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EFFECT OF DROUGHT STRESS ON THE PRODUCTION OF POTATO CROP GROWN UNDER SURFACE AND SUBSURFACE DRIP IRRIGATION SYSTEMS

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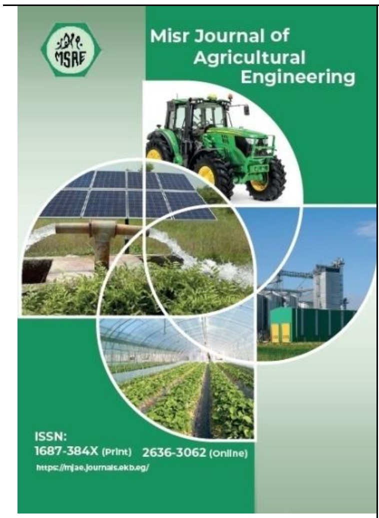


Keywords:
Deficit irrigation; Partial root zone drying; Potato growth and physiological parameters; Yield; Surface and subsurface drip irrigation.

ABSTRACT

Increasing water demand and climate change reduced agricultural water resources in arid and semi-arid regions. Field experiments were conducted at Demo Farm, Faculty of Agriculture, Fayoum University. Potato tubers were planted during two seasons (2021 and 2022). Three deficit irrigations (DI): I_1 (100% of ETc), I_2 (80% of ETc) and I_3 (60% of ETc). Two partial root zone drying (PRD) irrigations: (double laterals and single laterals). Three lateral depths: zero cm (surface drip irrigation) and 15 and 30 cm (subsurface drip irrigation, SDI). Some growth parameters and yield of the potato crop were determined. Results indicated that the highest mean values of plant growth and yield of potato plants were recorded with irrigation treatment I_1 under PRD and SDI with buried lateral depth of 15 cm. Also, the highest values of physiological parameters were recorded with irrigation treatment I_1 under PRD and SDI with buried lateral depth 15 cm. When DI treatments increased from I_1 to I_2 and I_3, the mean values of potato yield decreased. Using PRD treatment led to increasing the values of potato yield at irrigation treatments I_1, I_2 and I_3. It could be recommended when irrigation water is abundant, using the irrigation treatment I_1, PRD irrigation under SDI with buried lateral depth at 15 cm to reach the maximum yield of the potato crop. Meanwhile, under water scarcity, using DI treatment I_2, PRD irrigation under SDI with buried lateral depth at 15 cm, will save 20% of the IWA with a low decrease in potato yield.

INTRODUCTION

According to predictions by the United Nations, the global population is expected to reach about 9.55 billion by 2050, corresponding to a 70 % increase in food demands and a 19% increase in irrigation water use in agriculture **(Vollset et al., 2020).** The agriculture sector face challenges from water allocation and complications arising of the climate changes (Eeswaran et al., 2021). Agriculture consumes 70% of the water resources **(FAO,**

2023). A drip irrigation system is effective in improving crop growth, reducing water scarcity problems, and decreasing soil salinity and fertilizer leaching. It makes an ideal irrigation system when there is water resource scarcity globally **(Yang et al., 2023).**

Subsurface drip irrigation (SSDI) is defined by the American Society of Agricultural Engineers as the application of water below the soil surface through emitters with discharge rates commonly in the same range of the drip irrigation system (Ghazouani et al., 2015). SDI system is a very precise irrigation system, both in the conveying of water and nutrients to the root zone area and the timing and frequency of the applied water for optimal plant growth in semi-arid regions **(Camp et al., 2000 and** Consoli et al., 2014). SSDI system led to increases in yield **(Lamm and Camp, 2007)**. The better crop with higher yield was found under the SDI system **(Ahmed et al., 2017)**. The SDI system used slightly less water than the drip irrigation system; this was attributed to reduced evaporation losses at the soil surface **(Çolak et al., 2018)**. Full irrigation under the SSDI system maximizes potato yield crop **(Elansary, 2021).**

Increasing irrigation water requirements (IWR) of potatoes from 50 % to 100 % enhances the vegetative and tuber yields **(Farrag et al., 2016)**. The fresh and dry tubers yield was lowest with deficit irrigation 50% of IWR treatment (23.97 and 3.93 t ha^{-1}), followed by 70% (28.61 and 4.98 t ha^{-1}), and the highest with 100 % (34.43 and 6.67 t ha^{-1}), respectively, under SSDI system **(Mattar et al., 2021).** The highest and lowest tuber yields (52.8 and 25.5 t ha^{-1}) were related to full irrigation and deficit irrigation 65 % of IWR. Tuber's yield reduced by 8% in potato plants received 80% of IWR and PRD irrigation, and by 52% in plants received deficit irrigation 65% of IWR (Haghighati-Boroujeni, 2021). Deficit irrigation treatments resulted in significantly lower tubers yield of potato **(Akkamis and Caliskan, 2023).** Deficit irrigation (0.8 of ETc) and soil mulching with silver black polyethylene recorded significantly higher plant height (48.8 cm), number of plant leaves (48.7), and tuber yield of potato crop (37.1 t ha^{-1}) **(Santosh, 2024)**.

Partial root-zone drying (PRD) irrigation is the management techniques of applying low irrigation water to allow larger irrigation areas with the available water resources. Alternative PRD, where half of the roots system is allowed to dry, while the other half is fully wetted (**FAO, 2002**). In PRD, roots sense the soil drying and induce abscisic acid that reduces stomatal conductance and leaf expansion, and concurrently, the roots in the wet soil absorb sufficient water to maintain a high water status in the shoots; this mechanism increases both water use and water productivity (Ahmadi et al., 2010). PRD technique is the most popular due to saving irrigation water > 20-30% without or with a minimal effect on the crop yield (**Chai et al., 2016)**. The reduction in water availability in plants leads to a reduction in cell solutes, so the plasma membrane becomes thicker, which affects the cells turgidity and causes the closure of the stomata to prevent dehydration **(Sarto et al., 2017).** The plants showed better capability for surviving water stress if irrigated with PRD practice **(Kaman and Krda, 2017)**. Tubers yield of potato crop was similar under PRD compared to deficit irrigation. Potato seeds producers may be used this practice for increase the number of potato seeds per plant (Elhani et al., 2019). The PRD practice gave the highest values of potato crop (29.22 t ha^{-1}) as compared to 26.14 t ha^{-1} under the SDI system **(Al-Jabri and Al-Dulaimi, 2021).** The PRD practice achieved the highest values of plant height and leaf area (45.5 cm and 39.5 dm^2) as compared to 44.3 cm and

33.9 dm^2 when treated by drip irrigation system, while it was 45.10 cm, 44.4 dm^2, and 38.33 cm, 33.83 dm^2 for the deficit irrigation at 25 and 50% of field capacity (FC), respectively. Also, the PRD practice achieved the highest value of the yield when depleting at 25% of FC with a value of 28.63 t ha^{-1} and the lowest value of 27.08 t ha^{-1} when depleting at 50% **(Cheng et al., 2021).** Irrigation with PRD gave the highest efficiency level (97.07%) at depth 15-30 cm as compared to 95.35% for the SSDI system (Al-Jabri and Al-Dulaimy, 2021).

The installation depth of laterals in the SSDI system should not be more than 20 cm for better crop yield (Charlesworth and Muirhead, 2003). A dripper line that was buried at 15 cm depth was better than that at 10 cm depth **(Zin El-Abedin, 2006)**. The yield increased significantly attributed to the placement of the laterals at 10 and 15 cm below the soil surface. Maximum increase in the yield was 13.48% under SSDI with 10 cm depth as compared to drip irrigation system **(Singh et al., 2010)**.

The aim of this study is evaluate the effect of deficit irrigation, PRD irrigation and buried laterals depth on growth parameters, physiological characteristics, and yield of potato crops grown under surface and subsurface drip irrigation systems.

MATERIAL AND METHODS

Experiment site

Field experiments were conducted during two growing seasons of 2021 and 2022 at the Experimental Demo Farm (7 km East of Fayoum city), Faculty of Agriculture, Fayoum University, Fayoum Governorate, Egypt, (Latitude: 29° 17` 34.1`` N, Longitude: 30° 54` 57.3`` E, and Altitude: +25 m).

Disturbed and undisturbed soil samples were initially collected from the experimental soil at three depths: 0-20, 20-40 and 40-60 cm. Some physical characteristics of the experimental soil samples were determined and analyzed according to the methods and procedures outlined and described by **Jury and Horton (2004).** The experimental site could be characterized as sandy loam in texture. Also, some soil chemical properties were determined and analyzed according to the methods and procedures described by **Page et al. (1982)**. The chosen site was slightly salinity soil, and the soil salinity values (EC) ranged from 4.66 to 6.45 dS m^{-1} before planting. The experimental site was not alkaline and not calcareous soil. Physical and chemical properties were presented in Tables 1 and 2.

Table (1). Some soil physical properties of the experimental site (as mean values of two seasons).

Soil physical properties	Soil layer depth, cm		
	0-20	20-40	40-60
Particle size distribution, %			
Sand	74.6	74.0	73.5
Silt	11.0	11.2	11.4
Clay	14.4	14.8	15.1
Texture class	S.L.	S.L.	S.L.
Particle density, g cm^{-3}	2.65	2.65	2.66
Bulk density, g cm^{-3}	1.45	1.48	1.51
Field capacity, %	18.71	17.92	17.62
Wilting point, %	4.69	5.14	5.27
Available water content, %	14.02	12.78	12.35

Table (2). Some soil chemical properties of the experimental site (as mean values of two seasons).

Soil chemical properties	Soil layer depth, cm			irrigation water
	0-20	20-40	40-60	
pH	7.32	7.41	7.55	7.12
EC, dS/m	4.66	5.73	6.45	0.47
Soluble cations (meq. L^{-1})				
Ca^{++}	10.36	13.72	15.56	1.13
Mg^{++}	6.67	8.91	9.17	0.89
Na^{+}	28.46	33.68	39.82	2.18
K^{+}	0.54	0.81	0.96	0.28
Soluble anions (meq. L^{-1})				
CO_3^{--}	--	--	--	--
HCO_3^{-}	1.13	1.36	1.55	0.67
Cl^{-}	18.19	22.31	24.71	1.83
SO_4^{--}	26.71	33.45	39.25	1.98
SAR	9.75	10.01	11.32	2.17

Experiment design

It was a split-split plot design with three replicates. Drought stress is expressed as a deficit irrigation and the PRD. The main plots represented three deficit irrigation treatments, (I_1, irrigation with 100% of ETc, I_2, irrigation with 80% of ETc and I_3, irrigation with 60% of ETc). Each main plot was pounded with dikes (3 m in width) in order to avoid the horizontal movement of water from one treatment to another. Each main plot was divided into two sub-main plots, which received the partial root zone drying (PRD) irrigation treatments, i.e., double lateral lines and single lateral lines in the planting ridge. The double laterals were spaced at 0.25 m on each planting ridge, and the space between both planting ridges is 0.7 m. Also, each sub-main plot was divided into three sub-sub-main plots that received lateral depth treatments, i.e., zero cm depth (surface drip irrigation system), and subsurface drip irrigation system (SSDI) with two buried lateral depths of 15 and 30 cm in the cultivated ridge (Fig, 1).

Irrigation water requirement

Irrigation water requirements were calculated according to monthly mean weather data for two successive seasons 2021 and 2022, as shown in Table 3. The daily evapotranspiration (ETo) values were computed by applying the following equation, according to **Doorenbos and Pruitt (1992)**:

$$\mathrm{ETo} = \mathrm{E_{pan}} \times \mathrm{K_{pan}}$$

Where: $\mathrm{E_{pan}}$ is evaporation from the Class A pan (mm d^{-1}), $\mathrm{K_{pan}}$ is pan evaporation coefficient, ($\mathrm{K_{pan}}$ = 0.8) **(Allen et al., 1998)**.

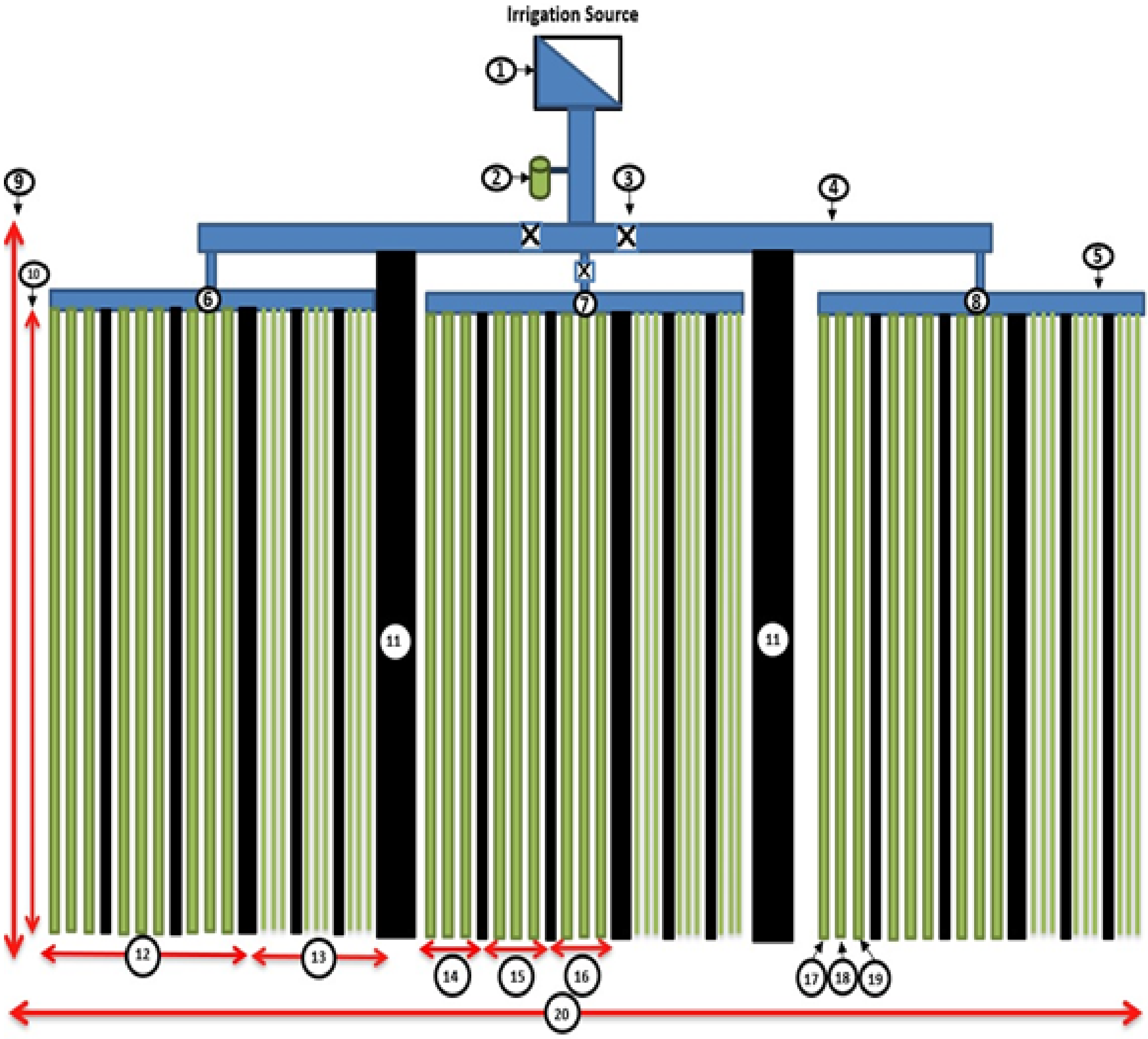
The crop evapotranspiration (ETc) values were estimated using the reference evapotranspiration (ETo) and crop coefficient (Kc) values according to the following equation **(Doorenbos and Pruitt 1992)**:

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc}$$

The amounts of irrigation water applied (IWA) (m^3 ha^{-1}) of each treatment was determined by using the following equation according to **Keller and Karmeli (1975)**:

$$\mathrm{IWA} = \frac{\mathrm{A} \times \mathrm{ETc} \times \mathrm{Ii} \times \mathrm{Kr}}{\mathrm{Ea} \times 1000} \times \frac{1}{1 - \mathrm{LR}}$$

Where: ETc is the crop evapotranspiration (mm day^{-1}), Ii is the irrigation intervals (day), Kr is the coverage coefficient (Kr = (0.10 + G_C) ≤ 1) , G_C is the ground cover, Ea is application efficiency (%), (Ea = 90%), and LR is the leaching requirements.



Where: 1. Pump, 2. Fertilizer unit, 3. Valve, 4. Main lateral, 5. Sub-mean lateral, 6. I_1, 100% of ETc, 7. I_2, 80% of ETc, 8. I_3, 60% of ETc, 9. The experimental wide, 10. The lateral length, 11. Dike, 12. Double laterals treatment, 13. Single lateral treatment, 14. Zero lateral depth, 15. 15 cm lateral depth, 16. 30 cm lateral depth, 17, 18 and 19 are the three replicates, and 20. The experimental length.

Fig. (1). Layout of the field experiment, shows the deficit irrigation, partial root zone drying irrigation and buried lateral depths treatments.

Potato plants were irrigated at three days' intervals by different amounts of irrigation water. Potato plants received 39 irrigations, the total amounts of irrigation water applied values (as mean two seasons) were 4294.07, 3435.26 and 2576.45 m^3 ha^{-1} at irrigation treatments I_1, I_2 and I_3, respectively. Deficit irrigation treatments started directly after full germination of potato plants. The network of surface and subsurface drip irrigation systems were installation. In the Agriculture Faculty farm, the irrigation water is taken from Baher Wahby canal which take the irrigation water from Baher Yousef canal. The irrigation water is conducted inside the faculty farm in a small well (3 m in length × 3 m in width × 2.5 m in depth) next to the experimental soil, with the water pump placed on the edge of the well.

Table (3). Monthly mean weather data for two successive seasons 2021 and 2022 years, class A pan evaporation readings and ETo values.

MONTH	YEAR	TEMPERATURE C^{O}			RELATIVE HUMIDITY (RH %)	Wind speed (M SEC^{-1})	NO. HOUR OF SUNSHINE (H)	E_{pan} (MM/ DAY)	ETO (MM/ DAY)
		$T_{MAX.}$	$T_{MIN.}$	MEAN					
FEB.	2021	23.4	9.7	16.6	41.0	2.0	9.46	2.36	1.89
	2022	22.0	8.3	15.2	42.0	1.9	9.44	2.22	1.78
MAR.	2021	29.4	12.7	21.1	37.0	2.1	10.19	3.47	2.78
	2022	26.7	12.7	19.7	36.0	2.2	10.21	3.93	3.14
APR.	2021	21.1	9.2	15.2	35.0	2.3	11.17	5.60	4.48
	2022	31.2	15.6	23.4	36.0	2.2	11.13	5.43	4.34
May	2021	36.0	19.8	27.9	51.6	4.2	11.70	6.58	5.26
	2022	36.1	19.7	27.9	51.8	5.6	11.83	6.85	5.48
June	2021	37.3	24.3	30.8	54.1	5.5	12.34	8.28	6.62
	2022	37.4	24.2	30.8	54.3	5.4	12.26	7.17	5.74

Irrigation system component

The drip irrigation system consists of water pump (3 horse), fertilizer tank, mainline (made of PVC in 75 mm of diameter), sub-mainline (made of PE in 50 mm of diameter), dripper lines (laterals) made of PE in 16 mm of diameter, drippers, and other accessories, i.e., control valves, pressure gauges, water meters gauges, valves, connectors, and the end of dripper lines. Each main plot had one valve in the main irrigation line. The length of each lateral line was 15 m, and the drippers were paced 0.3 m apart. Each dripper had a flow rate of 4 l h^{-1} at 1.0 bar operation pressure. One valve has been placed in the beginning of each dripper line. PRD irrigation is used in the double lateral treatment (one lateral is open during irrigation and the other is off, and opposite that in the following irrigation).

Plant type

Potato (*Solanum tuberosum* L.) seed tubers (Spunta variety) were planted in two successive springer seasons (2021 and 2022). Potato seeds were manually planted in the 10th February in the 1st and in the 12th February in the 2nd season, in hills 20 cm apart from each other. Potato plants were harvested after 120 days of planting. Compost was applied for all treatments in the experimental field (at rate 20 t ha^{-1}) before planting. Potato plants received NPK fertilizer requirements on the different doses as 285.71 kg N, 107.14 kg P_2O_5 and 114.29 kg K_2O units ha^{-1}, which in equal to 857 kg ha^{-1} of ammonium nitrate (33.5% N), 148 kg ha^{-1} of phosphoric acid (72.4% P_2O_5) and 238 kg ha^{-1} of potassium sulphate (48% K_2O), respectively. Before planting operation, 55.71 kg N, 35.14 kg P_2O_5 and 29.28 kg K_2O units of ammonium nitrate, superphosphate and potassium sulphate, respectively during land preparation. During plant growth season will be added 230 kg N, 72 kg P_2O_5 and 85 kg K_2O units of ammonium nitrate, phosphoric acid, and potassium sulphate, respectively, by fertigation.

Measurements and calculations

At the maximum growth stage (after 80 days of the potato planting), the physiological characteristics of the plants were determined as the followings:

1. Relative water content (RWC, %) was estimated according to **(Hayat et al., 2007)** and calculated using the following formula:

$$RWC, \% = \left\{ \frac{FM - DM}{TM - DM} \right\} \times 100$$

Where: FM is the fresh mass, TM is the turgid mass, and DM is dry mass.

2. Membrane stability index (MSI, %) was measured using the method of **Premchandra et al. (1990)** and calculated by the following equation:

$$MSI = [1 - (C_1/C_2)] \times 100$$

Where: C_1 is the electrical conductivity of the solution at 40 °C and C_2 is the electrical conductivity of the solution at 100 °C. Shoots fresh of plants were weighed and then placed in an oven at 70 ± 2 °C till a constant weight to measure their dry weights.

3. The relative chlorophyll concentration (SPAD) was determined using (SPAD502, KONICAMINOLTA. Inc., Tokyo). At harvest (188 and 186 DFP) in both seasons, respectively, 10 individual plants of each sub-plot were sampled randomly.

At the harvest time, seven plants were chosen randomly from each experimental unit and cut off at the ground level and immediately carried to the laboratory, and the following measurements were recorded:

1. Plant height (cm), measuring from starting the ground level to the apical meristem of the main stem.
2. Stem diameter (cm); measured using Sealy So707-Digital Electronic Vernier Caliper 0-150 mm/0-6″ at ground level.
3. Number of branches per plant.
4. Potato leaf area per plant.
5. Dry weight of potato plant (stems and leaves), (g $plant^{-1}$), was determined after oven drying the samples at 70 ºC for 72 hours.
6. Tubers yield of potato plants, was estimated by weighing the total harvested tubers (kg $plot^{-1}$) and then converted to t ha^{-1}.

Statistical and data analysis

All data were subjected to analysis of variance (ANOVA) according to **Gomez and Gomez (1984)** by InfoStat software estadistico. LSD between treatments were compared at $P \leq 0.05$.

RESULTS AND DISCUSSIONS

1. Plant height, stem diameter and No. of branches per plant

Table (4) showed that the effect of drought stress (deficit and PRD irrigation) and laterals depths treatments on each of plant height, stem diameter and No. of branches per plant values of the potato plants grown under SDI system.

A). Plant height

Results in Table (4) showed that the plant height values were significantly affected by deficit irrigation treatments. The average plant height decreased by 7.06 and 21.56% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. These findings align with those reported by **Ayas (2021).**

The plant height values were also significantly affected by the PRD irrigation (double laterals in the cultivation line). PRD treatment led to increases in the mean values of the plant height by 16.98% with full irrigation treatment (I_1) and by 17.16% with deficit irrigation treatment (I_2) and by 3.23% with deficit irrigation treatment (I_3) as compared to single lateral treatments. The results showed that the plant height values are higher at full irrigation (I_1) as compared to deficit irrigation treatments I_2 and I_3. Also, the values of the plant height were highly at deficit irrigation treatment (I_2, 80% of ETc) with PRD as compared to full irrigation treatment with a single lateral line.

The mean values of the plant height were increased by 10.71 and 3.50% with irrigation treatment (I_1), and by 7.46 and 3.77% with irrigation treatment (I_2), and by 5.93 and 1.79% with irrigation treatment (I_3), when the buried lateral depths changed from zero cm to 15 and 30 cm, respectively.

B). Stem diameter

Results in Table (4) indicated that the stem diameter values were significantly affected by deficit irrigation treatments. The mean values of the stem diameter decreased by 4.92 and 10.66% as deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. The stem diameter values were significantly affected by the PRD irrigation (double laterals in the cultivation line). PRD treatment led to increases in the mean values of the stem diameter by 8.55% with irrigation treatment (I_1) and by 10.53% with deficit irrigation (I_2) and by 4.72% with deficit irrigation (I_3) as compared to single lateral treatments.

Table (4). Effect of drought stress (deficit irrigation and partial root zone drying) and laterals depths on the plant height, stem diameter and No. of branches per plant values of potato plants grown under drip irrigation systems (as mean values of two seasons).

Deficit irr. treat.	Depth of lateral (cm)	Plant height (cm)			Stem diameter (cm)			No. of branches per plant		
		Partial root zone			Partial root zone			Partial root zone		
		Single lateral	Double laterals	Mean	Single lateral	Double laterals	Mean	Single lateral	Double laterals	Mean
I_1, 100% of ETc	0	45.53	53.41	49.47	1.11	1.19	1.15	2.50	3.01	2.76
	15	50.53	59.00	54.77	1.24	1.40	1.32	3.26	3.78	3.52
	30	47.21	55.19	51.20	1.15	1.21	1.18	3.47	3.21	3.34
	Mean	47.76	55.87	51.81	1.17	1.27	1.22	3.08	3.33	3.21
I_2, 80% of ETc	0	43.00	49.81	46.41	1.05	1.14	1.10	2.13	2.58	2.36
	15	45.59	54.15	49.87	1.15	1.32	1.24	2.75	3.52	3.14
	30	44.44	51.88	48.16	1.09	1.21	1.15	2.43	2.81	2.62
	Mean	44.34	51.95	48.15	1.10	1.22	1.16	2.44	2.97	2.70
I_3, 60% of ETc	0	38.90	40.34	39.62	1.00	1.04	1.02	2.06	2.27	2.17
	15	41.51	42.43	41.97	1.12	1.20	1.16	2.33	2.51	2.42
	30	39.57	41.08	40.33	1.07	1.08	1.08	2.21	2.31	2.26
	Mean	39.99	41.28	40.64	1.06	1.11	1.09	2.20	2.36	2.28

LSD values at 5%	DI	PRD	Depth	DI * PRD	DI * Depth	PRD* Depth	DI *PRD* Depth
Plant height	0.070	0.057	0.070	0.099	0.121	0.099	0.172
Stem diameter	0.009	0.007	0.009	0.012	0.015	0.012	0.021
No. of branches per plant	0.020	0.016	0.020	0.028	0.034	0.028	0.048

Where: Each value in this Table is an average of 3 replications. I_1, I_2 and I_3 are the deficit irrigation treatments, 100%, 80% and 60% of crop evapotranspiration (ETc), respectively, DI is deficit irrigation, PRD is partial root zone drying.

The results showed that the stem diameter values are higher at full irrigation (I_1) as compared to deficit irrigation treatments I_2 and I_3. Also, the values of stem diameter were higher at irrigation treatment (I_2) with PRD as compared to full irrigation treatment with single lateral. **Yousefi et al.** (**2022**) found that decreasing in the irrigation water amounts in the potato could have a negative effect on morphological parameters.

The mean values of stem diameter were increased by 14.78 and 2.61% with irrigation treatment (I_1), by 12.73 and 4.55% with deficit irrigation (I_2), and by 13.73 and 5.88% with deficit irrigation (I_3), when the buried lateral depths changed from zero cm to 15 and 30 cm, respectively.

C). No. of branches per plant

Results in Table (4) showed that the number of branches per plant values of potato plants were significantly affected by deficit irrigation treatments. The mean values of the number of branches per plant decreased by 15.89 and 28.97% when deficit irrigation increased from I_1 to I_2 and I_3, respectively. These results are in accordance.

Considering findings from **Shock (2004)**, who stated that, in comparison to other crops, potatoes are among those that are susceptible to high and low moisture shocks.

The number of branches per plant values of potato plants were significantly affected by the PRD irrigation (double laterals). PRD treatment led to increases in the mean values of the number of branches per plant by 8.12% with deficit irrigation (I_1), by 21.72% with deficit irrigation (I_2) and by 7.27% with deficit irrigation (I_3) as compared to single lateral treatments. The results showed that the number of branches per plant values was highly at irrigation treatment (I_1) with PRD as compared to other irrigation treatment with single lateral. Also, the number of branches per plant values was highly at irrigation treatment (I_2) with PRD as compared to deficit irrigation (I_2) with a single lateral. These results are in agreement with those found by de Lima et al. (2015) who found that the treatment 30% of deficit irrigation in both drip irrigation and PRD did not significantly decrease vegetative growth.

The mean values of the number of branches per plant were increased by 27.54 and 21.01% with irrigation treatment (I_1) and by 33.06 and 11.02% with deficit irrigation (I_2), and by 11.52 and 4.15% with deficit irrigation (I_3) when the buried lateral depths changed from zero cm (surface drip irrigation) to 15 and 30 cm (subsurface drip irrigation), respectively.

The highest values of the plant height, stem diameter (cm) and number of branches per plant were 59 cm, 1.40cm and 3.78 branches, and they were recorded when potato plants were irrigated with irrigation treatment I_1 under PRD and subsurface drip irrigation with buried lateral depth 15 cm. These results are in agreement with those reported by **Karam et al.** (**2016),** who found that potato plants irrigated under a drip irrigation system with different levels of deficit irrigation (40, 60, 80 and 100%) of the evaporation, gained a significant increase in the potato growth parameters values by increasing irrigation level**.**

2. Relative water content, membrane stability index and relative chlorophyll concentration

Table (5) illustrates the effect of drought stress (deficit irrigation and PRD irrigation) and lateral depth treatments on each of relative water content (RWC), membrane stability index (MSI), and the relative chlorophyll concentration (SPAD) values of the potato plants grown under the SDI system.

A). Relative water content

Table (5) showed that the values of RWC of potato plants were significantly affected by deficit irrigation treatments. The mean values of the RWC decreased by 4.84 and 10.14% when deficit irrigation increased from I_1 to I_2 and I_3, respectively. These results are compatible with those reported by **Mankotia and Sharma (**2020), who found that the values of soil moisture and relative leaf water contents were higher at 0.8 treatment of cumulative pan evaporation (CPE) as compared to 0.4 CPE.

The RWC values of potato plants were significantly affected by the PRD irrigation (double laterals). PRD irrigation led to increases in the mean values of the RWC by 4.02% with irrigation treatment (I_1), by 3.93% with deficit irrigation (I_2) and by 1.49% with deficit irrigation (I_3) as compared to single lateral treatments. The results showed that the values of RWC were highly at full irrigation treatment (I_1) with PRD as compared to other irrigation treatments with single lateral.

Table (5). Effect of drought stress (deficit irrigation and partial root zone drying irrigation) and laterals depths on the RWC, MSI and SPAD values of potato plants grown under drip irrigation systems (as mean values of two seasons).

Deficit irr. treat.	Depth of lateral (cm)	Relative water content (RWC), %			Membrane stability index (MSI), %			Relative chlorophyll concentration (SPAD)		
		Partial root zone			Partial root zone			Partial root zone		
		Single lateral	Double laterals	Mean	Single Lateral	Double laterals	Mean	Single lateral	Double laterals	Mean
I_1, 100% of ETc	0	74.06	75.84	74.95	62.81	63.69	63.25	51.24	53.25	52.24
	15	79.27	83.03	81.15	64.44	68.82	66.63	54.52	57.36	55.94
	30	75.01	78.63	76.82	63.60	65.51	64.56	52.63	54.70	53.66
	Mean	76.11	79.17	77.64	63.62	66.01	64.81	52.79	55.10	53.95
I_2, 80% of ETc	0	71.22	72.76	71.99	61.96	62.87	62.42	50.16	51.40	50.78
	15	74.51	78.68	76.60	62.97	64.57	63.77	52.63	54.70	53.66
	30	71.62	74.46	73.04	62.08	63.69	62.89	51.08	52.80	51.94
	Mean	72.45	75.30	73.88	62.34	63.71	63.02	51.29	52.96	52.13
I_3, 60% of ETc	0	68.32	69.31	68.82	60.41	60.82	60.62	47.49	48.74	48.11
	15	70.38	71.69	71.04	61.23	61.56	61.40	50.65	50.89	50.77
	30	69.07	69.87	69.47	61.01	61.28	61.15	49.61	49.85	49.73
	Mean	69.26	70.29	69.77	60.88	61.22	61.05	49.25	49.83	49.54

LSD values at 5%	DI	PRD	Depth	DI * PRD	DI * Depth	PRD* Depth	DI *PRD* Depth
Relative water content	0.058	0.048	0.058	0.083	0.101	0.083	0.143
Membrane stability index	0.047	0.039	0.047	0.067	0.082	0.067	0.116
Relative chlorophyll concentration	0.026	0.021	0.026	0.036	0.045	0.036	0.063

Where: Each value in this Table is an average of 3 replications. I_1, I_2 and I_3 are the deficit irrigation treatments, 100%, 80% and 60% of crop evapotranspiration (ETc), respectively, DI is deficit irrigation, PRD is partial root zone drying.

The mean values of RWC were increased by 8.27 and 2.49% with irrigation treatment (I_1), by 6.40 and 1.46% with deficit irrigation (I_2), and by 3.22 and 0.94% with deficit irrigation (I_3) when the buried lateral depths changed from zero cm to 15 and 30 cm, respectively.

B). Membrane stability index

Table (5) showed that the values of membrane stability index **(**MSI) of the potato plants were significantly affected by deficit irrigation treatments. The mean values of the MSI decreased by 2.76 and 5.80% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. These results are agreement with those reported by **Howladar (2018)**.

The MSI values of potato plants were significantly affected by the PRD irrigation (double laterals). PRD irrigation led to increases in the mean values of the MSI by 3.76% with irrigation treatment (I_1), by 2.20% with deficit irrigation (I_2) and by 0.56% with deficit irrigation (I_3) as compared to single lateral treatment. The results showed that the values of MSI were highly at irrigation treatment (I_1) with PRD as compared to other irrigation treatments (I_2 and I_3) with a single lateral.

The mean values of MSI were increased by 5.34 and 2.07% with irrigation treatment (I_1), and by 2.16 and 0.75% with deficit irrigation (I_2), and by 1.29 and 0.71% with deficit irrigation treatment (I_3) when the buried lateral depths changed from zero cm to 15 and 30 cm, respectively. 94

C). Relative chlorophyll concentration

Table (5) illustrates that the readings of relative chlorophyll concentration (SPAD) of the potato plants were significantly affected by deficit irrigation treatments. The mean values of the SPAD decreased by 3.37 and 8.17% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. The results showed that the values of SPAD readings were highly at irrigation treatment (I_1) as compared to other irrigation treatments (I_2 and I_3). These results are in agreement with those reported by **Zin El-Abedin et al. (2019)** who found that the SPAD of potato plants remains at par with full irrigation.

The SPAD values of potato plants were significantly affected by the PRD irrigation (double laterals). PRD treatment led to increases in the mean values of the SPAD by 4.38% with irrigation treatment (I_1) and by 3.26% with deficit irrigation (I_2) and by 1.18% with deficit irrigation (I_3) as compared to single lateral treatments. The results showed that the values of SPAD were highly at full irrigation treatment (I_1) with PRD as compared to other irrigation treatments. Also, the values of SPAD readings were highly at irrigation treatment (I_2) with PRD as compared to full irrigation treatment with a single lateral

The mean values of SPAD were increased by 7.08 and 2.72% with irrigation treatment (I_1), by 5.67 and 2.28% with deficit irrigation (I_2), and by 5.53 and 3.37% with deficit irrigation (I_3), when the buried lateral depths changed from zero cm depth to 15 and 30 cm, respectively.

The highest values of the relative water content (RWC,%), membrane stability index (MSI,%) and relative chlorophyll concentration (SPAD) readings were 83.03 cm, 68.82 cm and 57.36, and they recorded when potato plants irrigated with I_1 treatment under PRD and subsurface drip irrigation with buried lateral at 15 cm depth. These results in agreement with those reported by **Zhang et al. (2023)** who found that the drip irrigation can decrease the wetting of the leave surface and thus, the risk of leave sunburn and crop diseases.

3. Leaf area, dry weight of plants, and crop yield of potato plants

Table (6) showed that the effect of drought stress (deficit irrigation and PRD irrigation) and buried laterals depths treatments on each of the leaf area, dry weight of plants, and crop yield of potato plants grown under SDI system.

A). Leaf area

Table (6) illustrated that the values of the leaf area of potato plants were significantly affected by deficit irrigation treatments. The mean values of the leaf area per plant decreased by 19.36 and 29.79% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. These results showed that the values of leaf area are highly at full irrigation (I_1) as compared to other deficit irrigation treatments (I_2 and I_3). These results are compatible with those reported by Zhao et al. (**2014**) who found that the highest level of irrigation resulted to a highest increase in the leaf area index.

The leaf area values of the potato plants were significantly affected by the PRD irrigation (double laterals). PRD treatment led to increases in the mean values of the leaf area per plant by 1.88% with irrigation treatment (I_1) and by 3.02% with deficit irrigation (I_2) and by 4.17% with deficit irrigation (I_3) as compared to single lateral treatments. The increases in the values of leaf area were highly at deficit irrigation treatment (I_3) with PRD as compared to other irrigation treatments with single lateral. These results are agreement with those reported by **Al-Jabri and Al-Dulaimi (2021)** who found that the PRD significantly increased the antioxidant agents content in the plant by about 10%, which causes increased the plant adaptation to water stresses.

The mean values of leaf area per plant were increased by 9.72 and 5.94% with irrigation treatment (I_1), and by 8.04 and 4.63% with deficit irrigation (I_2), and by 9.32 and 3.21% with deficit irrigation (I_3) when the buried lateral depths changed from zero cm to 15 and 30 cm, respectively.

B). Dry weight of potato plants (stems and leaves)

Table (6) illustrated that the dry weight of potato plants were significantly affected by deficit irrigation treatments. The mean values of the dry weight of potato plants decreased by 14.04 and 27.09% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. These results showed that the values of the dry weight of potato plants are highly at full irrigation (I_1) as compared to deficit irrigation treatments (I_2 and I_3). These results are agreement with those reported by **Farrag et al. (2016).**

The values of dry weight of potato plants were significantly affected by the PRD irrigation (double laterals). PRD treatment led to increases in the mean values of the dry weight of potato plants by 8.55% with irrigation treatment (I_1) and by 11.78% with deficit irrigation (I_2) and by 5.22% with deficit irrigation (I_3) as compared to single lateral treatment. These increases in the values of dry weight of potato plants are highly at deficit irrigation treatment (I_2) as compared to other irrigation treatments with PRD. These results are agreement with those found by Zin El-Abedin et al. (2017). The mean values of dry weight of potato plants were increased by 40.83 and 11.98% with irrigation treatment (I_1), and by 37.09 and 12.04% with deficit irrigation (I_2), and by 26.54 and 9.92% with deficit irrigation (I_3), when the buried laterals depths changed from zero cm to 15 and 30 cm, respectively.

Table (6). Effect of drought stress (deficit irrigation and partial root zone drying irrigation) and laterals depths on the leaf area, dry weight of potato plants, and crop yield values of potato plants grown under drip irrigation systems (as mean values of two seasons).

Deficit irr. treat.	Depth of lateral (cm)	Leaf area, cm^2/plant			Dry weight of potato plants, g $plant^{-1}$			Potato crop yield, t ha^{-1}		
		Partial root zone			Partial root zone			Partial root zone		
		Single lateral	Double laterals	Mean	Single lateral	Double laterals	Mean	Single lateral	Double laterals	Mean
I_1, 100% of ETc	0	476.72	486.55	481.64	56.77	60.62	58.70	38.862	43.365	41.114
	15	520.49	536.40	528.45	78.78	86.56	82.67	43.961	49.441	46.701
	30	508.93	511.56	510.25	63.05	68.41	65.73	41.353	44.845	43.099
	Mean	502.05	511.50	506.78	66.20	71.86	69.03	41.392	45.884	43.638
I_2, 80% of ETc	0	384.38	399.84	392.11	48.34	53.61	50.98	36.322	38.675	37.499
	15	417.77	429.52	423.65	64.39	75.39	69.89	41.167	43.992	42.580
	30	405.66	414.85	410.26	55.38	58.92	57.15	37.984	41.044	39.514
	Mean	402.60	414.74	408.67	56.04	62.64	59.34	38.491	41.237	39.864
I_3, 60% of ETc	0	335.36	347.73	341.55	44.23	45.52	44.88	27.302	30.421	28.862
	15	367.12	379.65	373.39	54.37	59.20	56.79	30.067	35.619	32.843
	30	343.20	361.86	352.53	48.54	50.12	49.33	28.722	32.270	30.496
	Mean	348.56	363.08	355.82	49.05	51.61	50.33	28.697	32.770	30.734

LSD values at 5%	DI	PRD	Depth	DI * PRD	DI * Depth	PRD* Depth	DI *PRD* Depth
Leaf area	1.89	1.54	1.89	2.67	3.27	2.67	4.63
Dry weight of potato plants	0.040	0.033	0.040	0.056	0.069	0.056	0.098
Potato crop yield	0.060	0.049	0.060	0.085	0.104	0.085	0.147

Where: Each value in this Table is an average of 3 replications. I_1, I_2 and I_3 are the deficit irrigation treatments, 100%, 80% and 60% of crop evapotranspiration (ETc), respectively, DI is deficit irrigation, PRD is partial root zone drying.

C). Yield of potato crop

Table (6) illustrated that the yield of potato crop were significantly affected by deficit irrigation treatments. The mean values of the yield of potato crop decreased by 8.65 and 29.58% when deficit irrigation increased from I_1 (100% of ETc) to I_2 (80% of ETc) and I_3 (60% of ETc), respectively. The results showed that the values of the yield of potato crop are highly at irrigation treatment (I_1) as compared to deficit irrigation treatments (I_2 and I_3). These results are compatible with those reported by **Kiziloglu et al. (2006)** who found that the potato plants is sensitive to soil water deficit.

The values of the yield of potato crop were significantly affected by the PRD irrigation (double laterals). PRD treatment led to increases in the mean values of the potato crop yield by 10.85% with irrigation treatment (I_1) and by 7.13% with deficit irrigation (I_2) and by 14.19% with deficit irrigation (I_3) as compared to single lateral treatments. These increases are highly at irrigation treatment (I_3) with PRD as compared to other irrigation treatments. These results are agreement with those reported by **Lipiec et al. (2013)** who found that the roots growth of the plants and crop yield might be affected by the localized water distribution pattern under drip irrigation system.

The mean values of the yield of potato crop were increased by 13.59 and 4.83% with irrigation treatment (I_1), and by 13.55 and 5.37% with deficit irrigation (I_2), and by 13.79 and 5.66% with deficit irrigation (I_3), when the buried laterals depths changed from zero cm to 15 and 30 cm, respectively. It is clear that, all growth parameters, all physiological characteristics, and the yield of potato crop values under this study are decreasing as the following descending lateral depths order: 15 cm > 30 cm > zero cm, under all irrigation treatments. These results are agreement with those found by **Akkamis and Caliskan (2023).**

The highest values of the leaf area, dry weight of potato plant and yield of potato crop were 536.40 cm^2 $plant^{-1}$, 86.56 g $plant^{-1}$ and 49.441 t ha^{-1}, and they recorded when potato plants irrigated with I_1 treatment under PRD and SSDI with buried lateral at 15 cm depth. These results are agreement with those reported by **Makani et al. (2013)** who found that the lower yields was recorded under buried lateral at 30 cm depth, it could be attributed to increase the water stress during plant growth. Drip tape was placed below the seeds, which means the irrigation water moves up by capillarity rise. Unlike in the surface lateral depth (zero cm), where irrigation water moves down by gravity. Insufficient wetting of the plant root zone under lateral depth 30 cm could have causes moisture stress.

CONCLUSION

It could be recommend that, use the full irrigation treatment I_1, PRD irrigation (double lateral lines) and lateral buried in 15 cm depth to reach the maximum of growth and physiological parameters and yield production of potato crop. While, when irrigation water is scarce, it could be use deficit irrigation treatment I_2, PRD irrigation and lateral buried depth at 15 cm to save about 20% of the irrigation water applied with low decreased in the yield of potato crop grown under SSDI system.

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تأثير إجهاد الجفاف على انتاجية محصول البطاطس المنزرع تحت نظامي الري بالتنقيط السطحي وتحت السطحي

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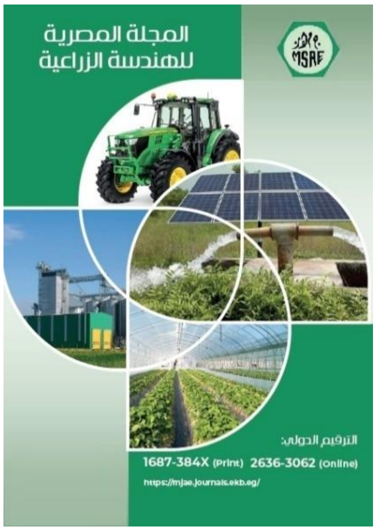

الكلمات المفتاحية:
الري المتناقص، الري بالتجفيف الجزئي لمنطقة جذور النبات، نمو وإنتاجية البطاطس، الخصائص الفسيولوجية، الري بالتنقيط السطحي وتحت السطحي.

الملخص العربي

أدى الطلب المتزايد على المياه والتغيرات المناخية إلى انخفاض الموارد المائية بالمناطق الجافة وشبه الجافة. أجريت تجارب حقلية بمزرعة دمو، كلية الزراعة، جامعة الفيوم. تم زراعة درنات البطاطس في موسمين زراعيين. أجريت ثلاثة معاملات للري المتناقص (DI) وهي I_1 (الري عند ١٠٠٪ من ETc)، I_2 (الري عند ٨٠٪ من ETc)، I_3 (الري عند ٦٠٪ من ETc)، وتم عمل معاملتان للري بالتجفيف الجزئي لمنطقة الجذور (PRD) وهما (استخدام خطان، خط واحد من خطوط المنقطات على خط الزراعة)، وتم استخدام نظامي الري بالتنقيط السطحي، تحت السطحي الذي به الخطوط مدفونة على عمق ١٥، ٣٠ سم. تم تقدير بعض صفات النمو والمحصول لدرنات البطاطس. تشير النتائج إلى أن أعلى متوسط لقيم الموسمين لصفات النمو ومحصول البطاطس كانت عند معاملة الري I_1 وأسلوب الري PRD والري بالتنقيط تحت السطحي وعمق خطوط المنقطات ١٥ سم. أيضا وجد أن أعلى قيم للصفات الفسيولوجية للنبات كانت عند معاملة الري I_1 وأسلوب الري PRD والري بالتنقيط تحت السطحي وعمق لخطوط المنقطات ١٥ سم. عندما زاد تناقص المياه DI من معاملة I_1 إلى المعاملات I_2 و I_3 انخفض متوسط قيم الموسمين لمحصول الدرنات. استخدام أسلوب الري PRD أدى لزيادة متوسط قيم الموسمين لمحصول البطاطس. يمكن التوصية بأنه عند توفر مياه الري تستخدم معاملة الري I_1 وأسلوب الري PRD مع نظام الري بالتنقيط تحت السطحي وعمق خطوط المنقطات ١٥ سم للوصول إلى أعلى قيم للمحصول. بينما في حالة ندرة مياه الري تستخدم معاملة الري المتناقص I_2 وأسلوب الري PRD مع نظام الري بالتنقيط تحت السطحي وعمق خطوط المنقطات ١٥ سم لتوفير ٢٠٪ من مياه الري مع حدوث انخفاض بسيط في محصول البطاطس.