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RESPONSE OF MANGO (Keitte var.) PRODUCTIVITY TO DEFICIT IRRIGATION IN SANDY SOIL

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ABSTRACT

A field experiment was conducted on drip–irrigated mango (*Mangifera indica* L.) trees grown in a private farm at kilometer 76 Cairo/Alexandria Desert Road, Egypt during the 2016 and 2017 growing seasons. The site represents newly reclaimed sandy soil at the west of Nile Delta region. The objectives of this study were to evaluate the effect of different ETo-dependent irrigation levels on amounts of applied irrigation water, water consumptive use, fruit yield and its components, fruit quality, water use efficiency, water productivity, electric energy used for irrigation, farm net income and to develop a local mango crop coefficient (Kc) under the experimental conditions. Four irrigation treatments (120, 100, 80, and 60% ETo) were compared to farmer irrigation practice. The experimental treatments were laid out in strip plot design with four replicates. Results indicated that distribution uniformity values, conducted at the beginning of each season, were 90 and 91 % in 1st and 2nd seasons,respectively. The 2–season average amounts of applied irrigation water for the 120, 100, 80, and 60% ETo and farmer treatments were 14320, 11930, 9545, 7155 and 22700 m^3 ha^{-1}, while the 2–season average water consumption were 12120, 9760, 7388, 5381 and 19504 m^3 ha^{-1}, respectively. Average total fruit yield values were 35.5, 28.3, 24.9, 19 and 24 t ha^{-1} for the same respective treatments.The highest fruits number $tree^{-1}$, fruit weight (g), fruit weight $tree^{-1}$ were produced from irrigation with 120% ETo.Results showed increase water-use efficiency (WUE) and water productivity (WP) by deficit irrigation. The highest water productivity values of 2.63 and 2.68 kg m^{-3} applied water were obtained as 60% ETo was applied in both the seasons. The average Kc values for the 120% ETo irrigation treatment at the initial, flowering, fruit growth, and fruit maturation growth stages were 0.58, 0.78, 0.97 and 0.89, respectively.Application of the proposed irrigation levels led to reduce consumed energy by values varied from 37 to 69% as compared with farmer practice.The 2-year average net income values for the 120, 100, 80, and 60% ETo irrigation treatments were 129.3, 79.1, 55.9 and 14.9% higher than that obtained under farmer irrigation practice. Under the experimental conditions and in case of water shortage, it could be concluded that irrigating mango trees in sandy soils with 100% ETo will save 47 % of applied irrigation water and the energy used for irrigation, gives the water use efficiency of 2.9 kg fruits/m^3 water consumed and water productivity of 2.38 kg fruits/m^3 water applied, as well as achieves 79 % more net income compared with farmer practice.

(Key words: Mango, deficit irrigation, energy saving, drip system, sandy soil, water productivity, water use efficiency, crop coefficient)

INTRODUCTION

The Egyptian renewable water resources are estimated by 58.3 billion m³ $year^{-1}$. These are divided into 55.5 billion m³ $year^{-1}$ from the Nile River, 500 million m³ $year^{-1}$ from internal renewable surface water resources and 1.3 billion m³ $year^{-1}$ from internal renewable ground water resources, and 1 billion m³ $year^{-1}$ from the Nubian Sandstone aquifer (Anonymous, 2016). Egypt is facing shortage in water resources, and demand for water is increasing due to growing population, competition between different water consuming sectors and the expansion in irrigated agriculture as well. Hence, attempts are required to increase water use efficiency of different crops. Management of water demand in on-farm irrigation level should be a focus point to reduce the increasing demand of water to match the future supplies, thereby reducing the effect of water deficit that the country will facing.

Egypt depends on irrigated agriculture for more than 95% of agriculture area (Abou Zeid, 2002). Water

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availability to the agricultural sector is becoming a major constraint to agricultural production, where it is the largest consumer of the Egyptian water resources. Egypt's water policy mainly depends on the expansion of modern irrigation techniques in the newly reclaimed soils of desert and irrigation practices improvement in old lands of the Nile Delta and Valley (Anonymous, 2002). Expanding newly land use in horticulture has intensified pressure on water availability making it to an increasingly scarce resource. In Egypt, a need has risen to investigate the sustainable use of irrigation water, in addition to water and energy saving techniques detrimental effects on crop productivity. The nature of the soils in the newly reclaimed lands is mainly sandy with low water storage capacity and low fertility and organic matter content as well, (Page *et al.,* 1982). It is worthy to mention that, in such areas, irrigation water is extracted from aquifers at depths ranging approximately from 10 to 100 meters or more, so, electrical energy or diesel power are required to operate the pumps and to lift water for irrigating the crops (Anonymous, 2017).Under such conditions, the choice of an irrigation method, which accomplish efficient water use, higher crop yield and quality, save energy and enhance farm profits, is the most important issue. In this respect, application of modern irrigation techniques such as drip, bubbler, and sprinkler to increase irrigation efficiency, which is one of the measures utilized for competent use of water, is highly recommended (NWRP, 2002). Drip and sprinkler irrigation systems are considered highly efficient methods of delivering water and fertilizer uniformly to crops (Abu Zeid, 1999). In addition, an advantage in using drip irrigation is that small amounts of water can be used even for saline water (Hanson and May, 2011).

Mango *(Mangi feraindica* L.*)* is a very delicious tropical fruit belongs to family Anacardiaceae, and it is very popular world-wide. Mango is an important fruit, ranking the 5^{th} amongst fruit production and consumption worldwide (Xiuchong *et al.,* 2001).The world's mango growing areas have increased by 42.5%, yet the fruit yield has only increased by 1.3%, from 7.5 to 7.6 tha^{-1}(Arauz, 2000; Anonymous, 2003;Evans, 2008). The leading mango producers in the world are India, China, Mexico and Thailand (Anonymous, 2003). Mango fruit is an abundant source of vitamins, minerals and is famous for its excellent flavor, attractive fragrance and nutritional value. It is as an emerging tropical export crop and is produced in about 90 countries in the world with a production of over 820,877 tons (Abbasi *et al.,*2011).

Mango is also one of the most important and popular fruits in Egypt. Recently, there is an increase in mango cultivation on a large scale in Egypt in newly reclaimed areas. The total cultivated area of mango is about 121,501 hectares, while cultivated area of mango in new land is about 66,531 hectares, which produce about 639,467 tons. The average yield by hectare is estimated to 9.12 ton (Economic Affairs Sector Ministry of Agriculture and Land Reclamation, 2018). Mango (Keitte var.) grown successfully under the Egyptian conditions thus, it is suitable to be cultivated in newly reclaimed lands in Egypt and its yield production comes late in its season from August to October.

In recent years, Egypt has turned from being a net exporter to a net importer of energy. The country has been experiencing growing shortages of electricity and diesel, currently the primary sources of energy used for irrigation. Furthermore, the government has been gradually lifting its subsidies on fossil fuels, and as a result increasing the costs of energy in the local market. Using irrigation scheduling and fertigation practices in sandy soil are considered useful practices to increase energy use efficiency. The energy required to pump irrigation water for crop production is measured in terms of fuel or electric power use to pump each unit of water. Additionally, the amount of irrigation water pumped depends on several irrigation system factors (specific system design factors, such as the potential irrigation system efficiency, the system design uniformity, and the relative area of coverage, and on crop factors include type of crop, size of plants, plant density, and other production system (Smajstrla *et al.,* 1998). Climate factors include solar radiation, temperature,humidity and wind speed have an effect on the pumped irrigation water (El-Qousy *et al.,* 2006). Moreover, management factors include irrigation scheduling decisions which affect irrigation frequencies and durations.

Until present time, there is little information available on required irrigation water and water consumption of mango in general and on Kaitte var. specially. Thus, the objectives of this study were to evaluate the effect of different ETo-dependent irrigation levels on amounts of applied irrigation water, water consumptive use, fruit yield and its components, fruit quality, water use efficiency, water productivity, electric energy used for irrigation, farm net income and to develop a local mango crop coefficient (Kc) under the experimental conditions.

MATERIALS AND METHODS

Experimental site

Field experiments were conducted on Mango *(Mangi feraindica* L.*)* trees in a private farm located at the kilometer 76 Cairo/Alexandria Desert Road, Egypt (30.36 02 N latitude, 31.01 E longitude, with an altitude of 17.90 m above mean sea level) during the 2016 and 2017 growing seasons. The experimental site represents newly reclaimed sandy soil at west Nile delta region. Average monthly weather data (2012 - 2016) at the experimental site are presented in table 1. These data were used to calculate monthly reference evapotranspiration (ETo) according to the Basic Irrigation Scheduling model (BISm) as described by Snyder *et al.* (2004).

Table1. Average weather data (2012-2016)* and the calculated reference evapotranspiration values at the experimental site

Months	Srad (MJ m^{-2} day^{-1})	Tmax (°C)	Tmin (°C)	Ws (m s^{-1})	Td (°C)	ETo (mm day^{-1})
January	12.33	18.47	7.45	3.92	4.14	3.18
February	14.44	21.06	8.07	3.89	4.05	4.02
Mach	20.14	25.33	10.43	4.31	4.87	5.84
April	23.48	29.77	13.06	4.26	6.27	7.49
May	25.67	32.22	15.86	4.29	8.30	8.45
June	26.73	36.69	19.83	4.58	12.70	9.82
July	29.06	37.49	20.83	4.34	15.14	9.83
August	27.00	37.86	22.13	4.09	16.27	9.29
September	23.11	35.35	20.80	4.04	15.27	7.99
October	17.84	30.72	17.74	3.89	13.55	5.88
November	13.48	25.54	14.56	3.67	10.96	4.17
December	11.56	20.20	9.58	3.78	6.42	3.23

Srad: Solar radiation, Tmax: mean maximum temperature, Tmin: mean minimum temperature, Ws: mean wind speed, Td: mean dew point temperature, ETo: mean daily reference evapotranspiration.

*Sources of weather data: https://power.larc.nasa.gov/data-access-viewer

Samples from the upper 60 cm soil surface were collected at 15 cm interval to determine some soil physical parameters (particle size distribution, bulk density, soil-moisture constants, e.g. field capacity, wilting point, and available water) and some chemical properties, e.g. pH, ECe, soluble cations and anions. Chemical and physical soil analyses were conducted by the standard methods as described by Tan (1996), and values are presented in table 2. Soil samples were also analyzed for available macro nutrients. The available soil macronutrient values of N, P, and K were 16.00, 5.40, and 62.30 mg kg^{-1}, respectively, which indicated that the soil is characterized by low fertility level for plant growth. In addition, electrical conductivity (dS m^{-1}) and pH values of the irrigation water were 1.51 and 7.66, respectively.

Experimental design and tested treatments

The field experiments were laid out in a strip plot design with four replications. The tested irrigation treatments were as follows:

I1: Irrigation with amounts of water equal to 120% ETo.

I2: Irrigation with amounts of water equal to 100% ETo.

I3: Irrigation with amounts of water equal to 80% ETo.

I4: Irrigation with amounts of water equal to 60% ETo.

I5: Farmer treatment (control).

The farmer applied irrigation and fertilizer amounts without interference from the researcher. Irrigation treatments started in the second week of February and stopped after harvesting, by the end of October, of the two seasons. Minimum amounts of irrigation water were applied during the rest of the season.

Mango *(Mangi feraindica* L.*)*Keittevariety, was grown in 2×3 m^{-2}, with total planting density of 1666 trees ha^{-1}. The age of mango trees was three years, irrigated via a surface drip irrigation system, and groundwater is the source of irrigation water. The surface drip system consists of:

1- Irrigation pump (60 hp) with discharge rate of 100 m^3 h^{-1}.

2- Sand and screen filters and a venturi fertilizer injector. Fertilizer was applied in 80% of irrigation time (fertigation).

3- The conveying pipeline system consists of:

A- 160 mm PVC main line.

B- 110 mm PVC sub-main line.

C- 50.8 mm PVC sub-sub-main line.

D- The drip lateral lines of 16 mm diameter are connected to the sub-sub-main line. Each lateral line is 24 m long, spaced at 1 to 1.20 m and is equipped with build-in emitters of 4 L h^{-1} discharge rate spaced at 0.3 m on the drip line. Each lateral has 16 mm PE valve to control the application of irrigation water. There were two drip lines per tree row.Venturi was use for fertigation.

Application of macro- and micro-nutrients

Two sources of N-fertilizer (solid: ammonium nitrate and calcium nitrate; liquid: nitric acid) were used.

Ammonium nitrate (NH_4NO_3, 33.5% N) was added at the rate of 450 kg N ha^{-1} and calcium nitrate ($Ca(NO_3)_2$, 15.5% N) was added at the rate of 325 kg N ha^{-1}. Potassium sulfate was added at the rate of 300 kg K_2O ha^{-1}. Magnesium sulfate was added at the rate of 250 kg $MgSO_4.7H_2O$ ha^{-1}. Sulfuric acid (98%) was added at the rate of 50 kg H_2SO_4

ha^{-1}.Nitric acid (72%) was added at the rate of 140 kg HNO_3 ha^{-1} and 140 kg $P_2O_5ha^{-1}$ of phosphoric acid (85%) were added 15 days from flowering and during flowering stage. Micro-nutrients, i.e. Fe, Zn and Mn as EDTA (13%), were also added at the rate of 500:500:500 g ha^{-1} during flowering stage by the regular hand sprayers.

Table 2. Particle size distribution, bulk density, soil moisture constants and some chemical properties of the soil at the experimental site

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	45-60
Particle size distribution:				
Coarse sand, %	69.20	72.51	73.70	75.25
Fine sand, %	25.15	23.10	22.40	20.40
Silt, %	3.78	2.84	2.80	3.50
Clay, %	1.87	1.55	1.10	0.85
Texture class	sand	sand	sand	sand
Bulk density, g cm^{-3}	1.58	1.68	1.74	1.77
Field capacity, % v/v	17.30	16.65	14.70	13.65
Permanent wilting point, % v/v	5.60	5.35	4.80	4.40
Available water, %	11.70	11.30	9.90	9.25
pH (1:2.5)	7.98	7.95	8.10	8.12
ECe, soil paste extract, dS m^{-1}	4.85			
Soluble cations, $meql^{-1}$				
Ca^{2+}	14.60	10.10	15.20	10.60
Mg^{2+}	6.80	4.30	6.10	4.10
Na^{+}	46.50	23.50	28.20	20.30
K^{+}	1.10	0.90	1.0	0.90
Soluble anions, $meql^{-1}$				
CO_3^{2-}	nd*	nd	nd	nd
HCO_3^{-}	0.40	0.10	0.30	0.20
Cl^{-}	65.40	36.50	46.00	31.80
SO_4^{2-}	3.20	2.20	4.20	3.90

*nd: not detected

Irrigation water measurements and crop-water relations

Distribution uniformity (DU)

The water distribution uniformity (DU) was measured in the field and calculated by the equation developed by Keller and Bliesner (1990) as:

$$DU = \frac{Qn}{Qa} \times 100$$

Where:

DU = Field distribution uniformity (%);

Qn = Average flow rates collected from emitters at the lowest quarter of the drip line.

Qa = Average flow rates collected from all tested emitters.

Water consumptive use (WCU)

Crop water use wasestimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$WCU = \sum_{i=1}^{i=4} \frac{\theta 2 - \theta 1}{100} \times Bd\ x\ d$$

Where:

WCU = water consumptive use or crop evapotranspiration, ETc (mm).

i = number of soil layer.

θ2 = soil moisture content after irrigation, (%, by mass).

θ1 = soil moisture content just before irrigation, (%, by mass).

Bd = soil bulk density, (g cm^{-3})

d = depth of soil layer, (mm).

$$WCU = \sum_{i=1}^{i=4} \frac{\theta 2 - \theta 1}{100} \times Bd\ x\ d$$

where:

AIW = depth of applied irrigation water (mm)

ETo = reference evapotranspiration (mm d^{-1}). ETo values were calculated using BISm, Snyder *et al.* (2004).

I = irrigation intervals (days)

Ea = irrigation application efficiency of the drip irrigation system (Ea = 87.2 and 88.8 % in the first and second seasons, respectively).

LR = leaching requirements (was not considered in this study to avoid the effect on the tested deficit irrigation treatments).

Crop coefficient (Kc):

The local crop coefficient values for mango trees were estimated according to Allen *et al.* (1998) as follows:

$$Kc = \frac{ETc}{ETo}$$

where:

ETc= crop evapotranspiration (mm d^{-1}) H" water consumptive use (WCU)

ETo = reference evapotranspiration (mm d^{-1}).

Yield and yield components

Yield component parameters:

1. Number of fruits $tree^{-1}$ was recorded at harvest time (end of October) for all treatments in both seasons.
2. Fruit weight (g).
3. Tree yield (kg).
4. Total fruit yield (tha^{-1})

Fruit chemical parameters:

1. Total soluble solids (TSS, %), was determined by using hand refractometer.
2. Sugar content (Total sugar, %), was determined according to Daniel and George (1972).
3. Total carotenoids content (mg100 ml^{-1}), One gram was taken from the whole fruit pulp and was extracted in 10 ml acetone (85%) and carotenoids contents was determined colorimetrically at a wave length 440 nm using spectro-photometer as described by Wintermans and Mats (1965).

Marketable yield:

Fruit cracking(%),was determined by the following equation according to El-Akkad *et al*.(2016):

$$\text{Fruit cracking}(\%) = \frac{\text{No. of Carked fruits}}{\text{Total no. of fruits}} \times 100$$

Mango of marketable fruits was determined by the following equation according to Bishop (2014) as:

$$\text{Marketable Fruit Yie} = \frac{\text{Total no. of fruit - no. of craccked fruits}}{\text{Total no. of fruits}} \text{ x } 100$$

Water use efficiency (WUE):

Water use efficiency is calculated according to Stanhill (1986) as:

$$WUE = \frac{Mango\ \ yield,\ Y\ \left(\frac{kg}{ha}\right)}{Consumed\ \ Irrigation\ \ Water,\ WCU\ \left(\frac{m3}{ha}\right)}$$

where:

Y= Mango yield (kg ha^{-1}).

WCU= Water consumed by the crop during entire growing season (m^3 ha^{-1}).Sw

Crop water productivity (WP):

Crop water productivity is calculated according to Zhang (2003) as follows:

$$WP,\ kg\ .\ m^{-3}\ \ \frac{Mango\ \ yield\ Y,\ \frac{kg}{ha}}{Applied\ \ Irrigation\ \ Water\ \ \frac{m3}{ha}}$$

Energy saving (ES, %):

Energy saving percentage: is the amount of energy saved from operating the irrigation pump according to the tested treatments compared with farmer practice (kwh). The ES values are calculated by using the following formula:

$$\text{Energy saving } (\%) = \frac{(\text{Aclual energy used})}{(\text{Energy used by farmer})} \times 100$$

Economic analysis:

Economic analysis was performed to evaluate the economic return due to the experimental treatments. The analysis was done through the calculation of differences between costs of production (L.E. ha^{-1}) and income profits (L.E. ha^{-1}) to obtain the net return (L.E. ha^{-1}) of the proposed treatments as compared with farmer practice and to identify the best treatments that achieved the highest net return (L.E. ha^{-1}). The income profits were calculated based on the actual prices of average mango production of 3500 L.E. t^{-1} at local market and 7000 L.E. t^{-1} for export (Anonymous, 2018).

Statistical analysis

Data were statistically analyzed according to the technique of analysis of variance (ANOVA) as published by Gomez and Gomez (1984). Means of the treatments were compared using Least Significant Difference (LSD) at 5% level of significance as developed by Waller and Duncan (1969).

RESULTS AND DISCUSSION

Distribution uniformity (DU)

The calculated water distribution uniformity (DU) values, as conducted at the beginning of the 1st and 2nd seasons, were 90 and 91%, respectively. The obtained results showed a little increase in DU values in 2nd season as compared to 1st season. This trend of results was close to that obtained by El-Tomy (2008) and Taha (2012 and 2013), who stated that the distribution uniformity values for lateral lengths of 20, 40 and 60 m were 97, 98 and 99%, respectively.These results were similar with those reported by Taha (2018),who stated that the distribution uniformity values for drip lateral length of 24 m were 89 and 90% in the 1st and 2nd seasons,respectively.

Applied irrigation water and water consumption

Results in Table 3 indicated that,depths of applied irrigation water were1445, 1204, 963, 722, and 2300 mm in 1st season, and were 1419, 1182, 946, 709, and 2240 mm in 2nd season for the 120, 100, 80, 60%ETo, and farmer treatments, respectively. An average amounts of applied irrigation water under 120, 100, 80, and 60% ETo irrigation levels and farmer treatment were 14320, 11930, 9545, 7155 and 22700 m^3 ha^1, respectively.The farmer irrigation practice exceeded the other tested treatments by 37 to 69%, which reflects the need of extension activities with farmers growing mango in the newly cultivated area to avoid over irrigation, reduce the cost of energy used for pumping water and alleviate the negative effect on crop yield. These results were similar to those obtained by Levin *et al*. (2018).They stated that, the total depths of seasonal irrigation water were 1216, 1295, 1322 and 1388 mm season for mango (Keitte var.) during 2010, 2011,2013, and 2014 growing seasons ,respectively. Also,the results were similar to the those reported by Mostert and Hoffman (1997), who stated that average water requirement for mango (Keitte var.) was 1198 mm season under South Africa growing conditions. The obtained results were in line with those of Ren *et al.* (2014), who indicated that the large amounts of applied water by the farmer could cause many environmental problems, where leaching of fertilizer away from root zone to ground water can occur, depletion of irrigation water from the aquifer, and the significant loss of energy used to lift irrigation water.

The results in table 3 indicated, in general, that increasing water availability to the plants increases the water consumption. The highest values of seasonal water consumptive use were 19741 and 19266 m^3 ha^{-1} under irrigation with farmer treatment in 1st and 2nd seasons, respectively. Whereas, the lowest values of 5890 and 5901 m^3 ha^{-1}were recorded under irrigation with 60% ETo in 1st and 2nd seasons, respectively.

Mango yield and its components

Results in table 4 indicated that, there is a significant effect of the adopted irrigation treatments on number of fruits $tree^{-1}$, fruit weight, fruit yield $tree^{-1}$and total fruit yield (t ha^{-1}) in the two growing seasons. An average total fruit yield values were 35.5, 28.3, 24.9, 19 and 24t ha^{-1} for the 120, 100, 80, and 60% ETo irrigation and farmer treatments, respectively.The highest fruits number $tree^{-1}$, fruit weight (g) and fruit yield $tree^{-1}$ (kg) were produced from theirrigation with 120% ETo treatment compared to the other treatments. Meanwhile, the lowest values of the traits were recorded for the 60% ETo treatment. Fruit weight $tree^{-1}$ (kg) increased slightly in 2nd season as compared to the 1stseason under all irrigation treatments. This result could be due to higher distribution uniformity of the drip system in the 2nd season with more efficient water and fertilizer distribution and availability to the plants.The low yield obtained as result of farmer practice compared to the 120,100 and 80% ETo treatments could be explained by leaching the fertilizer away from the root zone (Taha, 2012).Fruit weight was significantly higher forthe 120% ETo treatment as compared with the other treatments, which can be explained by obtaining the optimum amounts of water and fertilizer. The obtained results were in line with those reported by Levin *et al*. (2018). Results showed also that, there were significant differences between total fruit yields under the 120 and all other treatments in the two seasons. The obtained results were in line with those of Carlos *et al.* (2011), who stated that mango fruits yield increased significantly, with full irrigation (100% of ETc). From the obtained results it could be concluded that, in case of water shortage, irrigating mango trees with amount of water equal to 100% ETo will save about 47% of irrigation water and increase the total fruit yield by about 18% as compared with farmer practice.

Mango chemical properties

Results in table 5 showed significant effect of tested treatments on the studied traits. Generally, increasing amounts of applied water decreased the values of the selected chemical properties. The lowest TSS, total sugar,, and total carotenes values were recorded under the farmer practice treatment, while the highest values were recorded for the 60 ETo treatment in the two growing seasons showed significant differences under irrigation treatments as compared to farmer irrigation throughout the two seasons. The obtained results were in line with those of *Carlos et al. (2011).* They indicated that,it is possible to reduce water levels by the controlled deficit irrigation without losing fruit quality of mango orchard.The obtained results were also similar to the results reported by Khattab *et al.* (2011), who stated that total soluble solids, total sugars and total anthocyanin were gradually decreased with increasing irrigation level.

Marketable and non-marketable fruit yields

Results indicated that there was a significant effect of the tested irrigation treatments on marketable yield (Table 6). Furthermore, the values of marketable fruit yields in 2nd season were higher than those recorded in the 1st season under all irrigation treatments. This result could be due to the increase in distribution uniformity of the drip system in the 2ndseason, which resulted in more efficient water and fertilizer distribution and utilization. The decrease of marketable fruits under farmer irrigation treatment could be attributed to excessive applied irrigation water, which increased the cracking per cent in mango fruits. The obtained results agreed well with those reported by Carlos *et al.* (2011),who stated that it is possible to reduce water levels without negative effect on fruit quality or significant loss of productivity of mango orchard.Moreover, these findings were in agreement with those reported by Davies *et al.* (2000, 2002), who reported that reduced deficit irrigation (RDI) or partial root zone drying (PRD) to improve WUE in various crops as one of the irrigation techniques being used, is thought to reduce plants' water consumption by enhancing abscisic acid (ABA) in the water stressed half of the roots, a hormonal signal controlling the stomatal aperture, hence reducing transpiration of the leaves.

El-Gindy *et al.* (2000) found that low-head bubbler and gated pipe irrigation system produced better quality mango fruits.Thisresult was found by Carlos *et al.* (2011). It is possible to reduce water levels currently applied without losing fruit quality and significant loss of productivity in mango orchard, from the controlled application of deficits in irrigation during the growing fruit. The obtained results agreed well with those reported by Gonzales, *et al.* (2000), who reported that, by applying the technique (deficit irrigation) in tangerines, where a deficit of 50% of ETc, applied at the initial stage, achieved water savings of up to 23%, without negative effects on productivity and fruit quality, however, when the deficit lasted until the final stages, besides the quality, the productivity fell about 22% for a water saving of up to 54%. In this situation, they recommended the technique as alternative management only when the cost of water is high.From results we con concluded that, there was a significant effect of the tested irrigation levels on mango physical and chemical parameters, and on total and marketable fruit yields.

Water use efficiency (WUE) and water productivity (WP)

The results in table 7 showed that the highest water use efficiency, i.e. 3.46 and 3.61 kg m^{-3} were obtained from irrigating with 60% ETo in 1st and 2nd seasons,respectively. The lowest water use efficiency values (1.21 and 1.26 kg m^{-3} of consumed water) were obtained from the farmer practice. Results also showed that, the highest water productivity values of 2.63 and 2.68 kg m^{-3} applied water were obtained as 60% ETo was applied in both seasons. The obtained results were similar to those reported by Spreer *et al.* (2009), who mentioned increase in water-use efficiency (WUE) of mango by deficit irrigation,especially under dry conditions.From results we conclude that, in case of water shortage, irrigating mango trees in sandy soils with 100% ETo will save 47% of applied irrigation water and the energy used for irrigation, gives the water use efficiency of 2.9 kg fruits/m3 water consumed and water productivity of 2.38 kg fruits m^{-3} water applied, as well as achieves79% more net income compared with farmers practice.

Crop coefficient (Kc)

Average monthly Kc values of mango (Keitte var.) calculated for best irrigation treatment (i.e. 120% ETo), under this experimental conditions,were 0.58, 0.64, 0.80, 0.89, 0.90, 1.04, 0.98, 0.98, 0.91, 0.77, 0.65, and 0.50 for the period from January to December, respectively (Fig. 1).While, average Kc values for the initial (1 Nov. – end of Jan.), vegetation (15 Feb. – 30 Apr.), flowering fruit^{-1} development (26 May – 12 Jul.) and fruit maturity(13 Aug. – 15 Oct.)growth stages was 0.58, 0.78, 0.97 and 0.89, respectively (Fig. 2).Seasonal average Kc value of 0.8 is obtained for the mango (Kiette var.) under experimental condition.The obtained Kc values were similar with those reported by Mattar (2007), whoshowed that crop coefficient (kc) values at different growth stages were 0.66, 0.79, 0.91 and 0.88 using drip irrigation system.

Consumed electrical energy

Results in table 8 indicated that the highest values of the seasonal consumed electric energy of 11800 and 11492 kilowatts were recorded for farmer treatment in the 1stand 2nd growing seasons, respectively. Application of irrigation treatments reduced the consumed electric energy by 37 to 69% in the two growing seasons, respectively as compared with farmer practice. Energy saving was a direct result of using deficit irrigation technique which reduced the number of hours used to operate the irrigation pump in all proposed irrigation treatments.

Cost/Benefit analyses

The results in table 9 indicated that, the net income for the 120, 100, 80% and 60% ETo treatments were higher than the farmer treatment by 128.5, 74.2, 52.1 and 13.3% in the 1st season, and were 130, 84.1, 59.7 and 16.5% in 2nd season, respectively. The high net income in the both seasons can be attributed to the increase in marketable fruit yields resulted from improving the efficiency water distribution by the drip irrigation system,optimizing the amounts of applied water, and the efficient use of applied fertilizer through adopting the fertigation practice. These results were similar to those obtained by Taha (2018),who found that the net income values for the 120, 100, 80 and 60% ETo treatments were 114.2, 105.4, 95.6 and 23.9%, in the 1st season, and were 138.6, 129.5, 120.6 and 35.9% in 2nd season, respectively higher than the farmer treatment for pomegranate cultivation in the same area.The results also showed that, the 2-year average net income values of the 120, 100, 80, and 60% ETo irrigation levels were 129.3, 79.1, 55.9 and 14.9% higher than that obtained under farmer practice.

Based on the results of the present study it could be adopted by the farmers.

Table 3. Effect of tested treatments on the depths and amounts of applied irrigation water, per cent of water saved and water consumption by mango trees during 2016 and 2017 seasons

Irrigation treatments	2016			2017		
	Applied water (mm, $m^3 ha^{-1}$)	Saving %	Water consumption (m^3 ha^{-1})	Applied water (mm, m^3ha^{-1})	Saving %	Water consumption (m^3ha^{-1})
120 % ETo	1445 (14450)	+37	12362	1419(14190)	+37	11877
100% ETo	1204(12040)	+48	9958	1182 (11820)	+47	9562
80% ETo	963 (9630)	+58	7550	946 (9460)	+58	7225
60% ETo	722 (7220)	+69	5494	709 (7090)	+68	5268
Farmer	2300 (23000)	——-	19741	2240 (22400)	——-	19266

Table 4. Effect of irrigation treatments on average fruits number $tree^{-1}$, fruit weight (g), fruit weight $tree^{-1}$ (kg), and total mango fruit yield in 2016 and 2017 seasons

Irrigation treatments	Fruits number $tree^{-1}$		Fruit weight (g)		Fruit weight $tree^{-1}$ (kg)		Total fruit yield (tha^{-1})	
	2016	2017	2016	2017	2016	2017	2016	2017
120 % ETo	31.77a	31.00a	678 a	679 a	21.54 a	21.05 a	35.90 a	35.10 a
100% ETo	29.00a	29.33a	580 b	585 b	16.81 b	17.16 b	27.99 b	28.59 b
80 %ETo	27.11ab	27.44a	547 b	548bc	14.83 b	15.04 bc	24.70 c	25.10 c
60% ETo	23.00b	23.00b	495 b	495 c	11.38c	11.38 d	18.99e	18.99 d
Farmer	28.22a	28.77a	507 b	504 c	16.08 b	14.49 c	23.80d	24.20 c
LSD 0.05	5.06	3.84	89.58	67.38	2.56	2.38	0.86	1.17

Table 5. Effect of different levels of irrigation on total soluble solids (TSS, %), total sugars (%), and total carotenes mg 100 ml^{-1} of mango fruits in 2016 and 2017 seasons

Irrigation treatments	TSS (%)		Total sugar (%)		Carotenes (mg 100 ml^{-1})	
	2016	2017	2016	2017	2016	2017
120 %ETo	15.15 c	14.89 b	14.56 b	14.35 b	4.94 c	4.17 d
100%ETo	15.80 c	15.57 b	16.95 a	16.85 a	5.15bc	4.55 c
80 %ETo	17.27 b	17.11 a	16.17 a	16.10 a	5.40 b	5.21 b
60%ETo	18.49 a	17.76 a	16.43 a	16.85 a	5.95 a	5.59 a
Farmer	10.79 d	10.49 c	10.43 c	10.10 c	4.40 d	4.09 d
LSD 0.05	1.05	0.89	1.04	1.05	0.32	0.27

Table 6. Effect of irrigation treatments on marketable and non-marketable mango fruit yields in 2016 and 2017 seasons

Irrigation treatments	Marketable fruit yield(tha^{-1})		Non-marketable fruit yield(tha^{-1})	
	2016	2017	2016	2017
120%ETo	35.76 a	34.85 a	0.14 b	0.25b
100%ETo	27.88 b	28.39b	0.11 b	0.20 b
80 %ETo	24.61c	25.03c	0.09 b	0.07b
60 %ETo	18.94d	18.92d	0.05 b	0.07 b
Farmer	12.19 e	11.50e	11.61 a	12.70 a
LSD 0.05	0.84	1.22	0.40	0.28

Table 7. Water use efficiency and water productivity of mango trees as affected by different irrigation treatments 2016 and 2017 growing seasons

Irrigation treatments	WUE ($kg\ m^{-3}$ consumed water)		WP ($kg\ m^{-3}$ applied water)	
	2016	2017	2016	2017
120% ETo	2.90	2.96	2.48	2.47
100% ETo	2.81	2.99	2.33	2.42
80% ETo	3.27	3.47	2.56	2.65
60% ETo	3.46	3.61	2.63	2.68
Farmer (control)	1.21	1.26	1.03	1.08

Table 8. Effect of irrigation treatments on saving electric energy in the two growing seasons

Irrigation treatments	2016		2017	
	Energy consumed (kW)	Saving (%)	Energy consumed (kW)	Saving (%)
120% ETo	7434	37	7240	37
100% ETo	6136	48	6091	47
80% ETo	4956	58	4827	58
60% ETo	3658	69	3677	68
Farmer	11800	——-	11492	——

Table 9. Cost benefit analyses for the adopted irrigation treatments

Irrigation treatments	Cost elements					Benefits					Net income (LE***)
	Irrigation*	Fertilizer	Pests IPM	Fruits thinning	Total cost (LE)	Local market Ton	Local market Price (LE	Export market Ton	Export market Price (LE	Total benefits (LE)	
2016											
Farmer	5310	10378	6440	4760	26888	11.62	3500	12.19	7000	126008	99120
120% ETo	7434	10378	6440	-----	24252	0.14	3500	35.76	7000	250779	226527
100% ETo	6136	10378	6440	-----	22954	0.11	3500	27.89	7000	195584	172630
80% ETo	4956	10378	6440	-----	21774	0.09	3500	24.61	7000	172554	150780
60% ETo	3658	10378	6440	-----	20476	0.06	3500	18.94	7000	132767	112291
2017											
Farmer	5171	10998	6440	4760	27369	12.69	3500	11.51	7000	124985	97616
120% ETo	3258	10998	6440	-----	20696	0.13	3500	34.97	7000	245245	224549
100% ETo	2741	10998	6440	-----	20179	0.10	3500	28.50	7000	199850	179671
80% ETo	2172	10998	6440	-----	19610	0.07	3500	25.03	7000	175455	155845
60% ETo	1655	10998	6440	-----	19093	0.05	3500	18.95	7000	132825	113732

*used for irrigation

** Kilowatt (kw) price = 0.45 LE

***1$ =17.80 LE.

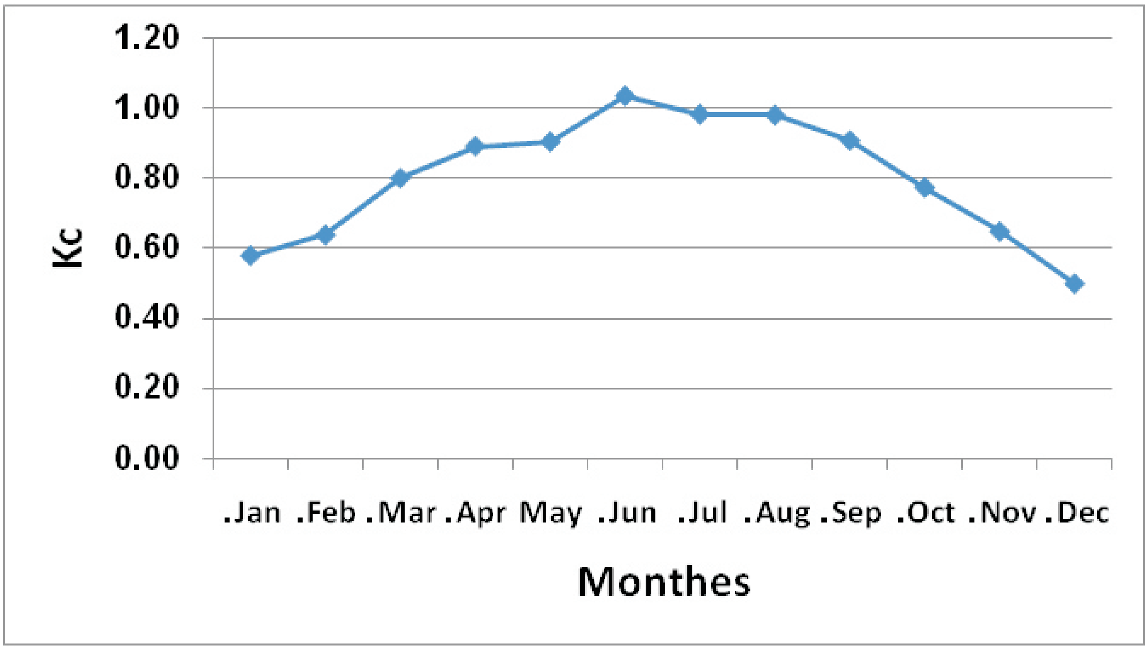

Fig. 1.Average monthly crop coefficient (Kc) values for mango (Keitte var.) developed for the 120% ETo irrigation treatment

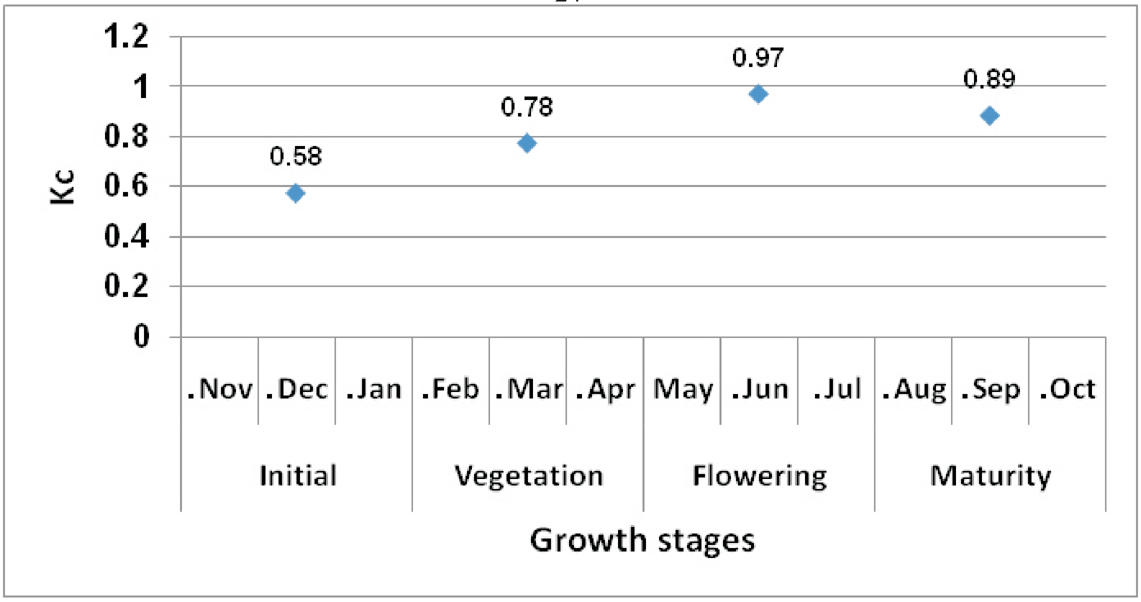

Fig. 2. Average mango(Keitte var.) crop coefficient (Kc) values at different growth stages developed for the 120% ETo irrigation treatment

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