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The beneficial effect of subsurface drip irrigation system on yield, fruit quality and leaf mineral content of Valencia orange trees

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Abstract: The effect of subsurface drip irrigation comparing with the surface one on yield, fruit quality and leaf mineral content of Valencia orange trees was studied. Trees were grown on sandy soil at the farm of National Research Centre, Nubaria district, Behaira governorate, Egypt. Three drip irrigation rates (12, 9, 6 drippers per tree) were used as surface or subsurface drip irrigation systems.

From the obtained results, it could be concluded that subsurface drip irrigation system shows a positive effect on maximizing water use efficiency which detected as increasing the yield and fruit quality. In general, subsurface irrigation was more effective comparing with the surface one. In this concern, treatment of 12 drippers per tree under subsurface irrigation was the promising one comparing with the other treatments, since this treatment was the superior in increasing fruit number, fruit weight and yield per tree in both studied seasons, also improved both physical and chemical fruit quality of Valencia orange trees.

Key words: Valencia orange – Subsurface irrigation – Yield – Fruit quality – Leaf mineral content.

Introduction

The global water crisis is one of the major environmental concerns in the world. In the arid and semi arid as well as sub-tropical regions, water shortage is a normal phenomenon and seriously limits the agricultural potential[1]. It should be noted that there is strong evidence of climate change that would lead to a further decrease of annual rainfall year by year[2]. Drought stress is the main problem, which was distributed widely throughout the world on the 1.2 billion ha in rain fed agricultural land[3]. Reactions of the plant affected by the amount of soil water are directly or indirectly. All physiological processes such as photosynthesis, transpiration, cell turgidity and the growth of tissues in plants are directly affected by the availability of water[4]. Drainage and evaporation play an important role in the loss of water. These reasons focus on the development of irrigation methods that reduce water use or to achieve maximum efficiency in the use of water. Therefore, it is proposed to find ways in which water available can benefit economically[5]**.** Drip irrigation has been used in horticultural operations since the middle of the 20th century[6] and it is the most effective way to apply directly water and nutrients to plants and not only save water but also increases yields[7, 8]. In many less developed parts of the world, traditional methods of subsurface irrigation can help conserve scarce water resources. Subsurface irrigation systems are capable of applying small amounts of water directly to the plant root zone where the water is needed, and these small amounts can be applied frequently to maintain favorable moisture conditions in the root zone. Some of the potential benefits of subsurface irrigation are improvements in yield and quality and the reduction of production costs[9, 10]. Subsurface drip irrigation can be a cost-effective alternative to solid set sprinkler irrigation, saving approximately 50% in investment costs. Fertilizers can be applied near the center of the crop root zone with subsurface irrigation[11].

So, the aim of this study is to maximize the water use efficiency and reduce the amount of irrigation water through using the subsurface irrigation system and evaluate its effect on the yield and fruit quality of Valencia orange trees grown under sandy soil conditions.

Material and Methods

This experiment was carried out during two successive seasons (2014 and 2015) to study the effect of subsurface drip irrigation comparing with the surface one on yield and fruit quality of Valencia orange trees grown on sandy soil, in orchard located at the National Research Centre farm, Nubaria district, Behaira governorate, Egypt.

The trees were budded on Volkamer lemon (*C. volkameriana*) rootstock and planted at 5X5 meters apart under drip irrigation system. The results of soil analysis according to[12] are given in Table 1 which shows that the texture of the soil is sandy.

Table (1): Mechanical and chemical analysis of experimental soil Al-Emam Malek village, Al-Nubaria district, Al-Behaira Governorate.

Sand %	Silt %	Clay %	pH	Organic matter, %	$CaCO_3$ %	E.C. dS/m	Soluble N, ppm	Available P, ppm	Exchangeable K, ppm
91.2	3.7	5.1	7.3	0.3	1.4	0.3	8.1	3.2	20

The experiment included six irrigation treatments as follows:

1. Surface irrigation with 12 drippers per tree (the orchard program).
2. Surface irrigation with 9 drippers per tree.
3. Surface irrigation with 6 drippers per tree.
4. Subsurface irrigation with 12 drippers per tree.
5. Subsurface irrigation with 9 drippers per tree.
6. Subsurface irrigation with 6 drippers per tree.

Note: Dripper discharge = 4 liters per hour.

Each treatment was replicated six times on one tree plots and the randomized complete block design was arranged.

The selected trees were seven years old and nearly uniform in vigor as possible. The fertilization program and other horticultural practices were the same for all trees under investigation.

To determine leaf mineral content, about forty leaves were taken in late August in each season from tagged non-fruiting and non-flushing spring growth cycle[13]. Leaf samples were washed with tap water, then with distilled water and dried at 70^{o}C finally ground and digested. The digested solution was used to determine N, P, K, Ca and Mg content as percentage on dry weight[14]. Total chlorophyll in the fresh leaf was determined as spad units (spad = 100 mg chlorophyll/gm fresh weight) by using Minolta chlorophyll meter (spad, 502).

At the harvesting time (early April of each season), yield per tree was determined as number and weight of fruits (kg)/tree.

For fruit properties determination, samples of ten fruits were taken from each replicate to determine the physical and chemical properties i.e. fruit length (cm), fruit diameter (cm), juice weight (gm), peel weight (gm), total soluble solids% and acidity content as the methods described[15].

The data were subjected to analysis of variance and Duncan's multiple range test was used to differentiate means[16].

Results

Yield and fruit number:

The fruit number per tree (Table 2) was different among irrigation water treatments in this study and the fourth treatment recorded the highest average of fruit numbers (291 and 310) during the first and second seasons, respectively. However, the differences were insignificant between fourth, fifth and sixth treatments in the first season. The lowest number of fruit was observed in the third treatment (116 and 123 in the first and second seasons, respectively). However, there was an increasing trend for this parameter in response to increase the amounts of irrigation water.

It is clear from Table 2 that, the fruit weight was at the highest value (235 and 245 in the two seasons, respectively) when the plants irrigated using the subsurface drip irrigation with the rate of 12 drippers per tree without significant differences between 12 and 9 drippers per tree under the same system of irrigation. On the contrary, using surface drip irrigation system by 9 drippers per tree gave the lowest value of fruit weight (163 and 179 gm in the first and second seasons, respectively).

The results in Table 2 show that fruit yield was increased gradually with increasing the amount of irrigation water and the maximum value of the average fruit yield per tree (67.60 and 76.34 kg/tree in the two seasons, respectively) was observed after using of 12 drippers per tree with subsurface irrigation system, while the lowest value was obtained with the surface irrigation (21.63 and 25.90 for first and second seasons, respectively). In another word, the fruit yield obtained by the subsurface drip irrigation was increased than the surface one by about 250 and 228% in the first and second seasons, respectively. The reduction in fruit yield average per tree across two seasons was observed due to the use of surface irrigation system compared with the subsurface one. Moreover, the reduction in the yield was more pronounced as a result of dripper numbers per tree because the amount of water that given for every tree was decreased too. From that the minimum value of fruit yield per tree (21.63 and 25.90 kg for both seasons, respectively) was found after using of 6 drippers per tree as surface irrigation system.

Table 2: The effect of irrigation system on fruit number, fruit weight and fruit yield /tree of Valencia orange in the two studied seasons.

Treat.	Fruit number		Fruit weight (gm)		Fruit Yield /tree (kg)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
1	158 bc	165 d	173 c	203 b	27.01 d	33.48 d
2	135 c	145 e	163 c	179 c	21.64 d	25.97 e
3	116 c	123 f	188 bc	210 b	21.63 d	25.90 e
4	291 a	310 a	235 a	245 a	67.60 a	76.34 a
5	266 a	269 b	216 ab	239 a	53.74 b	64.49 b
6	241ab	254 c	169 c	182 c	38.22 c	46.24 c

Means in columns followed by the same letter are not statistically different at the 0.05 probability level.

Fruit quality:

Results in Table (3) show that using 12 drippers per tree as the subsurface water supplementary gave the maximum significant length of the fruit (8.5 cm) during both seasons compared with those produced with the other treatments except the fifth treatment because of the differences lacked significance in the first and second seasons. On the other hand, using 6 drippers per tree as surface and subsurface drip irrigation had lower average of fruit length (6.96 cm) in the first season; also the same situation was happened in the second season where the third treatment recorded the minimum average of fruit length (7.21 cm) compared with those produced by the other treatments (Table 3). In all cases, using subsurface irrigation produced longer fruit than did surface irrigation.

Table 3 show that, fruit diameter was increased with increasing water irrigation amount with the subsurface drip irrigation system, so using 12 drippers per tree as subsurface soil gave the largest fruit diameter (7.8 cm) in both seasons, respectively and the same value of fruit diameter was found due to the fifth treatment in the second season. On the contrary, the smallest fruit diameter (6.7 and 6.8 cm) in both seasons was noticed when used 6 drippers per tree as surface irrigation.

Regarding juice weight among irrigation treatments, the highest juice weight was produced with 12 drippers using the subsurface irrigation system (113 and 120 gm for both seasons, respectively) in compare with the other irrigation treatments (Table 3). Moreover, it was noticed that the lowest juice weight (74.5 and 81.67 gm) in the first and second seasons, respectively was recorded with the plants grown under 6 drippers per tree with surface irrigation in the first season and the same rate as subsurface in the second one.

It is clear from the results in table 3 that the highest value of peel weight (98.33 and 108 gm) was observed with the trees irrigated with 12 drippers per tree under the subsurface drip irrigation. On the other side, the lowest value of peel weight (68.16 and 73.83gm) was found by using 6 drippers per tree with surface irrigation system.

The statistical analysis of the obtained results in table 3 shows that, the differences among treatments regarding the TSS percentage were significant. The presented results in Table 2 clearly indicate that with increasing irrigation rate, TSS percentage was gradually decreased to reach its lowest value (12.7 and 13.8 % for the first season and second one, respectively) under the condition of 12 drippers per tree using subsurface irrigation system. On the other hand, the highest value of TSS percentage (14.9 and 15.4 %) was observed with the treatment of 6 drippers per tree using subsurface drip irrigation system. However, the differences between the third and the sixth treatments under the condition as 6 drippers per tree either as surface or subsurface irrigation systems were not statically significant during first and second seasons.

Table 3 illustrate that the differences between treatments concerning acidity percentage were significant during both seasons. The maximum percentage of acidity (2.49 and 2.21 %) was recorded by the third treatment in the first and second seasons, respectively. In addition, the differences between the third and fourth treatments in the first season were insignificant and the same status was observed in the second season between all treatments, except the second one. The minimum percentage of the acidity (1.75 and 1.70 % during the two seasons, respectively) was found due to the second treatment (9 drippers per tree as surface irrigation).

Table 3: The effect of irrigation system on fruit length (cm), fruit diameter (cm), juice weight (gm), peel weight (gm), TSS (%) and acidity (%) of Valencia orange in the two studied seasons.

Treat.	Fruit length (cm)		Fruit diameter (cm)		Juice wt. (gm)		Peel wt. (gm)		TSS (%)		Acidity (%)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
1	7.9bc	8.1ab	7.1b	7.5ab	90.6bc	102.0abc	82.3b	80.5cd	13.0cd	13.8c	2.00bc	2.17a
2	7.8bc	7.2c	7.16 b	7.5ab	77.5c	98.33abc	77.5bc	89.5bc	13.7 bc	13.5c	1.75c	1.70b
3	6.9d	8.0b	6.7c	6.8c	74.5c	91.0bc	68.1c	73.8d	14.3a	15.0ab	2.49a	2.21a
4	8.5a	8.5a	7.8a	7.8a	113.8a	120.0a	98.3a	108.0a	12.7d	13.1c	2.19ab	2.15a
5	8.3ab	8.4a	7.4ab	7.8a	106.1ab	115.1ab	86.6ab	96.3b	13.4ecd	14.2bc	2.15b	2.09ab
6	6.96d	7.6bc	7.0bc	7.1bc	83.5c	81.6c	66.1c	79.8d	14.9a	15.4a	2.02bc	2.17a

Means in columns followed by the same letter are not statistically different at the 0.05 probability level.

Leaf mineral and chlorophyll content:

The results in table (4) show a significant difference in nitrogen content among the treatments. The highest value of nitrogen content (2.33 and 2.66 % in both seasons, respectively) was obtained from the tree leaves of the fifth treatment of 9 drippers per tree using the subsurface irrigation system. While, the lowest value of nitrogen content (1.46 and 1.50 % during both seasons, respectively) was found with the lowest number of drippers per tree (6 drippers) using the surface irrigation system.

Table (4) show that, the fifth treatment recorded the highest significant values of phosphorus content in the Valencia tree leaves (0.33 and 0.41 % in both seasons, respectively) compared with the other studied treatments. On the other hand, the third treatment gave the minimum value of phosphorus content (0.12 and 0.15 % in both seasons, respectively).

Leaf potassium content was increased when used the subsurface drip irrigation system and the maximum value of it (1.36 and 1.55 %) in the first and second seasons, respectively was noticed with the fifth treatment. Contrariwise, giving the minimum irrigation rate (6 drippers per tree) as the surface irrigation system gave the lowest value of leaf potassium content (0.59 and 0.67 %) in both seasons, respectively table (4).

It appears from table (4) that, the minimum and maximum value of calcium content (2.15 and 2.37%) for the minimum and (3.26 and 3.48%) for the maximum were found with the third and fifth treatments in the first and second seasons, respectively.

Concerning magnesium content in the leaves, Table 4 show that the highest magnesium content (0.72 and 0.85%) was recorded due to the fifth treatment (9 drippers/ tree) as subsurface irrigation in both studied seasons, while, he lowest value was obtained from the trees irrigated with 12 and 6 drippers as surface irrigation. This was true in the first and second seasons, respectively.

As for total chlorophyll content, it is notice from table (4) that the chlorophyll was concentrated by decreasing the amount of irrigation water reached every tree. Thus, the highest value of total chlorophyll content (77.3 and 80 spad unit) in the first and second seasons, respectively) was found after using 6 drippers per tree with surface irrigation system. While the lowest value of the total chlorophyll content (60.3 and 63.00 spad unit) in both seasons, respectively was noticed with the fourth treatment (12 drippers per tree) using the subsurface drip irrigation system.

Table 4: The effect of irrigation system on chlorophyll and leaf mineral content of Valencia orange in the two studied seasons.

Treat.	**N %**		**P %**		**K %**		**Ca %**		**Mg %**		**Chlorophyll (Spad)**	
	1st season	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**
1	1.46d	1.50f	0.15ed	0.19d	0.72cd	0.77cd	2.38c	2.48c	0.33e	0.39e	62.6b	63.3c
2	1.62c	1.74e	0.10cd	0.20c	0.86c	0.91c	2.53c	2.58c	0.41d	0.51d	76.8a	78.6a
3	1.70c	1.87d	0.12e	0.15e	0.59d	0.67d	2.15d	2.37c	0.34e	0.38e	77.3a	80.0a
4	2.20b	2.56b	0.21bc	0.31b	1.2ab	1.33b	2.32a	3.58a	0.62b	0.69b	60.3b	63.0c
5	2.33a	2.66a	0.33a	0.41a	1.36a	1.55a	3.26a	3.48a	0.72a	0.85a	73.5a	76.0b
6	2.14b	2.30c	0.24b	0.32b	1.14b	1.38b	2.75b	3.02b	0.52c	0.62c	73.5a	75.6b

Means in columns followed by the same letter are not statistically different at the 0.05 probability level.

Discussion

Generally, using subsurface irrigation had a positive effect comparing with the surface one, since all subsurface treatments were more effective comparing with the surface drip irrigation. The advances of subsurface irrigation may be due to that the distribution uniformity of soil moisture was greatly improved on this property after the subsurface irrigation system was installed[17]. In this respect, the higher irrigation rate (12 drippers/tree) was more effective in increasing fruit yield per tree of Valencia orange in this study besides, improving physical and chemical fruit quality parameters such as fruit length, fruit diameter, Juice weight, peel weight, TSS and leaf mineral content, and these results could be due to the effect of subsurface irrigation on increasing vegetative growth, photosynthesis rate and fruit set. This led to an overall positive effect on total production per tree. In this concern, **w**ater use efficiency was increased mainly due to yield increase, not less water use[18]. This means that using the treatment of 12 drippers has a great effect on maximizing the water use efficiency sine it recorded the highest yield per tree. However, yield for over 30 crops was greater or equal using subsurface irrigation than that obtained with other irrigation methods and in most of the cases required less water[19, 20, 21]. Also, yields with subsurface drip irrigation were approximately 22% higher than surface flood-irrigated fields while still reducing irrigation requirements by approximately 6%[11].

Bigger fruit size may be due to the positive effect of water availability in the root growth zone. In this respect, the soil moisture contents of subsurface drip irrigated layer increased dramatically, while salts accumulated at the surface away from the emitters of subsurface drip irrigation[22].

The difference in weight was mostly because of the fruit water content so it inversely proportional with the TSS and acidity. Evidently water stress, besides reducing plant activity, causes a drop in fruit water content and fruit growth, which is partially reversible after removing the stress[23]. Fruit yield of cucumber was reduced due to decreasing amounts of water applied[24]. It's observed a remarkable higher grain yield of wheat when grown along with irrigation[25]. The above mentioned results reflect the importance of water to the plant life and productivity. These results are in conformity with those of that low water availability adversely affects hormonal balance, plant development and assimilate translocation[26].

Higher values of leaf mineral content due to the subsurface irrigation may be attributed to that the fertilizers can be applied near the center of the crop root zone with subsurface irrigation[11]. However, Nitrogen fertigation of maize with subsurface irrigation can be effective in maintaining high grain yields while protecting the environment[11]. On the other hand, a study concluded that management practices which include application of natural clay deposits under subsurface drip irrigation have high potential for improving nutrient levels and consequently on the following growing crops[22].

Using the surface drip irrigation system provides costs but such methods allow significant losses of water through the evaporation. In this experiment, the use of subsurface drip irrigation system reduces these losses.

Conclusion

From the abovementioned results, it could be concluded that subsurface drip irrigation system had a positive effect on maximizing water use efficiency which detected as increasing the yield and fruit quality. In general, subsurface irrigation was more effective comparing with the surface one. In this concern, treatment of 12 drippers per tree under subsurface irrigation was promising one comparing with the other treatments, since this treatment increased fruit number, fruit weight and yield per tree in both studied seasons, also improved physical and chemical fruit quality of Valencia orange trees. However, using 12 drippers as subsurface drip irrigation increased yield by about 250 and 228% in the first and second seasons, respectively than the same rate as surface drip irrigation.

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