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Effect of irrigation scheduling on yield, quality and water use efficiency of potato plants grown under deficit irrigation conditions

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ABSTRACT
Under arid and semi-arid regions, increasing the efficiency of water consumption has become an imperative. In this concern two field experiments were carried out during the two growing seasons of 2020/2021 and 2021/2022, at the Experimental farm of National Research Centre, in El-Nubaria region, El-Behira Governorate, North of Egypt. Tomato plants were exposed to deficit irrigation (DI) treatments: 100% (control), 80%, 60% and 40% of ET_o (Reference evapotranspiration) and irrigation scheduling (one time per day and two times per day (in the morning and in the evening)) in order to investigate their effects on vegetative growth of potato plants and tubers yield and quality of potatoes. Results show that, deficit irrigation treatments significantly decreased the vegetative growth, tubers yield parameters, total chlorophyll content and tubers quality parameters (N, P, K and carbohydrates), leaf relative water content (LRWC) and membrane stability index (MSI) of potato plants, compared to 100% and 80% ET_o treatments. While, water stress treatments improved irrigation water use efficiency (IWUE). For irrigation scheduling, potato plants which irrigated two times per day produced the highest significant values of vegetative growth, tubers yield and quality characteristics, as well as LRWC and MSI, while the highest significant values of IWUE were observed with potato plants which irrigated one time per day. Regarding, the effect of interaction between deficit irrigation and irrigation scheduling treatments, potato plants were irrigated by 100% or 80% ET_o two times per day produced the highest significant values for vegetative growth and tubers yield of potato plants, as well as enhanced tuber quality parameters. It could be concluded that potato plants which grown under DI conditions (80, 60 and 40% ET_0) with applying the irrigation scheduling two times per day may improve the vegetative growth, tubers yield and quality under sandy soil conditions.

Keywords: Deficit irrigation, Irrigation scheduling, Potato, Yield, Leaf relative water content, Membrane stability index, IWUE.

1. Introduction
Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops in Egypt and all over the world. Potato comes in the fourth grade after wheat, rice and corn in terms of human consumption. It is rich in carbohydrate and it has a large variety of nutrients and various bioactive compounds such as flavonoids, carotenoids and phenolics (Hala *et al*., 2016; Shaheen *et al.* 2019; Mahmoud *et al.*, 2020).

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Actually shortage of water is considered the most important challenge that many countries are facing (Gohar and Ward, 2013). Egypt is located in semiarid to arid climates regions also water management and use are a continuing problem there, regardless the other problems such as climate change, population increase and urban. The effective irrigation management is considered the important factor in increasing agricultural productivity (Walters and Jha, 2016). The total amount of available water in Egypt is about 55.5 milliard m^3/year and the agricultural sector consumes about 85% of the total available water (El Shafei and Seleym, 2017). Therefore, irrigation system is one of the most important components affecting the yield and quality of agricultural production and water should be given in a proper amount and accurate time application.

Water is the most important component in the life, it is essential for most plant functions (Nahar, *et al.* 2011; Alaa, *et al.* 2012). For increasing the productivity of the vegetable crops with conserving the water resource in the same time, it needs to justify the demand of more crops per drop of water (Mukherjee *et al.*, 2010; Bhardwaj and Yadav, 2012). On the other hand, drought is the major stress affecting crop growth, development and yields (Bhardwaj and Yadav, 2012). Several studies have shown that a great reduction of leaf area in tomato plants and other vegetable crops was observed with decreasing the irrigation water quantity (Kahlaoui *et al.,* 2011; Mohawesh, 2016). In the same trend, all vegetative growth parameters of tomato plants (plant height, number of branches, fresh and dry weight/plant) were increased with increasing the irrigation water (Ibrahim, 2005; Sibomana *et al.,* 2013).

Concerning the effect of irrigation water on yield and productivity of vegetable crops, several studies have shown that drip irrigation at 100% ET_c treatment produced the highest fruit yield of potatoes (Onder *et al.*, 2005), tomatoes (Panigrahi *et al.,* 2010; Patane *et al.,* 2011; Liu *et al.,* 2013) and squash (Al-Omran *et al.,* 2005). In the same trend, Aksic *et al.* (2012) recommended that marketable tuber yields of potatoes were increased with increasing the irrigation water (0.25, 0.50, 0.75, 1.00 and 1.25 of water surface evaporation (Ep)). Moreover, Abdrabbo *et al.* (2007) and Mohamed *et al.* (2018) reported that the highest yield of potato tubers was obtained from the irrigation level of 1.00 (ET). While irrigation potato plants by 75% of ET_o may be it will be more suitable for increasing the cultivation area per drop. For the effect of irrigation water on the quality of potato tubers, Karafyllidis *et al.* (1996) found that, high soil moisture availability levels produced higher proportions of large tubers (> 60 mm), whereas, small tubers (< 35 mm) were more frequent in the water deficit treatments. The same results were observed on tomatoes (Liu *et al.,* 2013) and eggplants (Mohawesh, 2016). Furthermore, Amer *et al.* (2017) suggested that the highest tuber yield was under treatment irrigation level of 75% from available water. Improving quality and saving water were under irrigation level of 45% from available water.

Chlorophyll content in tomato leaves declined with water stress (Ghorbanli *et al.,* 2013; Sibomana *et al.,* 2013) and the same results were observed with potato plants (Mahmoud *et al.,* 2019). Furthermore, Mutava *et al.* (2015) and Mohawesh (2016) suggested that deceasing irrigation water significantly decreased the photosynthetic rate in the leaves of soybean and eggplant compared to full irrigation treatment. On the other hand, Ragab *et al.* (2019) found that deficit irrigation treatments significantly reduced the nitrogen, phosphorus and potassium contents in tomato leaves where the highest percentage was observed with plants which irrigated by 100% ET_o. Moreover, Mohawesh (2016) recommended that eggplant which irrigated by deficit irrigation treatment; 20 and 40% of field capacity significantly decreased the leaf mineral content. In addition, Mahmoud *et al.* (2019) reported that the highest values of carbohydrates, starch and mineral elements (N, P and K) in potato tubers were obtained with irrigation intervals every three days compared 4 days and 2 days. Water stress treatments induced a decrease in leaf relative water content (LRWC) in tomato plants (Sibomana *et al.,* 2013; Ragab *et al.,* 2019). In addition, Ragab (2012) suggested that decreasing irrigation water led to progressively decreased LRWC and membrane stability index (MSI) of snap bean plants. Also Mohawesh (2016) concluded that deficit irrigation treatments showed significant negative effects on LRWC and increased leaf water potential.

The combination of deficit irrigation and irrigation scheduling is more important to achieve the highest yield and WUE. For this concern, Abuarab *et al.* (2020) found that the yield of green beans and water use efficiency (WUE) increased with increasing irrigation interval (once every 1, 2 and 3 days), where the maximum yield were obtained with planted irrigated one day interval and 1.00 of ETc and the minimum yield were found with 3 days interval and 0.60 of ETc treatment. In addition, Mahmoud *et al.* (2019) recommended that the highest values of potato vegetative growth parameters, tubers yield and quality was obtained with irrigation interval every three days compared to 2 and 4 days. El-Hendawy and Schmidhalter (2010) recommended that with adequate irrigation water irrigation once every 2 days with 1.00 ETc is more suitable. While in case the irrigation water is limited, irrigation once a day with deficit irrigation treatment (0.6 ETc) is recommended as the best irrigation schedule for drip-irrigated maize in sandy soils. In the same trend, under loamy soil. Ertek *et al.* (2004) found that irrigation at 0.85 Kcp and a 5-day irrigation interval are recommended for summer squash, in order to produce higher summer squash yield. Also, Uçan *et al.* (2007) found that there are positive relationship between irrigation water amount and plant water consumption for producing the highest yield and water use efficiency of sesame plants. Moreover, with green bean plants Sezen *et al.* (2005) found that irrigation intervals and plant-pan coefficients had a significant effect on the yield and quality. Where the maximum yield was obtained with a 2–3 day irrigation interval and plant-pan coefficient of 1.00, which had the highest water use efficiency. The results also indicated that with increasing the irrigation interval, WUE and IWUE values decreased. Recently, Esam *et al.* (2021) suggested that bitter fennel plants irrigated every 6 days produced the highest vegetative growth, seed yield, NPK and essential oil contents compared 4 and 8 days irrigation intervals. So the purpose of the work is to find out the best management of the irrigation scheduling for improving the vegetative growth and tubers yield and quality of potato plants grown under deficit irrigation conditions.

2. Materials and Methods

Two field experiments were carried out on potato plants (*Solanum lycopersicum* L.) during 2020/2021 and 2021/2022 seasons, at the National Research Centre Experimental farm at El-Nubaria, El-Behira Governorate, North of Egypt.

This work aimed to study the effect of deficit irrigation treatments (DI levels were 100%, 80%, 60% and 40% of ET_o (Reference evapotranspiration)) and irrigation scheduling (one time per day and two times per day (in the morning and in the evening)) and their interaction on vegetative growth and tubers yield and quality of potato plants grown under sandy soil conditions. The experimental site is located at latitude: 30°15''N, longitude: 30°47''E. Geographical position of the experimental site is shown in Fig.1. Samples analyses of soil and irrigation water are shown in Tables (1 and 2). The total amounts of irrigation water during the growing seasons were calculated by using Penman–Montieth modified equation (Allen *et al.,* 1998) and data are showed in Table (3). Metrological data were calculated as monthly means such as maximum and minimum temperatures, relative humidity and the total rain are shown in Table (4).

Potato tubers, Spunta cv. were obtained from General Authority for Producers and Exporters of Horticulture Crops, Cairo, Egypt, for the experiment in the two seasons. The tubers were planted in the first of October during the two seasons on one side of ridge at distance of 25 cm between tubers and 80 cm within rows. All agriculture practices were performed as recommended by Egyptian Ministry of Agriculture and Land Reclamation for potato cultivation. Plants were fertilized with 200 units of N, 60 units of P_2O_5 and 100 units of K_2O/fed. during the growing season.

2.1. Experimental design:

The experiment was arranged in a split-plot design with three replications. Deficit irrigation treatments were arranged in the main plots and irrigation scheduling were assigned in the sub-plots. The area of the experimental plot was 12 m^2 consisted of one row with 15 m length and 0.8 m width and the plants were transplanted 25 cm spaced in the rows.

2.2. Measured characteristics:

2.2.1. Vegetative growth characteristics:

Five plants were randomly chosen from three replications at 70 days from cultivation date to determine the following Characteristics: plant length (cm), number of leaves per plant, number of stems per plant total leaves area (m^2)/plant (total leaves area was estimated with a 20 disc sampling per plant, dried and weighted separately. A relationship between disk dry matter and disk area was applied to total leaf dry matter to find total leaf area, according to Koller (1972)). As well as the fresh weight and dry weight of leaves (g) per plant.

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Table 1: Physical and chemical properties of the experimental soil.

Physical properties		**Values**
Sand, %		73.86
Clay, %		6.78
Silt, %		19.36
Soil texture		Sandy
Field capacity, (%)		12.79
Wilting point, (%)		3.90
Saturation percent, (%)		29.80
Chemical properties		
pH		7.98
EC (dS/m)		2.28
Soluble cations (meq./L)	Ca^{++}	5.60
	Mg^{++}	2.20
	Na^{+}	5.6
	K^{+}	0.71
Soluble anions (meq./L)	CO_3^{--}	Nil
	HCO_3^{-}	1.50
	Cl^{-}	2.40
	SO_4^{--}	7.72
Available nutrient (ppm)	N	20.75
	P	72.58
	K	173.25

Table 2: Chemical analysis of irrigation water.

Items		**Values**
pH		8.28
EC (dS/m)		2.96
Soluble cations (meq./L)	Ca^{++}	6.35
	Mg^{++}	4.11
	Na^{+}	5.95
	K^{+}	0.23
Soluble anions (meq./L)	CO_3^{--}	0
	HCO_3^{-}	2.97
	Cl^{-}	4.36
	SO_4^{--}	5.12

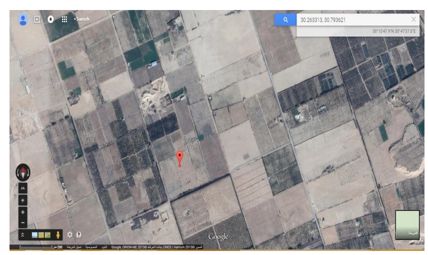

Fig.1: Experimental site (Google map, Satellite)

Table 3: Irrigation requirements (minute/plant per day) for irrigation treatments (100%, 80%, 60% and 40% of ET_o) for potato plants in both seasons of 2020/2021 and 2021/2022.

Weeks*	First season (2020/2021)				First season (2021/2022)			
	100%	80%	60%	40%	100%	80%	60%	40%
1	0.921	0.795	0.669	0.542	1.151	1.025	0.899	0.772
2	0.937	0.808	0.678	0.549	1.167	1.038	0.908	0.779
3	0.963	0.828	0.694	0.559	1.193	1.058	0.924	0.789
4	0.987	0.848	0.708	0.569	1.217	1.078	0.938	0.799
5	1.007	0.864	0.72	0.577	1.237	1.094	0.95	0.807
6	1.036	0.887	0.738	0.588	1.266	1.117	0.968	0.818
7	1.103	0.94	0.778	0.615	1.333	1.17	1.008	0.845
8	1.191	1.011	0.831	0.65	1.421	1.241	1.061	0.88
9	1.238	1.048	0.859	0.669	1.468	1.278	1.089	0.899
10	1.296	1.095	0.894	0.692	1.526	1.325	1.124	0.922
11	1.393	1.172	0.952	0.731	1.623	1.402	1.182	0.961
12	1.497	1.256	1.014	0.773	1.727	1.486	1.244	1.003
13	1.592	1.332	1.071	0.811	1.822	1.562	1.301	1.041
14	1.612	1.348	1.083	0.819	1.842	1.578	1.313	1.049
15	1.66	1.386	1.112	0.838	1.89	1.616	1.342	1.068
16	1.718	1.432	1.147	0.861	1.948	1.662	1.377	1.091
17	1.773	1.476	1.180	0.883	2.003	1.706	1.410	1.113
18	1.824	1.517	1.210	0.904	2.054	1.747	1.440	1.134

* Starting from 1st of October (2020 and 2021 for the first and second seasons, respectively)

2.3. Chemical contents:
2.3.1. Chlorophyll content in the potato leaves:

Total chlorophyll in plant leaf was measured by Minolta Chlorophyll Meter SPAD handheld device.

2.3.2. Nutrient analysis in potato tubers:

Nitrogen percent (N %) was determined using micro-Kjeldahl method as explained by Hesse (1971). Phosphorus percent (P%) was determined colorimetrically at wavelength 680 nm using Spectrophotometer (UV/VIS Spectrophotometer, CT 200) as described by Cottenie *et al*. (1982). Potassium percent (K %) was determined by using Flame photometer as mentioned by Cottenie *et al*. (1982).

2.3.3. Total carbohydrates:

Total carbohydrates were determined using Spectrophotometer in dry tuber tissues, using phenol sulphoric acid according to Dubois *et al.* (1956).

2.4. Tuber yield and its components

Five plants of each experimental plot were randomly taken and their tubers were collected to estimate and number of tuber / plant and tubers yield / plant. Total yield ton/fed..

2.4.1. Tubers quality*:* average tuber weight (g).

2.4.2. Categories of tuber yield

The total tubers yield of each experimental plot was divided into three categories, i.e. large (weight more than 200 g/tuber), small (weight less than 100 g/tuber) and medium (weight within 100-200 g/tuber).

Table 4: Metrological data* (monthly maximum and minimum air temperatures, relative humidity and total rain) in seasons (2020/2021 and 2021/2022).

Month	Minimum air Temp. (˚C)	Maximum air Temp. (˚C)	Total rain (mm)	Relative Humidity (%)
Sep - 2020	34.31	20.09	0.000	52.17
Oct - 2020	31.55	18.51	0.639	55.75
Nov - 2020	27.34	14.36	0.001	56.32
Dec -2020	20.46	14.27	0.702	65.50
Jan -2021	17.36	7.41	0.712	68.18
Feb - 2021	19.58	7.96	1.189	66.99
Sep - 2021	37.07	21.31	0.000	21.31
Oct -2021	32.52	18.75	0.025	55.62
Nov -2021	23.77	13.97	0.787	64.95
Dec -2021	21.84	10.60	0.034	63.53
Jan - 2022	20.71	8.51	0.175	63.05
Feb - 2022	21.11	8.48	0.778	62.14

* Metrological data were obtained from Central Laboratory for Agricultural Climate (CLAC), Egypt.

2.5. Water measurements:

2.5.1. Leaf relative water content (LRWC) (%):

For the estimation of LRWC, 20 leaf discs samples (10 mm in diameter) were taken with a cork borer (the fifth leaf from the top) and placed in a reweighed Petri dish to determine fresh weight (F.Wt.), discs were floated for 24 hours in distilled water inside a closed Petri dish until the discs became fully turgid. Discs samples were weighted after gently wiping the water to determine turgid weight (T.Wt.). Finally, the leaf discs were placed in a per-heated oven at 70º C to a constant weight (almost 48h) and weighted again to obtain discs dry weight (D.Wt.). So, LRWC % was calculated according to the equation of Kaya *et al.* (2003) as:

$$LRWC\ \% = [(FW-DW)/(TW-DW)] \times 100.$$

2.5.2. Membrane stability index (MSI):

Ten leaf discs (10mm in diameter) were obtained from the fifth leaf from the top and placed in the tube containing 10 ml of distilled water in two sets. One set was subjected to 40˚C for 30 min and its electrical conductivity (EC1) was determined at the end of incubation period using an electrical conductivity meter (HANNA H199301). Second set tubes were boiled in a temperature controlled water bath at 100˚C for 15 min, and then the electrical conductivity (EC2) was measured (Sairam *et al.,* 1997). Membrane stability index was calculated as percentage:

$$MSI\ (\%) = 1-(EC1/EC2) \times 100$$

2.5.3. Irrigation water use efficiency (IWUE) (kg/m^3):

IWUE under deficit irrigation treatments were determined using the following equations given by Howell *et al.* (1990):

$$IWUE = \text{Yield (kg/fed.)}/\text{Applied irrigation water amount (m}^3\text{/fed.)}.$$

Statistical analysis:

Analysis of variance of the obtained data from each attribute was computed using 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 mean values (Steel and Torrie, 1980).

3. Results and Discussion

3.1. Vegetative growth characteristics:

Data presented in Table (5) reveal the effect of deficit irrigation and irrigation scheduling and their interactions on some vegetative growth characteristics of potato plants (plant length, number of leaves per plant, number of stems per plant and leaves fresh weight (g) per plant). Results clearly indicated that decreasing irrigation water significantly decreased vegetative growth parameters of potato plants during the both studied seasons. Where the highest significant values were obtained by the irrigation treatment 100% and 80% ET_o, with nonsignificant differences between them, whereas, the lowest values were obtained by 40% ET_o treatment. Vegetative growth characteristics of potato plants significantly increased with increasing the irrigation water, where the increase in growth attributed to the function of water in the process of photosynthesis and therefore reflected on the increase in leaf area, fresh and dry weight and leaf chlorophyll fluorescence (Abd El-Gawad *et al*., 2017). These results are in harmony with those obtained by El-Dakroury (2008), which recommended that increasing irrigation level from 60% and up to 100% ET_o significantly increased the vegetative growth parameters. This may be due to the role of water in increasing the uptake of mineral elements from soil and translocation of photosynthetic assimilates, thus reflected increases in the leaf number and leaf area as well as foliage weight per plant (Leilah, 2009). Moreover, drought stress causes various harmful physiologic and biochemical effects in plants (Farooq *et al.,* 2009; Zhang and Huang, 2013). Furthermore, Kamal (2013) indicted that the deficit irrigation treatment (1000 m3/feddan) applied to the pepper plants recorded the lowest values of the vegetative growth characteristics compared with the highest level of irrigation water (2600 m3/feddan). The reduction in shoot fresh and dry biomass, leaf area per plant, photosynthetic rate, relative water content and leaf water potential were accompanied to drought water stress (Bhardwaj and Yadav, 2012; Mutava, *et al.,* 2015). Concerning the effect of irrigation scheduling (one time per day and two times per day (in the morning and in the evening)) on vegetative growth parameters of tomato plants, the obtained data revealed that irrigation scheduling two times per day showed superiority upon one time per day with all vegetative growth characteristics. Where, the highest significant values for plant length, number of leaves per plant, number of stems per plant and fresh weight of tomato leaves per plant were obtained with potato plants which irrigated two times per day in the both tested seasons. These results are in harmony with those obtained by El-Hendawy and Schmidhalter (2010) and Mahmoud *et al.* (2019) who mentioned that the highest values of potato vegetative growth parameters, tubers yield and quality was obtained with irrigation interval every three days compared to 2 and 4 days. Regarding the interaction between deficit irrigation and irrigation scheduling, plants were irrigated by 80% ET_o two times per day and 100 ET_o one or two times per day produced the highest significant values for plant length, number of leaves per plant, number of stems per plant and fresh weights of tomato leaves per plant in the two growing seasons. The results showed that the increasing of irrigation water with irrigation scheduling improved the behavior of potato plants which reflected on the vegetative growth characteristics (Davis *et al*., 2007; Abuarab *et al.*, 2019; Atia *et al.,* 2019; Mahmoud *et al.,* 2019).

Data in Table (6) present the effect of deficit irrigation and irrigation scheduling and their interactions on dry weights of potato leaves per plant, leaves area per plant and total chlorophyll content of potato leaf.

Results in Table (6) clearly indicated that deficit irrigation treatments significantly decreased dry weights of potato leaves per plant, leaves area per plant and total chlorophyll content of potato leaf compered to full irrigation treatment (control) during the both seasons of study. Where, the highest significant values for dry weights of potato leaves per plant and total chlorophyll content of potato leaf were obtained by the 100% and 80% ET_o treatments. While the highest significant values of leaves area per plant was achieved with 100% ET_o treatment only. This result was also consistent with Nemeskéri *et al.* (2015) and Osakabe *et al.* (2013) who observed that prolonged water stress decreases plant moisture content which reduces the leaf stomata opening and transpiration rate. These authors suggested that an increase in the ratio of leaf surface mesophyll tissue somewhat increases crop water use

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Table 5: Effect of deficit irrigation and irrigation scheduling on vegetative growth parameters of potato plants during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation times	Season 2020/2021				Season 2021/2022			
		Plant length (cm)	Number of leaves/plant	Number of stems/ plant	Leaves fresh weight/plant (g)	Plant length (cm)	Number of leaves/plant	Number of stems/plant	Leaves fresh weight/plant (g)
100% ET_o	One time per day	94.00 ab	46.00 b	5.00 b	644.70 b	97.33 ab	50.50 bc	6.35 b	666.20 b
	Two times per day*	96.00 ab	52.00 a	6.67 a	772.80 a	101.70 a	56.75 a	8.02 a	794.30 a
80% ET_o	One time per day	91.00 ab	44.67 b	4.33 c	587.00 bc	96.00 ab	48.17 c	5.63 c	610.20 bc
	Two times per day*	97.00 a	51.00 a	6.33 a	778.00 a	102.00 a	54.75 ab	7.63 a	801.20 a
60% ET_o	One time per day	83.33 cd	38.00 c	3.00 e	314.30 d	87.58 cd	42.50 de	4.20 e	324.80 d
	Two times per day*	89.00 bc	41.00 bc	4.00 cd	583.30 c	93.25 bc	46.50 cd	5.25 cd	593.80 c
40% ET_o	One time per day	70.00 e	21.00 e	2.00 f	144.30 e	74.05 e	27.50 f	3.20 f	167.20 e
	Two times per day*	79.67 d	33.00 d	3.67 d	288.00 d	83.72 d	38.50 e	4.92 d	308.20 d
Mean	100% ET_o	95.00 A	49.00 A	5.83 A	708.80 A	99.50 A	53.63 A	7.18 A	730.30 A
	80% ET_o	94.00 A	47.83 A	5.33 A	682.50 A	99.00 A	51.46 B	6.63 A	705.70 B
	60% ET_o	86.17 B	39.50 B	3.50 B	448.80 B	90.42 B	44.50 C	4.73 B	459.30 C
	40% ET_o	74.83 C	27.00 C	2.83 C	216.20 C	78.88 C	33.00 D	4.06 B	237.70 D
Mean	One time per day	84.58 B	37.42 B	3.58 B	422.60 B	88.74 B	42.17 B	4.85 B	442.10 B
	Two times per day*	90.42 A	44.25 A	5.17 A	605.50 A	95.16 A	49.13 A	6.45 A	624.40 A

*Two times per day (Morning & Evening)

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Table 6: Effect of deficit irrigation and irrigation scheduling on leaves dry weight, total leaves area per plant and total chlorophyll content of potato plants during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation time	Season 2020/2021						Season 2021/2022					
		Leaves dry weight/plant (g)		Total leaves area (cm^2)		Total chlorophyll content (SPAD)		Leaves dry weight/plant (g)		Total leaves area (cm^2)		Total chlorophyll content (SPAD)	
100% ET_o	One time per day	74.14	b	203.60	b	43.50	b	80.14	b	225.90	b	46.86	b
	Two times per day*	88.88	a	266.00	a	47.83	a	94.88	a	288.20	a	51.33	a
80% ET_o	One time per day	67.51	bc	174.70	c	41.47	b	73.76	b	197.40	c	45.07	b
	Two times per day*	89.47	a	256.70	a	47.90	a	95.72	a	279.40	a	51.70	a
60% ET_o	One time per day	36.15	d	132.90	de	36.73	cd	42.65	c	162.60	de	44.68	b
	Two times per day*	67.08	c	146.30	d	38.67	c	73.83	b	176.30	d	47.04	b
40% ET_o	One time per day	16.60	e	87.14	f	27.77	e	25.88	d	117.60	f	37.40	c
	Two times per day*	33.12	d	119.10	e	34.13	d	42.75	c	150.00	e	44.09	b
Mean	100% ET_o	81.51	A	234.80	A	45.67	A	87.51	A	257.00	A	49.10	A
	80% ET_o	78.49	A	215.70	B	44.68	A	84.74	A	238.40	B	48.38	A
	60% ET_o	51.62	B	139.60	C	37.70	B	58.24	B	169.50	C	45.86	B
	40% ET_o	24.86	C	103.10	D	30.95	C	34.32	C	133.80	D	40.74	C
Mean	One time per day	48.60	B	149.60	B	37.37	B	55.61	B	175.90	B	43.50	B
	Two times per day*	69.64	A	197.00	A	42.13	A	76.80	A	223.50	A	48.54	A

*Two times per day (Morning & Evening)

efficiency by increasing photosynthesis more than it increases transpiration. These results are in harmony with those obtained by Ghorbanli *et al.* (2013), which reported that leaf chlorophyll a and b significantly decreased in mild and severe stress conditions. In the same trend, Gao *et al.* (2012) reported that under drought stress, the content of chlorophyll is decline in the leaves of processing tomato. In addition, Mutava *et al.* (2015) reported that drought stress reduces photosynthetic rate in soybean which mainly due to the reduction in stomatal conductance caused by increased ABA concentration in the leaves. Because of this ability, leaf morphology and structure attributes, such as area, thickness, LA and specific leaf weight, are closely related to the external environment, especially to irrigation levels (Slabbert and Krüger 2014; Males and Griffihs 2017).

For the effect of irrigation scheduling (one time per day and two times per day) on dry weights of potato leaves per plant, leaves area per plant and total chlorophyll content of potato leaf, data in Table (6) revealed that he highest significant values for these mentioned characteristics were observed with potato plants which irrigated two times per day in the both tested seasons. Regarding the interaction between deficit irrigation and irrigation scheduling, plants were irrigated by 100% and 80% ET_o two times per day produced the highest significant values for dry weights of potato leaves per plant, leaves area per plant and total chlorophyll content of potato leaf in the two growing seasons.

3.2. Tubers yield:

Data in Table (7) show the effect of deficit irrigation and irrigation scheduling and their interactions on number of tubers per plant, tubers yield (g) per plants and total yield (ton/fed.).
Results clearly showed increasing irrigation water significantly increased the potato tubers yield, where the highest significant values of number of tubers per plant and total yield were obtained by the irrigation treatment 100%, while the maximum significant values of tubers yield per plants were obtained with irrigation treatments of 100% and 80% ET_o in the two growing seasons. These results are in agreement with those obtained Earl and Davis (2003) suggested that soil water deficit reduced crop yield by reducing canopy absorption of photosynthetically active radiation, leading to decreasing radiation-use efficiency. Moreover, Aldesuquy *et al.* (2012) reported that the reduction in yield can be attributed to the decrease in photosynthetic pigments, carbohydrates accumulation (polysaccharides) and nitrogenous compounds (total nitrogen and protein). Concerning the effect of irrigation scheduling (one time per day and two times per day) on number of tubers per plant, tubers yield per plants and total yield characteristics, the obtained data revealed irrigation scheduling two times per day produced the highest significant values for number of tubers per plant, tubers yield per plants and total yield in the both tested seasons. These results are in harmony with those obtained by Mahmoud *et al.* (2019), El-Hendawy and Schmidhalter (2010). Respecting the studied combination between deficit irrigation and irrigation scheduling, plants were irrigated by plants were irrigated by 100 ET_o or 80% ET_o two times per day produced the highest significant values for number of tubers per plant and total yield in the two growing seasons. While the highest significant values for tubers yield per plants were achieved with potato plants which irrigated by 100 ET_o two times per day with nonsignificant differences with 100 ET_o (one time per day) or 80% ET_o two times per day in the first season and with 80% ET_o two times per day only in the second season. Similar results were obtained by Yuan *et al.,* (2003) who found that total fresh tuber yields and marketable tuber yields (>85 g) increased with increasing amount of irrigation water. Irrigated water increased yields not only by increasing tuber number, but also by increasing the mean weight of the tubers. Irrigated water increased potato tuber quantity. In the same trend Mahmoud *et al.* (2019) suggested that the highest values of potato vegetative growth parameters, tubers yield and quality was obtained with irrigation interval every three days compared to 2 and 4 days. El-Hendawy and Schmidhalter (2010) reported that irrigation once every 2 days with 1.00 ETc is recommended with adequate irrigation water.

3.3. Tubers quality:

Data in Table (8) present the effect of deficit irrigation and irrigation scheduling and their interactions on tubers quality characteristics (average tuber weight (g) and tuber categories i.e. large (weight more than 200 g/tuber), small (weight less than 100 g/tuber) and medium (weight within 100-200 g/tuber)).

Results clearly indicated that decreasing irrigation water significantly decreased tubers quality characteristics of potatoes during the both studied seasons. Where the highest significant values of

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Table 7: Effect of deficit irrigation and irrigation scheduling on yield parameters of potato tubers during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation time	Season 2020/2021						Season 2021/2022					
		Number of tubers / plant		Tubers yield (g)/plant		Total yield ton/Fed.		Number of tubers / plant		Tubers yield (g)/plant		Total yield ton/Fed.	
100% ET_o	One time per day	20.00	b	2502.00	ab	21.42	a	25.00	b	2414.00	bc	23.17	a
	Two times per day*	31.67	a	2692.00	a	22.57	a	36.67	a	2770.00	a	24.32	a
80% ET_o	One time per day	17.33	bc	2280.00	b	18.01	b	21.67	c	2346.00	c	19.76	b
	Two times per day*	29.67	a	2575.00	ab	22.03	a	33.67	a	2641.00	ab	23.12	a
60% ET_o	One time per day	15.00	cd	1660.00	cd	13.43	d	18.00	de	1722.00	e	15.18	d
	Two times per day*	17.00	bcd	1921.00	c	15.52	c	20.00	cd	1983.00	d	17.27	c
40% ET_o	One time per day	9.00	e	1283.00	e	10.50	e	11.00	f	1338.00	f	12.25	e
	Two times per day*	13.00	d	1502.00	de	12.07	de	15.00	e	1554.00	ef	13.82	de
Mean	100% ET_o	25.83	A	2597.00	A	21.99	A	30.83	A	2592.00	A	23.74	A
	80% ET_o	23.50	B	2428.00	A	20.02	B	27.67	B	2494.00	A	21.44	B
	60% ET_o	16.00	C	1791.00	B	14.48	C	19.00	C	1853.00	B	16.23	C
	40% ET_o	11.00	D	1392.00	C	11.28	D	13.00	D	1446.00	C	13.03	D
Mean	One time per day	15.33	B	1931.00	B	15.84	B	18.92	B	1955.00	B	17.59	B
	Two times per day*	22.83	A	2172.00	A	18.05	A	26.33	A	2237.00	A	19.63	A

*Two times per day (Morning & Evening)

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Table 8: Effect of deficit irrigation and irrigation scheduling on quality parameters of potato tubers during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation time	Season 2020/2021				Season 2021/2022			
		Average tuber weight (g)	Large tubers ≥200g	Medium tubers ≤ 200 ≥ 100g	Small tubers ≤100g	Average tuber weight (g)	large tubers ≥200g	Medium tubers ≤ 200 ≥ 100g	Small tubers ≤100g
100% ET_o	One time per day	509.70 b	7.00 abc	8.33 b	6.00 c	564.60 b	8.33 bc	9.00 b	6.67 de
	Two times per day*	540.30 a	9.00 a	12.67 a	8.00 b	596.40 a	10.67 a	13.33 a	9.00 b
80% ET_o	One time per day	505.20 b	6.00 bcd	7.00 bc	5.33 cd	560.10 b	7.33 cd	8.67 b	8.00 c
	Two times per day*	541.70 a	8.00 ab	8.00 b	10.67 a	595.30 a	9.67 ab	9.67 b	11.67 a
60% ET_o	One time per day	407.30 d	4.00 de	4.00 cde	5.33 cd	453.50 d	5.33 e	5.33 c	6.00 e
	Two times per day*	440.00 c	5.00 cd	6.00 bcd	6.33 c	486.20 c	7.00 cde	7.67 b	7.00 d
40% ET_o	One time per day	258.00 f	2.00 e	2.00 e	4.33 d	302.60 f	3.33 f	3.33 c	5.00 f
	Two times per day*	358.50 e	4.00 de	3.00 de	5.33 cd	404.00 e	6.00 de	4.33 c	6.00 e
Mean	100% ET_o	525.00 A	8.00 A	10.50 A	7.00 A	580.50 A	9.50 A	11.17 A	7.83 B
	80% ET_o	523.40 A	7.00 B	7.50 B	8.00 A	577.70 A	8.50 B	9.17 B	9.83 A
	60% ET_o	423.70 B	4.50 C	5.00 C	5.83 B	469.90 B	6.17 C	6.50 C	6.50 C
	40% ET_o	308.30 C	3.00 D	2.50 D	4.83 B	353.30 C	4.67 D	3.83 D	5.50 C
Mean	One time per day	420.00 B	4.75 B	5.33 B	5.25 B	470.20 B	6.08 B	6.58 B	6.42 B
	Two times per day*	470.10 A	6.50 A	7.42 A	7.58 A	520.50 A	8.33 A	8.75 A	8.42 A

*Two times per day (Morning & Evening)

average tuber weight were obtained by the irrigation treatment 100% and 80% ET_o, with nonsignificant differences between them. Whereas, the highest significant values of tuber categories (large, medium and small) were obtained by 100% ET_o treatment only. Similar findings were obtained by Cetin *et al.* (2002) and Patane and Cosentino (2010), where the highest fruit weight and diameter were noticed with full irrigated treatment. The same results were observed on tomatoes (Liu *et al.,* 2013) and eggplants (Mohawesh, 2016). Furthermore, Karafyllidis *et al*. (1996) found that, high soil moisture availability levels produced higher proportions of large tubers (> 60 mm), whereas, small tubers (< 35 mm) were more frequent in the water deficit treatments. Concerning the effect of irrigation scheduling (one time per day and two times per day) on tubers quality characteristics (average tuber weight and tuber categories (large, medium and small)) of potatoes, the obtained data revealed that irrigation scheduling two times per day showed superiority upon one time per day with these mentioned characteristics. Where, the highest significant values for average tuber weight and tuber categories (large, medium and small) were obtained with potato plants which irrigated two times per day in the both tested seasons. These results are in harmony with those obtained by El-Hendawy and Schmidhalter (2010) and Mahmoud *et al.* (2019) who mentioned that the highest values of potato vegetative growth parameters, tubers yield and quality was obtained with irrigation interval every three days compared to 2 and 4 days. Regarding the interaction between deficit irrigation and irrigation scheduling, plants were irrigated by 100 ET_o or 80% ET_o two times per day produced the highest significant values of average tuber weight and large tubers. While the highest significant values of medium and small tubers were found with 100 ET_o two times per only in the two growing seasons.

3.4. Chemical contents of potato tubers:

Data in Table (9) present the effect of deficit irrigation and irrigation scheduling and their interactions on chemical contents of potato tubers i.e. total carbohydrates and mineral elements (N, P and K)

Results in Table (9) clearly indicated that the highest significant values for chemical contents of potato tubers i.e. total carbohydrates and mineral elements (N, P and K) were observed with potato plants irrigated by the 100% and 80% ET_o treatments. In the same trend,

El-Fawakhry (2004) suggested that drip irrigation system is important in increasing the availability and absorption of nitrogen and other minerals in the plant, thereby increasing the total chlorophyll content in the leaves. For the effect of irrigation scheduling (one time per day and two times per day) on chemical contents of potato tubers i.e. total carbohydrates and mineral elements (N, P and K), data in Table (9) revealed that he highest significant values for these mentioned characteristics were observed with potato plants which irrigated two times per day in the both tested seasons. Regarding the interaction between deficit irrigation and irrigation scheduling, plants were irrigated by 100% and 80% ET_o two times per day produced the highest significant values for total carbohydrates and mineral elements (N, P and K) of potatoes in the two growing seasons.

3.5. Water measurements of potato plants:

Data in Table (10) show the effect of deficit irrigation and irrigation scheduling and their interactions on water measurements for potato plants, i.e., leaf relative water content (LRWC), membrane stability index (MSI) and irrigation water use efficiency (IWUE).

Results clearly showed that he highest significant values of leaf relative water content (LRWC) and membrane stability index (MSI) were obtained with 100% ET_o irrigation treatment. While there were no significant differences among the irrigation treatments on irrigation water use efficiency (IWUE) of potato plants. These results are in harmony with those obtained by Kirda (2002), reported that the using of DI strategy is very important to increase crop water use efficiency (WUE). Moreover, Patane *et al.* (2011) concluded that the adoption of DI strategies at 50% reduction of ET_c could be suggested for processing tomato under open field conditions, for increasing WUE. Concerning the effect of irrigation scheduling (one time per day and two times per day) on LRWC, MSI and IWUE of potato plants, the obtained data revealed irrigation scheduling two times per day produced the highest significant values for LRWC and MSI in the both tested seasons. While the highest significant values of IWUE were obtained with potato plants which irrigated one time per day. These results are in harmony with those obtained by Mahmoud *et al.* (2019), El-Hendawy and Schmidhalter (2010). Respecting the studied

Table 9: Effect of deficit irrigation and irrigation scheduling on chemical quality parameters of potato tubers during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation time	Season 2020/2021								Season 2021/2022							
		N (%)		P (%)		K (%)		Carbohydrate (%)		N (%)		P (%)		K (%)		Carbohydrate (%)	
100% ET_o	One time per day	1.49	ab	0.641	ab	2.96	b	57.68	bc	1.74	b	0.722	ab	3.19	b	58.34	c
	Two times per day*	1.55	a	0.700	a	3.38	a	62.11	a	1.84	a	0.757	a	3.44	a	63.45	a
80% ET_o	One time per day	1.46	bc	0.615	b	2.68	c	56.27	cd	1.66	bc	0.693	b	2.77	c	56.65	d
	Two times per day*	1.52	a	0.672	ab	3.13	b	60.64	ab	1.86	a	0.761	a	3.55	a	61.72	b
60% ET_o	One time per day	1.41	c	0.542	c	2.20	d	54.13	de	1.58	cd	0.614	c	2.09	e	52.97	f
	Two times per day*	1.42	c	0.553	c	2.44	c	55.36	cde	1.61	c	0.662	bc	2.34	d	54.78	e
40% ET_o	One time per day	1.32	d	0.468	d	1.84	e	47.97	f	1.44	e	0.494	d	1.50	g	46.88	g
	Two times per day*	1.40	c	0.523	cd	2.08	d	52.39	e	1.52	de	0.546	d	1.86	f	51.67	f
Mean	100% ET_o	1.52	A	0.671	A	3.17	A	59.90	A	1.79	A	0.739	A	3.32	A	60.90	A
	80% ET_o	1.49	A	0.643	A	2.90	B	58.45	A	1.76	A	0.727	A	3.16	A	59.18	B
	60% ET_o	1.41	B	0.548	B	2.32	C	54.74	B	1.60	B	0.638	B	2.22	B	53.87	C
	40% ET_o	1.36	C	0.496	C	1.96	D	50.18	C	1.48	C	0.520	C	1.68	C	49.28	D
Mean	One time per day	1.42	B	0.566	B	2.42	B	54.01	B	1.60	B	0.631	B	2.39	B	53.71	B
	Two times per day*	1.47	A	0.612	A	2.76	A	57.62	A	1.71	A	0.681	A	2.80	A	57.90	A

*Two times per day (Morning & Evening)

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Table 10: Effect of deficit irrigation and irrigation scheduling on water measurements of potato plants during 2020/2021 and 2021/2022 seasons.

Irrigation levels	Irrigation time	Season 2020/2021						Season 2021/2022					
		SMI		LRWC (%)		IWUE (kg/m3)		SMI		LRWC (%)		IWUE (kg/m3)	
100% ET_o	One time per day	61.41	b	69.21	b	42.77	a	63.42	b	74.4	a	46.09	abc
	Two times per day*	70.24	a	70.94	a	40.57	ab	71.71	a	76.12	a	43.88	c
80% ET_o	One time per day	58.07	c	56.18	c	42.84	a	60.04	b	62.98	b	46.72	abc
	Two times per day*	70.02	a	70.91	a	35.1	b	72.39	a	76.35	a	40.04	c
60% ET_o	One time per day	49.76	e	52.62	d	47.55	a	52.98	c	58.42	c	52.04	ab
	Two times per day*	53.05	d	53.76	d	40.61	ab	55.27	c	59.69	c	45.28	bc
40% ET_o	One time per day	35.97	g	47.52	f	46.64	a	39.27	d	52.79	e	52.35	a
	Two times per day*	40.6	f	50.64	e	40.52	ab	43.61	d	56.29	d	46.37	abc
Mean	100% ET_o	65.82	A	70.08	A	41.67	A	67.57	A	75.26	A	44.99	A
	80% ET_o	64.04	A	63.54	B	38.97	A	66.21	A	69.67	B	43.38	A
	60% ET_o	51.4	B	53.19	C	44.08	A	54.12	B	59.05	C	48.66	A
	40% ET_o	38.29	C	49.08	D	43.58	A	41.44	C	54.54	D	49.36	A
Mean	One time per day	51.3	B	56.38	B	44.95	A	53.93	B	62.15	B	49.3	A
	Two times per day*	58.47	A	61.56	A	39.2	B	60.74	A	67.11	A	43.89	B

*Two times per day (Morning & Evening)

combination between deficit irrigation and irrigation scheduling, plants were irrigated by plants were irrigated by 100 ET_o or 80% ET_o two times per day produced the highest significant values for number of LRWC and MSI in the two growing seasons. While the highest significant values for IWUE were achieved with potato plants which irrigated by 40% ET_o one times per day with nonsignificant differences with the most of studies treatments. In the same trend Mahmoud *et al.* (2019) suggested that the highest values of potato vegetative growth parameters, tubers yield and quality was obtained with irrigation interval every three days compared to 2 and 4 days. El-Hendawy and Schmidhalter (2010) reported that irrigation once every 2 days with 1.00 ETc is recommended with adequate irrigation water

4. Conclusion

It could be concluded that, under sandy soil conditions with deficit and limited water resource, potato plants should be irrigate two times per day (in the morning and in the evening) to enhance the vegetative growth and tubers yield and quality and increase the water use efficiency.

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