Middle East Journal of Agriculture Research
ISSN 2077-4605
Volume : 06 | Issue : 03 | July-Sept. | 2017
Pages:587-604

Effect of deficit irrigation levels and NPK fertilization rates on tomato growth, yield and fruits quality

Salama A. Abdelhady[1], Nashwa A.I. Abu El-Azm[1] and El-Sayed H. El-Kafafi[2]

[1]*Hort. Dept., Faculty of Agric., Ain Shams Univ., Cairo, Egypt.*
[2]*Botany Dept., Faculty of Agric., Al-Azhar Univ., Cairo, Egypt*

Received: 15 May 2017 / Accepted: 25 June 2017 / Publication date: 03 July 2017

ABSTRACT

Water availability is a strong challenge in irrigated agriculture especially under water resources scarce as is of Egypt. The deficit irrigation practices become the main adopting policies for water saving. Under irrigation conditions, it is necessary to determine the fertilization level which is applied in order to not double the stress (drought and nutrient deficiency). This study was implemented during 2014 and 2015 summer seasons, in a loamy soil at the experimental station, Faculty of Agriculture, Ain Shams University, Kalyubia Governorate, Egypt to assess the impact of four irrigation treatments (SSI_{100}, SI_{100}, DI_{80} and DI_{60}) and three NPK fertilization rates (100%, 75% and 50% of tomato requirement) on growth, yield, fruit quality, water use efficiency, plant nutritional status and water relations of open field tomato cv. Elesa F1. The results proved that all measured parameters were worsened with decreasing both irrigation level and/or NPK fertilization rate. The highest water use efficiency and fruit quality were recorded in DI_{80} treatment either individually or combined with 100% NPK fertilization rate. The best result of all measured parameters was obtained with combined of SSI_{100} and 100% NPK fertilization rate followed by both SI_{100} and DI_{80} each combined with 100% NPK fertilization. Soil moisture content, of course, affected only by irrigation treatments where it was always higher than the readily available water level by applying SSI_{100}, SI_{100} and DI_{80}. The results proved that the combination of 100% NPK fertilization rate and mildly deficit irrigation of DI_{80} (80% of crop evapotranspiration) is the recommended practice.

Key words: *Solanum lycopersicum,* Deficit Irrigation, Nitrogen, Phosphorus, Potassium, Fertilization, Plant Growth, Fruit Yield, Fruit quality, WUE, Water Relations, Soil moisture

Introduction

At present and more so in the future, irrigated agriculture will implement under water scarcity (Fereres and Soriano, 2007). Especially since irrigated agriculture consumes more than two-thirds of the total fresh water on the planet. This issue causes substantial conflict in freshwater allocation between agriculture and other economic sectors (Chai *et al*., 2016). Egypt as a part of Central West Asia and North Africa region, where irrigated agriculture is critical for food security in these regions. In these areas plant water use efficiency (WUE) is becoming a substantial issue, because crop production relies on the use of great volumes of water. Thence most countries of these regions cannot have a productive form of agriculture without secure and sustainable irrigation supplies so the competition for fresh water this precious resource is increasing tremendously. Therefore, as stated by Fereres and Soriano (2007) irrigation management will shift from emphasizing production per unit cultivated area towards maximizing the production per unit of water consumed. Especially since the water productivity, it is becoming critically important to optimize WUE in agriculture (Pascale *et al.*, 2011). Water is the most limiting factor in these regions, so improving the productivity of existing water resources is an attractive alternative procedure to sustain irrigated agriculture. So there is a strong need to shift agriculturists thinking from "maximizing crop yields" to "optimizing crop yields". Substantial and sustainable improvement of water productivity and or WUE can be achieved through integrated farm resources management. On-farm irrigation water management techniques such as deficit irrigation if coupled with better cropping patterns together with appropriate cultural practices and improved genetic make-up will help to achieve this objective. The conventional water

Corresponding Author: Salama A. Abdelhady, Hort. Dept., Faculty of Agric., Ain Shams Univ., Cairo, Egypt.
E-mail: salamaelhady74@hotmail.com

management and cropping pattern guidelines, designed to maximize yield per unit area, need to be revised for achieving maximum water productivity. The wide ranges in recorded crop water productivities suggest that agricultural production can be maintained to its current level by using 20 to 40% less water if new water management practices are adopted (Dehghanisanij *et al.,* 2006). The WUE or water productivity is the same term for expression about the number of produced yield units for each irrigation water unit (m^3). The main pathways for enhancing WUE in irrigated agriculture on-farm are to increase the output per unit of water via aspects of engineering and agronomic management (Howell, 2006). There are a number of strategies that are likely to lead to improve water use or water productivity in agricultural production. Among these strategies, water irrigation strategies such as deficit irrigation and partial root drying (Morison *et al.,* 2008). Conserve water in agriculture appears to be more efficient through carefully managed deficit irrigation strategies which are supported by the advanced irrigation system and flexible, state-of-the-art water delivery systems (Evans and Sadler, 2008). Conventional deficit irrigation is one approach that can reduce irrigation water use without causing significant yield reduction (Kirda *et al.,* 2005). Deficit irrigation increases water productivity relative to full irrigation, as shown experimentally for many crops (Zwart and Bastiaansen, 2004; Fan *et al.,* 2005).

Indeed, the greatest increases in the productivity of water in irrigation have not only been from better irrigation technology or management, but rather from increased crop yields due to better seeds and fertilizers (Zobel, 2002). In agriculture, water and nutrients are the two most critical inputs and their efficient management is important not only for higher productivity but also for maintaining environmental quality. Vegetables have been found particularly responsive to fertigation due to their continuous need of water and nutrients at the optimal rate to give high yield with good quality, high capital turnover to investments and may be their cultivation by more skilled farmers (Jat *et al.,* 2011). Fertigation has the potential to supply a right mixture of water and nutrients to the root zone, and thus meeting plants' water and nutrient requirements in the most efficient possible manner (Patel and Rajput, 2001). A properly designed drip fertigation system delivers water and nutrients at a rate, duration and frequency, so as to maximize crop water and nutrient uptake while minimizing leaching of nutrients and chemicals from the root zone of agricultural fields (Gardenas *et al.,* 2005). Subsurface irrigation, as a new and modified method from drip irrigation, increased yield, water use efficiency and fertilizers efficiency as well as nutrients uptake compared to surface irrigation method (Badr *et al.,* 2012).

Tomato is popular vegetable crop all over the world where it cultivated in enormous areas (Xiukang and Yingying, 2016). Saving water strategies as deficit irrigation will be succeeded in achieving its aim when applied in large scale crops as in tomato (Costa *et al.,* 2007). This paper will report the optimal fertilization rate of both nitrogen, phosphorus and potassium could be applied in deficit irrigated tomato. This objective can achieve via both optimizing tomato yield and maximize irrigation water use efficiency via applying three fertilization rates of nitrogen, phosphorus and potassium together under three deficit irrigation regimes which were applied through subsurface drip irrigation vs full irrigation via surface drip system as a control.

Materials and Methods

Experimental location.

Tomatoes plants *(Solanum lycopersicum* L.) cv. "Elisa F1" used in this experiment were cultivated and grown in open field during 2014 and 2015 growing summer seasons at Shoubra El Kheima, Kalyubia Governorate, Egypt. The location of the experiment belongs to Horticultural Department, Faculty of Agriculture, Ain Shams University (latitude 30^o, 12' N, and longitude 31^o, 24' E, and mean altitude 26 m above sea level). The soil texture of the experimental area is clay loam. Irrigation water has been obtained from Nile river (located in the experimental area), with pH 7.2 and an average EC 0.63 dS m^{-1}. Before setting up of the experiment, a composite soil sample was taken from upper soil layer (0-60 cm) of the experimental area for physical and chemical analysis. Some physical and chemical properties of the experimental soil site are presented in table 1, 2 while meteorological data (absolute maximum and minimum values) during the experiment was summarized in Table 3.

Table 1: Some physical properties of the experimental site soil

Soil depth (cm)	Texture	Soil particles			F.C.% θ at 33 kPa	P.W.P. % θ at 1500 kPa	B.D. g cm^{-3}
		Sand %	Silt %	Clay %			
0-30	Clay loam	24	36	40	31.05	14.81	1.32
30-60	Clay loam	27	32	41	32.71	1 7.68	1.34

F.C.= field capacity, P.W.P.= permanent wilting point, were determined as percentage in weight, B.d. = Bulk density

Table 2: Some chemical properties of the experimental site soil

pH	EC ds m-1	$CaCO_s$ %	Organic mutter %	Cation meq/l				Anion meq/l		
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}
8.1	1.05	1.80	1.64	1.55	0.43	0.65	0.56	1.6	1.2	0.73

Table 3: Average temperatures and relative humidity during the growing seasons under Kaliobia Governorate conditions for five years.

Month	2014 season			2015 season		
	Temperature (°C)		Relative humidity %	Temperature (°C)		Relative humidity %
	Max.	Min.	Average	Max.	Min.	Average
March	33.1	6.8	55.0	36.8	8.4	56.0
April	38.1	12.7	49.0	38.8	9.8	48.0
May	43.0	14.4	46.0	44.3	16.7	48.0
June	43.8	18.5	48.0	39.3	19.1	52.0
July	40.0	22.3	56.0	38.9	21.7	55.0

**Metrological authority, Cairo.*

Experimental design and treatments

This study involved two factors were applied through three replications in split plot experimental design. The first or main factor was deficit irrigation which has two treatments along with two full irrigation treatments, all were randomly distributed in the main plots. Drip irrigation was used and designed for supplying water to soil subsurface at 25 cm depth in 3 treatments which were full and two deficit irrigation as well as full irrigation treatment applied via surface drip irrigation as control. The irrigation treatments were surface full irrigation (SI_{100}), subsurface full irrigation 100% (SSI_{100}) and deficit irrigation of 80% (DI_{80}) and 60% (DI_{60}) of the maximum evapotranspiration (ETc). The irrigation was done collected every three days because of the higher field capacity of the soil (Table, 1). Full irrigation water quantity was 6683 and 7167 m^3 ha^{-1}, for first and second growing season, respectively. The irrigation water quantity was applied along the period from March 16th and 20th (transplanting date) to June 14th and 10th (harvesting date) for the first and second season, respectively. The second factor was NPK fertilization rate where the elements of nitrogen, phosphorus and potassium were added together. The three fertilization rates were 100%, 75% and 50% of tomato requirements calculated based on the recommendation of Egyptian Ministry of Agriculture for tomato production in the experimental area and fertilization quantity was 120 kg nitrogen, 60 kg phosphorus and 100 kg potassium as recommended. Fertilization treatments were randomly distributed in the submain plots. The experiment included 12 treatments represent the combinations of four irrigation treatments and three fertilization rates. The experimental plot has three lines, each was 5 m long and 1.5 m wide, and 22.5 (3 x 5 x 1.5 = 22.5) m^2 in area. Each of three replicates has four main plots, each of them has three sub-main plots, were prepared and were separated by a water barrier sheet to prevent water leakage between them. Tomato transplants were cultivated at 50 cm apart. In the initial stage during transplanting for two weeks all the experiment plots were well watered, then deficit irrigation treatments began regularly to harvest stage.

Calculation of irrigation treatments

Irrigation water levels were calculated using FAO-CROPWAT software version 8 to calculate crop water requirements based on the reference crop evapotranspiration (ETc) as described by Penman-Monteith which has now become the standard for estimating reference crop evapotranspiration (Smith and Steduto, 2012). Evapotranspiration was calculated according to the water balance approach as described by James (1988).

$ET = I + P - Dr - Rf \pm Ds$……………………………………………………………………..(1)

where ET representatives the seasonal crop evapotranspiration, I representatives the applied irrigation water during the growth period, P representatives the effective rainfall during the growth period, Dr representatives the amount of deep percolation, Rf representatives the amount of runoff, and Ds representatives the change in the soil water content which determined by gravimetric sampling. All terms in Eq. (1) are expressed in millimeters. Rainfall below 5.0 mm was assumed to be lost by evaporation and therefore ineffective; it was treated as zero rainfall contribution. To determine evapotranspiration, soil moisture at 0 to 30, 30 to 60, and 60 to 90 cm depth was measured gravimetrically before each irrigation and at harvest. Because there was no observed runoff during the experiments and the water table was at 6 m depth, capillary flow to the root zone and runoff flow were assumed to be negligible in the calculation of evapotranspiration. Drainage below 90 cm, after negligibility of a numeral of soil-water content parameters was considered negligible. So the previous equation was reduced to

$ET = I + P \pm Ds$…………………………………………………………………………..(2)

Soil Water Content

For determining soil water content by the gravimetric method (θg), the weight of wet and dry soil has to be known. Samples were taken via a 4 cm auger from the middle row of each plot after transplanting and at three days after irrigation during initial stage, development stage, mid-season and at harvest stage. Each plot was sampled at 15 cm to 60 cm depth through eight sites perpendicular to the trickle line at distances of 15 cm from the line. After sampling wet soil mass has been calculated immediately. So soil samples were dried for 48 h at 105°C and θg calculated. Undisturbed soil samples were taken at the beginning of the experiment in order to calculate the bulk density which was used for determining volumetric (θv) soil water content. From soil water content, depleted fraction available water (fd) could be calculated as follows:

$fd = (\theta fc - \theta v)/(\theta fc - \theta wp)$

Where: θfc = field capacity, θwp = permanent wilting point, and θv = volumetric soil water content.

Table 4: Calculation of total irrigation water requirements for tomato crop per season

Items	Growth stages of tomato			
	Initial stage March - April.	Developmental stage April - May	Middle growth season May - June	Late stage June -July
No. of days/ stage	25	35	65	30
ETo (mm/day)	4.9	5.1	5.9	6.8
Crop coefficient, Kc	0.6	0.88	1.15	0.9
Reduction factor, Kr, %	0.24	0.7	0.82	0.9
Emission uiformity, EU	0.9	0.9	0.9	0.9
Application efficiency Ea,	0.91	0.91	0.91	0.91
LR, mm/day	0.07	0.16	0.30	0.35
R , mm	0	0	0	0

R = water received by plant from sources other than irrigation, mm (for example rainfall); IRg = Gross irrigation

1.1. Measured parameters

1.1.1. Plant growth parameters

Five plants were randomly chosen from each plot after 50 days from transplanting date to collect the following parameters. The plants were uprooted then plant length (cm), branches number per plant were measured then separated into shoots and roots. After separation of plant shoots and roots, the root length was measured as cm. The plant shoots and roots were dried at 70°C in an aerated oven until the weight became constant and the dry weight of roots and shoots and shoot/root ratio were calculated.

1.1.2. Leaf physical and physiological parameters

After 50 days from transplanting date the following parameters were collected on the fourth leaf from plant apex which recently full expanded. These parameters were carried out on five leaves from deferent five plants for each experimental plot as follows:

a- Leaf area cm^2 was measured on detached leaves by leaf area meter, Delta-T Devices, Cambridge, UK.

b- Leaf chlorophyll fluorescence (SPAD) was measured on attached leaves via chlorophyll meter device, the SPAD-502 plus by Konica Minolta.

c- Leaf relative water content (RWC %) was measured on a recent expanded leaf detached from three plants per plot.

Each leaf was recut under water and weighed to determine the leaf fresh mass (FM). Then, the leaf was covered with a plastic bag, and kept for rehydration with the cut end immersed in water in a dark cold room at 4 °C for 24 h. After rehydration, each leaf was re- weighed to determine the turgid mass (TM), and then oven-dried at 80 °C for 48 hours to determine dry mass (DM). The RWC (%) was calculated as follows:

$$RWC = 100 * (FM - DM)/(TM - DM)$$

d- Leaf electrolytes leakage (LEL %), fully expanded leaf samples were taken from five plants per plot after 50 days from transplanting then were cut into discs 1 cm^2. Thirty discs were put into a 100 ml flask then washed slowly three times by deionized distilled water to remove surface adhered electrolytes. The leaf discs were submerged in a 30 ml solution of polyethylene glycol (PEG 600) for a certain period at 10°C in the dark to minimize secondary effects. The concentration of the PEG solution as well as the duration were adjusted to reach the severity of desiccation desired. After that, the leaf discs were washed quickly for three times with deionized distilled water. Thirty ml of deionized distilled water were then added and kept for 24 hours at 10°C in the dark. Then the flask was warmed to 25 °C, shaken well and the electrical conductivity (ECi) was measured. After measuring the electrical conductivity, the leaf tissues were killed via autoclaving for 15 minutes to release all ions from the tissue, cooled to 25°C and then the electrical conductivity (ECt) was re-measured. The value of electrical leakage (EL) is calculated using the following equation:

$$EL = (ECi/ECt - Ci/Ct) \times 100$$

Where ECi is the initial electrical conductivity, ECt is the total electrical conductivity, Ci is the initial electrical conductivity of non-desiccated control, Ct is the total electrical conductivity of the control.

e- Leaf water potential, midday leaf water potential (ψ) was measured using a pressure chamber (SKPM 1400, Skye Instruments, Powys, UK). One recent expanded leaf per plant (five plants per plot) was detached, quickly sealed into the humidified chamber to determine bulk of water potential (ψ).

1.2.1. Fruit yield

a- Average fruit weight (g).
b- Average plant fruits yield (kg).
c- Total fruit yield per hectare (ton).
d- Marketable fruit yield per hectare (ton).

The fruits were harvested four times along three weeks. The data of fruits yield as kg/plant and fruits number per plant were collected as an average of fruits yield of ten plants from each plot. Fruit weight was calculated as average of 10 fruits chosen randomly of the chosen plants of each plot of all harvests. Fruit yield per hectare was estimated via multiplying number of plants per hectare and average fruit yield per plant. Marketable fruit yield per hectare was calculated based on total fruit yield after exclusion malformed fruit, disordered fruit and fruits not suitable for human consumption or marketing.

A random fruits sample of each harvest time, approximately 2 kg fruits from each plot were taken for laboratory analyses. The homogenized fruits juice was subjected to the following measurements as described in A.O.A.C. (1990):

1.2.2. Fruit quality.

a- Total soluble content of fruits (T.S.S, °Brix) was measured using a portable refractometer.
b- L ascorbic acid content of fruits or vitamin C content was measured using the pigment of 2,6-dichlorophenol-indophenol.
c- Total titratable acidity was measured using titration of certain fruits juice volume against sodium hydroxide solution with known concentration (0.1 N).

1.3. Water use efficiency based on total and marketable fruit yield

Irrigation water use efficiency (WUE) was calculated as the ratio of the total or marketable fruit yield (kg hectare $^{-1}$) and the total irrigation water volume applied per ha (m^3 hectare $^{-1}$) seasonally.
It was expressed as kg fruits per cubic meters of irrigation water (Howell, 2002).

1.4. Content of nitrogen, phosphorus and potassium of leaves

At the same date of measured plant growth parameters, leaves samples were taken and subjected to analyze some macronutrients in tomato leaves; i.e., 4^{th} leaf from main stem apex. Samples were dried at 70 °C to reaching to constant weight and then milled to a fine powder phase. From each sample 0.2 g was wet digested using 5 cm^3 from the mixture of sulfuric (H_2SO_4) and perchloric ($HClO_4$) acids (1:1) as described by Peterburgski (1968) to obtain the digestive extract subjected to measuring nutrient. Nitrogen percent (N%) was measured using micro-Kjeldahl method according to Hesse (1971). Phosphorus percent (P%) was measured calorimetrically at wavelength 680 nm using Spectrophotometer device (UV/VIS Spectrophotometer, CT 200) as described by Cottenie *et al.* (1982). Potassium percent (K%) was measured via Flame photometer device as mentioned by Cottenie *et al.* (1982). Also, calcium percent (Ca %) was measured through Flame photometer device according to the method described by Brwon and Lilliland (1964).

1.5. Yield Reductions and Water Saving Determination:

Calculation reduction of fruits yield in exchange for the provision of irrigation water by using the following equations described by (Ismail, 2010):
Reduction of fruit yield = 100 - (yield of the experimental treatment / yield of control) x 100
Water saving = 100 - (water consumption of the experimental treatment / yield of control) x 100
Where control = a full irrigation water requirement (control treatment).

Statistical Analysis:

Analysis of variance of the obtained data from each parameter was computed through the MSTAT Computer Program (MSTAT Development Team, 1989). The Duncan's New Multiple Range test at 5% level of probability was used to test the significance of differences among means values of treatments (Steel and Torrie, 1980). The displayed data is the combination of the two experimental two seasons.

Results and Discussion

Soil moisture content

Collecting of soil moisture content measurements was started after transplanting until the end of growing season along tomato plant growing period which has divided to stages of transplanting (initial stage), development, mid-season and harvesting. Data proved that soil moisture percent directly affected by the amount of supplied water through both surface and subsurface drip irrigation at different irrigation rates of full or deficit-irrigation. The higher moisture percent of soil profile for all the treatments at initial or transplanting stage due to supplying more irrigation water before transplanting to replenish soil profile to field capacity and also due to that all treatments at initial stage had received the same quantity of water at rate of 100% ETc for 15 days after transplanting. Soil moisture percent of root zone at the initial stage was averaged as 26.7% and 28.2%, respectively, for SI_{100} and SSI_{100} as well as fraction of depletion which was averaged as 33% and 23%, respectively of SI_{100} and SSI_{100} treatments. The soil water depletion fraction under non-stress condition is that fraction of the total available soil water that a crop can extract from its root zone without experiencing water stress. According to Allen *et al*. (1998) the fraction of depletion for tomato crop is about 40% of total water holding capacity of the soil. Soil moisture content recorded the highest value in SSI_{100} treatment followed by in both SI_{100} and then DI_{80} while the least value was obtained with DI_{60} during all tomato plants growth stages. Therefore, applying DI_{80} treatment led to water saving, minimizing water depletion and rising water productivity compare to treatments of SI_{100} or SSI_{100} and either to DI_{60}. This is due to reduce evaporation from soil surface and delivering water directly to the root zone by setting drip line under soil surface. This result is consistent with findings of Singh (2007) and Douh *et al.* (2013). Also EI-Awady *et al.* (2003) reported that water evaporation had reduced with increasing burring depth of trickle irrigation line, wherever the evapotranspiration could be reduced to 40 % when the trickle line is buried at 15 cm depth from surface compared to irrigation via surface trickle line in sorghum crop. The data in figure (1) illustrates soil moisture proportion of root zone at both field capacity (FC), permanent wilting point (PWP), total available water (TAW) and readily available water (RAW) affected by all irrigation treatments of full irrigation, SI_{100} and SSI_{100}, and deficit irrigation, DI_{80} and DI_{60}. For all tomato plant growth stages, soil moisture content was always higher than soil moisture content at the RAW level when applying both SI_{100} and SSI_{100} as well as DI_{80}. Otherwise, soil moisture content was near the RAW level when applying DI_{60} without occurrence any serious water stress. Soil moisture content measurements were in agreement with the crop stress coefficient values, which were less than that with applying deficit irrigation level of 60% ETc. Our data in a parallel line with those of Al Omran and. Luki (2012) on cucumber and Al-Mansor *et al.* (2015) on tomato.

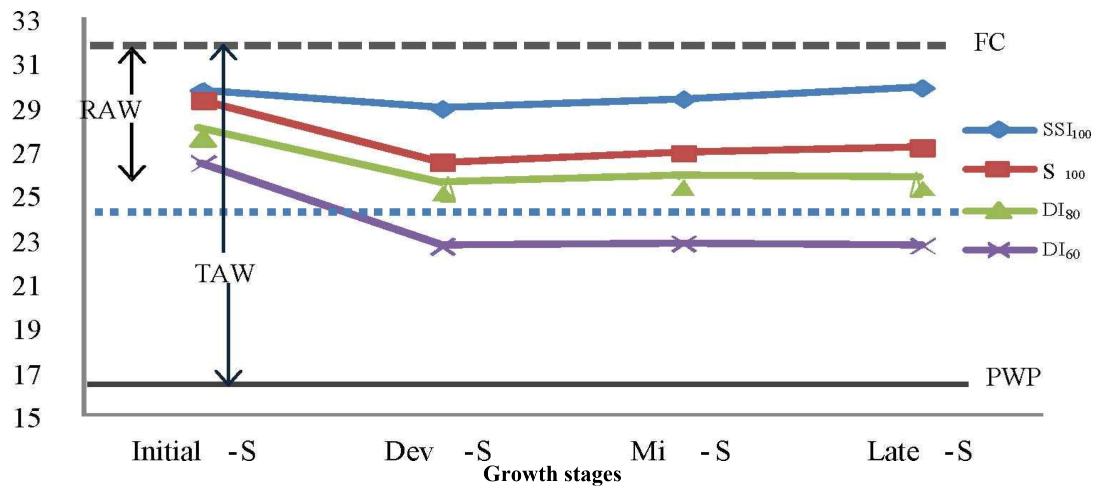

Fig. 1: Average soil moisture percent based on weight under irrigation rates for surface and subsurface drip irrigation systems during the growth stages of tomato plants.

Plant growth

Generally, the data clarify that plant growth parameters expressed as plant length, branches number, dry weight of shoot and root and shoot/root ratio were fell progressively decreased with decreasing both irrigation level and fertilization rate except root length were significantly superior with applying SSI_{100} than other irrigation treatments. Except for shoot dry weight and root length, the remaining growth parameters were recorded a resemble values when applying both SI_{100} and deficit irrigation of DI_{80}. Meanwhile, shoot dry weight under deficit irrigation treatment of DI_{80} was significantly heavier than under SI_{100} treatment. The longest root was found in deficit irrigation treatment of DI_{80}. All the above plant growth measurements of tomato were significantly affected by the bilateral interaction between deficit irrigation levels and NPK fertilization rates at $p<0.05$. Thence all mentioned measurements recorded greater values with irrigation treatments of control treatments (SI_{100}, SSI_{100}) and deficit irrigation treatments (DI_{80}, DI_{60}) under higher NPK fertilization rate (100%) compared to the same treatments under lower NPK fertilization rates (75% and 50%). Under each NPK fertilization rate the greatest values of these parameters were recorded with SSI_{100} followed by DI_{80} then SI_{100} but the lowest values were recorded with DI_{60}. Except root dry weight and root length, the greatest values of other plant growth measurements were recorded by treatment of combined of SSI_{100} and 100% NPK fertilization rate while the lowest values were obtained by combined DI_{60} irrigation level and 50% NPK fertilization rate. Nevertheless, roots recorded higher dry weight in both SSI_{100} and DI_{80} irrigation rate under 100% NPK fertilization rate compared to other interactive treatments. Root length appeared to be significantly superior in DI_{80} irrigation level than in SSI_{100} each combined with 100% NPK fertilization rate.

At first, attention should be paid that irrigation water is a substantial factor in plant life where it must be offered at a secure level to enabling the plant to produce a higher yield and quality. While the demand for fresh water is increasingly and the agriculture is the main consumer of water wherefore adopting deficit irrigation policies are a must. Deficit irrigation means irrigation by less water quantity than that of crop evapotranspiration (Dodd, 2009). Concerning our results, the superiority of plant performance in SSI_{100} than in SI_{100} may be due to many reasons. What described in Figure (1) where soil water content at 30 and 60 cm depth (rhizosphere zone) was higher in SSI_{100} than SI_{100} but depletion of water was higher in SI_{100} than SSI_{100} although irrigation water was equally. This means more available water in the soil with SSI_{100} than SI_{100}. Applying subsurface irrigation in SSI_{100} treatment directly supplied water to rhizosphere zone so led to minimizing losing the water through evaporation compared to applying surface irrigation in SI_{100}. This proposition corresponds to what found by Zobel (2002) who stated that irrigation practices contribute to improving plant performance and increase the water productivity. Our result in parallel line with findings by Douh *et al*. (2013), Hassan and Abuarab (2013) and Al-Mansor *et al.* (2015) and consistent to cited reviewing in the article of Lamm *et al.* (2012).

When irrigation was at suboptimal supply the relationship between crop evapotranspiration and its yield is near-linear (Fereres and Soriano, 2007). So deficit irrigation could lead to occurring plant stress, where the water quantity less than that of evapotranspiration, depending on the severity of water deficiency. Irrigation is a substantial factor of plant life so that increasing of irrigation deficiency level may lead to decreasing vegetative measurements values. Because of deficit irrigation reduce soil water constants and subsequently reduce water availability of soil layers. The treatment of DI_{80} recorded values of soil water constants much less than in SSI_{100} treatment but little less than in SI_{100} treatment. Therefore, the differences between SI_{100} and DI_{80} appeared to be not significant for most vegetative measurements except root attributes but appeared to be significantly lower than SSI_{100}. Man *et al.* (2016) mentioned that moderate soil water content increases root distribution over soil layers as well as Li *et al.* (2010) who reported that restricted irrigation regimes increase root density in soil layers. This matches with our results which reveal to recording longer and heavier root with mild deficit irrigation (DI_{80}) compared to either full or deficit irrigation severely.

Furthermore, these result related with root shoot ratio measurement which was affected by the same manner for the same reason. Where the highest root shoot ratio was recorded with the DI_{80} application. Garcia *et al.* (2007) stated that increasing root to shoot ratio is a plant mechanism for ameliorating its performance under drought conditions. Harris (1992) concluded that root length is probably a better measure of the absorbing ability of roots this is proved by our results whereby the longer roots in DI_{80} treatment led to the converging effect of DI_{80} and SI_{100} although different irrigation water quantity.

Table 5: Effect of combination of deficit irrigation levels and NPK fertilization rates on vegetative growth parameters of tomato plants (The displayed data is a combined of the collected data within the two growing seasons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Plant length (cm)				Branches number				Shoot dry weight (g)			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	72.4bc	68.5d	60.3f	67.1b	8.67b	8.00c	7.33de	8.00ab	136.83c	113.66d	101.26ef	117.25c
Subsurface 100%(SSI_{100})	75.1a	73.1b	70.6c	72.9a	9.33a	8.67b	7.67cd	8.56a	173.75a	139.96c	106.97e	140.23a
Subsurface 80% (DI_{80})	72.8b	67.5d	63.8e	68.0b	8.67b	8.00c	7.00e	7.89b	150.87b	115.48d	100.68fg	122.34b
Subsurface 60% (DI_{60})	58.3g	55.6h	40.2i	51.4c	6.33f	6.00f	4.33g	5.55c	94.63g	76.1h	54.41i	75.05d
Average	69.7a	66.2b	58.7c		8.25a	7.67a	6.58b		139.02a	111.3b	90.83c	

Averages followed by the same letter of each group do not differ significantly.

Irrigation rate (% ETc) and type (surface - subsurface)	Root dry weight (gm)				Root length (cm)				Shoot : Root ratio			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	33.56b	28.81cd	26.62e	29.66b	36.5bc	34.6d	29.8ef	33.6b	4.08bc	3.95c	3.80c	3.94b
Subsurface 100%(SSI_{100})	36.34a	32.08b	26.8e	31.74a	37.2b	36.8bc	30.2e	34.7b	4.78a	4.36b	3.99c	4.38a
Subsurface 80% (DI_{80})	37.38a	29.86c	25.9e	31.05ab	43.6a	35.4cd	30.3e	36.4a	4.04bc	3.87c	3.89c	3.93b
Subsurface 60% (DI_{60})	27.64de	23.49f	18.48g	23.20c	27.0f	25.7g	20.2h	24.6c	3.42d	3.24e	2.94e	3.20c
Average	33.73a	28.56b	24.45c		36.3a	33.1b	27.6c		4.08a	3.85b	3.66c	

Averages followed by the same letter of each group do not differ significantly

Water uptake and plant nutrient absorption are closely correlated. When plant roots absorb water, dissolved nutrients are moved to the root surface. When water uptake is restricted, the delivery of nutrients to the root also is limited. As the soil dries and the films of water between the particles shrink, the processes of mass flow and diffusion that bathe the roots with nutrients eventually stopped. Tomato has a strict requirement of a balanced fertilization management, without which the growth becomes poor. Tomato is a heavy remover of nutrients so for optimal growth the optimum dose and balanced proportion of fertilizers is a must. As shown by Hebbar *et al.* (2004) tomato responds well to fertilization and to be a severe feeder of nitrogen (N), phosphorus (P), and potassium (K) fertilizer. Furthermore, under deficit irrigation conditions, reduction fertilization rate leads to duplicate the adverse effect and consequently further poor growth. Thus, for saving irrigation water by about 20% as which in DIs0 treatment and without a greater reduction in most vegetative growth parameters, it has to applied full NPK fertilization rate. As well-known nitrogen, phosphorus and potassium play vital roles in plant life. Under normal conditions or in other words without stress, the beneficial impact of balance of combined nitrogen, phosphorus and potassium fertilization on tomato was previously reported by many researchers as Melton and Dufault (1991), Liu *et al*. (2008), Kumar *et al* (2013) and Ortas (2013). However, under mild drought Saneoka *et al*. (2004) observed that increasing nitrogen fertilization rate may stimulate drought tolerance. Also, Garcia *et al*. (2007) concluded that tolerance of moderate water stressed tomato could be improved by limited nitrogen fertilization. Otherwise, Xiukang, and Yingying (2016) found that tomato plant growth is more sensitive to irrigation than NPK fertilization and the interaction between them does not significant.

Leaf area and chlorophyll content.

Leaf area and leaf chlorophyll florescence as SPAD of tomato plants were affected by both deficit irrigation level and fertilization rate. So the highest value of each of these parameters was recorded with SSI_{100} treatment however, the lowest value was obtained with deficit irrigation treatment of DI_{60}. Meanwhile, these two variables appeared to not differ significantly under both SI_{100} and DI_{80} treatments. The two variables significantly decreased as NPK fertilization rate decreased from 100% to 50% of NPK fertilization requirements.

Xiukang, and Yingying (2016) reported that tomato leaf expansion more sensitive to irrigation amount but leaf composition more sensitive to NPK fertilization rate. Also, the plant may be developed small leaves as a mechanism of drought alleviation (Garcia *et al.,* 2007). Therefore, our results revealed to the highest leaf area was obtained with SSI_{100} but the least leaf area was recorded in DI_{60}. Leaf chlorophyll content expressed as SPAD was found sensitive to fertilization rate so its values were linearly correlated with NPK fertilization rate.

As for the bilateral interaction effect of irrigation level and fertilization rate, it is appeared to be statistically significant on leaf area and chlorophyll SPAD. The data of leaf area and chlorophyll SPAD proved that under full NPK fertilization rate (100%), each irrigation treatments of SI_{100}, SSI_{100}, and deficit irrigation of DI_{80} treatment did not significantly differ but have significantly higher values compared to irrigation with DI_{60}. The lowest values of both leaf area and chlorophyll SPAD were recorded in the treatment of 50% NPK fertilization rate combined with DI_{60} treatment. Leaf growth response to the interaction between irrigation level and NPK fertilization rate appeared to be not significant according to findings of Xiukang, and Yingying (2016). However, according to Hebbar *et al*. (2004), tomato leaf area and chlorophyll content were affected significantly by the interaction between irrigation and NPK fertilization. Hebbar *et al.* (2004), Sack and Scoffoni (2013) and Xiukang, and Yingying (2016) highlighted that the main function of plant leaves is photosynthesis process and construction the organic compounds mainly carbohydrates, so that any factors or practice primarily fertilization and irrigation improves leaves growth then increases net assimilation of organic nutrients and subsequently plant growth and yield and quality.

Table 6: Effect of combination of deficit irrigation levels and NPK fertilization rates on leaf area and chlorophyll florescence of tomato plants (The displayed data is a combined of the collected data within the two growing seasons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Leaf area (cm^2)				Leaf chlorophyll SPAD			
	NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	48.47a	45.88b	41.94cd	45.43b	46.33a	43.85c	40.58d	43.59b
Subsurface 100%(SSI_{100})	49.16a	47.64ab	45.89b	47.56a	46.68a	46.46ab	44.21bc	45.78a
Subsurface 80% (DI_{80})	48.30a	43.11c	41.15d	44.19b	47.48a	43.18c	39.39d	43.35b
Subsurface 60% (DI_{60})	38.20e	31.37f	26.77g	32.09c	38.36d	31.67e	27.42f	32.48c
Average	46.03a	41.98b	38.94c		44.71a	41.29b	37.90c	

Averages followed by the same letter of each group do not differ significantly

Leaf water relations

Leaf relative water content (RWC) did not differ significantly between irrigation treatments SI_{100}, SSI_{100} and DI_{80} but it recorded least significant value under treatment of DI_{60}. For the response of RWC to NPK fertilization rate, it decreased significantly with decreasing fertilization rate from 100% to 50%. RWC was affected by the combination of NPK fertilization rate and deficit irrigation level, where RWC values were changed between 89.44% and 58.36% in the treatment of combined SSI_{100}

and full NPK fertilization rate and the treatment of combined DI_{60} and 50% NPK fertilization rate, respectively. Under 100% of NPK fertilization rate, each irrigation treatments recorded a significant higher value of RWC than the parallel treatment under lower NPK fertilization rate. On the other hand, the greatest values of RWC were obtained under full of NPK fertilization rate combined with irrigation treatments of SI_{100}, SSI_{100} and DI_{80}.

Table 7: Effect of combination of deficit irrigation levels and NPK fertilization rates on Leaf relative water content, Electrolyte leakage and Leaf water potential of tomato plants (The displayed data is a combined of the collected data within the two growing seasons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Leaf relative water content (%)				Electrolyte leakage (%)				Leaf water potential (MPa)			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	88.63a	79.46cd	72.58f	80.22a	13.42a	15.46a	32.68d	20.52a	-0.05a	-0.07bc	-0.09de	-0.070a
Subsurface 100%(SSI_{100})	89.44a	85.39ab	75.94de	83.59a	12.96a	14.39a	28.84c	18.73a	-0.05a	-0.07bc	-0.08cd	-0.067a
Subsurface 80% (DI_{80})	87.88a	82.76bc	73.66f	81.43a	13.74a	16.24a	33.47e	21.15a	-0.06ab	-0.10e	-0.19f	-0.117b
Subsurface 60% (DI_{60})	73.28f	66.52f	58.36g	66.05b	18.52b	27.84c	44.23f	30.20b	-0.25g	-0.28h	-0.36i	-0.297c
Average	84.81a	78.53a	70.14b		14.66a	18.48b	34.81c		-0.103a	-0. 130ab	-0.180b	

Averages followed by the same letter of each group do not differ significantly

Concerning electrolytes leakage percent (EL) of plant leaves as an indicator of cell membrane stability, the data proved variation in the electrolytes leakage percent affected by both irrigation level and NPK fertilization rate. Thence the higher significant value of EL measurements was recorded with application DI_{60} compared to irrigation treatments of SI_{100}, SSI_{100} and DI_{80}. Also, the EL was significantly increased by decreasing NPK fertilization rate where the amount of electrolyte leakage was increased more than doubled with reduction the NPK fertilization rate to half.

The effect of interaction between irrigation level and fertilization rate proved to be significant on EL in plant leaves. Generally, EL was increased by reducing both irrigation level and fertilization rate. The greatest significant values of EL were obtained with interaction treatments of application of either deficit irrigation level of 60%ETc or 50% fertilization rate either individually or together. Meanwhile, the least significant values of EL were recorded by interaction between irrigation treatments of either SI_{100} or SSI_{100} or DI_{80} with either 100% or 75% NPK fertilization rate.

Data of Leaf water potential (ψ) proved that the water potential of leaves decreased affecting by decrease either irrigation level or NPK fertilization rate. It is noticeable that ψ was more sensitive to irrigation level deficiency than to decreasing NPK fertilization rate. So the ψ decreased from -0.67 to -0.297 when irrigation level decreased from 100%ETc to 60%ETc meanwhile decreased from -0.25 to -0.36 when NPK fertilization rate decreased from 100% to 50%.

The effect of interaction between deficit irrigation level and NPK fertilization rate appeared to be significant on ψ**.** Therefore, the reduction in ψ which related with irrigation deficiency appeared to be severe (-0.05 to -0.25) under full NPK fertilization rate (100%) comparing with its reduction (-0.09 to -0.36) under the least NPK fertilization rate (50%). While ψ values did not show significant differences with either SSI_{100}, SI_{100} and DI_{80} each under fertilization rate of 100%. The least ψ value was recorded in treatment which combined DI_{60} and least fertilization rate (50%).

RWC, ψ and partially EL were linearly correlated and reflect the water status of the plant. Water availability in the soil affects water status of the plant and subsequently closely relate to nutrients absorption by the plant. Thence according to Jones (1990) measuring water potential of plant leaf has been used as a tool to monitor the water status of the plants. Therefore, as reported by Arndt *et al*. (2001) maintenance of a sufficiently high water content and leaves water potential is the essential factor in plant water relations during drought periods to permit growth. Drought led to a reduction in water contents of plant tissue and subsequently water potential, leaf expansion, leaf photosynthesis, and changes in protein synthesis, nitrogen metabolism, and cell membrane properties, resulting in a reduction in plant productivity (Shangguan *et al*., 2000; Saneoka *et al*., 2004). Topcu (2007) reported that measurements of ψ, stomatal conductance and the photosynthetic rate showed the similar behavior.

Mineral nutrition is one of the most important factors affecting plant growth and water relations (Goldstein *et al.*, 2013) so that the proper mineral nutrition mainly with nitrogen phosphorus and potassium might be fundamental for plant hydraulic properties. In well-watered *Laurus nobilis* L. plants, short-term potassium fertilization increased xylem sap potassium concentration, resulting in an increase in plant hydraulic conductance (Kplant), leaf-specific shoot hydraulic conductivity and plant transpiration (Oddo *et al*., 2011, Oddo *et al*., 2014). Moreover, there is increasing evidence that an optimal potassium nutritional status can reduce the effects of abiotic stresses such as drought, heat, high light intensity or salinity (Oosterhuis *et al*., 2013). In fact, potassium plays a key role in many processes related to adaptation to drought stress (Grzebisz *et al*., 2013), such as cell osmoregulation, leading to the maintenance of cell turgor and cell expansion necessary to promote root growth as well as stomatal conductance and subsequently gas exchange. Adequate levels of potassium are also required for regulation of stomatal aperture and optimization of water-use effiiency (Egilla *et al*., 2005). While potassium deficiency appeared to be negatively affect the water status and photosynthesis in tomato (Kanai *et al*., 2011). Garcia *et al*. (2007) found that moderate water stressed tomato showed decrease in leaf water potential and increase in leaf osmotic potential and subsequently decrease in stomatal conductance and gas exchange. Meanwhile balanced nitrogen addition quantity and form contribute to recovery the adverse effect of drought through a process of osmotic and elastic adjustment. Liu *et al*. (2012) suggested that water and nitrogen are closely related, and nitrogen at low rate enhance drought tolerance and WUE through increased photosynthetic capacity and water uptake. Therefore, an appropriately low nitrogen supply would be recommended under dry conditions however excess nitrogen supply should be avoided. For phosphorus nutrition combined with stress, Dosskey *et al*. (1993) indicated to that adjusting phosphorus nutrition does not alleviate drought stress when the plants show a nitrogen deficiency. Finally, the results support that irrigation level and NPK fertilization rate affect strongly leaf growth, characteristics and function. The balance between N, P and K nutrients especially under drought conditions is a must to ameliorate stress and maintain growth and yielding. Our results in accordance with those of Xiukang and Yingying (2016) where our results prove that full NPK fertilization rate could efficiently alleviate mildly deficit irrigation stress (restitution $DI_{80)}$ and maintain leaf properties and functions.

Leaf NPK content

Data in Table (8) demonstrate the content of NPK of tomato plant leaves affected by NPK fertilization rate under irrigation levels. It is noticed that nutrient content of tomato plant leaves was decreased with decreasing both NPK fertilization rate and deficit irrigation level. In terms of interaction effect, it was observed that NPK nutritional content in plant leaves was significantly affected by combination of both NPK fertilization rates and irrigation levels. NPK nutritional content recorded higher values in all irrigation treatments under full NPK fertilization rate (100%) than the counterparts under lower N|PK fertilization rates of either 75% or 50%. The highest nitrogen content was obtained with both full irrigation (SI_{100} and SSI_{100}) and DI_{80} each combined with 100% NPK fertilization rate. The highest value of phosphorus content was obtained in full irrigation SSI_{100} and DI_{80} each combined with 100% NPK fertilization rate. However, the highest value of potassium content was observed with full irrigation SSI_{100} combined with 100% NPK fertilization rate. In contrast, the least significant value of nitrogen, phosphorus and potassium was an accompanying of 50% NPK fertilization rate combined with DI_{60}.

Maintaining proper soil conditions will enhance the volume of soil that roots exploit. For example, a soil that has a compacted zone or a hard pan will present a barrier to plant roots and restrict their use of moisture deeper in the soil profile. Similarly, when subsoil water content is least of which meet the plant needs, plant growth is stunted and roots cannot grow and exploit the soil to utilize water and nutrients. So that when soil conditions are proper since nutrients are balanced in concentration and form along with water content within available water range, the roots are healthy and enable to absorb water and nutrients efficiently. Our results are consistent with this proposition where the presented data in figure (1) indicates that soil water content is within the range of readily water content in SI_{100}, SSI_{100} and DI_{80} although soil water content of DI_{80} was near the low limit of readily water content meanwhile soil water content in DI_{60} is lower than readily water content. Otherwise according to the data in table (5) which indicated to that the highest root weight and length are obtained in DI_{80}, followed by SSI_{100} and SI_{100} and then DI_{60}, respectively. Moreover, shoot: root ratio measurement recorded the highest value in SSI_{100} followed by both SI_{100} and DI_{80} but the lowest value is recorded in DI_{60}. Concerning the interaction between deficit irrigation treatment and NPK fertilization treatments, the irrigation treatments show the previous mentioned behavior when combined with the experimental NPK rates but their performance was superior under the highest NPK fertilization level. Based on the presented above and since the absorbed nutrients and water are transferred to the leaves where the process of photosynthesis and plant food preparation (Monclus *et al*., 2006), the activity of roots in the absorption process clearly reflected in NPK content of leaves. Therefore, the highest N, P and K values in leaves are got in SSI_{100} followed by either of SI_{100} and DI_{80} and lastly DI_{60}. NPK fertilization rates show affect linearly on NPK content of leaves with NPK fertilization rate may be due to that the experimental rates lay within tomato NPK fertilization range. Our results are in line with those findings by Melton and Dufault (1991), Ortas, I. (2013), Al-Mansor *et al*. (2015) and Xiukang and Yingying (2016). Also, Zhen *et al*. (1996) reported that the N, P and K uptake of eggplant seedlings increased with increasing application rates of N, P and K fertilizers.

Table 8: Effect of combination of deficit irrigation levels and NPK fertilization rates on leaf NPK content (The displayed data is a combined of the collected data within the two growing sea sons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Nitrogen content of plant (%)				Phosphorus content of plant (%)				Potassium content of plant (%)			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	0.64a	0.56bcd	0.36ef	0.52b	0.29bc	0.25cd	0.19ef	0.24b	0.87b	0.76de	0.62gh	0.75b
Subsurface 100%(SSI_{100})	0.66a	0.59abc	0.42e	0.56a	0.32a	0.29bc	0.22de	0.28a	0.94a	0.79cd	0.68fg	0.80a
Subsurface 80% (DI_{80})	0.63ab	0.51d	0.31fg	0.48c	0.30ab	0.24d	0.17fg	0.24b	0.85bc	0.75de	0.6h	0.73b
Subsurface 60% (DI_{60})	0.52cd	0.37ef	0.24g	0.38d	0.23de	0.19ef	0.13g	0.18c	0.72ef	0.68fg	0.46i	0.62c
Average	0.61a	0.51b	0.33c		0.29a	0.24ab	0.18b		0.85a	0.75b	0.59c	

Averages followed by the same letter of each group do not differ significantly

Yield component

Average fruit weight, average plant fruits yield, estimated yield and marketable yield have found to be correlated positively (Bachmann *et al.,* 2014) and appeared to be significantly affected by deficit irrigation level and/or NPK fertilization rates. All yield variables recorded the highest values in SSI_{100}, however, the least values were recorded in DI_{60}. Average fruit weight did not significantly differ between SI_{100}, SSI_{100} and DI_{80}. Plant yield and total and marketable yield did not significantly differ with both SI_{100} and DI_{80} meanwhile appeared to be significantly least than SSI_{100} but higher than DI_{60}. For the absolute effect of NPK fertilization rate on yield and its variables, it has significantly decreased with decreasing the NPK fertilization rate. The data proved that the yield and its variables were highly sensitive to both irrigation and fertilization. So the effect of irrigation treatments combined with NPK fertilization rates on yield and its variables appeared to be significant. all yield parameters altered by irrigation level and/or NPK fertilization rate. The yield and its coponent are increased by increasing either or both irrigation rate and/or NPK fertilization rate. Total yield was reduced about 11.66% and 47.57 when irrigation water reduced to 80%ETc and 60%ETc, respectively. While the yield component were reduced with decreasing NPK fertilization rate from 100% to 50% by about 23.87%, 45.61%, 46.61 and 45.61% in average fruit weight, average plant yield and marketable and estimated yield per hectare, respectively.

Table 9: Effect of combination of deficit irrigation levels and NPK fertilization rates on yield component and water use efficiency of tomato plants (The displayed data is a combined of the collected data within the two growing seasons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Average fruit weight (g)				Average fruits yield/ plant				Estimated yield per hectare (ton)			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	Average	100%	75%	50%	Average
Surface 100% (SI_{100})	158.67bc	148.86bc	120.29gh	142.61ab	6.78b	5.24d	3.86g	5.29b	84.75b	65.50d	48.25g	66.17b
Subsurface 100%(SSI_{100})	170.46a	160.57b	138.42e	156.54a	7.57a	5.92c	4.36ef	5.95a	94.63a	74.00c	54.50ef	74.38a
Subsurface 80% (DI_{80})	157.32bc	145.38ce	123.69gh	142.13ab	6.52b	5.17d	4.08fg	5.26b	81.50b	64.63d	51.00fg	65.71b
Subsurface 60% (DI_{60})	133.64fg	110.88h	90.06i	111.53c	4.65e	3.24h	1.58i	3.16c	58.13e	40.50h	19.75i	39.46c
Average	155.02a	141.42a	118.12b		6.38a	4.89b	3.47c		79.75a	61.16b	43.38c	

Irrigation rate (% ETc) and type (surface - subsurface)	Marketable yield per hectare (ton)				Water use efficiency kg/m^3			
	NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	average
Surface 100% (SI_{100})	76.45b	50.56d	36.35ef	54.45b	11.44c	7.57f	5.44h	11.44c
Subsurface 100%(SSI_{100})	87.73a	56.44c	41.48e	61.88a	13.13b	8.45e	6.21g	13.13b
Subsurface 80% (DI_{80})	75.32b	51.83cd	39.26e	55.47b	14.09a	9.7d	7.34f	14.09a
Subsurface 60% (DI_{60})	34.43f	26.67g	10.57h	23.89c	8.59e	6.65g	2.64j	8.59d
Average	68.48a	46.38b	31.92c		11.81a	8.09b	5.41c	

Averages followed by the same letter of each group do not differ significantly

To obtain higher yield and maximum profit in commercial tomato production, optimal management of both fertilizer and water are required (Scholberg *et al*., 2000). Tomato appeared to be a gluttonous feeder of nutrients of nitrogen, phosphorus, and potassium so that it is responded well to fertilization with these elements (Hebbar *et al*., 2004, Xiukang and Yingying, 2016). Ozbahce and Tari (2010) and Xiugang and Yingying (2016) showed that tomato fruit yield responded significantly to NPK fertilization and irrigation individually or interactive. Anyway, yielding is a final conclusion of the previous plant stages and which closely related. So that maintaining proper growth factors will enhance vegetative growth and subsequently improve yield parameters. According to the previously presented data, mildly deficit irrigation (DI_{80}) combined with full NPK fertilization rate produced higher root length which exploited wide rhizosphere area and had enabling absorption more water and nutrients. Finally, based on the above and as provided elsewhere in this paper the treatments which augmented shoots and roots growth and metabolism potential, mainly absorption of water and nutrients and photosynthesis processes, are able to produce higher yield and quality. Our data revealed that SSI_{100} followed by both SI_{100} and DI_{80} then lastly DI_{60} is the proposed arrange for the experimental treatments based on the efficient of them in improving plant growth and yielding.

Statistically, the difference between SI_{100} and DI_{80} often not significant while DI_{60} resulted in the adverse effect on plant growth and yield. Therefore, to determine the best treatment if SI_{100}, SSI_{100} or DI_{80}, it is necessary to utilize a proper criterion as water use efficiency (Howell, 2006). DI_{80} is the best irrigation treatment due to the highest WUE recording (Table, 9). DI_{80} as a mild deficit irrigation caused a certain drought stress on the plant. So as to does not double the stress on the plant due to irrigation and fertilization, full NPK fertilization is the best fertilization treatment either individual or combined with DI_{80}. On the other hand, NPK fertilization improves plant performance under light stress (Ozbahce and Tari, 2010, Xiukang and Yingying, 2016). Our results are consistent with those of Ozbahce and Tari (2010), Ortas (2013) Al- Mansor *et al*. (2015) and Xiukang and Yingying, 2016).

Fruit quality parameters

According to the findings of Xiukang and Yingying (2016) which revealed that tomato dry matter accumulation was mainly due to irrigation and fertilization. The results of Ozbahce and Tari (2010) proved that tomato yield quantity responded mainly to irrigation but soluble solids content responded mainly to fertilization. Our results demonstrate that total soluble content (TSS) in tomato fruits appeared to be more sensitive to NPK fertilization than irrigation. So the highest value of TSS was obtained when combined mild deficit irrigation (DI_{80}) and full NPK fertilization but the least value of TSS was obtained with combined severe deficit irrigation and least NPK fertilization rate. Titratable acidity (TA) of tomato fruit juice has altered affected by irrigation and NPK fertilization in the same manner of the TSS response to irrigation and fertilization. L ascorbic acid content in tomato fruit juice appeared to be sensitive to both irrigation and fertilization. The magnitude content of L ascorbic acid was recorded in 80% ETc (DI_{80}) irrigation and 100% NPK fertilization. So the mild deficit irrigation increased L ascorbic content but severe deficit irrigation reduced its content. The interaction between deficit irrigation and fertilization appeared to be significant and the higher content of L ascorbic acid was recorded in treatment of combined 80% ETc (DI_{80}) irrigation and 100% NPK fertilization. These results were consistent with those of Ozbahce and Tari (2010), Wahba-Allah and Omran (2012) and Xiukang and Yingying (2016).

Table 10: Effect of combination of deficit irrigation levels and NPK fertilization rates on fruits quality of tomato plants (The displayed data is a combined of the collected data within the two growing seasons 2014 and 2015).

Irrigation rate (% ETc) and type (surface - subsurface)	Total soluble content (%)				L ascorbic content				Total titratable acidity			
	NPK rate (% of requirements)				NPK rate (% of requirements)				NPK rate (% of requirements)			
	100%	75%	50%	Average	100%	75%	50%	average	100%	75%	50%	average
Surface 100% (SI_{100})	5.57b	4.82d	2.98f	4.46a	18.82a	16.27b	14.34d	16.48a	0.56b	0.50b	0.43c	0.50b
Subsurface 100%(SSI_{100})	5.26b	4.96cd	3.06f	4.43a	18.86a	16.42b	14.65d	16.64a	0.58b	0.51b	0.48c	0.52b
Subsurface 80% (DI_{80})	6.08a	5.38bc	3.14f	4.87a	18.42a	15.68c	14.02d	16.04b	0.69a	0.59b	0.50b	0.59a
Subsurface 60% (DI_{60})	4.34e	3.86e	2.17g	3.46b	15.36c	13.67e	11.94f	13.66c	0.67a	0.46c	0.33d	0.49b
Average	5.31a	4.76b	2.84c		17.87a	15.51b	13.74c		0.63a	0.52b	0.44c	

Averages followed by the same letter of each group do not differ significantly

Conclusion

Deficit irrigation becomes a targeted strategy for rationalization and saving the consumed water in irrigated agriculture especially in regions suffer from water-scarce as the case of Egypt. Although limited or slight deficit irrigation leads to optimizing production and subsequently rising water use efficiency or water productivity but it may have adversely effect on plant growth and yield and quality. Otherwise, plants grown under deficit irrigation must be a well-fertilized so as not to suffer from double stress. Our results of the combination of NPK fertilization at three rates and irrigation at four treatments on open field tomato proved that providing plants with full NPK fertilization requirements can minimize deficit irrigation stress especially when soil water content was above the wilting point. Therefore, our results suggest applying the treatment of combined of deficit irrigation level of 80%ETc and full NPK fertilization requirements for tomato cv. Elisa production under an environment conditions like that of the experiment. Thus this treatment enhanced plant performance to near of that unstressed treatment although saving 20% of irrigation water as well as higher fruit quality.

References

Al-Mansor, A.N., A.M.El-Gindy, M.M Hegazi, K.F., El-Bagoury and S.A. Abd-El Hady, 2015. Effect of surface and subsurface trickle irrigation on yield and water use efficiency of tomato crop under deficit irrigation conditions. Misr J. Ag. Eng. 32(3): 1021 -1040.

Alomran, M. and I.I. Luki, 2012. Effects of deficit irrigation on yield and water use of grown cucumbers in Saudi Arabia. WIT Transactions on Ecology and The Environment, Vol. 168, WIT Press, www.witpress.com, ISSN 1743-3541, (online) doi: 10.2495/SI120301.

Arndt, S.K., S.C. Clifford, W. Wanek, H.G. Jones and M.Popp, 2001. Physiological and morphological adaptation of the fruit tree Ziziphus rotundifolia in response to progressive drought stress. Tree Physiol. 21: 705-715.

Badr, M.A., S.I. Shedeed and S.D.Abou Hussein, , 2012. Tomato fruit yield and nitrogen use efficiency as affected by drip irrigation method and rate of nitrogen in a hot dry climate. Journal of Applied Sciences Research 8(8): 4486-4495.

Boyer, J.S., 1967. Leaf water potentials measured with a pressure chamber. Plant Physiol. 43: 1056-1062.

Chai, Q., Y.Gan, C.Zhao, H.L. Xu, R.M.Waskom, Y. Niu and K.H.Siddique, 2016. Regulated deficit irrigation for crop production under drought stress. A review. Agron. Sustain. Dev. 36: 1- 21.

Dehghanisanij, H., T.Oweis and A.S.Qureshi, 2006. Agricultural Water Use and Management in Arid and Semiarid areas: Current Situation and Measures for Improvement. Annals of Arid Zone 45(2): 1-24.

Dodd, I. C., 2009. Rhizosphere manipulations to maximize 'crop per drop' during deficit irrigation. Journal of Experimental Botany 60 (9): 2454-2459.

Dosskey, M.G., L.Boersma and R.G.Linderman, 1993. Effect of phosphorus fertilization on water stress in douglas fir seedlings during soil drying. Plant and Soil 150: 33-39.

Douh, B., A.Boujelben, S.Khila and A. Bel Haj Mguidiche, 2013. Effect of subsurface drip irrigation system depth on soil water content distribution at different depths and different times after irrigation. Larhyss Journal 13: 7-16.

Evans, R.G. and E.J.Sadler, 2008. Methods and technologies to improve efficiency of water use. Water Resources. Res. 44 (7) :1—15.

Fan, T., B.A.Stewart, W.A.Payne, Y.Wang, S.Song, J. Luo and C.A.Robinson, 2005. Supplemental irrigation and water: yield relationships for plasticulture crops in the loess plateau of China. Agronomy Journal 97: 177—188.

FAO-CROPWAT software version 8 to calculate crop water requirements. (see http://www.fao.org/nr/water/infores_databases_cropwat.html)

Fereres, E. and M.A.Soriano, , 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany 58(2): 147—159.

Garcia, A.L., L.Marcelis, F.Garcia -Sanchez, N.Nicolas and V.Martinez, 2007. Moderate water stress affects tomato leaf water relations in dependence on the nitrogen supply. Biologica Plantarum 51 (4): 707712.

Gardenas, A.I., J.W. Hopman, B.R.Hanson and J.Simunek, 2005. Two-dimensional modeling of nitrate leaching for various fertigation scenarios under micro-irrigation. Agric. Water Management 74(3): 219-242.

Hachmann, T.L., M.M.Echer, G.M. Dalastra, E.S. Vasconcelos and V.F.Guimaraes, 2014. Tomato cultivation under different spacing and different levels of defoliation of basal leaves. Bragantia 73 (4) 399406.

Harris, R.W., 1992. Root - shoot ratio. Journal of Arboriculture 18(1): 39-42.

Hassan, A.M. and M.E.Abuarab, , 2013. Effect of deficit irrigation water on the productivity and characteristics of tomato. Misr J. Ag. Eng. 30(2):403-424.

Hebbar, S.S., R B.K.amachandrappa, H.V.Nanjappa and M.Prabhakar, , 2004. Studies on NPK drip fertigation in field grown tomato (*Lycopersicon esculentum* Mill.). European Journal of Agronomy 21 (1): 117-127.

Howell, T.A., 2006. Challenges in increasing water use efficiency in irrigated agriculture. International Symposium on Water and Land Management for Sustainable Irrigated Agriculture, April 4-8, 2006, Adana, Turkey. p. 11.

James, L.G., 1988. Principles of farm irrigation system design. John Wiley & Sons Inc., New York. 480 pages.

Jat, R.A., S.P.Wani, K.L.Sahrawat, P.Singh and B.L.Dhaka, 2011. Fertigation in vegetable crops for higher productivity and resource use efficiency. Indian Journal of Fertilizer 7 (3): 22-37.

Jones, J.A., 1990. Valuable information from accurate crop estimation. Adelaide. Aust. Grape grow. Winemak., (31 6): 59-60.

Kanai, S., R.E.Moghaieb, H.A.El-Shemy, R. Panigrahi, P.K.Mohapatra, J.Ito, N.T.Nguyen, H.Saneoka and K. Fujita, 2011. Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in green house tomato prior to its effects on source activity. Plant Sci. 180: 368-374.

Kirda, C., S.Topcu, H.Kaman, A.C. Ulger, A. Yazici, M. Cetin and M.R.Derici, 2005. Grain yield response and N-fertilizer recovery of maize under deficit irrigation. Field Crops Res., 93: 132-141.

Kumar, M., M.L.Meena, S.Kumar, S. Maji and D.Kumar, 2013. Effect of nitrogen, phosphorus and potassium fertilizers on the growth, yield and quality of tomato var. Azad T-6. The Asian Journal of Horticulture 8(2): 616-619.

Lamm, F.R., J.P.Bordovsky, L.J.Schwankl, G.L.Grabow, J.Enciso-Medina, R.T. Peters, P.D. Colaizzi, T T.P.rooien and D.O.Porter, 2012. Subsurface drip irrigation: status of the technology in 2010. American Society of Agricultural and Biological Engineers 55(2): 483-491.

Li, Q.Q., B.D. Dong, Y. Z.Qiao, M. Y.Liu and J.W.Zhang, 2010. Root growth, available soil water, and water-use efficacy of winter wheat under different irrigation regimes applied at different growth stages in North China. Agricultural Water Management 97: 1676-1682.

Liu, B., L.Cheng, M.Li, D.Liang, Y.Zou and F.Ma, 2012. Interactive effects of water and nitrogen supply on growth, biomass partitioning, and water-use efficiency of young apple trees. African Journal of Agricultural Research 7(6): 978-985.

Liu, Z.H., L.H Jiang, X.L.Li, R.Hardter, W.J.Zhang, Y.L.Zhang and D.F.Zheng, 2008. Effect of N and K fertilizers on yield and quality of greenhouse vegetable crops. Pedosphere 18:496-502.

Melton, R.R. and R.J.Dufault, 1991. Nitrogen, phosphorus, and potassium fertility regimes affect tomato transplant growth. HortScience 26(2):141-142.

Man, J., Y. Shi, Z.Yu and Y. Zhang, 2016. Root growth, soil water variation and grain yield response of winter wheat to supplemental irrigation. Plant Production Science 19 (2): 193-205.

Monclus, R., E.Dreyer, M. Villar, F.M. Delmotte, D. Delay, J.M.Petit, C. Barbaroux, D.L. Thiec, C.Brechet and F.Brignolas, 2006. Impact of drought on productivity and water use efficiency in 29 genotypes of Populus deltoides, Populus nigra. New Phytol., 169: 765-777.

Morison, J. I., L.N. R.Baker, P. M.Mullineaux and W. J Davie, 2008. Improving water use in crop production. Philos. Trans. R. Soc. B. 363: 639- 658.

Oddo, E., I S.nzerillo, F.Grisafi, M. Sajeva, S.Salleo and A.Nardini, 2014. Does short-term potassium fertilization improve recovery from drought stress in laurel? Tree Physiology 34: 906-913.

Ortas, I., 2013. Influences of nitrogen and potassium fertilizer rates on pepper and tomato yield and nutrient uptake under field conditions. Scientific Research and Essays 8(23): 1048-1055.

Ozbahce, A. and A.F.Tari, , 2010. Effects of different emitter space and water stress on yield and quality of processing tomato under semi-arid climate conditions. Agricultural Water Management 97: 1405-1410.

Pascale, S.D., L.D.Costa, S.Vallone, G. Barbieri and A.Maggio, 2011. Increasing water use efficiency in vegetable crop production: from plant to irrigation systems efficiency. Hort. Technology 21(3): 301-308.

Patel, N. and T. B. S.Rajput, 2001. Effect of fertigation on growth and yield of onion. Micro Irrigation, CBIP Publication, no 282, p 451.

Sack, L. and C. Scoffoni, 2013. Leaf venation: structure, function, development, evolution, ecology and applications in the past, present and future. New Phytologist 198: 983-1000.

Saneoka, H., R.E.A.Moghaieb, G.S.Premachandra and K.Fujita, 2004. Nitrogen nutrition and water stress effects on cell membrane stability and leaf water relation in Agostis palustris Huds. Environ. Exp. Bot. 52: 131-138.

Shangguan, Z.P., M.G.Shao and J.Dyckmans, 2000. Effects of nitrogen nutrition and water deficit on net photosynthesis rate and chlorophyll fluorescence in winter wheat. J. Plant Physiol 156: 46-51.

Wahba-Allah, M.A. and A.M. AL-Omran, 2012. Effect of water quality and deficit irrigation on tomato growth, yield and water use efficiency at different developmental stages. J. Agric.& Env. Sci. Dam. Univ., Egypt 11 (2) 80:110.

Xiukang, W. and X.Yingying, 2016. Evaluation of the effect of irrigation and fertilization by drip fertigation on tomato yield and water use efficiency in greenhouse. International Journal of Agronomy, Article ID 3961903, 10 pages http ://dx.doi. org/10.1155/2016/3 961903.

Zoebl, D., 2002. Crop water requirements revisited: the human dimensions of irrigation science and crop water management with special reference to the FAO approach. Agric. Hum. Values 19: 173-187.

Zwart, S.J. and W.G.M.Bastiaanssen, , 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management 69: 115-133.