according to A.O.A.C (1995). T.S.S was estimated by hand refractometer as Brix.

Economic Analysis

Economics of the treatments were calculated according to the prevailing market price in the area. The prices inputs and outputs were calculated for each of the tested different treatments. Concerning costs of irrigation in whole season for different treatments were calculated on the basis of rent of water, as follows:

Total production costs (LE/fed.) :

It was calculated using the following equation:

Total production costs (LE/fed.) = Irrigation system costs (fixed and running cost) + cost of cultivation (Preparation of soil, different agriculture practices, price of seed, labours and harvesting) (6)

Total return (LE/fed):

It was calculated using the following equation:

Total return = Price (LE/ton) × Fruit yield (ton/fed) (7)

Net return:

It was calculated using the following equation:

Net return = Total return - Total costs (8)

Water productivity, (WP, LE/m^3):

It was calculated using the following formula:

$$Water\ productivity = \frac{\text{Net return (LE/fed.)}}{\text{Amount of water applied (m}^3\text{/fed)}} \text{ LE/m}^3 \qquad (9)$$

Statistical Analysis.

The obtained data were subjected to statistical analysis of the least significance difference (LSD) at 5% level of probability to compare treatment means when F-test was significant (SAS Institue, 1996).

RESULTS AND DISCUSSION

Vegetative growth parameters :

Table 6 showed that all the vegetative growth parameters were significantly affected by deficit irrigation and biochar application.

Pseudostem height

As shown in Table 6 the recorded pseudostem plant height were 251.1 , 261.4 , 273.2 , 253.2 , 268.1 , 215.8 and 235.1 cm due to D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in the growing season 2016/2017 and were 253.8 , 262.8 , 275.7 , 255.6 , 269.3 , 219.9 and 237.8 cm for the same treatments, respectively in the growing season 2017/2018 . There is significant increase in pseudostem plant height between D_1B_0, D_1B_1 and D_1B_2 as a result of biochar application in the two growing seasons. However, application of 0.4 wt. % biochar was more effective than 0.2 wt.% biochar .This significant effect of biochar was also shown between D_2B_1 and D_2B_2 treatments , and between D_3B_1 and D_3B_2 treatments in the two growing seasons. These data indicate the highly positive significant effect of 0.4 wt.%biochar than 0.2 wt.% biochar . However, the results showed no significant difference between D_1B_2 and D_2B_2 treatments in the two growing seasons (Table 6). The highest pseudostem height (273.2 and 275.7 cm) was recorded for treatment D_1B_2 (100 % of ET_c + 0.4 wt. % biochar) , respectively in the two growing seasons 2016/2017 and 2017/2018 .However, the lowest pseudostem height (215.8 and 219.9 cm) was recorded for D_3B_1 treatment (60 % of ET_c + 0.2 wt.% biochar) , respectively in the two growing seasons 2016/2017 and 2017/2018 . The increase in pseudostem height with decreases of deficit irrigation and increases of biochar application rate could be mainly due to high availability of soil moisture and adequate uptake of nutrients which has enhanced the vegetative growth of banana.

Pseudostem girth

The pseudostem girth (Table 6) were 81.6 , 92.6 , 95.2 , 88.1 , 93.8 , 65.8 and 75.2 cm due to D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in the growing season 2016/2017 and 82.6 , 93.2 , 97.8 , 89.9 , 93.1 , 67.7 and 77.4 cm for the same treatments, respectively in the growing season 2017/2018 . These results showed no significant difference between D_1B_1, D_1B_2 and D_2B_2 treatments in the two growing seasons (Table 6). The highest pseudostem girth (95.2 and 97.8 cm) was recorded for D_1B_2 treatment (100 % of ET_c + 0.4 wt. % biochar) , respectively in the two growing seasons 2016/2017 and 2017/2018 . However, the lowest pseudostem girth (65.8 and 67.7 cm) was recorded for D_3B_1 treatment (60 % of ET_c + 0.2 wt. % biochar) , respectively in the two growing seasons 2016/2017 and 2017/2018.

Number of leaves/plant

The mean number of leaves/plant (Table 6) were 11.5, 14.5 , 15.3 , 13.1 , 15.0 , 9.2 and 10.2 for D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in the growing season 2016/2017 and 11.7 , 14.6 , 15.4 , 13.2 , 15.1 , 9.4 and 10.6 for the same treatments, respectively in the growing season 2017/2018 (Table 6) . The highest number of leaves/plant (15.3 and 15.4) were recorded by D_1B_2 (100 % ET_c + 0.4 wt.% biochar) followed by D_2B_2 (80 % of ET_c + 0.4 wt.% biochar) which were (15.0 and 15.1) in both seasons, respectively. The lowest number of leaves/plant (9.2) was recorded by D_3B_1 treatment in the two growing seasons. It is clear from table 6 that application of biochar significantly increased the number of leaves per plant since there were significant increases between D_1B_0 , D_1B_1 and D_1B_2 treatments . This is also observed between treatments D_2B_1 and D_2B_2 and also D_3B_1 and D_3B_2 treatments in the two growing seasons. These results showed the positive significant of biochar application especially at a rate of 0.4 wt.% biochar.

Leaf area

The mean leaf area values were 1.97 , 2.06 , 2.21 , 2.00 , 2.13 , 1.85 and 1.90 m^2 for D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in the growing season 2016/2017 and 1.97 , 2.09 , 2.23 , 2.03 , 2.15 , 1.89 and 1.93 m^2 for the same treatments, respectively in the growing season 2017/2018 (Table 6) . The highest leaf area (2.21 and 2.23 m^2) was registered by D_1B_2 in the two growing seasons, respectively. On other hand, the lowest leaf area (1.85 and 1.89 m^2) was recorded due to D_3B_1 treatment in the two growing seasons, respectively.

Shooting and harvesting duration

There was no significant difference in the values of shooting and harvesting duration due to D_1B_2(100 % of ET_c + 0.4 wt.% biochar) and D_2B_2 (80 % of ET_c + 0.4 wt.% biochar) treatments in the two growing seasons (Table 6). However early shooting and harvesting duration was observed under the D_3B_1 (60% of ET_c + 0.4 wt. % biochar)treatment in both seasons.

It is clear from Table 6 that, all vegetative growth parameters of Grande Naine banana plant i.e. pseudostem height (cm), pseudostem girth (cm.), number of leaves/plant, leaves area (cm^2), number of days taken for shooting and number of days taken for harvesting were greatly affected by D_1B_2 treatment followed by D_2B_2 treatment in both seasons. The obtained results are in agreement with those obtained by Baiea *et al.*, (2015 b) , Abd El-Naby *et al.*, (2004) , Baiea and El-Gioushy (2015) .

Table 6. Effect of deficit irrigation and biochar application on vegetative growth parameters of Banana crop cv. Grand Naine grown in sandy during2016 / 2017 and2017/ 2018 growing seasons.

Treatments	Pseudostem plant height (cm)	Pseudostem plant girth (cm.)	Number of leaves/plant	Leaf area (m^2)	Days taken for shooting	Days taken for harvesting
			2016/2017			
D_1B_0	251.1 c	81.6 bc	11.5 d	1.97 bcd	246.8 cd	361.8 cd
D_1B_1	261.4 bc	92.6 a	14.5 b	2.06 abc	251.6 bc	363.2 bc
D_1B_2	273.2 a	95.2 a	15.3 a	2.21 a	260.3 a	369.3 a
D_2B_1	253.2 c	88.1 ab	13.1 c	2.00 bcd	250.1 c	363.1 bc
D_2B_2	268.1 ab	93.8 a	15.0 ab	2.13 ab	256.5 ab	367.3 ab
D_3B_1	215.8 e	65.8 d	9.2 f	1.85d	240.2 e	358.2 d
D_3B_2	235.1 d	75.2 c	10.2 e	1.90 cd	243.6 de	359.5 cd
$LSD_{0.05}$	10.6	7.5	0.6	0.17	6.3	4.6
			2017/2018			
D_1B_0	253.8 de	82.6 c	11.7 d	1.97 de	239.6 b	354.4 b
D_1B_1	262.8 bc	93.2 a	14.6 b	2.09 bc	244.3 b	357.1 b
D_1B_2	275.7 a	97.8 a	15.4 a	2.23 a	254.2 a	364.4 a
D_2B_1	255.6 cd	89.9 b	13.2 c	2.03 cd	242.2 b	356.2 b
D_2B_2	269.3 ab	93.1 a	15.1 ab	2.15 ab	253.1 a	366.1 a
D_3B_1	219.9 f	67.7 d	9.4 f	1.89 f	238.2 b	356.2 b
D_3B_2	237.8 e	77.4 c	10.6 e	1.93 ef	241.6 b	359.6 ab
$LSD_{0.05}$	10.2	6.9	0.6	0.09	7.0	5.3

Where, D_1, D_2, D_3 = 100, 80 and 60 % of ET_c (deficit irrigation level)

B_0, B_1, B_2 = 0, 0.2 and 0.4 wt.% (biochar application rates)

D_1B_0, D_1B_1, D_1B_2, D_2B_1, D_2B_2, D_3B_1 and D_3B_2 are the treatment combination.

Yield and Yield Components

Tables 7 and 8 showed that all yield and yield components were significantly affected as a result of deficit irrigation and biochar application rate, in the two growing seasons.

Bunch weight

Table 7 showed significant effect on bunch weight by deficit irrigation and biochar application during the two growing seasons. As shown in Table 7 there is significant increase of bunch weight of banana due to treatment by biochar , since it was the highest due to D_1B_2(100 % of ET_c + 0.4 wt.% biochar) and the lowest due to D_1B_0 treatment (100% of ET_c as a control (without biochar)) , in the two growing seasons . Biochar application rate of 0.4 wt.% significantly increased bunch weight as compared with 0.2 wt.% biochar with 80 or 60 % of ET_c, in the two growing season . However, there is no significant differences were found between D_1B_2 and D_2B_2 treatments on bunch weight. The highest mean values of bunch weight (32.61 and 34.54 kg) were obtained due to D_1B_2 treatment in the first and the second season, respectively. On the other hand, the lowest values of bunch weight (20.61 and 21.98 kg) were obtained as a result of treatment by D_3B_1 in the first and the second growing seasons, respectively.

Bunch length

The average value of bunch length of banana plant was significantly ($P < 0.05$) affected by deficit irrigation and rate of application of biochar (Table 7). It is clear from the results that the bunch length was the highest under D_1B_2 treatment (101.9 and 108.3 cm) followed by D_2B_2 treatment (98.7 and 99.4 cm) in the two growing season, respectively. The lowest bunch length was recorded due to D_3B_1 treatment (83.64 and 88.96 cm) in the two growing season, respectively. It is clear from these data that biochar application at a rate of 0.4 wt.% has significantly increased bunch length with the three water regime (100,80.60 % of ET_c)for banana in the two growing seasons.

Bunch girth

Bunch girth of banana plant grown in the two seasons (2016/2017 and 2017/2018) significantly increased by deficit irrigation and application rate of biochar (Table 7). D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) produced the highest significant increase of bunch girth of banana plant compared to other treatments. The highest mean values of bunch girth (113.6 and 115.3 cm) were obtained due to D_1B_2 treatment in the first and the second season, respectively. On the other hand, the lowest values of bunch girth (92.3 and 93.3 cm) were obtained as a result of D_3B_1treatment in the two growing seasons, respectively. It is also clear from Table 7 that increasing application rate of biochar significantly increased bunch girth of banana plant as a result of D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) as compared to the D_1B_1 treatment (100 % of ET_c + 0.2 wt.% biochar) as compared to the control (D_1B_0 = 100% of ETc without biochar). Biochar stimulating effects on bunch girth was significant between D_2B_1 and D_2B_2 treatments and also between D_3B_1 and D_3B_2 treatments in two growing seasons.

Number of hands per bunch and Number of fingers per bunch

Table 7 showed that the number of hands per bunch and number fingers per bunch is significantly affected by deficit irrigation and biochar application treatments during the two growing seasons. There were no significant differences between D_1B_2 and D_2B_2 treatments on number fingers per bunch. Table 7 also showed that the highest number hands per bunch (10.36 and 11.52) and number of fingers per bunch (278.7and 272.6) were obtained by D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) in the two growing seasons, respectively. On the other hand, the lowest number of hands per bunch (7.34 and 7.36) and number of fingers per bunch (201.5 and 204.4) have been recorded by D_3B_1 treatment (60 % of ET_c + 0.2 wt.% biochar) in the two growing seasons, respectively. Table 7 also showed that the biochar application rate of 0.4 wt.% significantly increased the number of hands per bunch and number fingers per bunch with all irrigation (100,80 and 60 %of ET_c) as compared to 0.2 wt.% of biochar application rate.

Finger length

Lengths of the fingers of banana grown in the two seasons due to different treatments were significantly affected by deficit irrigation and application rate of biochar (Table 8). No significant differences were found between D_1B_2 and D_2B_2 treatments with respect to finger length. The highest finger length (19.7 and 19.9 cm) has been obtained under D_1B_2 treatment followed by D_2B_2 treatment (19.2 and 19.4cm) in the two growing season, respectively . The lowest finger length were (16.5 and 16.6 cm) recorded due to D_3B_1 in the two growing season, respectively. Biochar application with each irrigation regime significantly increased finger length. This can be clearly observed between the treatments: D_1B_0, D_1B_1 and D_1B_2 , and also between the treatments : D_2B_1 and D_2B_2 and between D_3B_1 and D_3B_2 . These data point out the positive significant effect on the finger length of banana plants grown in the two seasons.

Finger girth

Deficit irrigation and application biochar significantly effected finger girth in the two growing seasons (Table 8) . The highest values of finger girth (3.5 cm) was obtained as a result of D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) in both seasons. The lowest values of finger girths (2.9 and 3.0 cm) were recorded by D_3B_1 treatment (60 % of ET_c + 0.2 wt.% biochar) in the two growing seasons, respectively. Application of biochar significantly increased finger girth as indicated by the data obtained as a result of D_1B_0 and D_1B_1 as compared with D_1B_2 (Table 8). This can be observed with treatments D_2B_1 and D_2B_2 and also between D_3B_1 and D_3B_2 in the two growing seasons.

Table7. Effect of deficit irrigation and biochar application rate on Bunch weight (kg), Bunch length (cm), Bunch girth (cm), Number of hands per bunch and Number of fingers per bunch of Banana grown in sandy soil during 2016/ 2017 and2017/ 2018 growing seasons.

Treatments	Bunch weight (kg)	Bunch length (cm)	Bunch girth (cm)	Number of hands per bunch	Number of fingers per bunch
			2016 /2017		
D_1B_0	25.72 c	89.2 de	98.2 cd	8.42 d	233.8 cd
D_1B_1	28.53 b	95.7 bc	109.5 b	9.13 c	252.6 b
D_1B_2	32.61 a	101.9 a	113.6 a	10.36 a	268.7 a
D_2B_1	26.41 bc	93.8 cd	101.3 c	9.03 c	247.2 bc
D_2B_2	30.82 ab	98.7 ab	111.1 ab	9.46 b	261.3 ab
D_3B_1	20.61 d	83.6 f	92.3 e	7.34 f	201.5 e
D_3B_2	24.68 c	88.3 ef	95.5 de	8.14 e	223.0 d
$LSD_{0.05}$	2.31	4.7	3.6	0.31	14.6
2017 /2018					
D_1B_0	27.44 d	92.0 de	99.1 d	8.46 e	236.1 d
D_1B_1	30.96 b	96.6 bc	110.0 b	9.66 c	255.5 bc
D_1B_2	34.54 a	108.3 a	115.3 a	11.52 a	272.6 a
D_2B_1	28.06 c	94.9 cd	103.4 c	9.04 d	250.2 c
D_2B_2	31.81 b	99.4 b	112.7 ab	10.44 b	264.3 ab
D_3B_1	21.98 e	88.9 e	93.3 e	7.36 f	204.4 e
D_3B_2	25.53 d	90.4 e	97.4 de	8.21 e	225.6 d
$LSD_{0.05}$	1.99	4.2	3.8	0.36	13.8

Table 8. Effect of deficit irrigation and biochar application on Finger length (cm), Finger girth (cm), Finger weight (g) and Yield (ton/ fed.) of Banana grown in sandy soil during 2016/ 2017 and2017/ 2018 growing seasons.

Treatments	Finger length(cm)	Finger girth(cm)	Finger weight (gm)	Yield (ton/ fed.)
D_1B_0	17.7 d	3.1 d	98.5 cd	27.64 de
D_1B_1	19.0 b	3.3 bc	106.8 b	32.37 bc
D_1B_2	19.7 a	3.5 a	112.3 a	36.20 a
D_2B_1	18.3 c	3.2 cd	101.4 c	30.08 cd
D_2B_2	19.2 ab	3.4 ab	109.8 ab	34.43 ab
D_3B_1	16.5 e	2.9 e	87.8 e	21.23 f
D_3B_2	17.6 d	3.0 de	93.9 d	25.13 e
$LSD_{0.05}$	0.5	0.1	4.8	3.4
D_1B_0	17.9 cd	3.2 cd	99.3 d	28.13 d
D_1B_1	19.1 b	3.4 b	107.8 b	bc 33.05
D_1B_2	19.9 a	3.5 a	111.2 a	36.38 a
D_2B_1	18.3 c	3.3 bc	102.1 c	30.65 cd
D_2B_2	19.4 ab	3.4 ab	109.0 ab	34.57 ab
D_3B_1	16.6 e	3.0 de	88.6 f	21.73 f
D_3B_2	17.4 d	3.1 d	93.5 e	25.31 e
$LSD_{0.05}$	0.6	0.1	3.7	2.53

Finger weight

Table 8 showed, that finger weight of banana was significantly ($P < 0.05$) affected by deficit irrigation and rates of application biochar. The means of finger weights were 98.5 , 106.8 , 112.3 , 101.4 , 109.8 , 87.8 and 93.9 gm for D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in the growing season of 2016/2017 and 99.3 , 107.8 , 111.2 , 102.1 , 109.0 , 88.6 and 93.5 gm for the same treatments, respectively in the growing season of 2017/2018. The highest finger weight (112.3 and 111.2 gm) were recorded by D_1B_2 (100 % of ET_c + 0.4 wt.% biochar) treatment ,while the lowest finger weight (87.8 and 88.6 gm) were recorded by D_3B_1 (60% of ET_c + 0.2 wt.% biochar) treatment in 2016/2017 and 2017/2018 growing seasons , respectively. These results indicate the positive significant effect of biochar in increasing finger weight of banana plants grown in the two seasons.

Yield of Banana

Table 8 showed that the average yield of banana were 27.64 , 32.37 , 36.20 , 30.08 , 34.43 , 21.23 and 25.13 (ton/fed.) due to D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D_2B_2 , D_3B_1 and D_3B_2 treatments , respectively in 2016/2017 growing season and were 28.13 , 33.05 , 36.38 , 30.65 , 34.57 , 21.73 and 25.31 (ton/fed.) due to the same treatments, respectively in 2017/2018 growing season. It is clear that yield of banana (ton/fed.) confirmed the same trend in component yield (Table 8). The average yield of banana was significantly ($P < 0.05$) affected by deficit irrigation and application biochar in 2016/2018 and 2017/2018 growing seasons. No significant differences were found between D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) and D_2B_2 treatment (80 % of ET_c + 0.4 wt.% biochar) on yield of banana plants in the two growing seasons.

The yield of banana (Table 8) was the highest due to D_1B_2 treatment (36.20 and 36.38 ton/fed.) followed by D_2B_2 treatment (34.43 and 34.57 ton/fed.) in the two growing season, respectively . The lowest yields of banana were recorded due to D_3B_1 treatment (21.23 and 21.73 ton/fed.) in the two growing season, respectively.

It is clear from Table 8 that, the yield and yield components were scored by D_1B_2 treatment (100 % of ET_c + 0.4 wt.% biochar) followed by D_2B_2 treatment(80 % of

ET_c + 0.4 wt.% biochar) in both seasons, whereas the lowest values of yield and yield components were registered by D_3B_1 treatment (60 % of ET_c + 0.2 wt.% biochar) in 2016/2017 and 2017/2018 growing seasons. The decrease in yield and yield component with increases of deficit irrigation and decreases of application rate of biochar could be mainly due to soil moisture stress which cause up to 60% banana yield loss .It has been found that the moisture stress is considered among the main causes for yield of banana reduction (Nyombi, 2013). Crops with yield response factors greater than one (Ky>1), such as banana (1.2–1.35), are classified as very sensitive to water depletion and any decrease of soil moisture below the ETc requirements will negatively affect yield (Steduto *et al*., 2012) .The obtained results of yield and yield components agree with the results obtained Goenagea and Irizarry (1998), Goenagea and Irizarry (2000) and Ibrahim (2003).

Fruit chemical properties

The results of total soluble solids, total sugars and starch content of banana exhibited significant differences between all treatments in the two growing seasons as a result of deficit irrigation and application of biochar (Table 9). Total acidity (TA.%) exhibited no significant differences between all treatments in the two growing seasons (Table 9).The highest values of total soluble solids (20.9 and 20.5 %), and total sugar (17.82 and 17.51%) were due to the D_1B_2 treatment in the two growing seasons, respectively. However, the lowest values of TSS (18.7 and 19.1 %) and total sugar (14.31 and 14.11%) were due to the D_3B_1 treatment in the two growing seasons, respectively. The obtained data showed that, the highest values of total acidity (0.40 and 0.41%) and fruit starch content (2.21 and 2.15 %) were due to D_3B_1 treatment in both two seasons, respectively. Also, the lowest values of total acidity (0.33 %) and fruit starch content (1.63 and 1.76 %) were obtained as a result of D_1B_2 treatment in 2016/2017 and 2017/2018 growing seasons, respectively. It is clear, therefore, that, increasing soil moisture and rate of biochar led to the increases of T.S.S. and Total sugar in fruits and the decreases of total acidity and starch content. These results are in agreement with those obtained by Barakat *et al.,* (2011) , Merwad *et al.,* (2016) and Villocino and Quevedo (2013) .

Table 9. Effect of deficit irrigation and biochar application rate on Total soluble solids (TSS %), Total acidity (TA %), Total sugar (%) and Starch (%) of Banana grown in sandy soil during2016/ 2017 and 2017/2018 growing seasons.

Treatments	Total soluble solids (%)		Total acidity(%)		Total sugar (%)		Starch (%)	
	2016/ 2017	2017/2018	2016/ 2017	2017/2018	2016/ 2017	2017/ 2018	2016/ 2017	2017/ 2018
D_1B_0	20.1 b	19.8 b	0.36	0.37	15.36 c	15.62 c	1.95 c	2.05 b
D_1B_1	19.5 d	19.6 b	0.34	0.35	16.61 b	16.83 b	1.85 de	1.85 cd
D_1B_2	20.9 a	20.5 a	0.33	0.33	17.82 a	17.51 a	1.63 f	1.76 e
D_2B_1	19.4 d	19.4 c	0.35	0.36	16.36 b	16.13 c	1.89 cd	1.91 c
D_2B_2	19.9 bc	20.2 a	0.32	0.33	17.32 a	17.01 ab	1.78 e	1.82 de
D_3B_1	18.7 f	19.1 c	0.37	0.38	14.31 d	14.11 e	2.21 a	2.15 a
D_3B_2	19.6 cd	19.8 b	0.36	0.35	14.81 cd	14.93 d	2.07 b	2.12 a
$LSD_{0.05}$	0.35	0.32	NS	NS	0.62	0.58	0.92	0.08

Reference Evapotranspiration (ET_0) , Crop Evapotranspiration (ET_c) and Irrigation Requirements (IR.)

Table 10 showed that, the values of reference or potential evapotranspiration (ET_0 or ET_p) are affected by climatic factors, since ET_0 increased in summer and decreased in winter. Maximum values of ET_0 or ET_p were recorded in July which recorded 6.05 and 5.99 mm/day in 2016 / 2017 and 2017 / 2018 growing seasons, respectively.

Minimum values of ET_0 or ET_p were recorded in December 2016/2017 recorded 1.57 mm/day while minimum value of ET_0 was found in January 2018/2019 recorded 1.56 mm/day. Monthly water consumptive use values by banana were obtained from daily water use multiplied by the number of days in one month. It is also clear that daily and monthly crop or actual evapotranspiration (ET_c) had the same behavior as reference evapotranspiration (ET_0) ,where the values of daily and monthly ET_c increased in summer and decreased in winter . This might be due to the increase in growth during summer months afterwards, the daily consumptive use, again, gradually decreased. Maximum values of daily ET_a or ET_c were found in July and recorded 6.53 mm/day in both two growing seasons. Minimum values of daily ET_a or ET_c were found in December 2016/2017 which recorded 1.68 mm/day while minimum value of ET_c was found in January 2017/2018 recorded 1.64 mm/day. Cumulative crop evapotranspiration in the growing season of 2016/2017 recorded 1405.75 mm, while in the growing season of 2017/2018 it recorded 1347.93 mm.

The irrigation requirement for the two growing seasons was calculated by using the data of monthly crop evapotranspiration and monthly effective rainfall. The results showed that irrigation requirements had ascending values from January to July and descending values from august to December (Table 10). Cumulative irrigation requirements (IR.) in the growing season of 2016/2017 recorded 1219.45 mm, while in the growing season of 2017/2018 recorded 1172.13 mm. Similar results were obtained since water management practices resulted in maximum yield, and that plants growth is depending on crop load and yearly climatic change (Garrot *et al*. 1990) . There was an increase in transpiration and water uptake from summer to autumn followed by a decrease until spring.

Table 10. Monthly reference evapotranspiration (ET_0), crop evapotranspiration (ET_c), effective rainfall and irrigation requirements for banana plants grown in sandy soil during the growing seasons: 2016 / 2017 and 2017/ 2018.

Months	ET_0 (mm/ day)	K_c	ETc (mm/ day)	ETc (mm/ month)	Effective Rainfall (mm/ month)	Irr. Req. (mm/ month)
				2016 / 2017		
Mar.	3.29	0.78	2.57	79.67	4.60	75.07
Apr.	4.46	0.65	2.90	87.00	5.70	81.30
May	5.39	0.79	4.26	132.06	0.00	132.06
June	5.95	1.00	5.95	178.50	0.00	178.50
July	6.05	1.08	6.53	202.43	0.00	202.43
Aug.	5.66	1.08	6.11	189.41	0.00	189.41
Sep.	4.70	1.08	5.08	152.40	0.00	152.40
Oct.	3.36	1.08	3.63	112.53	21.60	90.93
Nov.	2.19	1.08	2.36	70.80	24.60	46.20
Dec.	1.57	1.07	1.68	52.08	62.40	-10.32)(
Jan.	1.61	1.06	1.71	53.01	42.40	10.61
Feb.	2.23	1.04	2.32	64.96	24.40	40.56
Mar.	2.97	1.04	3.09	30.90	0.60	30.30
∑				1405.75	186.30	1219.45
				2017 / 2018		
Mar.	3.08	0.78	2.40	50.40	18.20	32.20
Apr.	3.85	0.65	2.50	75.00	3.60	71.40
May	5.19	0.79	4.10	127.10	0.00	127.10
June	5.80	1.00	5.80	174.00	0.00	174.00
July	5.99	1.09	6.53	202.43	0.00	202.43
Aug.	5.51	1.09	6.01	186.31	0.00	186.31
Sep.	4.67	1.09	5.09	152.70	0.00	152.70
Oct.	3.35	1.09	3.65	113.15	25.7	87.45
Nov.	2.25	1.08	2.43	72.90	13.1	59.80
Dec.	1.66	1.06	1.76	54.56	58.6	-4.04)(
Jan.	1.56	1.05	1.64	50.84	33.30	17.54
Feb.	2.12	1.03	2.18	61.04	21.9	39.14
Mar.	2.67	1.03	2.75	27.50	1.4	26.1
∑				1347.93	175.80	1172.13

Amount of applied irrigation water(AIW) :

The amount of applied irrigation water (AIW), for banana, during 2016/2017 and 2017/2018 growing seasons are presented in Table 11. Amounts of applied water also expressed as, liter / plant / day and m3/fed./month. The obtained data were recorded 9247.87 (m^3/fed/season) for D_1B_0, $D_1B_1$and D_1B_2 treatments followed by $D_2B_1$and D_2B_2 treatments which recorded 7398.3 (m^3/fed/season) and 5548.72 (m^3/fed/season) for $D_3B_1$and D_3B_2 treatments in the 1st season. At the 2nd season, D_1B_0, $D_1B_1$and D_1B_2 treatments which recorded 8814.42 (m^3/fed/season) followed by $D_2B_1$and D_2B_2 treatments which recorded 7051.51 (m^3/fed/season) and 5288.65 (m^3/fed/season) for $D_3B_1$and D_3B_2 treatments. At the beginning of the growing season, the amount of applied water was low and then increased after that due to increasing vegetative growth of banana plant. After words, the amounts of applied water declined at maturity. The maximum value of AIW for banana plant was occurred in July (1522.27 m^3/fed/ month) in the 2016/2017 and 2017/ 2018 growing seasons by applying 100% of ET_c (D_1B_2) , while the minimum value of AIW was occurred in January (47.87 m^3/fed/ month)in the 2016/2017 growing season by applying 60 % of ET_c (D_1B_2). The obtained results agreed with those obtained by Fandika *et al.*(2006) , Goenaga and Irizarry (2000) and Eckstein *et al.*(1998).

Water Use Efficiency (WUE):

Figure 6 showed that the values of water use efficiency (WUE) were significantly affected by deficit irrigation and rate of biochar application. The maximum values of WUE were 4.65 and 4.90 kg banana / m^3 applied irrigation water, in the first and second seasons , respectively , and were obtained as a result of D_2B_2 treatment (80 % of ET_c + 0.4 wt.% biochar). The lowest values of WUE were (2.99 and 3.19 kg banana /m^3) applied irrigation water, in the 2016/2017 and 2017/2018 growing seasons , respectively , and were obtained by the D_1B_0 treatment (100 % of ET_c without biochar). These results are in agreement with those obtained by Tanny *et al.* (2010) , Tanny *et al.* (2012) , Ibrahim *et al.* (2012) and Pirkner *et al.*(2014).

Economic Analysis

Table 12 showed that, in the first growing season (2016/2017), there is a constant costs that included the drip irrigation system and its components, and banana seedlings as well as variable costs that include both labor, fertilizers, and energy (fuel).In the second season (2017/2018) the costs are limited to labor, fertilizers, and fuel. The results showed that banana production is highly dependent on labor and fertilizers. In the first growing season , the total cost recorded 64400 , 67600 , 69400 , 65100 , 66900 , 62700 and 64500 LE./fed. with D_1B_0 , D_1B_1 , D_1B_2 , D_2B_1 , D2B2 , D_3B_1 and D_3B_2 treatments , respectively while in the second growing season the total cost recorded 69800 for D_1B_0 , D_1B_1 and D_1B_2 treatments, 63600 for D_2B_1 and D_2B_2, 60800 for D_3B_1 and D_3B_2 . Among the list of cost items, labor alone accounted for more than 50 and 77% of the cost of operations in 2016/2017 and 2017/2018 growing seasons, respectively.

Gross return values (LE. / fed.) for banana were obtained from banana yield (ton / fed.) multiplied by price of banana(LF./kg).The highest gross return values (

144800 and 163710 LE. / fed.) of banana plants (Table 12) were recorded due to D_1B_2 treatment followed by D_2B_2 treatment (137720 and 155565 LE. / fed.) in the two growing season, respectively . The lowest gross return values (84920 and 97785 LE. / fed.) of banana were recorded under D_3B_1 in the two growing season, respectively. The net return values (LE. / fed.) by banana were obtained from gross return (LE. / fed.) minus total cost(LF./fed.). The highest net return values (75400 and 93910 LE. / fed.) were recorded due to D_1B_2 treatment followed by D_2B_2 treatment (70820 and 91965 LE. / fed.) in the two growing season, respectively . The lowest net return values (22220 and 36980 LE. / fed.) of banana were recorded under D_3B_1 in the two growing season, respectively. The maximum values of water productivity (WP) were 9.57 and 8.15 LE/ m^3.due to D_2B_2 and D_1B_2 treatments, respectively in 2016/2017 and were 13.04 and 10.65 (LE/ m^3) under the same treatments, respectively in 2017/2018 . The lowest water productivity (WP) was obtained due to D_1B_0 treatment, which recorded 4.99 and 6.44 LE/ m^3, respectively for the two growing season 2016/2017 and 2017/2018.

Table 11. Applied irrigation water (AIW, L/plant/ day and m^3/fed./month) for banana plants grown in sandy soil as affected by deficit irrigation and biochar application treatments during the growing seasons 2016 /2017 and 2017 /2018 .

Months	AIW	2016/2017			2017/2018		
		Treatments					
		D_1B_0=D_1B_2=D_1B_2	D_2B_1= D_2B_2	D_3B_1= D_3B_2	D_1B_0=D_1B_2=D_1B_2	D_2B_1= D_2B_2	D_3B_1= D_3B_2
Mar.	L/plant/ day	15.17	12.14	9.10	6.51	5.21	3.91
	m^3/fed./month	564.53	451.62	338.72	242.14	193.71	145.28
Apr.	L/plant/ day	16.98	13.58	10.19	14.91	11.93	8.95
	m^3/fed./month	611.38	489.10	366.83	536.93	429.54	322.16
May	L/plant/ day	26.70	21.36	16.02	25.70	20.56	15.42
	m^3/fed./month	993.09	794.47	595.85	955.79	764.63	573.47
June	L/plant/ day	37.29	29.83	22.37	36.35	29.08	21.81
	m^3/fed./month	1342.32	1073.86	805.39	1308.48	1046.78	785.09
July	L/plant/ day	40.92	32.74	24.55	40.92	32.74	24.55
	m^3/fed./month	1522.27	1217.82	913.36	1522.27	1217.82	913.36
Aug.	L/plant/ day	38.29	30.63	22.97	37.66	30.13	22.60
	m^3/fed./month	1424.36	1139.49	854.62	1401.05	1120.84	840.63
Sept.	L/plant/ day	31.83	25.46	19.10	31.90	25.52	19.14
	m^3/fed./month	1146.05	916.84	687.63	1148.30	918.64	688.98
Oct.	L/plant/ day	18.38	14.70	11.03	17.68	14.14	10.61
	m^3/fed./month	683.79	547.03	410.27	657.62	526.10	394.57
Nov.	L/plant/ day	9.65	7.72	5.79	12.49	9.99	7.49
	m^3/fed./month	347.42	277.94	208.45	449.70	359.76	269.82
Dec.	L/plant/ day	No irrigation					
	m^3/fed./month						
Jan.	L/plant/ day	2.14	1.71	1.28	3.55	2.84	2.13
	m^3/fed./month	79.79	63.83	47.87	131.90	105.52	79.14
Feb.	L/plant/ day	9.08	7.26	5.45	8.76	7.01	5.26
	m^3/fed./month	305.01	244.01	183.01	294.33	235.46	176.60
Mar.	L/plant/ day	19.00	15.20	11.40	16.36	13.09	9.82
	m^3/fed./month	227.86	182.29	136.72	196.27	157.02	117.76
∑	L/plant/season	265.97	212.78	159.58	252.79	202.23	151.67
	m^3/fed./season	9247.87	7398.30	5548.72	8814.42	7051.54	5288.65

D_1B_0= 100 % of ET_c without biochar (Control) **D_1B_1= 100 % of ET_c + 0.4 wt.% biochar**
D_1B_2= 100 % of ET_c + 0.2 wt.% biochar **D_2B_1= 80 % of ET_c + 0.4 wt.% biochar**
D_2B_2= 80% of ET_c + 0.2 wt.% biochar **D_3B_1= 60 % of ET_c + 0.4 wt.% biochar**
D_3B_2= 60 % of ET_c + 0.2 wt.% biochar

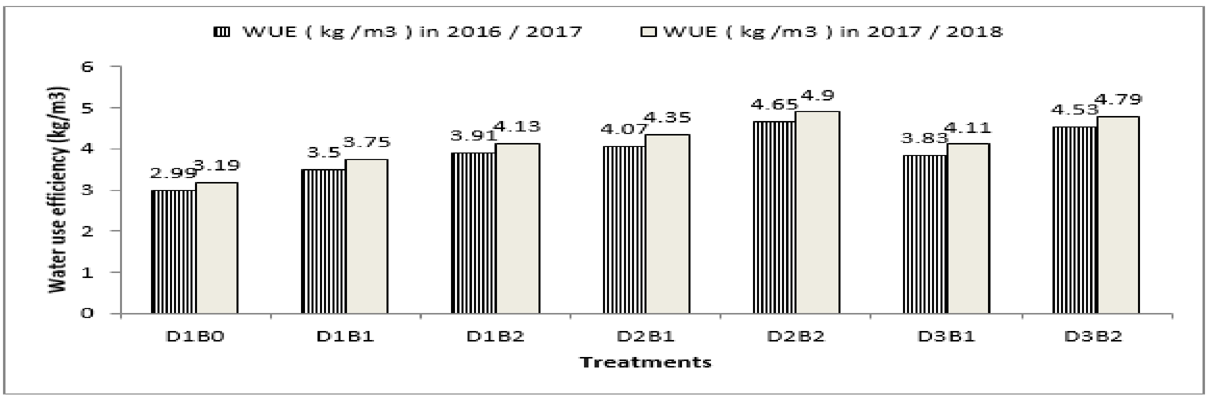

Fig .6. Effect of deficit irrigation and biochar application treatments on crop water use efficiency (kg/m^3) during the growing seasons 2016 /2017 and 2017 /2018 of banana grown in sandy soil.

Table 12. Economic analysis of banana under deficit irrigation and biochar application during the growing seasons 2016 / 2017 and 2017 / 2018.

No. Particulars	Treatments						
	D_1B_0	D_1B_1	D_1B_2	D_2B_1	D_2B_2	D_3B_1	D_3B_2
1-Variable cost (LE/fed.)				2017/ 2018			
a. Irrigation system	3000	3000	3000	3000	3000	3000	3000
b. Organic manure	8000	8000	8000	8000	8000	8000	8000
c. Seedling	7500	7500	7500	7500	7500	7500	7500
d. Biochar	-	3200	5000	3200	5000	3200	5000
e. Labor	32000	32000	32000	30000	30000	28000	28000
f. Fertilizer	11400	11400	11400	11400	11400	11400	11400
g. Power	2500	2500	2500	2000	2000	1600	1600
2-Total cost (LE/fed.)	64400	67600	69400	65100	66900	62700	64500
3-Banana yield (ton/fed.)	27.64	32.37	36.20	30.08	34.43	21.23	25.13
4- Price of banana (LE/ kg)	4.00	4.00	4.00	4.00	4.00	4.00	4.00
5-Gross return (LE/fed.)	110560	129480	144800	120320	137720	84920	100520
6-Net return (LE/fed.)	46160	61880	75400	55220	70820	22220	36020
7- Amount of applied water (m^3/ fed.)	9247.87	9247.87	9247.87	7398.30	7398.30	5548.72	5548.72
8-Water productivity(LE/m^3)	4.99	6.69	8.15	7.46	9.57	4.00	6.49
1- Variable cost (LE/fed.)				2017/ 2018			
e. Labor	50000	50000	50000	45000	45000	43000	43000
f. Fertilizer	13600	13600	13600	13600	13600	13600	13600
g. Power	6200	6200	6200	5000	5000	4200	4200
2-Total cost (LE/fed.)	69800	69800	69800	63600	63600	60800	60800
3-Banana yield (ton/fed.)	28.13	33.05	36.38	30.65	34.57	21.73	25.31
4- Price of banana (LE/ kg)	4.5	4.5	4.5	4.5	4.5	4.5	4.5
5-Gross return (LE/fed.)	126585	148725	163710	137925	155565	97785	113895
6-Net return (LE/fed.)	56785	78925	93910	74325	91965	36985	53095
7- Amount of applied water (m^3/ fed.)	8814.42	8814.42	8814.42	7051.54	7051.54	5288.65	5288.65
8-Water productivity (LE/m^3)	6.44	8.95	10.65	10.54	13.04	6.99	10.04

Where, D_1, D_2, D_3 = 100, 80 and 60 % of ET_c (deficit irrigation level)
B_0, B_1, B_2 = 0, 0.2 and 0.4 wt.% (biochar application rates)
D_1B_0, D_1B_1, D_1B_2, D_2B_1, D_2B_2, D_3B_1 and D_3B_2 are the treatment combination.

CONCLUSIONS

The results obtained in this study showed that all vegetative growth parameters, yield, and yield components were significantly affected by deficit irrigation and biochar application. The highest yields of banana (36.20 and 36.38 ton/fed.) were recorded as a result of D_1B_2 treatment followed by D_2B_2 treatment (34.43 and 34.57 ton/fed.) in the two growing seasons, respectively. However, the lowest yield (21.23 and 21.73 ton/fed.) of banana was due to D_3B_1 treatment in the two growing season, respectively. Amounts of applied water were recorded (9247.87 m^3/fed/season) for D_1B_0, $D_1B_1$and D_1B_2 treatments followed by $D_2B_1$and D_2B_2 treatments which recorded (7398.3 m^3/fed/season) and (5548.72 m^3/fed/season) for $D_3B_1$and D_3B_2 treatments in the 1st season. In the 2nd season D_1B_0, $D_1B_1$and D_1B_2 treatments recorded (8814.42 m^3/fed/season) followed by $D_2B_1$and D_2B_2 treatments which recorded (7051.51 m^3/fed/season) and (5288.65 m^3/fed/season) for $D_3B_1$and D_3B_2 treatments. The maximum values of WUE were 4.65 and 4.90 kg banana / m^3 applied irrigation water, in the first and second seasons , respectively , and were obtained by the D_2B_2 treatment (80 % of ETc + 0.4 wt % biochar). The highest economic net return and water productivity (WP) values were recorded due to D_1B_2 and D_2B_2 treatments, in the two growing seasons, respectively.

The obtained results clearly recommend that, it is preferable to use the application of biochar (0.4% by weight) with irrigation deficit of crop evaporation (ETc) for banana plants grown in sandy soil under drip irrigation, in order to save water and reduce water consumption by banana plants under limited irrigation water.

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تاثير نقص الرى وإضافة البيوتشار على كفاءة إستخدام المياه والانتاجية المائية لمحصول الموز المزروع فى التربة الرملية تحت نظام الرى بالتنقيط

أشرف السيد النماس

قسم علوم التربة والمياه ، كلية الزراعة ، جامعة الإسكندرية

أجريت تجارب حقلية خلال موسمين زراعيين متتاليين (2016/ 2017) و (2017/ 2018) لكى يتم دراسة تاثير كلا من النقص فى الرى (100 , 80 , 60 % من البخر – نتح المحصولى) و معدلين للبيوتشار (0.2% , 0.4% بالوزن) على كلا من كفاءة إستخدام المياه والنمو الخضري والمحصول ومكوناته وصفات جودتة وإنتاجية المياه لمحصول الموز المزروع فى التربة الرملية تحت نظام الرى بالتنقيط. تم تنفيذ التجربة في تصميم القطاعات العشوائية الكاملة بثلاثة مكررات. أوضحت النتائج المتحصل عليها أن كل صفات النمو الخضرى و المحصول و مكوناتة قد تاثرت معنويا تحت تاثير كلا من النقص فى ماء الرى وأضافات البيوتشار.سجلت المعاملة 100 % بخر نتح- محصولى و 0.4 % بالوزن بيوتشار أقصى محصول موز حيث سجلت هذة المعاملة (36.20 و 36.38 طن / فدان) خلال موسمى النمو (2016 / 2017) و (2017 / 2018) على الترتيب. أظهرت نتائج جودة المحصول أن المواد الصلبة الذائبة الكلية والسكريات الكلية ومحتوى النشا (٪) في نباتات الموز تظهر فروقاً معنوية بين جميع المعاملات في موسمي النمو بسبب نقص الري وتطبيق الفحم الحيوي بينما لم تظهر الحموضة الكلية (٪) أي اختلافات معنوية بين جميع المعاملات خلال موسمى نمو. وكانت قيم كفاءة إستخدام المياه أقصى مايمكن عند تطبيق معاملة 80 % بخر نتح- محصولى و 4 % بالوزن بيوتشار حيث سجلت هذة المعاملة (4.65 و 4.90 كجم / م3) خلال موسمى النمو (2016 / 2017) و (2017 / 2018) على الترتيب. سجل أقصى إنتاجية للماء (جنية / م3) عند تطبيق معاملة 80 % من البخر نتح المحصولى و0.4 % بيوتشار(9.57 و 13.04جنية / م 3) خلال موسمى النمو(2016 / 2017) و (2017 / 2018) على الترتيب . توصى نتائج هذا البحث بتطبيق معاملة 80 % بخر –نتح محصولى مع إضافة بيوتشار بنسبة 0.4 % على أساس الوزن حيث أدت إلى تحسين صفات محصول الموزالمنزرع فى التربة الرملية الكميه والنوعية والوفرة فى كمية المياة (20 % من كمية مياة الرى المضافة) فى ظل محدودية مصادر المياة .