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INCREASING IRRIGATION EFFICIENCY BY USING SUBSURFACE IRRIGATION SYSTEM AND HYDROGEL AND ITS EFFECT ON GROWTH AND PRODUCTIVITY IN MURCOTT MANDARIN TREES UNDER NEW VALLEY CONDITIONS

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A two-year study was carried out during two successive seasons of 2019 and 2020 in a private orchard of 7 years old Murcott mandarin trees budded on Volkamer lemon rootstock, grown in sandy soil under a drip irrigation system from a well at El-Farafrah Oasis of the New Valley Governorate, Egypt. The study was a split-plot design. Three levels of subsurface drip irrigation depths (0, 15, and 30 cm depth from surface soil) were assessed in the main plot and three levels of hydrogel (0, 100, and 150 g/tree) were assessed in sub plots, with three replicates for each treatment and each replicate was represented by two trees. The goals of this research were to study the effect of three subsurface drip irrigation depths from surface soil (0, 15, and 30 cm) and three doses of hydrogel and their combinations on vegetative growth, yield and fruit quality of Murcott mandarin under heat stress of El-Farafrah Oasis of the New Valley Governorate, Egypt. The best results were achieved with 15 cm drip irrigation depth combined with 150 g/tree hydrogels. This combination also ensured the best physical and chemical properties of the fruits, improved irrigation efficiency, and minimized the fruit's total acidity percentage.

Keywords: Murcott mandarin, subsurface drip irrigation, hydrogel, yield, fruit quality

INTRODUCTION

Mandarins are one of the most popular edible fruits. They are simple to peel, have a delicious flavor, and are second to sweet oranges in popularity. The mandarin group contains many types, including Murcott mandarin. The Murcott mandarin tree is Rutaceae family and is a hybrid between *Citrus reticulata* Blanco and *Citrus sinensis* (L.) Osbeck (Hodgson, 1967). Other names for it are Smith Tangerine and Honey Tangerine or Honey Murcott (Morse, 1957 and Futch and Jackson, 2003). One of Egypt's most significant new exportable fruit crops is Murcott mandarin (*Citrus reticulata* Blanco). Commercial harvesting occurs from January to March, but it has a poor shelf life (Tucker et al., 1998 and Futch and Jackson, 2003). Growing citrus in soils with high temperatures produces fruits with poor quality specifications and a small percentage of juice (Huchche et al., 2010) as a result, farmers frequently raise irrigation rates, particularly in hotter climates, to enhance the quality of their produce, particularly by raising the proportion of fruit juice.

This research focuses on irrigation techniques that consume less water or utilize water as efficiently as possible. Drip irrigation systems significantly save water and increase yields in newly reclaimed soil, overcoming water scarcity issues by utilizing surface and subsurface techniques (Talat et al., 2012). Modern agriculture includes drip irrigation systems and subsurface drip irrigation. Subsurface drip irrigation systems will likely continue to be used more frequently in the future, according to current commercial and farmers' demand levels. Using buried drip tapes, subsurface drip irrigation distributes water below the soil's surface (ASAE, 2001). Subsurface drip irrigation uses hidden tubes and emitters to apply water directly to plant roots, requiring high supervision and performance in challenging conditions like shallow water tables and dense soils (Baille, 1997). Subsurface drip irrigation on Manfalouty pomegranate trees improved leaf area, chlorophyll, fruit length, diameter, weight, grain weight, TSS, and total sugar content, while surface drip irrigation produced the highest overall acidity (El–Desouky and Abd El-Hameid, 2014).

The other new technique in this research was using hydrogels to improve water hold efficiency in soil. Hydrogels have been utilized to aid plant establishment and growth in dry soils since they were developed to increase the sandy soil's capacity to store more water (Chen et al., 2004). When under water stress, they can absorb water many times their weight, hold onto it, and give it to plant roots, which aids in the survival and improvement of plants (Callaghan et al., 1988 and Akhter et al., 2004). The ability of super absorbent polyacrylates (SAPs) to absorb water depends on the amount of initiator, the amount of the monomer acid that has been neutralized, and the volume of the polymerization mixture (Bapai et al., 2006). Hydrogels are sometimes referred to as “root watering crystals” because they swell like sponges to be as numerous times their original volume, when in contact with freely available irrigation water, consequently increasing soil irrigation water holding capacity and decreasing irrigation frequency (Koupai et al., 2008), and decrease nutrient (NPK) leaching (Abdel-Aziz et al., 2020). According to Pattanaaik et al. (2015), the productivity and vegetative development of Assam lemons (citrus limon) were significantly higher when stockosorb was applied to the soil at a concentration of 100 g/tree as compared with the control treatment. Additionally, Abdel-Aziz et al. (2020) found that in arid and semi-arid regions, the use of a hydrogel agent can enhance the yield and fruit quality of Murcott mandarin trees.

This study aims to investigate the effect of three subsurface drip irrigation depths from surface soil (0, 15, and 30 cm) and three doses of hydrogel and their combinations on vegetative growth, yield, and fruit quality of Murcott mandarin under heat stress of El-Farafrah Oasis of the New Valley Governorate, Egypt

MATERIALS AND METHODS

At a private orchard in the El-Farafrah Oasis of the New Valley Governorate, Egypt, the experiment was held for two consecutive seasons in 2019 and 2020. The seven-year-old Murcott mandarin (*Citrus reticulata* Blanco) trees budded on Volkamer lemon rootstock (*Citrus volkameriana)* grown in sandy soil and spaced 5 X 5 meters apart, subjected to a drip irrigation system from a well. Physical and chemical analysis of the experimental soil is shown in Table (1). Meanwhile, the chemical analysis of the used water for irrigation is recorded in Table (2).

Table (1). Analysis of experimental soil.

Soil depth (cm)	Texture class	pH soil past	EC (ppm)	$CaCO_3$ %	Soluble cations (meq/l)				Soluble anions (meq/l)		
					Ca^{++}	K^+	Na^+	Mg^{++}	Cl^-	$SO_4^=$	CO_3+ HCO_3
0-30	Sand	7.99	1910	8.05	7.6	1.3	14.0	3.6	17.1	9.8	0.3
30-60	Sand	7.85	1960	7.15	8.1	1.6	12.5	3.1	20.8	10.0	0.2

Table (2). Chemical analysis of water used for irrigation.

pH	EC (dSm^{-1})	Soluble cations (meq/l)				Soluble anions (meq/l)		
		Ca^{++}	Mg^{++}	Na^+	K^+	Cl^-	CO_3^-	HCO_3
6.56	0.33	1.47	2.18	3.16	0.61	4.98	*	1.18

Fifty-four healthy trees, nearly uniform in shape, size, and productivity, received the same horticulture practices and were treated with three levels of three drip irrigation depths and three levels of hydrogel as soil applications. The study was a split-plot design. Three levels of subsurface drip irrigation depths (0, 15, and 30 cm depth from surface soil) were assessed in the main plot and three levels of hydrogel (0.0, 100, and 150 g/tree) were assessed in sub plots, with three replicates for each treatment and each replicate was represented by two trees.

The Gr dripper, with an 8 l/h/m discharge, was used for irrigation by subsurface drip irrigation in three depths from surface soil (0, 15, and 30 cm depths) and four hoses were used for every row of trees.

On December 1st, the hydrogel was applied as a soil application at 20 cm depth from the surface soil and 50 cm from the tree trunk. Response of

Murcott mandarin trees to the tested treatments was evaluated through the following determinations:

1. Vegetative Growth

Twenty spring-flushed shoots evenly spaced around each tree's periphery were tagged in late March of the first and second seasons of the years 2019 and 2020, respectively. The shoot length, number of leaves/shoot, and shoot diameter were measured in late September of each season.

2. No. of Fruits/Tree, Yield and Fruit Quality

2.1. Yield (kg/tree)

At harvest time (1^{st} week of January) the number of fruits per treated tree was counted and reported then the yield (kg) per tree was weighed and recorded.

2.2. Fruit physical and chemical properties

To evaluate the quality of the fruit, ten mature fruits were chosen at random from each tree or duplicated at harvesting dates during each season.

2.2.1. Fruit physical characteristics

Ten fruits were randomly selected from each replicate, and their weights (g), volume (m^3), lengths (cm), diameters (cm), shapes index, peel thickness (cm), peel weights (g), pulp weights (g), juice volumes (cm^3), and juice percentages (%) were measured.

2.2.2. Fruit chemical properties

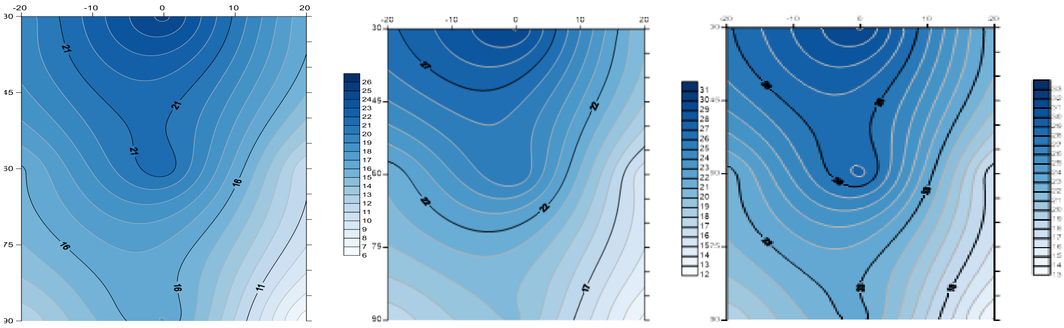
According to Chen and Mellenthin (1981), the juice was extracted, and the proportion of total soluble solids (TSS) was calculated. By titrating with sodium hydroxide and using phenolphthalein 1% as an indicator, the total acidity percentage was calculated by the approved techniques of analysis. The amount of ascorbic acid in the juice, which was measured as milligrams per 100 ml of juice (A.O.A.C., 1985) using titration with 2, 6-dichlorophenol-indo-phenol, was determined.

3. Soil Moisture Distribution

Soil samples were taken with a screw auger at three points from the start of the drip main line; the samples were spaced 20 cm apart, and the samples were taken at three depths (0-30, 30-60, and 60-90 cm) at two direct X and Y locations, where the sample's horizontal and vertical spaces were 30 cm. Samples were analyzed to find the moisture content of the soil. SURFE (version 10) was used to develop the contour maps for moisture distribution pattern (Fig. 1). Soil moisture distribution was used to assess the Murcott mandarin trees responded to the various irrigation treatments.

4. Statistical Analysis

The statistical analysis was performed according to Snedecor and Cochra (1990). The means were separated using Duncan's multiple range tests, which were applied after the data underwent analysis of variance (Duncan, 1955).



(a) (b) (c)

Fig. (1). Subsurface drip irrigation at depth **a.** 15 cm with zero hydrogels, **b.** 15 cm with 100 g hydrogels/tree and **c.** 15 cm with 150 g hydrogels /tree.

RESULTS AND DISCUSSION

1. Vegetative Characteristics

1.1. Shoot length (cm)

Results provided in Table (3) suggest a positive relationship between shoot length, and addition of hydrogels to the soil in both seasons. Thus, adding 150 g/tree hydrogels earned the highest values of the Murcott mandarin tree shoot length. In addition, there are significant differences in subsurface drip irrigation depth treatments. However, the trees irrigated subsurface drip irrigation depth of 15 cm from soil gave the best values of shoot length during the first season, followed by irrigated 30 cm subsurface drip irrigation depth in the second season. The minimum shoot length of Murcott mandarin trees was recorded by surface drip irrigation during both seasons. As for the interaction effect between subsurface drip irrigation depths and hydrogel treatments, it was clear that subsurface drip irrigation depth at 15 cm and the addition of 150 g/tree of hydrogels recorded the highest values of shoot length, However, the lowest values occurred by surface drip irrigation and without adding hydrogels to the soil, in the first and second seasons.

1.2. Number of leaves/shoot

Regarding the effect of the subsurface drip irrigation depths and hydrogels on the number of leaves/shoot for the Murcott mandarin trees, the results in Table (3) show, that the number of leaves/shoot was affected by subsurface drip irrigation depths treatments in both seasons. The highest values of the number of leaves/shoots were obtained with irrigated Murcott mandarin trees with a subsurface drip irrigation depth of 15 cm. Meanwhile, irrigated trees with surface drip irrigation caused the lowest values of the number of leaves/shoot, which reached 7.77 and 6.97 in both seasons, respectively. In this respect, there was a positive impact between the used hydrogels to soil and the number of leaves/shoot. Anyway, the highest number of leaves/shoot was scored by adding the hydrogels at the rate of 150 g, it recorded 9.09 and 8.50 in both seasons, respectively. However, untreated Murcott mandarin trees with hydrogels (no adding hydrogels to the soil) achieved the minimum values of the number of leaves/shoots in both seasons (7.62 and 7.44 respectively).

Regarding the interaction between the subsurface drip irrigation depths and hydrogels treatments, the highest number of leaves/shoot was attained with the irrigated Murcott mandarin trees with subsurface drip irrigation depth of 60 cm and added soil hydrogels to the soil at the rate of 100 g/tree during the two seasons. Likewise, irrigation surface drip irrigation and not adding the hydrogels to the soil produced the lowest number of leaves/shoot, which amounted to 7.53 and 6.56 during both seasons, respectively.

1.3. Shoot diameter (cm)

Data illustrated in Table (3) show that there was a positive relation between subsurface drip irrigation depths and the shoot diameter, when increased the depth of the subsurface irrigation, the shoot diameter was increased in the two seasons. The maximum shoot diameter of Murcott mandarin trees was achieved with irrigated trees with a subsurface drip irrigation depth of 30 cm, followed by a subsurface drip irrigation depth of 15 cm, in the first and second seasons. However, data were not statistically different between the two treatments, during the first and second seasons. While the minimum shoot diameter was a result of irrigation surface drip irrigation as registered 0.260 and 0.277 cm in both seasons.

In this regard, adding hydrogels to Murcott mandarin trees resulted in increased shoot diameter when applied hydrogels (added hydrogels at the rate of 100 g/tree to the soil) recorded the greatest shoot diameter during the two growing seasons. Furthermore, untreated trees of Murcott mandarin with soil conditioners (without adding hydrogels to the soil) had the lowest shoot diameter values, which were 0.262 and 0.272 cm during the two growing seasons, respectively.

Concerning the response of the shoot diameter of Murcott mandarin trees to the interaction between the subsurface drip irrigation depths and hydrogels. The obtained data showed that the maximum shoot diameter values were gained because of irrigated trees with subsurface drip irrigation depth of 30 cm by adding the hydrogels at 100 g/tree, which reached 0.300 and 0.313 cm during the two seasons, respectively. Followed by irrigated subsurface drip irrigation depth of 15 cm with adding the hydrogels at 100 g/tree, without a significant difference between them in both seasons. On the contrary, the minimum values of shoot diameter were statistically coupled with treated trees irrigated with the surface drip irrigation method and without adding hydrogels to the soil during the two seasons.

Table (3). Effect of subsurface irrigation, hydrogels, and their interaction on some vegetative growth traits of Murcott mandarin trees during the two seasons 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels											
	Shoot length (cm)				Number leaves/shoot				Shoot diameter (cm)			
	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean
	First season (2019)											
0 cm surface drip irrigation depth	11.30h	11.95e	11.73f	11.66C	7.53f	7.97cd	7.82de	7.77C	0.243c	0.280a-c	0.257bc	0.260B
15 cm subsurface drip irrigation depth	11.52g	13.14c	14.45a	13.04A	7.68ef	8.76b	10.56a	9.00A	0.273a-c	0.300a	0.293ab	0.289A
30 cm subsurface drip irrigation depth	11.47g	12.13d	13.35b	12.32B	7.65ef	8.09c	8.90b	8.21B	0.270a-c	0.300a	0.290ab	0.287A
Mean	11.43C	12.41B	13.18A		7.62C	8.27B	9.09A		0.262B	0.293A	0.280AB	
	Second season (2020)											
0 cm surface drip irrigation depth	9.84h	11.60f	11.94e	11.13C	6.56g	6.97f	7.37e	6.97C	0.250c	0.300ab	0.280bc	0.277B
15 cm subsurface drip irrigation depth	10.46g	12.40d	13.61a	12.16B	7.85d	9.11b	9.68a	8.88A	0.287ab	0.303ab	0.303ab	0.298A
30 cm subsurface drip irrigation depth	12.62c	12.71b	12.67b	12.67A	7.91d	8.44c	8.45c	8.27B	0.280bc	0.313a	0.300ab	0.298A
Mean	10.97C	12.24B	12.74A		7.44C	8.17B	8.50A		0.272B	0.305A	0.294A	

The means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

2. Yield and Fruit Quality

2.1. Number of fruits/tree

Data provided in Table (4) suggest that the trees of Murcott mandarin irrigated by subsurface drip irrigation depth at 15 cm gave the highest values of the number of fruits/trees reached 145.8 and 153.7, respectively, in both seasons. On the other side, treated trees watered by irrigation surface drip irrigation caused the minimum quantities of the number of fruits/tree reached 106.3 and 115.8 in each of the two growing seasons, respectively.

Results in Table (4) clear that there was a positive connection between the number of fruits/tree mentioned afore and the addition of hydrogels to the soil, hence the values of the number of fruits/tree increased to reach the maximum increase at 150 g/tree rate. Thus, adding 150 g/tree of hydrogels to the soil scored the highest values of number of fruits/tree (146.0 and 155.3) in the two seasons, respectively. In contrast, untreated trees by hydrogels reached 98.0 and 106.8 in two seasons, respectively.

Though, as for the interaction effect between the irrigation method and hydrogel treatments, it was clear that irrigation subsurface drip irrigation depth at 15 cm and the addition of 150 g/tree of the hydrogels led to the highest values of several fruits/trees, as registered 164.0 and 177.0, respectively, followed by irrigated subsurface drip irrigation depth at 15 cm with adding the hydrogels at the rate 100 g/tree descendingly with significant difference in both seasons. However, the lowest values occurred by irrigating Murcott mandarin trees by surface drip irrigation and without adding hydrogels to the soil, during the first and second seasons.

2.2. Yield (kg/tree) and fruit weight (g)

Table (4) clearly shows that during the first and second seasons, respectively, treatments with subsurface drip irrigation depth at 15 cm produced the highest values of yield and fruit weight, while treatments with surface drip irrigation produced the lowest levels of Murcott mandarin yield and fruit weight. In this respect, the application of hydrogels to the soil led to improved values of the yield and fruit weight. Anyway, the maximum values of the yield and fruit weight were recorded by application of the hydrogels (adding hydrogels to the soil) at the rate of 150 g/tree, during both growing seasons. In the meantime, both seasons' lowest yield and fruit weight numbers were attained without the addition of hydrogels to the soil.

The interaction between the irrigation method and hydrogels showed that the highest values of yield and fruit weight were recorded with irrigation subsurface drip irrigation depth at 15 cm and the addition of 150 g/tree of the hydrogels followed by irrigation subsurface drip irrigation depth at 15 cm and the addition of 100 g/tree of the hydrogels, while, surface drip irrigation and without adding hydrogels to the soil achieved the minimum values in both seasons.

The results of hydrogel and subsurface drip irrigation depths, which had a favorable impact on tree development and yield, are consistent with the

Table (4). Effect of subsurface irrigation, hydrogels, and their interaction on the number of fruits/tree, yield, and fruit weight of Murcott mandarin trees during the two seasons 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels											
	Number of fruits/tree				Yield (kg/tree)				Fruit weight (g)			
	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean
	First season; 2019											
0 cm surface drip irrigation depth	79.00i	115.3g	124.7e	106.3C	10.45i	16.84g	19.03e	15.44C	132.3i	146.0g	152.7f	143.7C
15 cm subsurface drip irrigation depth	118.3f	155.0b	164.0a	145.8A	18.34f	25.68b	29.19a	24.40A	155.0e	165.7b	178.0a	166.2A
30 cm subsurface drip irrigation depth	96.67h	136.7d	149.3c	127.6B	13.76h	21.59d	24.09c	19.82B	142.3h	158.0d	161.3c	153.9B
Mean	98.00C	135.7B	146.0A		14.19C	21.37B	24.11A		143.2C	156.6B	164.0A	
	Second season; 2020											
0 cm surface drip irrigation depth	88.00i	122.0g	137.3e	115.8C	12.79h	18.98f	22.57e	18.10C	145.3i	155.3f	164.3e	155.0C
15 cm subsurface drip irrigation depth	126.3f	157.7b	177.0a	153.7A	19.33f	28.22b	32.98a	26.84A	153.0g	179.0b	186.3a	172.8A
30 cm subsurface drip irrigation depth	106.0h	144.7d	151.7c	134.1B	18.97g	24.50d	26.79c	22.42B	150.7h	169.3d	176.7c	165.6B
Mean	106.8C	141.4B	155.3A		16.03C	23.89B	27.45A		149.7C	167.9B	175.8A	

The means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

findings of Ahmed et al. (2012) on date palm fruit trees, Pattanaaik et al. (2015) on Assam lemon (citrus lemon), Abobatta and Khalifa (2019) on Washington navel orange trees, El-Attar et al. (2019) on mango trees, Rabeh et al. (2022) on grape and Abdel-Aziz et al. (2020) on Murcott mandarin trees. They mentioned that the irrigation of fruit trees with a subsurface drip irrigation system and/or adding hydrogel increased tree growth and the previously listed fruit species' output.

Subsurface drip irrigation depth can increase output by directly hydrating the root zone below the soil's surface and reducing soil evaporation, which can also be utilized to conserve water (Lamm et al., 1995; Camp, 1998 and Phene, 1999) and improve water use efficiency in semiarid regions (Phene et al., 1993 and El-Gindy and El-Arabi, 1996).

However, hydrogels are also known as "root watering crystals" because, when exposed to freely available irrigation water, they expand like sponges, many times their original volume. This increases the amount of water that the soil can hold for irrigation and reduces the frequency of irrigation (Koupai et al., 2008). Additionally, Abdel-Aziz et al. (2020) claim that hydrogels reduce the leaching of nutrients.

2.3. Fruit volume, length, and fruit diameter

The results shown in Table (5) make it clear that the largest amount of the fruit volume, length, and fruit diameter were obtained with trees of Murcott mandarin irrigated by subsurface drip irrigation depth at 15 cm during the first and second seasons. Meanwhile, irrigated Murcott mandarin trees by surface drip irrigation resulted in the minimum values of these traits during both seasons.

Data in Table (5) reveal that hydrogel levels significantly improved fruit volume, length, and fruit diameter. Adding hydrogels at 150 g/tree to the soil gave the highest values in both seasons, but untreated the soil hydrogels recorded the minimum values in both seasons.

The interaction between subsurface drip irrigation depth and hydrogels cleared significant differences between treatments (Table 5), revealing different trends in the fruit volume, length, and fruit diameter, the greater values were obtained with irrigation subsurface drip irrigation depth at 15 cm, and the addition of 150 g/tree of the hydrogels followed by irrigation subsurface drip irrigation depth at 15 cm and the addition of 100 g/tree of the hydrogels. However, surface drip irrigation with unused hydrogels recorded the lowest values in both seasons.

2.4. Fruit shape index

Results in Table (5) regarding fruit shape index, the highest values were attained with irrigated Murcott mandarin trees by subsurface drip irrigation depth at 30 cm in the first season. During the second season, however, there was no significant difference in the subsurface drip irrigation depths used for irrigation. In contrast, irrigated trees by subsurface drip irrigation depth at 15 cm caused the lowest values of fruit shape index in the first season.

Table (5). Effect of subsurface irrigation, hydrogels, and their interaction on fruit volume, length, diameter, and fruit shape index of Murcott mandarin trees during the two seasons 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels															
	Fruit volume (cm3)				Fruit length (cm)				Fruit diameter (cm)				Fruit shape index			
	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean
First season; 2019																
0 cm surface drip irrigation depth	148.5i	163.8g	172.0f	161.4C	7.32h	8.13f	8.47e	7.97C	9.30h	10.39f	11.41e	10.37C	0.787b	0.782b	0.742cd	0.771B
15 cm subsurface drip irrigation depth	174.0e	184.5b	196.7a	185.0A	8.62d	9.21b	9.92a	9.25A	11.85d	12.36b	13.34a	12.52A	0.727d	0.745cd	0.744c	0.739C
30 cm subsurface drip irrigation depth	160.0h	176.8d	182.3c	173.0B	7.94g	8.77c	9.89a	8.87B	10.19g	11.82d	12.03c	11.35B	0.779b	0.742cd	0.822a	0.781A
Mean	160.8C	175.0B	183.7A		7.96C	8.70B	9.43A		10.45C	11.52B	12.26A		0.765AB	0.757B	0.769A	
Second season; 2020																
0 cm surface drip irrigation depth	154.2i	165.0f	174.7e	164.7C	8.38h	8.88f	9.46e	8.91C	9.90i	10.65f	11.26e	10.60C	0.846a	0.834a	0.840a	0.840A
15 cm subsurface drip irrigation depth	162.5g	189.0b	198.0a	183.2A	8.70g	10.43b	10.85a	9.99A	10.56g	12.33b	12.81a	11.90A	0.824a	0.846a	0.847a	0.839A
30 cm subsurface drip irrigation depth	159.7h	178.7d	186.9c	175.1B	8.67g	9.70d	10.26c	9.54B	10.35h	11.69d	12.17c	11.40B	0.838a	0.830a	0.843a	0.837A
Mean	158.8C	177.6B	186.5A		8.58C	9.67B	10.19A		10.27C	11.56B	12.08A		0.836A	0.836A	0.843A	

The means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

In this regard, hydrogels when added at the rate of 150 g/tree produced the greatest values of fruit shape index and came to second place for untreated trees by hydrogels, with no significant difference between them during the first season. However, the lowest values of the fruit shape index obtained by adding hydrogels at 100 g/tree in the first season. Likewise, all additions of hydrogels during the second season did not cause significant change.

Subsurface drip irrigation depth at 30 cm with the addition of 150 g/tree of the hydrogels scored the highest significant values of fruit shape index compared with other treatments in the first season. Nevertheless, there was no significant difference between any of the treatments for the interactions of subsurface drip irrigation depths and hydrogels in the second season.

2.5. Peel thickness (cm)

It is clear from the results in Table (6) that treated trees watered by subsurface drip irrigation depth at 30 cm gave the lowest values during the first season, while there was no significant difference in subsurface drip irrigation depths in the second season. Generally, the maximum values of the peel thickness were obtained by irrigated trees by surface drip irrigation in both seasons.

Hydrogel treatments had no impact on the peel thickness in both seasons. Hence, treated soil with a high concentration of hydrogel reported the lowest values of peel thickness in both seasons. Meanwhile, non-adding hydrogels to the soil gave the highest values during the two seasons of study.

The interaction between subsurface drip irrigation depths and hydrogels illustrated that subsurface drip irrigation depth at 15 cm with the addition of 150 g/tree of the hydrogels gave the lowest significant peel thickness (0.250 in the first and 0.250 cm in the second season) compared to other treatments. However, surface drip irrigation with untreated soil by hydrogel treatment gave the maximum significant peel thickness (0.343 in the first and 0.320 cm in the second season) compared to other treatments.

2.6. Peel weight (g) and Pulp weight (g)

Table (6) indicated a considerable variation in this respect. Herein, the largest peel weight and pulp weight were noticed when subsurface drip irrigation depth at 15 cm for both seasons. On the contrary, the smallest values of these traits were observed with surface drip irrigation in both seasons.

Regarding peel weight and pulp weight of Murcott mandarin trees treated with hydrogel were considerably enhanced in both study seasons as soil addition rates rose. Furthermore, as compared to the other treatments, the addition of hydrogel greatly raised the peel weight and pulp weight, with superiority for a high addition rate of 150 g/tree for hydrogel.

Concerning the response of peel weight and pulp weight to the interaction between subsurface drip irrigation depths and hydrogel treatments, the highest values were significantly coupled with the trees subjected to the treatment watered subsurface drip irrigation depth at 15 cm with the addition of 150 g/tree of the hydrogels during both seasons, respectively. On the contrary,

Table (6). Effect of subsurface irrigation, hydrogels, and their interaction on peel thickness, peel weight, and pulp weight of Murcott mandarin trees during the two seasons 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels											
	Peel thickness (cm)				Peel weight (g)				Pulp weight (g)			
	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean
	First season; 2019											
0 cm surface drip irrigation depth	0.343a	0.260c	0.257c	0.287A	23.26g	25.31f	26.26e	24.94C	109.1i	120.7g	126.4f	118.7C
15 cm subsurface drip irrigation depth	0.297b	0.243c	0.250c	0.263B	27.37d	29.53b	31.82a	29.57A	127.6e	136.1b	146.2a	136.6A
30 cm subsurface drip irrigation depth	0.283b	0.250c	0.253c	0.260B	25.15f	27.53d	28.30c	26.99B	117.2h	130.5d	133.0c	126.9B
Mean	0.307A	0.250B	0.253B		25.26C	27.46B	28.79A		118.0C	129.1B	135.2A	
	Second season; 2020											
0 cm surface drip irrigation depth	0.320a	0.257cd	0.250d	0.276A	25.35g	27.18f	28.65e	27.06C	120.0i	128.2f	135.7e	127.9C
15 cm subsurface drip irrigation depth	0.297b	0.263cd	0.250d	0.270A	26.72f	31.56b	32.45a	30.24A	126.3g	147.4b	153.9a	142.5A
30 cm subsurface drip irrigation depth	0.297b	0.270c	0.257cd	0.274A	26.42f	29.47d	30.66c	28.85B	124.2h	139.9d	146.0c	136.7B
Mean	0.304A	0.263B	0.252C		26.16C	29.40B	30.59A		123.5C	138.5B	145.2A	

The means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

the minimum values were recorded when the trees were treated with surface drip irrigation with untreated soil by hydrogel which ranked statistically last during both experimental seasons, compared to the other treatments.

2.7. Juice volume and Juice volume %

Table (7) shows that the subsurface drip irrigation depth at 15 cm treatment recorded the highest significant values of juice volume and juice volume % in Murcott mandarin trees in both seasons compared with the other studied treatments. However, in contrast, the surface drip irrigation treatment gave the minimum value of juice volume and juice volume % in both seasons. Juice volume and juice % were increased when using the hydrogel and the maximum values in the first and second seasons, were noticed by adding 150 g/tree of hydrogel. Contrariwise, giving the minimum hydrogel rate (no adding hydrogel to the soil) achieved the minimum values in both seasons.

Concerning the response of juice volume and juice % to the interaction between subsurface drip irrigation depths and hydrogels, Table (5) shows a considerable variation in this respect. Subsurface drip irrigation depth at 15 cm with the addition of the hydrogels at 150 g/tree achieved the highest values in both seasons. However, surface drip irrigation with no addition of hydrogels recorded the lowest values in both seasons.

2.8. TSS %, acidity, TSS/acidity, and Vitamin C

Table (8) illustrates that the differences between treatments concerning TSS %, acidity, TSS/acidity, and vitamin C were significant during the two seasons. The maximum values of these traits were recorded by the subsurface drip irrigation depth at 15 cm treatment in the first and second seasons. In addition, the minimum of TSS %, TSS/acidity, and vitamin C during both seasons were found due to the surface drip irrigation to the trees of Murcott mandarin. On the other hand, subsurface drip irrigation depth at 15 cm provided the least amount of acidity in both seasons, whereas surface drip irrigation produced the most acidity.

A significant difference in TSS %, acidity, TSS/acidity, and vitamin C among the treatments. The highest values of TSS %, TSS/acidity, and vitamin C were obtained from the trees treated with 150 g/tree of hydrogels during both seasons. While the lowest values were obtained from the trees untreated by hydrogels during both seasons. On the other hand, adding 150 g/tree of hydrogels gave the minimum acidity in both seasons, while untreated trees with hydrogels gave the maximum acidity in the first and second seasons.

The interaction of subsurface drip irrigation depths and hydrogels was successful in improving and raising TSS %, TSS/acidity, and vitamin C and reducing acidity. Trees of Murcott mandarin treated by subsurface drip irrigation depth at 15 cm with the addition of the hydrogels at 150 g/tree have given positive output for TSS %, TSS/acidity, and vitamin C in both seasons. On the other hand, treated trees by subsurface drip irrigation depth at 15 cm with the addition of the hydrogels at 150 g/tree gave the lowest acidity in both seasons.

Table (7). Effect of subsurface irrigation, hydrogels, and their interaction on Juice volume and Juice volume percentage of Murcott mandarin trees during the two seasons of 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels							
	Juice volume				Juice volume %			
	0	100	150	Mean	0	100	150	Mean
	First season; 2019							
0 cm surface drip irrigation depth	68.21h	76.41f	81.33e	75.32C	45.55c	46.64b	47.28a	46.69C
15 cm subsurface drip irrigation depth	82.48d	87.51b	94.86a	88.28A	47.40a	47.43b	48.22a	47.68A
30 cm subsurface drip irrigation depth	75.12g	84.23c	84.77c	81.37B	46.95ab	47.64a	46.50b	47.03B
Mean	75.27C	82.72B	86.99A		46.76B	47.23AB	47.33A	
	Second season; 2020							
0 cm surface drip irrigation depth	70.07h	75.54e	79.02d	74.88C	45.44c	45.78b	45.23cd	45.48B
15 cm subsurface drip irrigation depth	74.59f	86.34b	91.69a	84.21A	45.90b	45.68b	46.33a	45.97A
30 cm subsurface drip irrigation depth	72.36g	82.07c	86.60b	80.34B	45.30d	45.92bc	46.30ab	45.84B
Mean	72.34C	81.32B	85.77A		45.66B	45.79AB	45.95A	

This means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

Table (8). Effect of subsurface irrigation, hydrogels, and their interaction on TSS, acidity, TSS/acid ratio, and vitamin C content of Murcott mandarin trees during the two seasons of 2019 and 2020.

Subsurface drip irrigation depth	Hydrogels															
	TSS %				Acidity %				TSS/acidity				Vitamin C			
	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean	0	100	150	Mean
	First season; 2019															
0 cm surface drip irrigation depth	10.25f	11.17d	12.35c	11.26C	1.120a	0.980d	0.910e	1.003A	9.15i	11.40f	13.57e	11.37C	38.94f	41.99e	41.70e	40.88C
15 cm subsurface drip irrigation depth	11.07d	12.70ab	12.89a	12.22A	1.010c	0.810h	0.800h	0.873C	10.96g	15.68b	16.11a	14.25A	44.45c	46.24a	46.67a	45.79A
30 cm subsurface drip irrigation depth	10.84e	12.43c	12.68b	11.98B	1.080b	0.890f	0.860g	0.943B	10.04h	13.97d	14.74c	12.92B	42.87d	44.29c	45.37b	44.18B
Mean	10.72C	12.10B	12.64A		1.070A	0.893B	0.857C		10.05C	13.68B	14.81A		42.09C	44.17B	44.58A	
	Second season; 2020															
0 cm surface drip irrigation depth	10.75e	11.41c	12.46b	11.54C	0.990a	0.860bc	0.820d	0.890A	10.86i	13.27g	15.20e	13.11C	40.39d	43.55c	46.41b	43.45C
15 cm subsurface drip irrigation depth	12.36cd	12.74b	12.91a	12.67A	0.840c	0.780f	0.720g	0.780C	14.71f	16.33b	17.93a	16.33A	44.65c	48.09a	48.19a	46.98A
30 cm subsurface drip irrigation depth	11.14d	12.50b	12.68b	12.11B	0.870b	0.810de	0.800e	0.827B	12.80h	15.43d	15.85c	14.70B	43.98c	45.56b	47.14a	45.56B
Mean	11.42C	12.22B	12.68A		0.900A	0.817B	0.780C		12.79C	15.01B	16.33A		43.01C	45.23B	47.25A	

This means having the same letter (s) in each column, row or interaction is not significantly different at a 5% level.

Meanwhile, treated trees with surface drip irrigation with non-addition of hydrogel (control) reported the maximum acidity in both seasons.

The results acquired about the impact of subsurface drip irrigation depths on fruit quality are consistent with El-Attar's (2019) findings that subsurface irrigation outperformed surface irrigation. Furthermore, the number of drippers exhibits varying impacts concerning the quality of the fruit or the output per tree. According to Rabeh et al. (2022), Oscop drip irrigation a subsurface irrigation system with 50 g of the polymer under 75% of the water requirements produced the best results in terms of raising the yield and its constituent parts, providing the best berry and cluster physical and chemical properties, and enhancing the efficiency of water use for Flame Seedless grapevines.

However, compared to the control, Barakat et al. (2015) found that adding various amounts of hydrogel along with different irrigation rates improved the physical characteristics of the fruit in the "Grand Nain" banana cultivar. The highest levels of physical characteristics were attained when the hydrogel was applied to the soil at either 100 or 150 g/plant along with varying irrigation levels. Furthermore, Pattanaaik et al. (2015) reported that the production and fruit quality of Assam lemons (citrus limon) were considerably higher than those of the control when soil application with stockosorb (hydrogel) at a concentration of 100 g/tree was made. According to Abdel-Aziz et al. (2020), hydrogel agents can be applied to arid and semi-arid regions to enhance the yield and fruit quality of 'Murcott' mandarin trees.

3. Soil Moisture Distribution

3.1. Subsurface drip irrigation (depth at 15 cm with zero hydrogels)

Data showed that the highest and lowest values for soil moisture contents were 25.36% and 6.27%, respectively. Soil moisture movement in the vertical direction was dominating for all treatments. Consideration must be taken to reduce the excess vertical movement of water from the dripper. The excess movement of water below the crop root zone leads to water and nutrient loss by deep percolation, which represents a hazard to the environment and the ecosystem as well as loss of water and nutrients. Crop water stress due to water loss in deep percolation may lead to significant yield reductions.

3.2. Subsurface drip irrigation (depth at 15 cm with 100 g hydrogels)

Data showed that the maximum value of soil moisture content was 30.11%, while the minimum value was 12.71%. This means that 18.73% increase in moisture content in the soil profile was obtained as compared to the control. This increase in soil moisture shows the effect of hydrogel in improving soil moisture retention.

3.3. Subsurface drip irrigation (depth at 15 cm with 150 g/tree hydrogels)

Data showed that the highest value of soil moisture contents was 32.15%, while the lowest value was 13.82%. There was an increase of 26.78%

in moisture contents of the soil profile as compared to the control. The highest average of soil moisture values was found under subsurface drip irrigation at a depth of 30 cm with 150 g/tree hydrogels. This result indicates that hydrogel will hold soil moisture in water-limited areas and support the required and optimum water into the plant root system when the soil gets dry. Several results have indicated that hydrogel can absorb and retain large quantities of soil moisture under full irrigation and rainfall events and release it back into the soil to mitigate crop water deficits (Akhter et al., 2004 and Koupai et al., 2008).

CONCLUSION

The present study concludes that the application of subsurface drip irrigation at a depth of 15 cm and the addition of hydrogels at a rate of 150 g/tree, either separately or in combination, had a positive impact on fruit quality, yield, and vegetative growth while reducing the overall acidity percentage of the fruit. Additionally, it increases the Murcott mandarin trees' water-use efficiency in the New Valley governorate when they are under heat stress.

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زيادة كفاءة الري باستخدام نظام الري تحت السطحي والهيدروجيل وتأثير ذلك على نمو وإنتاجية أشجار اليوسفي موركوت تحت ظروف الوادي الجديد

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أجريت هذه التجربة خلال الموسمين المتتاليين ٢٠١٩ و٢٠٢٠ على أشجار اليوسفي الميركوت المنزرع في تربة رملية تحت نظام الري بالتنقيط بمزرعة خاصة بواحة الفرافرة بمحافظة الوادي الجديد بمصر. يهدف هذا البحث إلى عدم زيادة معدلات الري عن المعدل الطبيعي ورفع كفاءة استخدام مياه الري وتحسين النمو الخضري والمحصول ونوعية ثمار اليوسفي الميركوت تحت ظروف الإجهاد الحراري. تم تصميم التجربة في قطع منشقة مرة واحدة بثلاثة مكررات. تم تقسيم القطع الرئيسية إلى ثلاثة أعماق للري تحت السطحي أي الري السطحي بالتنقيط (٠.٠ سم)، الري بالتنقيط تحت السطحي على عمق ١٥ سم، والري بالتنقيط تحت السطحي على عمق ٣٠ سم. تم تخصيص القطع الفرعية إلى إضافة ثلاثة مستويات من الهيدروجيل (٠.٠، ١٠٠ و١٥٠ جم/شجرة). أظهرت النتائج المتحصل عليها أن استخدام الري بالتنقيط تحت السطحي على عمق ١٥ سم مع إضافة مادة الهيدروجيل بمعدل ١٥٠ جم/شجرة أدى إلى أفضل النتائج من حيث زيادة المحصول ومكوناته وجميع الخواص الفيزيائية والكيميائية للثمار. وكذلك تحسين كفاءة الري وتقليل نسبة الحموضة الكلية لثمار اليوسفي ميركوت تحت ظروف الإجهاد الحراري بمحافظة الوادي الجديد.