Effect of alternate partial root zone drip irrigation and mulching on zucchini

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Abstract: Innovative irrigation agricultural and irrigation strategies are desirable in the face of dwindling water resources and increasing demand for food, especially in arid and semi-arid areas. The presented work investigated the effect of alternate partial root-zone drying (APRD), mulching and drip irrigation system on yield productivity and water use efficiency (WUE) of zucchini. Field experiments were conducted at Testing and Research Station for Tractors and Farm Machinery, Alexandria Governorate**.** The experimental treatments were: two types of irrigation management (full and APRD), and two soil covering (plastic mulching and without plastic mulch) under both surface and subsurface drip irrigation systems. The soil electrical conductivity was 8.19 dS m^{-1}, which is classified as moderate saline soil. Results showed that the highest zucchini yield was 14.64 t ha^{-1} where the lowest yield was 10.21 t ha^{-1} for full subsurface drip irrigation with mulch (MCSS) and alternate surface drip irrigation without mulch (WAS) treatments, respectively. APRD technique enabled a decrease in zucchini yield ranging from 12% to 17% because the plant was exposed to a water stress 50% of the needed irrigation water requirements**.** Otherwise, applying both APRD and mulching under subsurface drip irrigation increased the WUE. The highest WUE was 6.28 kg m^{-3}, being the lowest 2.93 kg m^{-3} for alternate subsurface drip irrigation with mulch (MASS) and full surface drip irrigation without mulch (WCS) treatments, respectively. The statistical analysis showed a highly significant effect for the irrigation treatments on zucchini productivity, WUE, and plant morphological characteristics. Thus, it is recommended to apply APRD technique with a water stress less than 50% of the needed irrigation water requirements.

Keywords: microirrigation, APRD, mulching, saline soil, Cucubita pepo

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1 Introduction

Available fresh water resources are subjected to an ever-increasing pressure due to extensive agricultural water demand for irrigated lands, which result in water shortages, especially in arid and semi-arid areas, that highlight an urgent solution for innovative irrigation strategy and agricultural water management. The partial root-zone drying (PRD) irrigation technique has proved to hold the potential to increase water use efficiency (WUE) without significantly reducing yields. This technique essentially involves irrigating approximately half of the root system of a crop while the other half is left to dry. Following a certain period of time, the dry half

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of the root system is irrigated, while the wet half is left to dry (Dry and Loveys, 1998). PRD applied in an alternate strategy (alternate partial root-zone drying, APRD) can regulate plant physiological and antioxidative defense system responses, and it is considered as an irrigation water-saving method while other physiological and growth parameters are practically unaffected (Consoli et al., 2017; Howladar, 2018). The new evolving irrigation practice PRD increased irrigation WUE without significant yield reduction of grape (Dry and Loveys, 1998), potato (Yactayo et al., 2013), maize hybrid (Abdul et al., 2016), sugar beet (Topak et al., 2016 and Li et al., 2017), apple (Du et al., 2017), and tomato (Wang et al., 2019).

Subsurface drip irrigation is adapted for partial root zone drying technique, which requires wetting part of the root zone and leaving the other part dry, thereby utilizing reduced amount of irrigation water applied. Such a practice increases irrigation-water-use efficiency (WUE) leading to reduction in irrigation water requirement, while maintaining tomato yields (Kirda et al., 2004; Zegbe et al., 2006).

Plastic mulches substantially reduce the evaporation of water from the soil surface, especially under drip irrigation systems. Associated with the reduction in evaporation is a general increase in transpiration from vegetation caused by the transfer of both sensible and radiative heat from the surface of the plastic cover to adjacent vegetation. Even though the transpiration rates under mulch may increase by an average of 10%-30% over the season as compared to using no mulch, the crop coefficient values decrease by an average of 10%-30% due to the 50%-80% reduction in soil evaporation. (Allen et al., 2006). Mulching enhanced the capacity of maize plants to uptake nutrients, capture soil water and resulted in increased crop productivity (Zhang et al., 2019).

Zucchini (*Cucubita pepo L.*) is fast-growing summer squash, as it can be harvested in 35 to 55 days. It is highly rated for economic value, based on the period between planting and harvest, as well as the number of fruits produced per surface unit. Zucchini is a rich source of nutrients, vitamins, natural antioxidants, and healthful minerals (Rana, 2018). The annual total cultivated area in Egypt is about 39,900 ha with a total yield of 725,000 t on an average of 18.17 t ha^{-1} (Eldwiny et. al, 2009). Zucchini highest yield is at 4.9 dS m^{-1} and it is classified as moderately salt tolerant crop (Tanji and Kielen, 2002). Zucchini is just similar to the other cucurbits in that the secondary roots are spread in the thirty centimeters depth from the soil surface (Ismail, 2002).

The objective of this paper was studying the effect of APRD, plastic mulching, and drip irrigation system type on zucchini yield and WUE under saline soil condition.

2 Material and methods

2.1 Field experiment description

The field experiments were carried out for zucchini (*Cucubita pepo L.*) at Testing and Research Station for Tractors and Farm Machinery, Alexandria Governorate, Egypt (Latitude 31.24 N, and Longitude 29.98 E) during summer season of 2019. A simple drip irrigation subunit of 10 × 10 m size was installed. The water source was the Nile river. The water was stored in a 0.5 m^3 tank. The water was pumped to the subunit using a 0.37 kW electric pump with a maximum discharge of 25 L min^{-1} and a total head of 23 m. The mainline was a 10 m long PVC pipe of 32 mm diameter with a maximum pressure of 600 kPa. Three pipes were branched for every side of the mainline. Lateral lines were 16 mm diameter PE tube with 2.5 m length and they contained built-in cylindrical non-pressure compensating emitters with a nominal discharge of 4 L h^{-1} at 100 kPa and a manufacturing coefficient of variation of 6.9%. The experimental treatments were as shown in Table (1):

Table 1 The experimental treatments and its abbreviations

Treatment	Abbreviation
1 Full surface drip irrigation without mulch	(WCS)
2 Alternate surface drip irrigation without mulch	(WAS)
3 Full subsurface drip irrigation without mulch	(WCSS)
4 Alternate subsurface drip irrigation without mulch	(WASS)
5 Full surface drip irrigation with mulch	(MCS)
6 Full subsurface drip irrigation with mulch	(MCSS)
7 Alternate subsurface drip irrigation with mulch	(MASS)

Two lateral lines were installed for each treatment with 0.4 m separating distance between them and every line was controlled with a 16 mm drip tape valve. The subsurface laterals were buried at 0.1 m depth to ensure water supply in the active secondary root zone of the plant. The treatments in each replicate were randomly assigned across 8 strips as shown in Figure 1.

2.2 Measurements and calculations

2.2.1 Soil analysis

Soil samples between rows of each treatment were taken using a soil tube (0.025 m diameter and 0.1 m high). In 2019, soil samples were collected monthly during the growing season (from May to August) after two days of irrigation. The sampling distance was distributed between two lateral lines at 0-15 cm and 15-30 cm depth.

Texture and chemical analysis of soil was carried out from nine samples in Soil Salinity Laboratory-Agricultural Research Center as shown in Tables 2 and3.

Table 2 The soil texture and physical properties

Soil Depth	Clay (%)	Silt (%)	Sand (%)	Soil texture	Organic matter (%)	Bulk density (g cm^{-3})
0-30 cm	21.55	30.14	47.11	Loam	1.2	1.22 -1.33

Table 3 Chemical analysis for soil

Depth of soil	pH	EC		Cations, meq L^{-1}				Anions, meq L^{-1}		
		%	dS	Ca	Mg	N	K	HCO	Cl -	SO
0-30	8.5	2.6	8.10	10.5	19.5	51	0.15	16.1	54.0	10

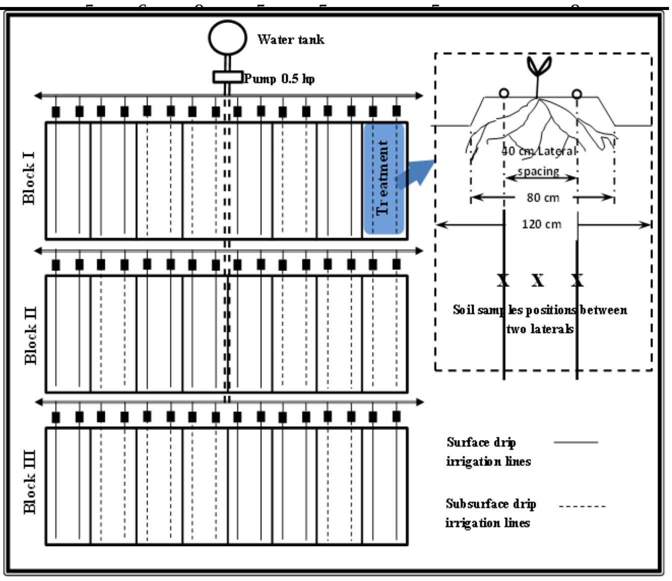


Figure 1 Layout of drip irrigation system and experimental treatment strips distribution.

2.2.2 Soil moisture content

Soil moisture content was determined by the gravimetric method and represented using contouring program Surfer (Golden Software, USA) to obtain the contouring maps for different moisture levels.

2.2.3 Soil pH

Soil samples of about 20 g were dried and sieved then weighted and a 100 ml of distilled water was added to make a hanging solution of 1:2.5, then soil pH was measured using the color strips.

2.2.4 Soil salinity

All soil samples were air-dried and sieved through a 2 mm sieve. The electrical conductivity (EC) values were based on soil: water 1:5 extracts (EC 1:5, on a volume basis), and were determined using a TDS-3 conductivity meter (HM Digital, USA).

2.2.5 Water use efficiency (WUE)

WUE was calculated according to James (1988) as follows:

$$\mathrm{WUE} = \frac{y}{w_a} \tag{1}$$

Where: WUE is the water use efficiency, (kg m^{-3}), y is the total crop yield (kg ha^{-1}), and w_a is the total applied water (m^3 ha^{-1}).

2.2.6 Plant growth and productivity response to salinity

Plant growth and productivity response to salinity was evaluated according to the threshold–slop (Maas and Hoffman, 1977) model as follows:

$$RY = 100 - S\,(EC_e - EC_t) \tag{2}$$

Where: RY is the relative yield (%), S is the percent yield decreases per unit salinity increase above the threshold, EC_t is the threshold maximum root zone electrical conductivity without yield reduction (dS m^{-1}), and EC_e is the average root zone soil electrical conductivity (dS m^{-1}).

2.2.7 Data treatment

The experiments followed a randomized complete block design (RCBD) for one variable. The obtained data were statistically analysed using Minitab 16 software package (Minitab, USA). The mean values of the eight treatments were compared using L.S.D. test at a significance level of 0.05.

3 Results and discussion

3.1 Soil parameters

3.1.1 Soil moisture distribution

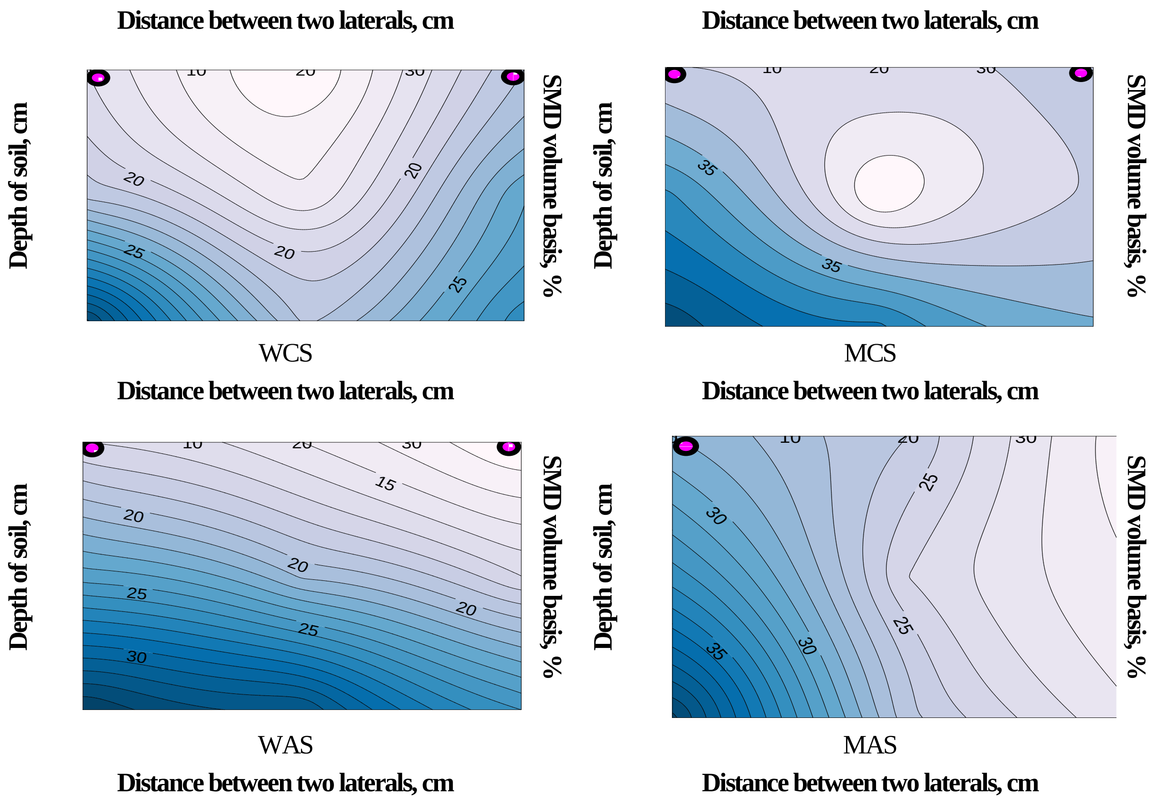
Results demonstrated that the soil moisture distribution (SMD) as shown in Figure 2 was increased in the horizontal direction more than vertical direction for MCS and MCSS treatments, which reduced water loss by evaporation from the soil surface. On the contrary, SMD increased in vertical direction more than horizontal direction under APRD treatments because of reduction water consumption up to 50%. Also, it was found that soil moisture content percentages improved under MASS treatment due to the decrease of evaporation from the soil surface, which was reflected in the increase of zucchini crop yield and irrigation WUE.

3.1.2 Soil pH

The soil initial chemical analysis of the experimental site indicated that the soil pH was 8.5 as shown in Table 2, which classified as strongly alkaline soil (United States Department of Agriculture [USDA], 1998). The soil pH had decreased between 6.8 to 7.1 after the sowing (Table 4) as a result of alternately weekly addition of phosphoric and nitric acid during zucchini growth season. There were no significant effects (p = 0.771) of both pPRD, and plastic mulching on soil pH under both surface and subsurface drip irrigation systems.

3.1.3 Soil salinity distribution

The soil of experimental site classified as moderate saline soil (USDA, 1998) whereas, the initial EC was 8.19 dS m^{-1}. The soil salinity decreased appropriately due to application of irrigation water. Results indicated that plastic mulching under subsurface drip irrigation reduced water loss by preventing evaporation from soil surface. As a result, salts accumulation on the soil surface and root zone decreased as shown in Figure 3. Considering MASS treatment, it was found a decrease of soil salinity in the root zone. Otherwise, in WAS treatment there was a decrease in soil salinity in the irrigated side than the dried side but salts accumulated on the soil surface for increased evaporation. The highest reduction percentage of soil salinity after irrigation was 47% under plastic mulching and subsurface drip irrigation of MCSS treatment as shown in Figure 4.



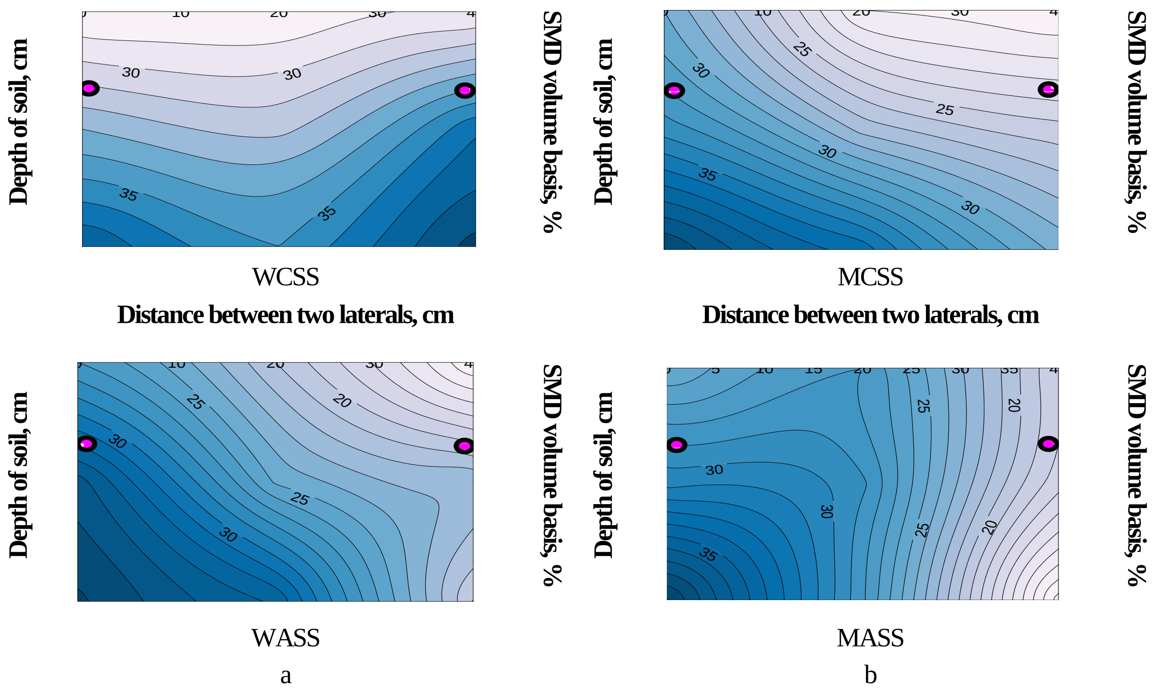
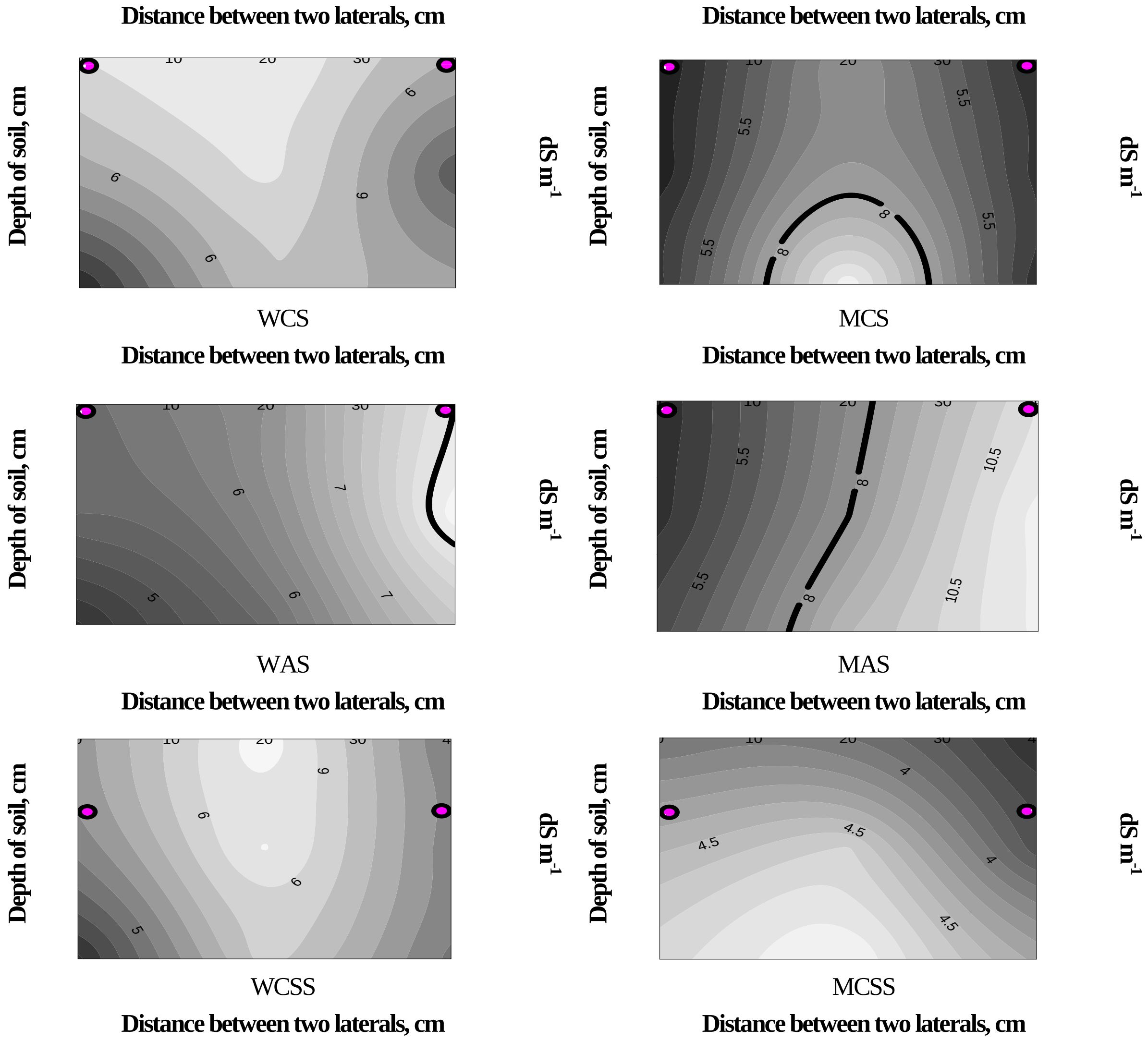
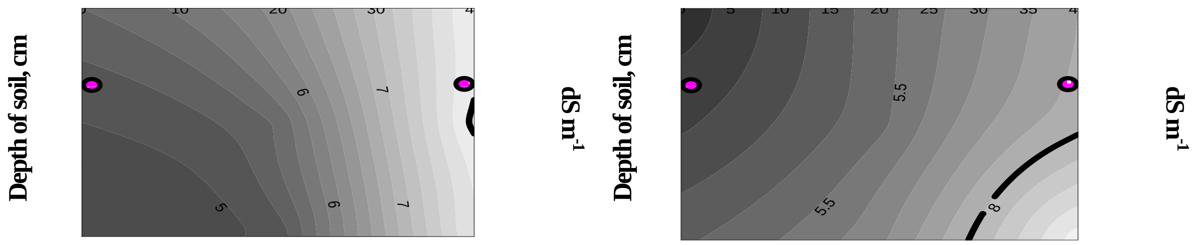


Figure 2 Averaged soil moisture distribution (SMD) between the two laterals after two days irrigation under surface, and subsurface drip irrigation systems with alternate partial root zone drying technique: a) without and, b) with plastic mulch





WASS MASS

a b

Figure 3 Averaged soil electrical conductivity (dS m^{-1}) distribution between the two laterals after two days irrigation under surface and subsurface drip irrigation systems with alternate partial root zone drying technique: a) without and, b) with plastic mulch

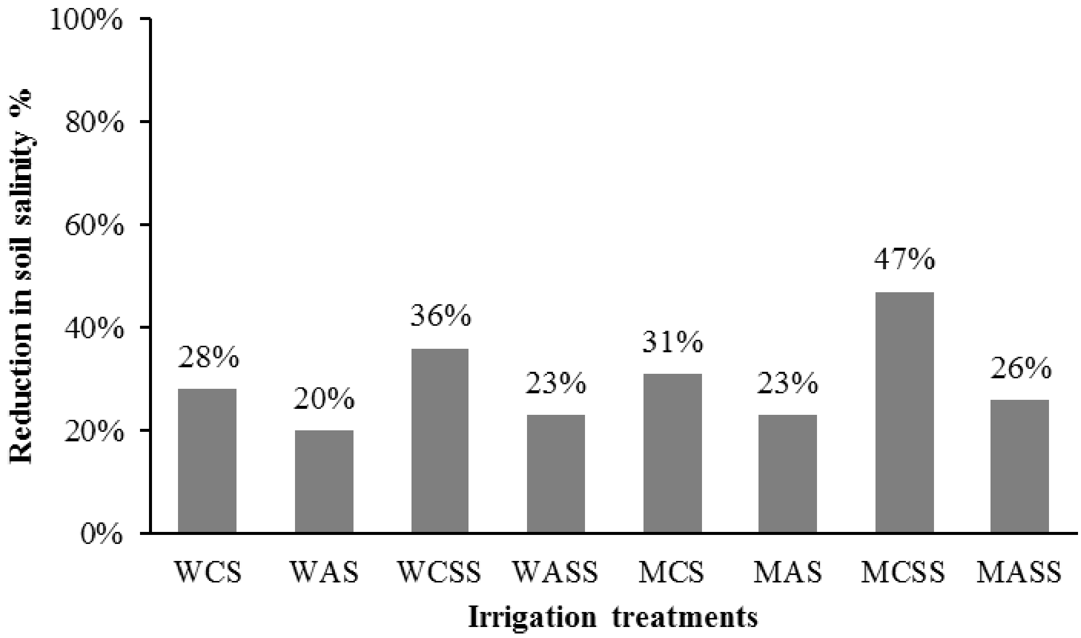


Figure 4 Reduction percentage of soil salinity after irrigation under different treatments

3.2 Crop parameters

3.2.1 Height of plants

The average lengths of zucchini plants were 44 cm, 41 cm, 39 cm, 38 cm, 36 cm, 36 cm, 36 cm, and 33 cm for WASS, MCSS, MCS, MAS, WCS, WCSS, MASS, and WAS treatments, respectively, as shown in Table 4. The highest length (44 cm) was observed for the WASS treatment, despite it was exposed to water stress for using APRD technique. It can be noted there were no significant difference (p>0.01) in the length of zucchini plants as result of applying APRD technique and plastic mulch cover under subsurface drip irrigation system. The statistical analysis showed that there were significant effects (p<0.01) due to irrigation treatments on plant height.

3.2.2 Number of leaves

The average number of leaves per plant was 43, 35, 33, 32, 30, 27, 27, and 27 for MCSS, WCSS, WAS, MASS, MCS, WCS, WASS, and MAS treatments, respectively, as shown in Table 4. The highest leaves number (43 leaves per plant) was for MCSS treatment. It was not exposed to water stress using APRD technique. Applying MASS treatment the leaves number was 32 leaves per plant for both APRD technique and plastic mulching under subsurface drip irrigation. The statistical analysis showed that there were significant differences in number of zucchini plant leaves at the 0.05 probability level and as of result using APRD technique and plastic mulch cover with subsurface drip irrigation system.

3.2.3 Zucchini yield

Under the effect of moderate saline soil condition, zucchini yield (Y) was 14.64, 13.21, 12.9, 12.57, 12.26, 11.42, 10.85, and 10.22 t ha^{-1} for MCSS, MCS, MASS, WCSS, WCS, MAS, WASS, and WAS treatments, respectively. The highest yield (14.64 t ha^{-1}) was achieved with the MCSS treatment, being 12% higher than the yield of MASS treatment (12.9 t ha^{-1}). The lowest yield was 10.21 t ha^{-1} for WAS, while the yield of WCS was 12.26 t ha^{-1}, which was 17% higher than WAS as a result of using APRD technique. Irrigation using APRD technique would enable a decrease in zucchini yield over the yield than full irrigation in all treatments. Zucchini yield percentage was decrease due to using APRD technique were 12%, 13%, 14%, and 17% for treatments MASS, MAS, WASS, and WAS, respectively, but it was increased due to plastic mulching were 19%, 16%, 12%, and 8% for treatments MASS, MCSS, MAS, and MCS, respectively, as shown in Figure 5. There was an increase in Zucchini yield percentage under subsurface drip irrigation system were 13%, 11%, 6%, and 3% for treatments MASS, MCSS, WASS, and WCSS, respectively as shown in Figure 6. A significant effect ($p<0.05$) was observed for the irrigation treatments on zucchini crop productivity as shown in Table 4.

From the mentioned above, zucchini yield productivity decreased under the application of APRD without mulching due to the plant exposure to the stress of both APRD application and soil salts. On the other hand, both the mulching and full irrigation decreased soil salinity in the root zone under subsurface drip irrigation system which, improved zucchini yield productivity.

3.2.4 Water use efficiency (WUE)

The use of APRD was positively reflected on the increase of WUE as opposed to productivity, which was exposed to high water stress with 50% of water consumption requirements with low reduction percentage of zucchini yield. The WUE of zucchini was found highest in MASS treatment (6.3 kg m^{-3}), while, WUE of MCSS treatment was less than MCSS (3.6 kg m^{-3}) with 76.3%. The lowest WUE were for WCS and WCSS (2.9 kg m^{-3}), while WAS had 4.8 kg m^{-3}, a 66% more than WCS due to the use of APRD technique (Figure 7). Irrigation with APRD would enable an increase in WUE than full irrigation in all treatments. Increase percentages of WUE for APRD technique were 76.3%, 73%, 72.5%, and 66.7% for treatments MASS, MAS, WASS and WAS, respectively (Figure 5). Increase percentages of WUE for plastic mulch cover were 24%, 22%, 17%, and 12% for treatments MASS, MCSS, MAS and MCS, respectively (Figure 5). On the other hand, WUE increase for subsurface drip irrigation system were 13%, 11%, 6%, and 3% for treatments MASS, MCSS, WASS and WCSS, respectively (Figure 6). The statistical analysis of APRD with plastic mulching under surface and subsurface drip irrigation systems showed that there was a highly significant effect at the 0.01 probability level for the irrigation treatments on WUE as shown in Table 4.

Table 4 Statistical analyses of soil pH, growth parameters, zucchini yield and WUE under different treatments

TREATMENTS (T)	Soil pH	Length of plants (cm)		Number of leaves		Yield (t ha^{-1})		WUE (kg m^{-1})	
WCS	7.1	36	abc	27	b	12.26	ab	2.86	c
WAS	6.8	33	a	33	b	10.22	b	4.77	b
WCSS	7.0	36	bc	35	ab	12.57	ab	2.93	c
WASS	7.1	44	abc	27	ab	10.85	b	5.06	b
MCS	7.0	39	ab	30	a	13.21	ab	3.22	c
MAS	7.0	38	bc	27	b	11.42	ab	5.57	ab
MCSS	7.0	41	bc	43	ab	14.64	a	3.56	c
MASS	7.1	36	c	32	ab	12.89	ab	6.28	a
p	0.771	0.004		0.018		0.016		0.000	
Significance L	Non	**		*		*		**	

N: *: significance at the 0.05 probability level, and **: significance at the 0.01 probability level. Means with the same letter are not significantly different.

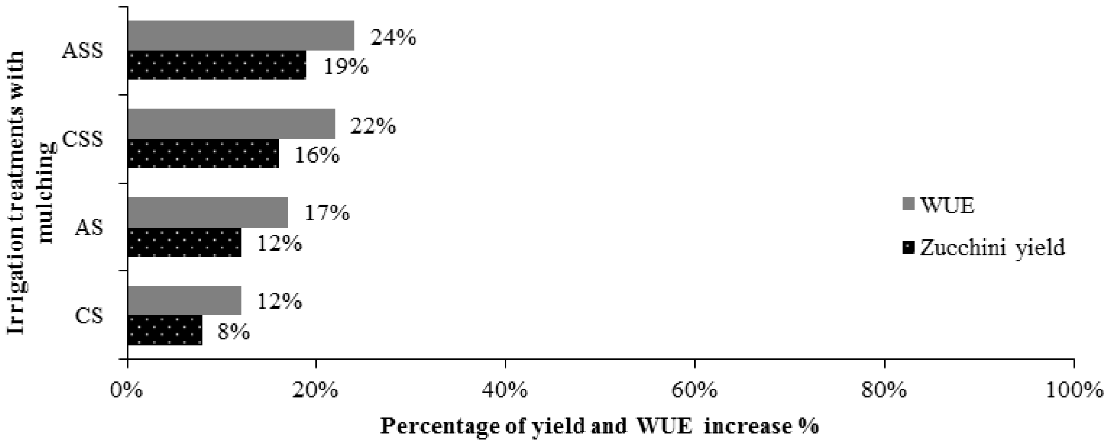


Figure 5 Percentage of increase in zucchini yield and WUE resulting from use of plastic mulching

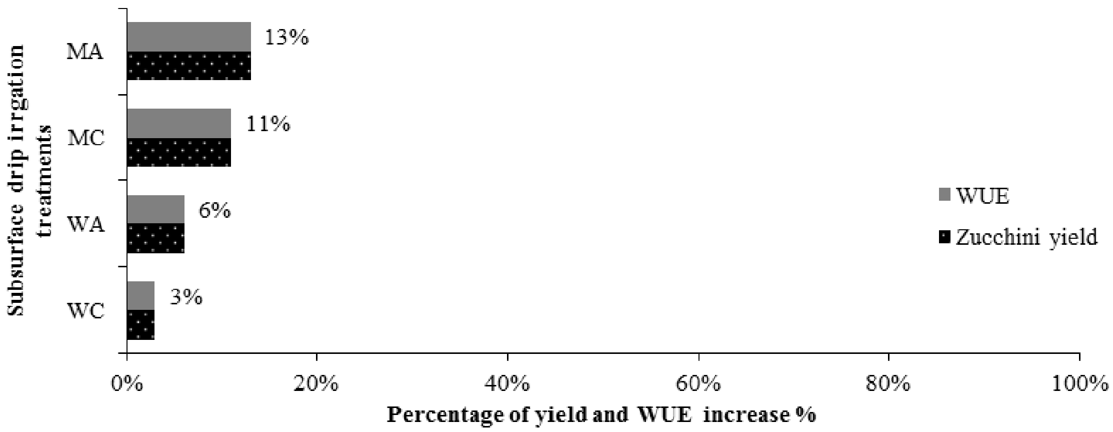


Figure 6 Percentage of increase in zucchini yield and WUE resulting from subsurface drip irrigation system (SS)

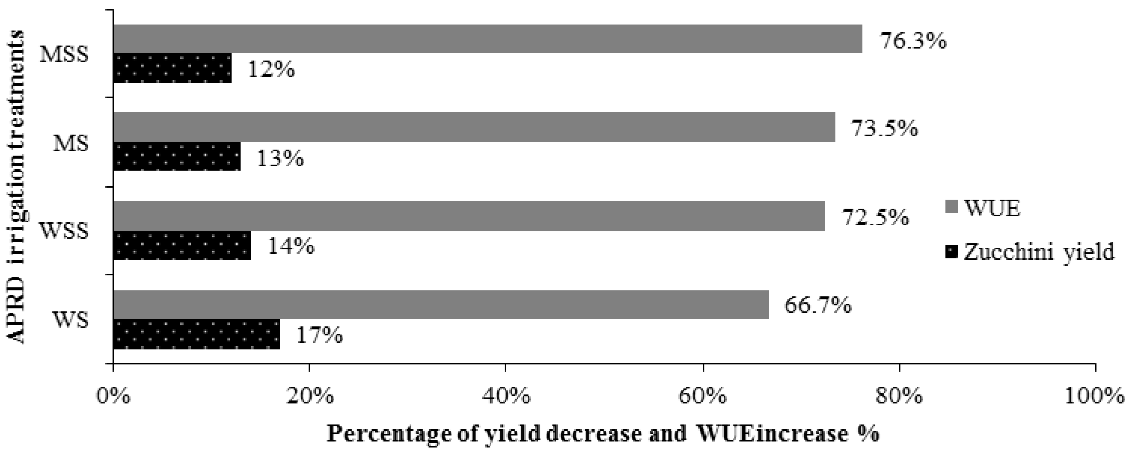


Figure 7 Percentage of decrease in zucchini yield and in exchange for increasing WUE resulting from APRD technique

3.2.5 Zucchini yield (Ym) and WUE without effect soil salinity

The maximum zucchini yield and WUE without soil salinity effect were calculated using Equation 2. There was a 33% reduction in the relative yield RY regarding the actual yield and WUE as a result of high initial soil salinity (8.19 dS m^{-1}). The highest yields of zucchini were recorded for a soil salinity at more or equal 4 dS m^{-1} (El-shimmy and Abd-elathem, 2001). Soil salinity stress begins its effect on zucchini yield after 4.7 dS m^{-1}. The highest zucchini yield without soil salinity effect was 22.13 t ha^{-1} where it was 14.64 t ha^{-1} and the lowest yield was 10.22 t ha^{-1} for MCSS and WAS treatments, respectively. Otherwise, the highest WUE of zucchini was 9.5 kg m^{-1}, where the lowest WUE was 4.3 kg m^{-3} for MASS and WCS treatments, respectively.

4 Conclusions

Field experiments were conducted to study the effect of APRD technique, plastic mulching, and drip irrigation type on both zucchini yield productivity and WUE under soil salinity of 8.19 dS m^{-1}. It was found that soil moisture content percentages improved within a range of 18.75% to 22.73% under APRD technique, plastic mulching, and subsurface drip irrigation system because of decrease evaporation from soil surface. Application of APRD technique, plastic mulching, and subsurface drip irrigation systems decreased soil salinity in the root zone within the ranges of 23% to 26%, 23% to 47%, and 26% to 47% respectively. Without mulching, the plant was exposed to stress of both APRD technique application (50% of irrigation water consumption requirements) and salt of soil, which decreased zucchini yield by 14% to 17%. The highest zucchini yield (14.64 t ha^{-1}) was achieved under treatment of application full irrigation, plastic mulching, and subsurface drip irrigation systems, where the highest WUE (6.28 kg m^{-3}) was recorded for application of APRD technique, plastic mulching, and subsurface drip irrigation systems. Under conditions of moderate saline soil, it is recommendable to apply APRD technique with plastic mulching under subsurface drip irrigation, but with water stress less than 50% of irrigation water consumption requirements.

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