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Impact of Irrigation Systems and Applied Water on Crop Yield, WUE, Certain Nematicides Efficiency, and Plant-Parasitic Nematodes Activity Infected Tomato Plants

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ABSTRACT

A field experiment was conducted to study the effect of two drip irrigation systems (surface and subsurface drip irrigation) and different levels of applied irrigation water (60%, 80%, 100% of ET) on the efficiency of three nematicides [Vaydate (oxamyl); Bio-zeid (*Trichoderma album*) and Nemaless (*Serratia marcescens*)] in eliminating parasitic nematodes infected tomato plants. The observed results demonstrated that the subsurface drip irrigation system at water level 80 % of ET led to an increase in the efficiency of nematicides in eliminating parasitic nematodes. There are significant differences between the effect of applicable nematicides in eliminating parasitic nematodes. Vydate gives the best result on the highest death rate with superiority in its efficiency against plant-parasitic nematodes (87.9%) followed by Bio-zeid (81.2%) and Nemaless (71.2%), descending. The activity of parasitic nematodes on tomato plants increases with the increase of applied water in the soil. Where, the lowest average of the numbers of parasitic nematodes juvenile occurred at the lowest applied water level (60 % of ET), reaching (3007.4) with the appliance of a surface drip irrigation system, and the highest average (3697.3) was observed at a higher applied water level (100 % of ET) under the subsurface drip irrigation system. Vaydate led to a decrement in whole mature females of root-knot nematodes, egg masses, and root gall index in percentages (-93.9, -91.5, and -80.0%), followed by Bio-zeid with proportions (-81.2, -75.6, and -60.0%), respectively, under a subsurface drip irrigation system and a water application level of 80% of ET. The reported data of fruit yield confirmed in general that, there were significantly affected by the applied amount of water and different nematicides. The obtained results showed that the IWUE increased by increasing the applied amount of water and there were significant differences in the applied amount of water. Where the higher values of IWUE were recorded under the water application levels of 100% of ET.

INTRODUCTION

Tomato is one of the crops rich in nutrients that are beneficial to the body, as it supports the health of the skin and heart as well as helps in losing weight, protects against cancer and maintains blood pressure and is of great economic importance because they

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contain carbohydrates, vitamins, sugars, and proteins (Bashir *et al.*, 2018). Tomatoes attack many pests, the most important of which are plant-parasitic nematodes, especially root-knot nematodes (*Meloidogyne spp*), which directly attack tomato roots and cause huge economic losses, or act as vectors for many other pests that damage tomato plants (Shady, 2011); (El-Shennawy, and Abo Korah, 2016).

Plant-parasitic nematodes cannot survive without an appropriate level of moisture, their activity is affected by different watering methods and the level of soil moisture content (Brye *et al.*, 2018). Drip (Trickle) irrigation is one of the best irrigation systems for irrigating tomatoes in clay and sandy soils in Egypt, as it saves (30%) of water compared to other methods (Elshamly, 2016) also it reduces the activity of nematodes parasitizing plants (Mohawesh, 2016). Drip irrigation increases the effectiveness of nematicide in eliminating plant-parasitic nematodes (Schneider *et al.*, 1992).

Nematicide is considered one of the most effective means of controlling plant-parasitic nematodes, and its use becomes necessary when other methods such as planting resistant varieties and biological control agents are insufficient to keep plants safe from nematodes infections. Vaydate is considered one of the best nematicide in eliminating plant-parasitic nematodes (Khalil *et al.*, 2012). Bio-zeid (Trichoderma album) inhibits nematode reproduction and leads to the death of juvenile plant-parasitic nematode which infected tomato plants, considered one of the most efficient bio-pesticides (El-Deeb *et al.*, 2018a&b). Nemaless (Serratia marcescens) is considered one of the biological nematicides that can be used on a large scale in biological control, as it results in a higher reduction in the numbers of nematodes parasitizing strawberries (Hammam *et al.*, 2019).

Water supply In Egypt is a major constraint to agricultural production. where the country's economy relies heavily on watered crop production. In Egypt, the main used irrigation method is surface irrigation, and it results in low watering efficiency as well as problems with drainage and salinity. Therefore, efficient water use by watering is becoming very important, and alternative irrigation systems such as pressured irrigation (drip and sprinkler) may give substantially toward making the greatest use of water for agriculture and improving the efficiency of irrigation. The freshwater decreasing in the world has become a big problem, especially in the arid and semiarid countries. where irrigating the agricultural land exploited more than 80% of water resources (Wang *et al.*, 2001). To deal with the problem of water shortage, it is so important to adopt water-saving agriculture countermeasures as efficient use of water became increasingly very urgent. Many types of research were carried out in the past decades to determine the impacts of water stress on crop physiology and production under different conditions of climate (Kumar *et al.*, 2007a&b). Enciso *et al.* (2009 & 2015) conducted two experiments in the field to study the impacts of emitter space on crop yield of sweet onion at two different lands of Rio Grande valley. the reported results showed that the non-significant difference between the experimental treatments and the soil wetted volume was more critical than the space between drippers. Schedule crops irrigation by pressured modern irrigation systems (sprinkler and drip), and the good water management strategies are so principal for water-saving, especially under conditions of water scarcity (Zaman *et al.*, 2001; Zheng *et al.*, 2002; Zeng *et al.*, 2009). There are many advantages of drip and sprinkler irrigation for agriculture such as water-saving, and economic aspects; therefore, their use of them is increasing worldwide. When using the drip irrigation system not only water-saving has been happened but also increases the crop production (Dhawan, 2002; Tiwari *et al.*, 2003; Yuan *et al.*, 2003), and also the efficiency of irrigation increases to reach 90% when an effectively managed trickle irrigation system is applied.

The drip irrigation system is considered an efficient system that can produce enough water for the root zone with excellent accuracy. In this way, some papers reported that the drip irrigation method is a perfect system that improves the water productivity of the crop by saving more water (Al-Jamal *et al.,* 2000; and Sarkar *et al.,* 2008). Trickle irrigation compared with traditional irrigation, can be divided into the surface (SDI) and subsurface drip irrigation (SSDI) helps to save more water (Martínez and Reca, 2014). In trickle irrigation, water can be applied from a point source or from a line source. In SDI, a wetted bulb volume is created under each point source (dripper). The wetted soil area on the soil surface is considered a small fraction area compared to the total soil surface area. While in SSDI, the wetted bulk volume is quite different: where the water moves downward and at the same time some of the water moves to some extent upwards. The movement of water under subsurface drip irrigation in the soil follows a 3D flow pattern while following a one-dimensional vertical movement pattern under surface and sprinkler irrigation. There are two forces affecting the movements of water inside the soil. The two forces are gravity, and capillary. The downwards movement of water is due to the Gravity force. While the capillary force affects water movement inside the soil in all directions. The interaction between gravity and capillary forces determines the water distribution inside the soil (Sne, 2006). Yazar and Sesveren, 2017; and Aydinsakir *et al.,* 2021 reported that using both SDI and SSDI can increase crop production. Subsurface drip irrigation can reduce the amount of water produced by evaporation (Phogat *et al.,* 2016; Roy *et al.,* 2019) and has a higher water use efficiency than surface drip irrigation (Martínez-gimeno *et al.,* 2018a&b; Çetin and Kara, 2019). The conducted research on the water requirement of crops demonstrated that both the water use efficiency and crop yield were affected by the amount of irrigation water. For example, when the grapes were regulated with deficit irrigation, and the amount of irrigation is appropriately reduced, the quality of the fruit is higher (Yang *et al.,* 2020). Hanson and May (2004) reported no significant difference between drip irrigation and sprinkler irrigation methods but believed that drip irrigation provided more water in the onion root zone. Also, subsurface drip irrigation (SSDI) is more advantageous. Despite this fact, furrow irrigation has less efficiency with some benefits such as minimizing the cost, which is more prevalent than the drip and sprinkler irrigation methods. Among the irrigation methods, this irrigation method has the most leaching friction. So, when high amounts of nitrogen fertilizers are applied in onion cultivation, water resource contamination will be increased intensively (Shock *et al.,* 2004). Hassan (1984) reported that acceptable economic yield was obtained when water and fertilizer use was saved at the same time, by different methods of irrigation. Noticeably, some other farming operations such as using plastic mulch can help to increase in water use efficiency (WUE) of onion (Zheng *et al.,* 2013). The main aim of this work is to study the effect of two drip irrigation systems (surface and subsurface drip irrigation) and different levels of applied irrigation water (60%, 80%, and 100% of ET) on the efficiency of three nematicides [Vaydate (oxamyl); Bio-zeid (Trichoderma album) and Nemaless (Serratia marcescens)] in eliminating parasitic nematodes infected tomato plants.

MATERIALS AND METHODS

A field experiment was conducted at the experimental farm of the Faculty of Agriculture, Menoufia University, Shibin El-Kom, Egypt, to study the effect of two irrigation systems (surface and subsurface drip irrigation systems) and three levels of water quantities (60, 80 and 100% of ET) on the efficiency of three nematicides Vaydate (oxamyl);

Bio-zeid (*Trichoderma album*) and Nemaless (*Serratia marcescens*) in eliminating tomato parasitic nematodes.

1. Field Experimental Site and Soil Description:

A field study was carried out at an agriculture faculty farm, Menoufia University, Egypt (Shebin EL-Kom area, 17.9 m above sea level, 30˚32/N, and 31˚03/E) during the 2020 Falls growing seasons to investigate the response of the Tomato crop to a different drip irrigation system, irrigation management strategies under different levels of crop evapotranspiration (60 %, 80 %, and 100 % of ET). The crops were planted on beds spaced 100 cm apart. The soil of the study area was classified as clay loam with 1.28 g cm^{-3} bulk density. The physical and chemical properties of the experimental soil are shown in Tables (1 and 2). The Tomatoes plants were transplanted on the first of October 2020 to the experimental field. The experimental treatments were arranged in a randomized split-plot design with an irrigation system as main plots and different irrigation water quantities randomly distributed within either different nematicides Vaydate (oxamyl); Bio-zeid (Trichoderma album) and Nemaless (*Serratia marcescens*). The irrigation water quantity was applied as a percent of crop evapotranspiration (ET) as 60 %, 80 %, and 100 % of ET. The experimental treatments were replicated three times. All experimental treatments were separated as surrounded by a 1.0 m no irrigated area as shown in Figure (1). All experimental treatments were watered in the first irrigation with the same amount of water. The irrigating of treatments was initiated with the second irrigating. In both surface and subsurface drip irrigation, a single lateral was placed for each plant row. The system was operated at 100 kPa throughout the growing season. The control unit of the system consisted of a pump, filters unit, a flow meter, control valves, a fertilizer unit, and pressure gauges as shown in Figure (1).

2. Irrigation System and Management:

The irrigation schedule was to refill the top 0.6m depth of the root zone. Irrigation scheduling for 60 %, 80 %, and 100 % of ET under each surface and subsurface drip irrigation. In the experimental site, there was no rainfall or groundwater to avoid the side effects, where the water table was deeper than 2.0 m, during the study period. During the irrigation period, water was applied every three days based on crop evapotranspiration calculations. The crop coefficient function for tomatoes was adapted according to FAO 56 (Allen *et al.,* 1998) and ranges from 0.6 to 1.1 as a function of crop age. The fertilization was applied to the experiment treatments as the recommended rate for Tomato crop production in this area. The calculated amounts of fertilizers were applied with irrigation water. To accurately control applied irrigation water, single lateral surface drip irrigation (SDI) line with an emitter spacing of 25 cm and emitter flow rate of 4 L h^{-1} was fixed for each plant growing on the soil bed surfaces. In addition, single lateral subsurface drip irrigation (SSDI) with the same specifications was placed for each plant row at a depth approximately 20 cm below the soil surface, as shown in Figure 2.

Table 1: Some soil physical properties of the experimental soil

Soil depth [cm]	Sand content	Silt content	Clay content	Bulk density [g cm^{-3}]	Field capacity [g g^{-1}]	Permanent wilting point [g g^{-1}]
0 – 30	21.50	31.35	47.15	1.26	0.36	0.16
30 – 60	16.70	26.65	56.65	1.30	0.38	0.18
Average	19.10	29.00	51.90	1.28	0.37	0.17

Table 2: Some soil chemical properties of the experimental soil

Soil depth [cm]	pH	EC ds m^{-1}	Soluble cations, meq. l^{-1}				Soluble anions, meq. l^{-1}		
			Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Cl^{-1}	HCo_3^{-2}	So_4^{-2}
0 - 30	8.78	0.34	3.44	0.08	0.30	0.16	1.20	1.70	1.18
30 - 60	8.98	0.32	3.32	0.08	0.24	0.18	1.20	1.76	1.20
Average	8.88	0.33	3.38	0.08	0.27	0.17	1.20	1.73	1.19

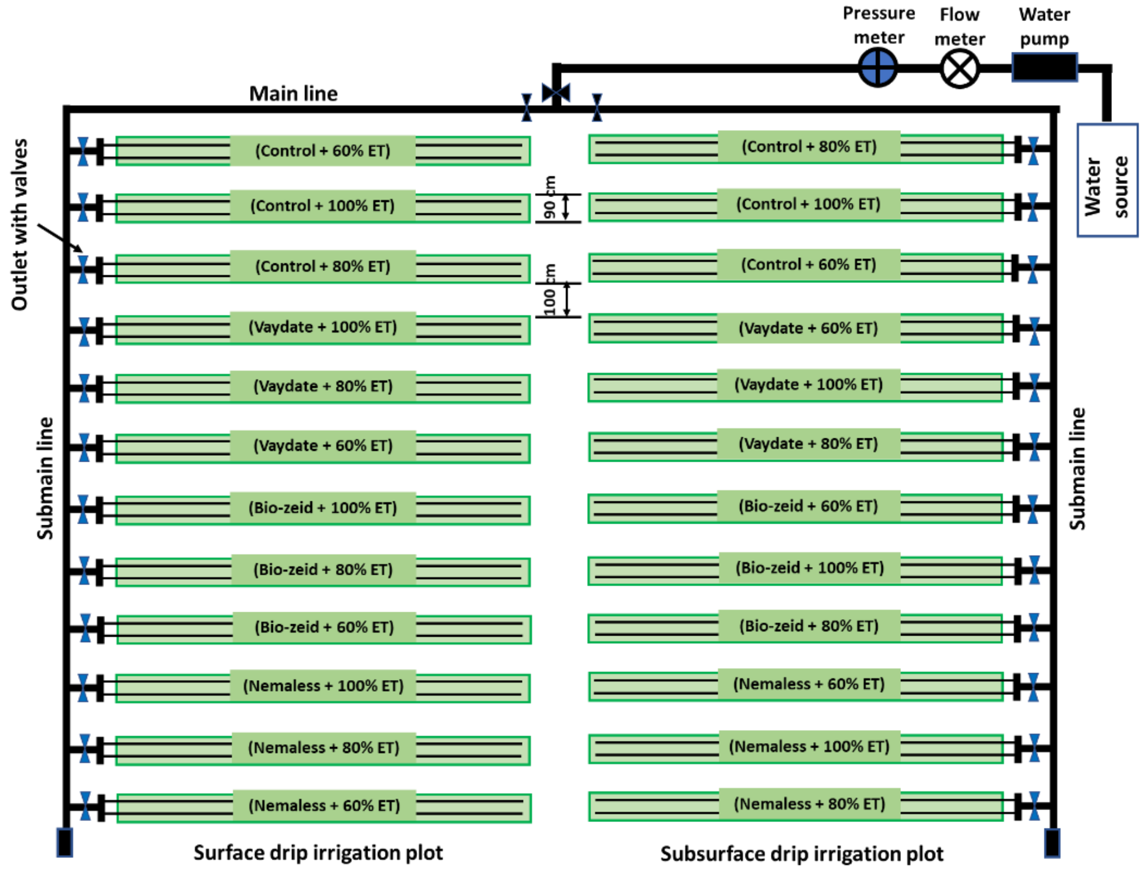
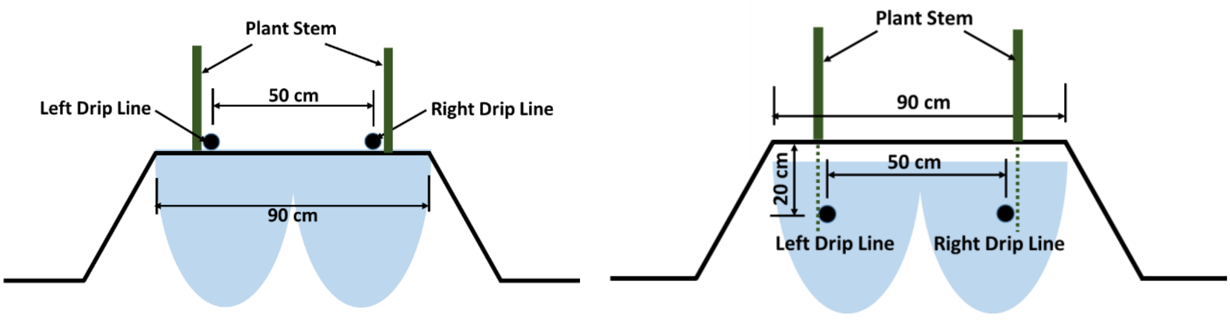


Fig. 1: Schematic diagram of the field experimental treatments layout.



a- Surface Drip Irrigation setup (SDI) **b-** Subsurface Drip Irrigation setup (SSDI)

Fig. 2: Drip irrigation systems management for surface drip irrigation (SDI) and, subsurface drip irrigation (SSDI).

3.Experimental Preparation and Design:

The experiment was conducted in a tomato field (*Solanum lycopersicum* L. var. super strain b) selected for this study during the Fall season from October to January 2020/2021. At transplanting time, the treatments were arranged as a completely randomized split-block design. Each treatment was replicated three times (three rows). 25-days-old tomato seedlings were transplanted and the distance between each two tomato seedlings was 30 cm., taken into our consideration that the treatment as a none treated one was used as a check (control) and normal agricultural practices were followed. Soil samples were collected from each treatment before planting and the soil samples collected were repeated at 30, 60 and 90 days after planting. The treatments were applied with seedling cultivation.

Vydate 24% L: Oxamyl [carbamate (2-dimethylthio) glyoxal-0-methylcarbamoyl monoxime)] was applied around the roots of plants at a rate of 2 ml/plant. Bio-zeid bio-nematicide ($1x10^{10}$ vital spores per gram product of fungus, *Trichoderma album*) was applied at the rate of 0.2 g/plant. Nemaless bio-nematicide (containing10^9 colony forming unit (CFU)/ml of *Serratia marcescens* was applied at 85 ml/10 L/plant.

4. Nematode Extraction and Enumeration:

Soil samples were taken before planting and nematode extraction modified Baermann funnels for 72 hours were used, different plant-parasitic nematode genera were identified and counted using Hawksely counting slide with the aid of Stereomicroscope key references (Mai and Lyon, 1975) were consulted, and found parasitic nematode genera *Meloidogyne; Pratylenchus*; *Helicotylenchus* and *Xiphinema* identified. *Meloidogyne* represents the majority of the numbers of parasitic nematodes on tomato roots and the rest of the genera were found in little numbers. Monthly soil samples were taken from the rhizosphere area of tomato plants after each treatment for three months. Three replicates, each one of 100 g soil and roots were taken from each treatment to extract nematodes, counted, and identified according to methods described by (Southey, 1970). At the end of the experiment, plant roots were submerged, thoroughly washed in tap water, immediately stained with acid fuchsin in lactophenol and stored in it for not less than (24 hours). Plant roots were rinsed in water, root-knot nematode females were counted with the help of a dissecting microscope and the number of galls was rated as mentioned in Table 3 (Taylor and Sasser 1978). Egg masses were assessed by staining the roots with Phloxin-B solution (0.15 g/l tap water) for 20 minutes according to (Daykin and Hussey 1985), and vegetative and fruiting measurements of tomato plants were taken.

Table 3: Rating scale levels of galls numbers

Number of galls/ root system	Gall index
0	0
1-2	1
3-10	2
11-30	3
31-100	4
>100	5

5. Irrigation Water Use Efficiency:

The soil water content in each point around the irrigation emitter of the experimental treatment was measured at different places during the complete growing season for the top 60 cm of the soil profile. A soil tube was used to collect the soil samples from each point of the experimental treatments to measure the soil water content using the gravimetric method. However, irrigation water use efficiency (IWUE) of the experimental treatments was calculated using the following equation according to **Kirda *et al.* (2004)**:

$$IWUE = \frac{Y}{I} \qquad (1)$$

Where: IWUE: irrigation water use efficiency [Mg m^{-3}]; Y: yield per area [Mg ha^{-1}]; and I: applied irrigation water per the same area [m^3 ha^{-1}].

6.Statistical Analysis:

The obtained data were subjected to analysis of variance (ANOVA) using CoStat Software, Version 6.4 (2008). The mean differences were compared by Least Significant Difference (L.S.D. 5%). Reduction percentages were counted using the formula 2 and 3 according to (Henderson and Tilton 1955), (Fleming and Retnakaran 1985) as follows:

$$\text{Reduction \%} = \left[1 - \left(\frac{\text{Treatment after}}{\text{Treatment before}} \text{ x } \frac{\text{Control before}}{\text{Control after}}\right)\right] \text{ x } 100 \qquad (2)$$

$$\text{Increase or decrease \%} = \frac{Control - Treatment}{Control}\, x\, 100 \qquad (3)$$

RESULTS AND DISCUSSION

Volumetric Soil Water Content Redistribution Under Irrigation System:

Figure 3 represents the contour map of soil volumetric water content under 100 % of ET for both surface and subsurface drip irrigation. In surface drip irrigation, a wetted bulb is created beneath each emitter. Maximum soil volumetric water content under surface drip point (0.45 m^3 m^{-3}) occurred at zero point of the soil surface and decreased with distance from the axis of soil wetted volume. But it was smoothly surrounded in hemispherical shape under trickle point source. Thus, the wetted soil fraction was determined using hemispherical wetted shape under the trickle point source. These results are in agreement with the reported results of Amer, (2011) and Amer *et al.,* (2016). In subsurface drip irrigation, the wetting pattern is quite different because water movement within the soil follows a three-dimensional flow pattern, where the water moves downward laterally and to some extent upwards. Therefore, the maximum volumetric soil water content (0.46 m^3 m^{-3}) was found in a soil depth of 20 cm, and then decreased downward and upwards the soil depth. The same results were reported by Sne, (2006). The same trend of soil water redistribution was found under other water application rates (80 % and 60 % of ET) but with fewer values of volumetric soil water content as shown in Figures 4 and 5. Where, the maximum values of volumetric soil water content for surface and subsurface drip irrigation were 0.40 and 0.42 m^3 m^{-3}, respectively, the underwater application rate of 80 % of ET. While the maximum values of volumetric soil water content for surface and subsurface drip irrigation were 0.35 and 0.40 m^3 m^{-3}, respectively, underwater application rate of 60 % of ET.

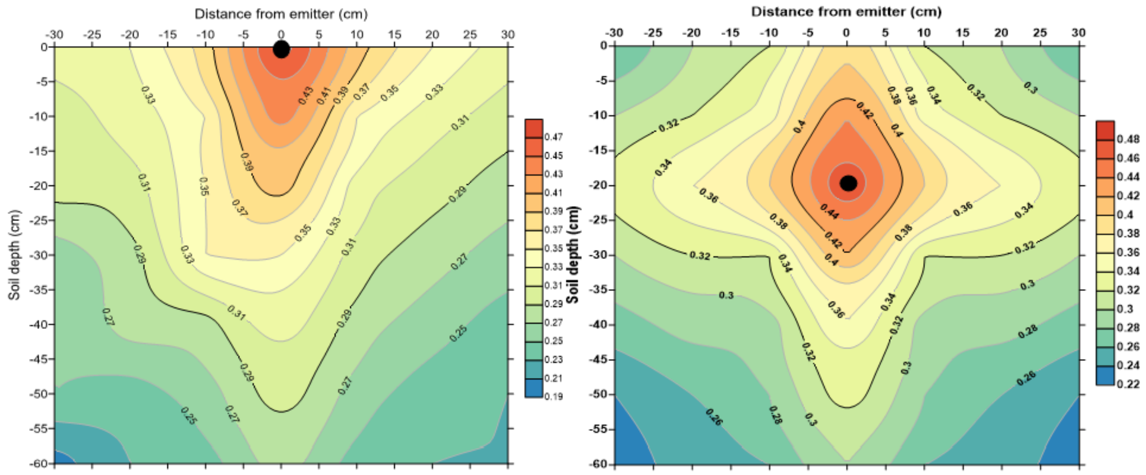


Fig. (3). Volumetric moisture content (m^3 m^{-3}) after soil-water redistribution under surface and subsurface drip irrigation irrigated by 100% of ET.

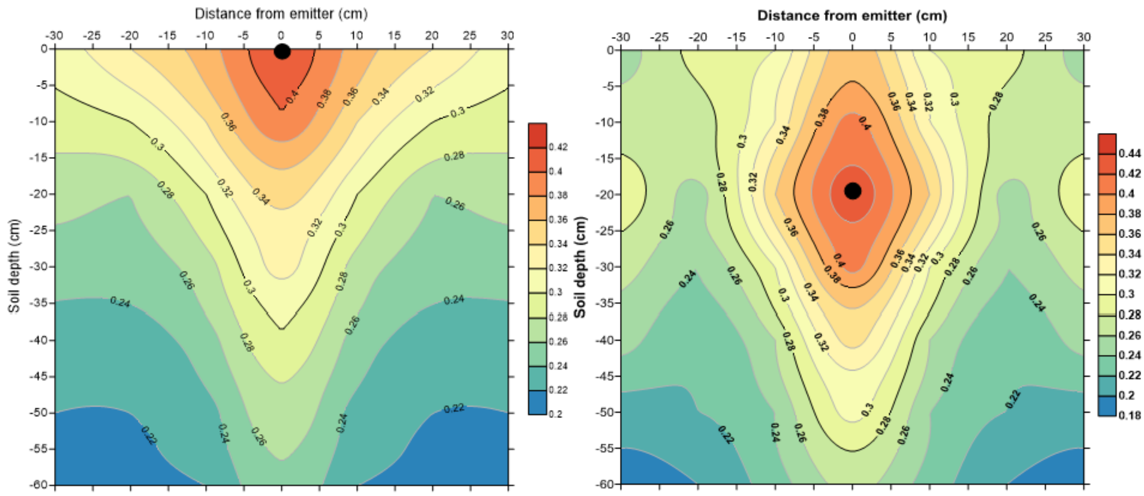


Fig. (4). Volumetric moisture content (m^3 m^{-3}) after soil-water redistribution under surface and subsurface drip irrigation irrigated by 80% of ET.

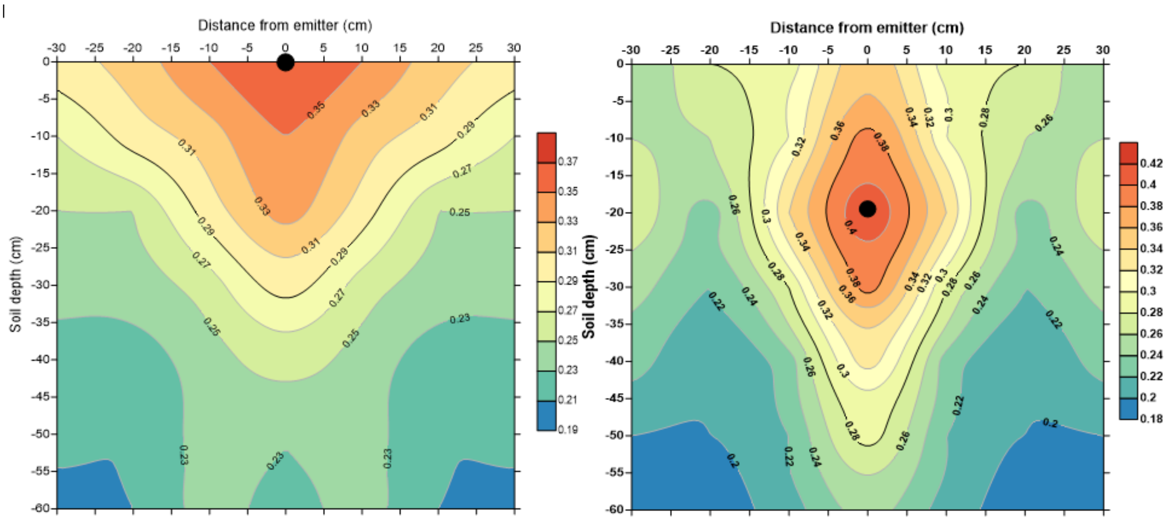


Fig. (5). Volumetric moisture content (m^3 m^{-3}) after soil-water redistribution under surface and subsurface drip irrigation irrigated by 60% of ET.

The Efficiency of The Nematicides in Eliminating Parasitic Nematodes:

Results in **Table (4)** revealed that the subsurface drip irrigation system is more favorable than the surface drip irrigation system by increasing the efficiency of the three nematicides in eliminating parasitic nematodes under the three levels of used water application rates. There are significant differences between the applicable three nematicides under the adoption of the two irrigation systems and three water application levels. The subsurface drip irrigation system at a water application level of (80 % of ET) led to the superiority of Vydate over the rest of the other nematicides and it was more efficient by causing a death rate of nematodes parasitizing on tomatoes plants that reached (87.9%), followed by water application level of (100 % of ET) with a death rate of (87.2%). While its death rate (79.3%) occurred under the surface drip irrigation system and water application level of (60 % of ET).

Bio-zeid occupied the second place after the Vydate, as it caused a death rate in parasitic nematodes (81.2%) in the application of the subsurface drip irrigation system under a water application level of (80 % of ET), followed by Nemaless, which gave a death rate of (71.2%). The surface drip irrigation system under a water application level of (60, 80, and 100% of ET) obtained an average number of tomato parasitic nematode juveniles (3007.4, 3217.1 and 3510.7), respectively. While the average number of parasitic nematode juveniles increased under subsurface drip irrigation systems with a water application level of (60 & 80 & 100% of ET) to (3062.0 & 3250.4 & 3697.3), respectively.

Data in Table (5) cleared that, Vaydate under a subsurface drip irrigation system with a water application level of (80% of ET) reduced the percentage of mature female root-knot nematodes; egg masses and root gall index to (-93.9 & -91.5 & -80%), respectively. Followed Bio-zeid, it decreased by (-81.2 & -75.6 & -60.0%), respectively. These percentages have been reduced when using other irrigation methods and other water levels. These results are in agreement with (Mohawesh, 2016) who recognized that drip irrigation systems lead to a decrease in the moisture content in the soil and thus reduce the activity of nematodes parasitizing on tomato plants, compared to other irrigation systems. Drip irrigation systems provide a favorable amount of water for the growth of plant roots, as well as increase the effectiveness of nematicides in eliminating parasitic nematodes (Schneider *et al.*, 1992) and (Apt and Caswell, 1988). Vaydate (chemical nematicide) is water-soluble that is more effective in eliminating parasitic nematodes than bio-nematicides (Khalil *et al.*, 2012). Bio-zeid is also an effective bio-nematicide and has a high ability to eliminate root-knot nematodes that infect tomato plants (El-Deeb *et al.*, 2018).

Table 4:Effect of drip irrigation systems and different water application rates on certain nematicides efficiency and activity of parasitic nematodes infecting tomato plants under field conditions.

Treatments	Aver. no. of plant-parasitic nematode (juveniles/ 100 g soil)																				
	Days Pre-treatments							Days post-treatments													
								Thirty days							Sixty days						
	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%	
Control	2372.9	2317.0	2349.3	2402.9	2391.0	2361.0	-	2614.3 Ae	2693.0 Ad	2741.0 Ab	2587.0 Af	2702.3 Ac	2809.0 Aa	8.8	3012.0 Ae	3349.3 Ac	3694.0 Aa	2971.0 Af	3103.0 Ad	3686.0 Ab	7.1
Vaydate	2406.3	2401.0	2359.3	2397.0	2381.3	2389.3	-	921.0 Da	713.0 De	786.0 Dc	822.0 Db	701.0 Df	741.0 Dd		589.0 Da	331.0 De	399.0 Db	401.0 Db	362.0 Dc	350.0 Dd	
Bio-zeid	2317.0	2326.0	2337.0	2301.3	2289.0	2294.0	-	1406.0 Ca	1139.0 Cd	1194.0 Cc	1253.0 Cb	941.0 Cf	1003.0 Ce		901.0 Ca	634.0 Cd	753.0 Cc	831.0 Cb	471.0 Cf	573.0 Ce	
Nemaless	2299.9	2311.3	2290.3	2320.9	2285.0	2291.0	-	1761.0 Ba	1438.0 Bd	1694.0 Bb	1697.0 Bb	1237.0 Be	1458.0 Bc		1103.0 Ba	827.0 Bd	1019.3 Bb	957.0 Bc	742.0 Be	821.0 Bd	
L.S.D 5%	-						-	9.4						-	7.5						-
	Reduction %																				
Treatments	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%	
Vaydate	-	-	-	-	-	-	-	65.3 Ad	74.5 Aab	71.5 Abc	68.2 Acd	76.9 Aa	73.8 Aab	3.5	80.7 Ac	90.5 Aa	89.2 Aa	86.5 Ab	89.2 Aa	90.6 Aa	2.6
Bio-zeid	-	-	-	-	-	-	-	44.9 Bd	59.2 Bb	56.2 Bb	49.4 Bc	63.3 Ba	63.2 Ba		69.3 Bc	81.1 Bb	79.1 Bb	70.8 Bc	84.1 Aa	84.0 Ba	
Nemaless	-	-	-	-	-	-	-	31.0 Cd	46.5 Cb	36.6 Cc	32.1 Cd	52.1 Ca	46.5 Cb		62.2 Cd	75.3 Ba	71.7 Cb	66.7 Bc	74.9 Ba	77.1 Ca	
L.S.D 5%	-						-	3.9						-	5.9						-

Table (4- continue): Effect of drip irrigation systems and different water application rates on certain nematicides efficiency and activity of parasitic nematodes infecting tomato plants under field conditions.

Treatments	Aver. no. of plant-parasitic nematode (juveniles/ 100 g soil)													
	Days post-treatments													
	Ninety days							Overall mean						
	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%	
Control	3396.0 Ae	3609.0 Af	4097.0 Ab	3628.3 Ad	3946.0 Ac	4597.0 Aa	17.7	3007.4 Af	3217.1 Ad	3510.7 Ab	3062.0 Ae	3250.4 Ac	3697.3 Aa	14.2
Vaydate	270.0 Da	142.0 Dc	167.0 Db	181.0 Db	91.0 Dd	131.0 Dc		593.3 Da	395.3 Dde	450.7 Dc	468.0 Db	384.7 De	407.3 Dd	
Bio-zeid	510.0 Ca	246.0 Cd	317.0 Cc	429.0 Cb	141.0 Cf	209.0 Ce		939.0 Ca	674.0 Cd	754.7 Cc	837.7 Cb	517.7 Cf	595.0 Ce	
Nemaless	912.0 Ba	513.0 Be	806.0 Bb	712.0 Bc	501.0 Be	598.0 Bd		1258.7 Ba	926.0 Be	1173.1 Bb	1122.0 Bc	826.7 Bf	959.0 Bd	
L.S.D 5%	18.8						-	11.3						-
	Reduction %													
Treatments	Surface drip			Sub surface drip			L.S.D 5%	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%		60%	80%	100%	60%	80%	100%	
Vaydate	92.1 Ac	96.2 Aab	95.9 Aab	95.0 Ab	97.6 Aa	97.1 Aab	2.3	79.3 Ad	87.1 Aab	85.5 Ab	83.2 Ac	87.9 Aa	87.2 Aab	1.7
Bio-zeid	84.6 Be	93.2 Abc	92.2 Ac	87.7 Bd	96.2 Aa	95.3 Aab		66.3 Be	77.8 Bb	75.8 Bc	69.3 Bd	81.2 Ba	80.8 Ba	
Nemaless	72.3 Cc	85.7 Ba	79.8 Bb	79.9 Cb	86.7 Ba	86.5 Ba		55.2 Ce	69.2 Cb	62.7 Cc	59.6 Cd	71.2 Ca	70.0 Cab	
L.S.D 5%	4.9						-	1.9						-

* The capital letters compare the treatments inside the column, and the small letters compare the treatments inside the row**.**

Table 5: Effect of drip irrigation systems, different water application rates and different nematicides on Mature females; egg masses and root gall index on tomato plants.

Treatments	Mature females per5g/root						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Control	19.0 Ad	22.3 Ab	25.3 Aa	16.3 Ae	21.3 Ac	26.0 Aa	0.7
Vaydate	3.3 Db	2.3 Dc	5.3 Ca	3.0 Dbc	1.3 Dd	5.0 Ca	
Bio-zeid	8.3 Ca	5.0 Cc	6.3 Cb	8.0 Ca	4.0 Cd	5.3 Cc	
Nemaless	14.0 Ba	10.0 Bc	13.3 Bab	13.0 Bb	9.0 Bd	10.3 Bc	
L.S.D 5%	1.8						-

Treatments	No. egg-masses						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Control	48.0 Aa	39.0 Ad	41.0 Ac	39.0 Ad	41.0 Ac	43.0 Ab	1.2
Vaydate	6.0 Db	4.0 Dcd	9.0 Da	5.0 Dbc	3.5 Dd	10.0 Ca	
Bio-zeid	16.0 Cb	11.0 Cde	13.0 Cc	21.0 Ca	10.0 Ce	12.0 Ccd	
Nemaless	31.0 Bb	22.0 Bd	34.0 Ba	32.0 Bb	24.0 Bc	25.0 Bc	
L.S.D 5%	3.7						-

Treatments	Root gall index						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Control	5.0 Aa	5.0 Aa	5.0 Aa	5.0 Aa	5.0 Aa	5.0 Aa	0.2
Vaydate	1.0 Db	1.0 Db	2.0 Ca	1.0 Db	1.0 Db	2.0 Ca	
Bio-zeid	3.0 Ca	2.0 Cb	2.0 Cb	3.0 Ca	2.0 Cb	2.0 Cb	
Nemaless	4.0 Ba	3.0 Bb	4.0 Ba	4.0 Ba	3.0 Bb	3.0 Bb	
L.S.D 5%	0.9						-

Increase or decrease %

Treatments	Mature females per5g/root						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Vaydate	-82.6 Ac	-89.7 Ab	-70.1 Bd	-81.6 Ac	-93.9 Aa	-80.8 Ac	2.0
Bio-zeid	-56.3 Bd	-77.6 Bb	-75.1 Ac	-50.9 Be	-81.2 Ba	-79.6 Aa	
Nemaless	-26.3 Ce	-55.2 Cc	-47.4 Cd	-20.2 Cf	-57.7 Cb	-60.4 Ba	
L.S.D 5%	2.9						-

Treatments	No.egg-masses						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Vaydate	-87.5 Ab	-89.7 Aa	-78.0 Ac	-87.2 Ab	-91.5 Aa	-76.7 Ac	2.1
Bio-zeid	-66.7 Bc	-71.8 Bb	-68.3 Bc	-46.2 Bd	-75.6 Ba	-72.1 Bb	
Nemaless	-35.4 Cb	-43.6 Ca	-17.1 Cc	-17.9 Cc	-41.5 Ca	-41.9 Ca	
L.S.D 5%	4.3						-

Treatments	root gall index						
	Surface drip			Sub surface drip			L.S.D 5%
	60%	80%	100%	60%	80%	100%	
Vaydate	-80.0 Aa	-80.0 Aa	-60.0 Ab	-80.0 Aa	-80.0 Aa	-60.0 Ab	0.2
Bio-zeid	-40.0 Bb	-60.0 Ba	-60.0 Aa	-40.0 Bb	-60.0 Ba	-60.0 Aa	
Nemaless	-20.0 Cb	-40.0 Ca	-20.0 Bb	-20.0 Cb	-40.0 Ca	-40.0 Ba	
L.S.D 5%	1.1						-

* The capital letters compare the treatments inside the column, and the small letters compare the treatments inside the row**.**

Tomato Fruits Yields:

Table (6) presents the results of plant height, shoot weight, root weight, and fruit yield of a tomato crop under different experimental treatments. The reported data confirmed generally that, there were significantly affected by different applied irrigation water and different nematicides. The results clarified that the average plant height, shoot weight, root weight, and fruit yield of tomato plants increased by increasing applied irrigation water under both drip irrigation systems. But there were no significant affected on two irrigation systems (SDI and SSDI) in the treatment with no nematicides, but there was a significant affecting in the treatments with nematicides. The reported results confirmed that the highest results were found with Vaydate nematicide treatment then Bio-zeid and finally Nemaless under both irrigation systems and different water application rates. Data in Table (6) clarified that Vaydate under surface drip irrigation (SDI) system increased the fruits yield by 50, 78.6, and 107.7 % compared to control treatment for 60 %, 80 %, and 100 % of ET, respectively. While, under subsurface drip irrigation (SSDI) system increased the fruits yield by 92, 133, and 114 % compared to the control treatment for 60 %, 80 %, and 100 % of ET, respectively. On the other hand, Bio-zeid under surface drip irrigation (SDI) system increased the fruits yield by 16.7, 71.4, and 69.2 % compared to control treatment for 60 %, 80 %, and 100 % of ET, respectively. While, under subsurface drip irrigation (SSDI) system increased the fruits yield by 53.8, 106, and 100 % compared to the control treatment for 60 %, 80 %, and 100 % of ET, respectively. Finally, Nemaless under surface drip irrigation (SDI) system increased the fruits yield by 25, 42.9, and 46.2 % compared to control treatment for 60 %, 80 %, and 100 % of ET, respectively. While, under subsurface drip irrigation (SSDI) system increased the fruits yield by 38.5, 73.3, and 78.6 % compared to control treatment for 60 %, 80 %, and 100 % of ET, respectively. In addition, the reported results confirmed that all results were affected by irrigation treatments and there were significant differences between experimental treatments. These results are in agreement with results reported by Sezen *et al.*, (2014) & Piria, and Naserin (2020). The appliance of (80 % of ET) water capacity in soil subsurface stratum inducement behalf forthright and more favorable for each deficit of irrigation water quantity as it saves (20%) and implicitly increases applicable nematicides efficiency and its qualification in eliminating parasitic nematodes.

Table 6: results of plant height, shoot weight, root weight, and fruit yield of tomato plants under drip irrigation systems, different water application rates and different nematicides.

Treatments	Plant height (cm)						Shoot weight (g)						Root weight (g)						Fruit weight (kg/plant)					
	Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip		
	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%
Control	44.6 A,a	47.0 A,a	46.3 A,a	44.8 A,a	46.5 B,a	45.0 B,a	50.1 A,a	54.0 A,a	55.0 A,a	51.3 B,a	56.0 B,a	54.0 B,a	11.0 A,a	12.3 B,a	12.0 A,a	11.3 A,a	13.0 B,a	12.3 B,a	1.2 A,a	1.4 A,a	1.3 B,a	1.3 A,a	1.5 B,a	1.4 B,a
Vaydate	49.0 A,b	52.3 A,ab	50.0 A,b	49.3 A,b	56.3 A,a	51.0 A,ab	59.0 A,b	62.3 A,ab	60.0 A,ab	61.0 A,ab	69.0 A,a	67.0 A,ab	15.0 A,ab	17.0 A,ab	15.9 A,ab	14.9 A,b	20.0 A,a	17.0 A,ab	1.8 A,b	2.5 A,ab	2.7 A,ab	2.5 A,ab	3.5 A,a	3.0 A,ab
Bio-zeid	48.0 A,b	50.0 A,ab	49.0 A,ab	50.0 A,ab	54.0 A,a	53.3 A,ab	57.0 A,a	61.3 A,a	61.0 A,a	59.0 B,a	65.0 A,a	64.0 A,a	14.0 A,a	16.0 B,a	15.3 A,a	15.0 A,a	19.0 A,a	17.0 A,a	1.4 A,b	2.4 A,ab	2.2 B,ab	2.0 A,ab	3.1 A,a	2.8 A,a
Nemaless	47.3 A,a	48.5 A,a	48.0 A,a	47.0 A,a	52.3 A,a	51.0 A,a	55.3 A,a	59.0 A,a	58.0 A,a	56.0 B,a	61.0 B,a	60.0 B,a	13.3 A,a	14.0 B,a	14.9 A,a	14.0 A,a	17.0 A,a	15.9 AB,a	1.5 A,a	2.0 A,a	1.9 B,a	1.8 A,a	2.6 A,a	2.5 AB,a
L.S.D 5%	5.52						9.06						4.44						1.24					
Treatments	Increase or decrease percent (%)																							
	Plant height (cm)						Shoot weight (g)						Root weight (g)						Fruit weight (kg/plant)					
	Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip		
	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%
Vaydate	+9.9	+11.3	+8.0	+10.0	+21.1	+13.3	+17.8	+15.4	+9.1	+18.9	+23.2	+24.1	+36.4	+38.2	+32.5	+31.9	+53.8	+38.2	+50.0	+78.6	+107.7	+92.3	+133	+114
Bio-zeid	+7.6	+6.4	+5.8	+11.6	+16.1	+18.4	+13.8	+13.5	+10.9	+15.0	+16.1	+18.5	+27.3	+30.1	+27.5	+32.7	+46.2	+38.2	+16.7	+71.4	+69.2	+53.8	+106	+100
Nemaless	+6.1	+3.2	+3.7	+4.9	+12.5	+13.3	+10.4	+9.3	+5.5	+9.2	+8.9	+11.1	+20.9	+13.8	+24.2	+23.9	+30.8	+29.3	+25.0	+42.9	+46.2	+38.5	+73.3	+78.6

* The capital letters compare the treatments inside the column, and the small letters compare the treatments inside the row**.**

Irrigation Water Use Efficiency (IWUE):

Table 7 and Figure (6) present the results of irrigation water use efficiency (IWUE by kg m^{-3}) based on the tomato fruit yields under surface (SDI) and subsurface drip irrigation (SSDI) treated by three different nematicides. The obtained results showed that in general, the IWUE increased by increasing the applied irrigation water and there were significant differences in the applied water. Where the higher values of IWUE were recorded under the water application levels of 100 % of ET. However, the results demonstrated that the IWUE of SSDI treatments was higher than the SDI treatments, and there was a significantly affecting on the irrigation system, water application rates and different nematicides. Considering the drip irrigation systems, a difference between SDI and SSDI could be found concerning the IWUE and the results observed that there was a significant affecting. The results of the present study showed that the SSDI system increased the IWUE compared to the SDI system when applying it under all water application rates and different nematicides. The same results were reported by Abd El-Wahed and Ali (2013); Martínez-gimeno *et al.*, 2018a&b; Çetin and Kara, 2019; Piria, and Naserin (2020). When considering the different nematicides treatments, the reported results showed that the highest results of IWUE were found with Vaydate nematicide treatment then Bio-zeid and finally Nemaless under both two irrigation systems and different water application rates with significant differences between the treatments. Where the highest amount of IWUE (36 Kg m^{-3}) was reported with Vaydate nematicide under subsurface drip irrigation with a water application level of 100 %

of ET treatment. But the lowest value of IWUE (8.6 Kg m^{-3}) was observed with no nematicide (control treatment) under surface drip irrigation with a water application level of 60 % of ET treatment.

Table 7: results of applied water and water use efficiency for tomato crop under drip irrigation systems, different water application rates and different nematicides.

Treatments	Applied water per plant (mm)						Fruit weight (Mg/ha)						Water use efficiency, [Kg m^{-3}]					
	Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip		
	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%
Control	222	296	370	222	296	370	32.0 A,a	37.3 B,a	34.7 B,a	34.7 A,a	40.0 B,a	37.3 B,a	8.6 A,a	12.6 B,a	15.6 C,a	9.4 A,a	13.5 C,a	16.8 B,a
Vaydate	222	296	370	222	296	370	48.0 A,b	66.7 A,ab	72.0 A,ab	66.7 A,ab	93.3 A,a	80.0 A,ab	13.0 A,c	22.5 A,b	32.4 A,a	18.0 A,bc	31.5 A,a	36.0 A,a
Bio-zeid	222	296	370	222	296	370	37.3 A,a	64.0 B,ab	58.7 AB,ab	53.3 A,ab	82.7 A,a	74.7 A,a	10.1 A,d	21.6 A,bc	26.4 AB,ab	14.4 A,cd	27.9 AB,a	33.6 A,a
Nemaless	222	296	370	222	296	370	40.0 A,a	53.3 B,a	50.7 AB,a	48.0 A,a	69.3 A,a	66.7 AB,a	10.8 A,d	18.0 AB,cd	22.8 BC,bc	13.0 A	23.4 B,ab	30.0 A,a
L.S.D 5%	-						33.0						8.64					
Treatments	Increase or decrease percent (%)																	
	Applied water per plant (mm)						Fruit weight (Mg/ha)						Water use efficiency, [Kg m^{-3}]					
	Surface drip			Sub surface drip			Surface drip			Sub surface drip			Surface drip			Sub surface drip		
	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%	60%	80%	100%
Vaydate	-	-	-	-	-	-	+50.0	+78.6	+107.7	+92.3	+133	+114	+50.0	+78.6	+107.7	+92.3	+133	+114
Bio-zeid	-	-	-	-	-	-	+16.7	+71.4	+69.2	+53.8	+106	+100	+16.7	+71.4	+69.2	+53.8	+106	+100
Nemaless	-	-	-	-	-	-	+25.0	+42.9	+46.2	+38.5	+73.3	+78.6	+25.0	+42.9	+46.2	+38.5	+73.3	+78.6

* The capital letters compare the treatments inside the column, and the small letters compare the treatments inside the row.

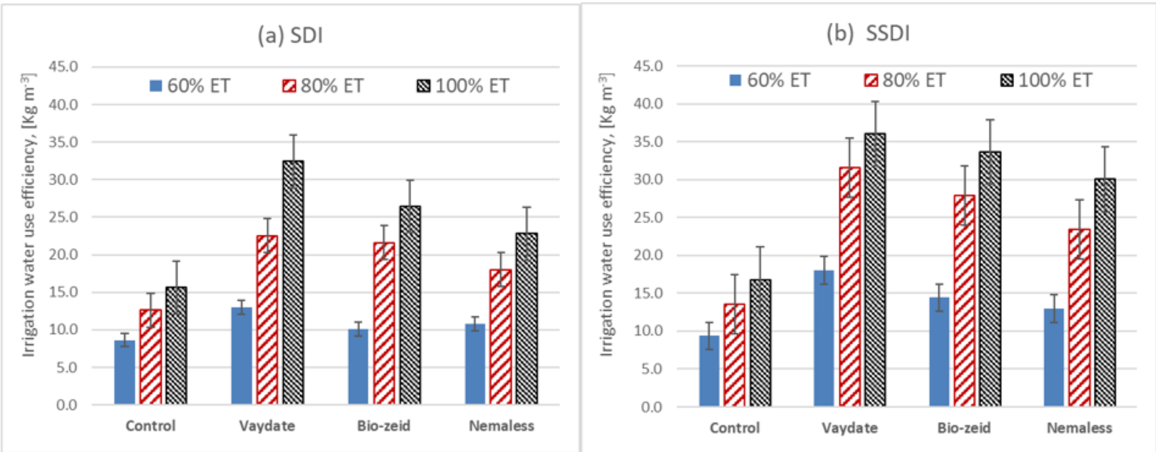


Fig. 6: Irrigation water use efficiency (kg m^{-3}) for tomato crop based on fruit yields under surface (SDI) and subsurface drip irrigation (SSDI) treated by three different nematicides.

Summary and Conclusion:

The obtained results clarified the subsurface drip irrigation system is more favorable than the surface drip irrigation system by increasing the efficiency of the three nematicides in eliminating parasitic nematodes under the three levels of used water application rates. There are significant differences between the applicable three nematicides under the adoption of the two irrigation systems and three water application levels. The subsurface drip irrigation system at a water application level of (80 % of ET) led to the superiority of Vydate over the rest of the other nematicides and it was more efficient by causing a death rate of nematodes parasitizing on tomatoes plants that reached (87.9%), followed by water application level of (100 % of ET) with a death rate of (87.2%). The reported results of fruit yield confirmed in general that, there were significantly affected by different applied irrigation water and different nematicides. The reported results confirmed that the highest results were found with Vaydate nematicide treatment then Bio-zeid and finally Nemaless under both irrigation systems and different water application rates. The obtained results of

IWUE confirmed that the IWUE increased by increasing the applied irrigation water and there were significant differences in the applied water. Where the higher values of IWUE were recorded under the water application levels of 100 % of ET. However, the results demonstrated that the IWUE of SSDI treatments was higher than the SDI treatments, and there was a significantly affecting on the irrigation system, water application rates and different nematicides. The results of the present study showed that the SSDI system increased the IWUE compared to the SDI system when applying it under all water application rates and different nematicides.

The reported results from the current study led to conclude that planting the tomato plants under the subsurface drip irrigation system irrigated by 100% ET was found to be suitable for producing high fruit yields and irrigation water use efficiency. Where, the treatment irrigated by 80% of ET produced a relatively high yield saving 20% of the applied irrigation water without significant effect. In addition, the Vydate nematicide was more efficient with a subsurface drip irrigation system over the rest of the other nematicides by causing a death rate of nematodes parasitizing on tomato plants under all water application levels. Therefore, in conditions of limited irrigation water, the application level of 80% of ET treatment under a subsurface drip irrigation system was found to be suitable to save 20% of the applied irrigation water and produced the same amount of tomato yield and irrigation water usage efficiency.

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