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Full Length Research Paper

The effects of different irrigation methods on root distribution, intensity and effective root depth of young dwarf apple trees

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The aim of this study is to determine the effects of different irrigation methods (drip, subsurface drip, surface and under-tree micro sprinkler) on the root distribution, intensity and effective root depth of "Williams Pride" and "Jersey Mac" apple cultivars budded on M9, rapidly grown in Isparta Region. The rootstocks were shallow root system and their root distribution was placed near trunk center and accumulated in diameter of 0.5 m and depth of 0.4 m of soil volume as bowl shape. The root intensity was reduced gradually away from surface and trunk; the root distribution was uniform in all irrigation methods used in the study. In other words, the effect of irrigation methods on root distribution was similar. Generally, the amount of "Williams Pride" root was higher than that of "Jersey Mac" variety. Therefore, these varieties have partial effect on root of the rootstock. Also, effective root depth was increased during the experimental years. Over the years, effective root depths obtained were 28.4 - 36.6 cm in 2006; 32.3 - 42.5 cm in 2007 and 37.1 - 45.2 cm in 2008, respectively. As a result, effective root depths for irrigation of the varieties can be taken as 40 - 45 cm until 3 years old.

Key words: Jersey Mac, Williams Pride, root distribution and intensity, effective root depth, different irrigation methods.

INTRODUCTION

Apple is one of the most consumed fruits in the world and it has an increasing production value. Turkey has an apple production value of 2.55 million tons and is the third country in apple production after China and USA. Isparta Province has an important role in Turkey by the means of apple production, since almost 20% of total apple production of Turkey is satisfied by Isparta Province (Anonymous, 2007).

In spite of the growing techniques, which include using Golden Delicious and Red Delicious cv. drafted on the seedling rootstocks and spur types, recently, dense planting orchards using new varieties drafted on dwarf (M9) and semi-dwarf (MM106) rootstocks in the region have been started. Williams Pride and Jersey Mac varieties drafted on M9 clonal rootstocks are commonly used in these orchards. While Isparta has a mean annual precipitation value of 520 mm, only 162 mm of the total precipitation (31%) occurred between May and October. Due to the fact that a semi-arid climate condition occurs, irrigation becomes a vital importance for an effective horticultural production. Therefore, irrigation applications (properties of water resource, irrigation method, plant water requirement, irrigation quantity, irrigation frequency, etc), related plant parameters (effective root magnitude, root distribution, planting or sowing ranges, etc) and soil properties (texture, moisture constants, infiltration rate, etc) as well as topographical properties (inclination, etc.) must have been fully defined.

There is comprehensive literature on seasonal water consumption and planning of irrigation time within different regions and different fruit varieties in Turkey. But there is limited number of research on dwarf varieties of apple trees and the monitoring of their development.

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Abbreviations: DI, Drip irrigation; **SDI,** subsurface drip irrigation; **MSI,** under-tree micro sprinkler; **SI,** surface irrigation; **BR,** between rows; **OR,** on the rows; **TB,** tree's bottom.

Table 1. Some physical properties of trial field soils.

Soil profile depth (cm)	Structure	Volume weight (g cm^{-3})	Field capacity		Wilting point		Available water holding capacity	
			%	mm	%	mm	%	mm
0 - 30	CL	1.46	29.70	130.09	13.57	59.44	16.13	70.65
30 - 60	CL	1.41	31.81	134.56	15.48	65.48	16.33	69.08
60 - 90	CL	1.39	27.46	114.51	11.70	48.79	15.76	65.72
90 - 120	CL	1.36	27.37	111.67	11.35	46.31	16.02	65.36
Total (0 - 120 cm)				490.82		220.01		270.81

Almost all the literature works related to dwarf apple trees are aimed at the green part of the plant. The most important problem of the dwarf apple growers is lack of information on the properties of underground part of the plant like root magnitude, root distribution, root intensity, effective root depth and time dependent development.

Plant properties like root magnitude, root distribution, root intensity, effective root depth for irrigation and time dependent development of these properties are important design criteria for the choice of irrigation methods, parameters to be considered for designing the irrigation system, water requirements, irrigation frequency and irrigation period. On the other hand, it is not fully understood for the agricultural growers, which methods should be used for irrigation and what must be the irrigation water quantity, since some irrigation methods and depth have known effects on plant root development, both positively and negatively.

However, dwarf apple growers in the region have a conviction that, the drip irrigation system had unfavorable effects on plant root development and that root development has not being observed to be effectively developed. Moreover, some growers use surface or under tree sprinkler systems prior the drip irrigation system when a new orchard is set up. The present research is aimed at assessing the effects of different irrigation methods (drip irrigation, subsurface drip irrigation, surface irrigation and under tree micro sprinkler) on root magnitude, distribution, intensity, effective root depth and time dependent development of William Pride and Jersey Mac cultivars drafted on M9 rootstocks.

MATERIALS AND METHODS

This study is conducted to determine the effects of different irrigation methods on Williams Pride and Jersey Mac cultivars drafted on M9 rootstock apple trees. Field trials were conducted at an apple orchard in Süleyman Demirel University, Faculty of Agriculture Research and Application Farm, Turkey.

Soil properties of field trials were medium and medium-light structure, depth, unsalted, mild and moderate alkaline, a significant portion slightly inclined alluvial with a weak soil profile development (Akgül and Başayiğit, 2005). Some physical properties of the trial field soils are shown in Table 1 as determined from the basics of the studies (Güngör and Yıldırım, 1989; Demiralay, 1993).

Apple cultivars, Williams Pride and Jersey Mac, drafted on M9 rootstock were used in this study. Due to their rapid increasing number in the orchards of Isparta Region, an orchard established in April 2006 was used. Trees were planted on rows 3 m apart with 1 m spacing between rows.

The orchard was irrigated with different irrigation methods for the experimental period (3 years for 2006 - 2008). These are the drip irrigation (DI), subsurface drip irrigation (SDI), under-tree micro sprinkler (MSI) and surface irrigation (SI). Engineering principles of irrigation methods are determined from the principles given in Yildirim (2003).

Quantity of irrigation amount was determined by using a Class A pan evaporation tank which is located in a meteorological station close to the orchard. The amount of water was calculated using Equation 1 by the means of daily open water surface evaporation values within 5 days interval in the Class A pan evaporation tank.

$$d_n = K_{cp} \times E_{pan} \times P \quad (1)$$

Where, d_n is the quantity of irrigation water, mm; K_{cp} is plant-pan coefficient (1.0); E_{pan} is total evaporation amount in 5 days irrigation intervals, mm and P is wetting percent (%). Irrigation was maintained identically within the period of last frost and the first one for experimental period.

The study presented here aimed to determine the effects of different irrigation methods on root distribution and root intensity. For this reason, in the third year of study (when the trees are 3 years old) at the end of the vegetation of root development, that is, when the soil temperature decreased below 6°C (Westwood, 1995) (which is late October in the year 2008), soil samples were taken from the field plots which had same irrigation method and program. Samples were collected by a soil root collection auger. Soil samples were taken from the locations of randomly selected 3 trees at 0.25, 0.50 and 0.75 m distance between rows (BR) and 0.00 (tree bottom, TB), 0.25 and 0.5 m on the rows (OR) and from the depth of 0 - 100 cm by 20 cm layers each (0 - 20, 20 - 40, 40 - 60, 60 - 80 and 80 - 100 cm) (Figure 1).

Collected root samples were analyzed as weight per unit soil volume (mg cm$^{-3)}$ as defined by Böhm (1979), Kanber et al. (1996), Tanasescu and Paltineanu (2004). Effective root depth was defined by substantial suggestion made by Kanber (1997) as “the depth of 85% of used water necessary for the plants’ usual vegetation period”. For this purpose, used water content of each soil layers from 0 - 10, 10 - 20, 20 - 30, 30 - 40, 40 - 60, 60 - 80 and 80 - 100 cm was calculated. Irrigation method and effective root depth were determined for the above mentioned varieties using these values.

RESULTS AND DISCUSSION

The amount of total water supplied for each different irrigation methods and plant seasonal mean water consumption for the apple varieties between the years 2006, 2007 and

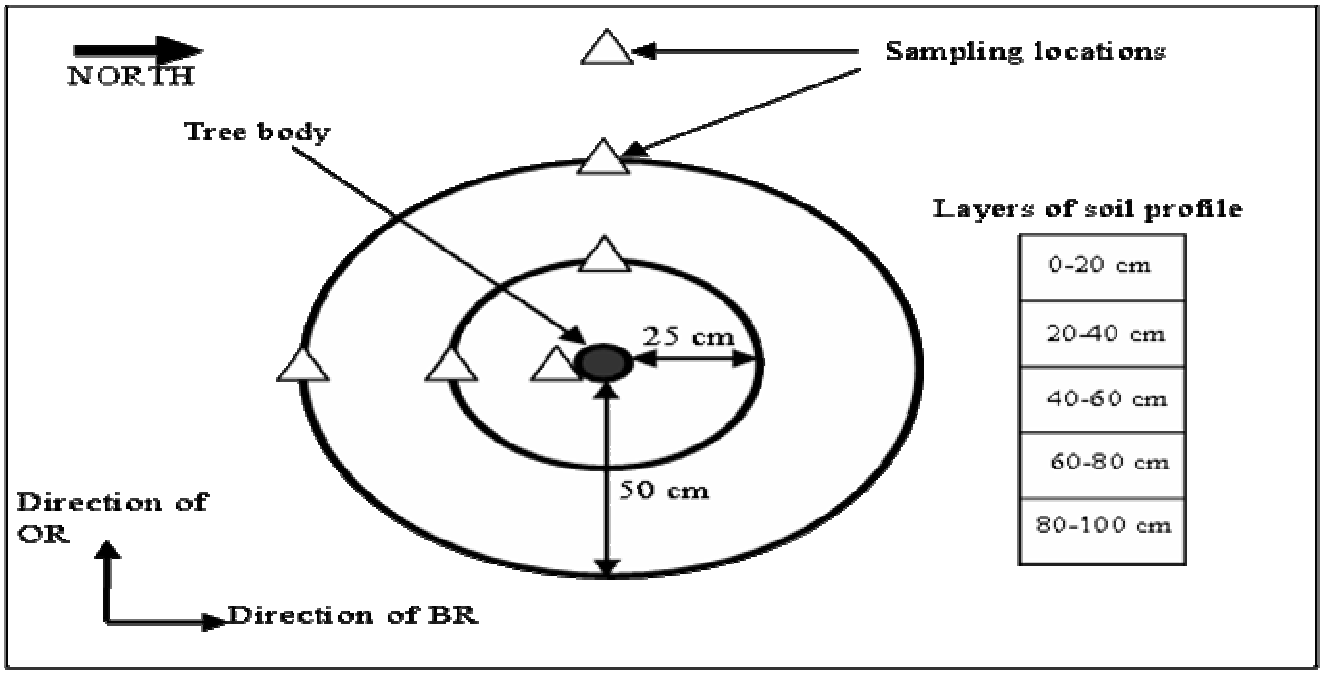

Figure 1. Schematic view of places taken root samples.

Table 2. Total applied water depth to trial issues in 2006, 2007 and 2008 years.

Irrigation method	2006		2007		2008	
	mm	m^3	mm	m^3	mm	m^3
Total applied water depth						
DI	349.5	94.3	391.2	105.9	348.3	94.3
SDI	349.5	94.3	391.2	105.9	348.3	94.3
MSI	724.0	203.7	1186	338.7	1056.0	301.2
SI	724.0	195.4	1186	320.4	1056.0	285.3
Average water consumption (mm season^{-1})						
DI	475.1		431.0		427.3	
SDI	465.2		431.7		477.0	
MSI	859.0		1304.4		1248.8	
SI	846.3		1253.7		1189.5	

2008 are given in Table 2.

At the end of the vegetation period, 2008 (the trees were three years old), the amounts of root were determined as weight per unit soil volume (mg cm^{-3}) and presented in Figures 2 and 3. Moreover, root distribution on soil layers between 0 - 100 cm and also at TB, OR and BR is shown in Tables 3 and 4.

Amounts of water consumed by all the root areas of the plants and soil layers were measured; and “a depth of 85% of used water necessary for the plants’ usual vegetation period” was calculated and shown in Table 5 for each irrigation method.

As shown in Tables 3 and 4, and Figures 2 and 3, highest root development occurred in soil layer (0 - 20 cm) nearest to the soil surface for both varieties. 63.0 - 74.1 and 61.1 - 72.5% of the total amounts of root were measured in the soil layer for Jersey Mac and Williams Pride cultivars, respectively. Root distribution was increased by a depth of 0 - 20 cm. Moreover, it was found that the important portion of root distribution (77.6 - 94.8%) occurred in soil profile of 0 - 40 cm, and for the soil layers of 60 - 100 cm, there were insignificant amounts of roots (2.8 - 17.1%) observed for all of the treatments. Highest number of root distribution (17.2 mg cm^{-3}) was found on surface irrigation and the lowest number (9.6 mg cm^{-3}) was found for under-tree micro sprinkler treatment. It was also determined that apple varieties showed differences by the means of root distri-

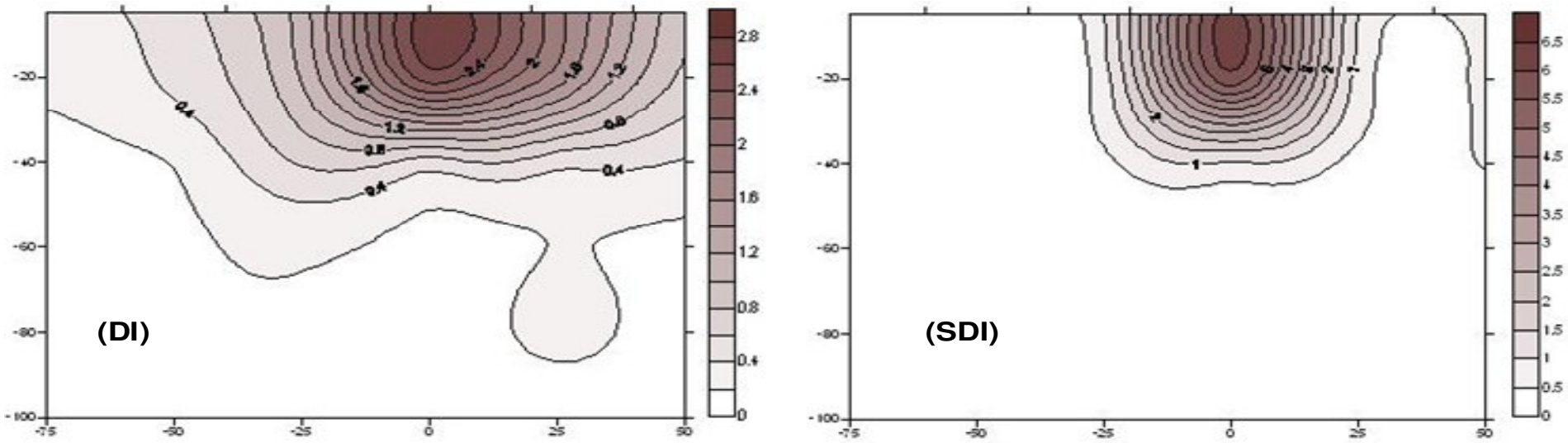

Figure 2. Total spatial root distribution of Jersey Mac cv. trees irrigated by different methods with a depth of 0 - 100 cm and a width of 0 - 75 cm for direction of between roots (BR) and 0 - 50 cm for direction of on roots (OR), mg cm^{-3}.

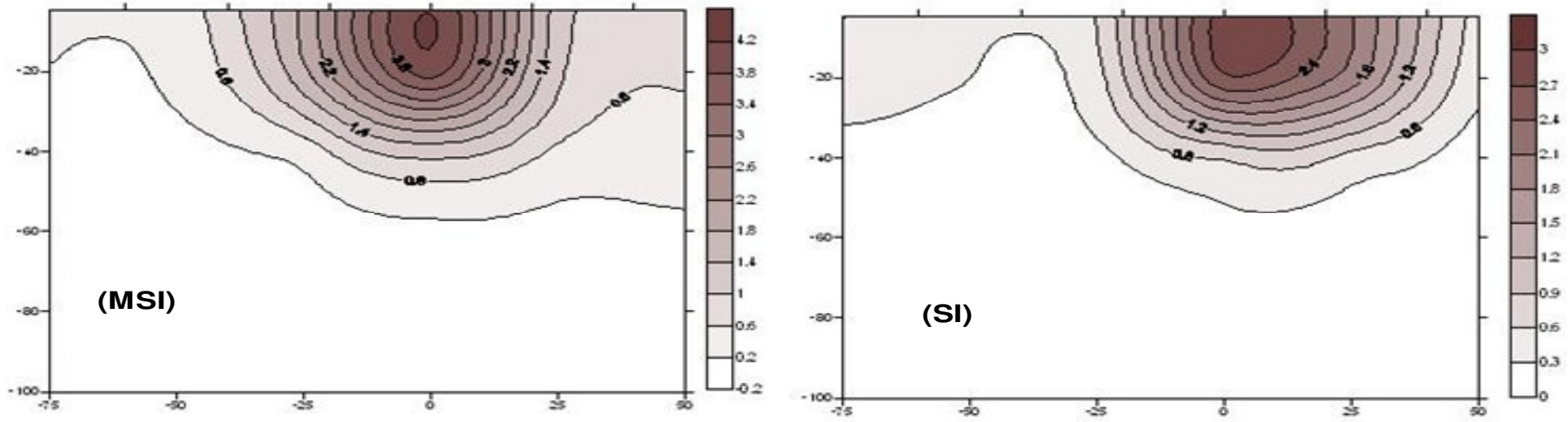

Figure 2. Continued.

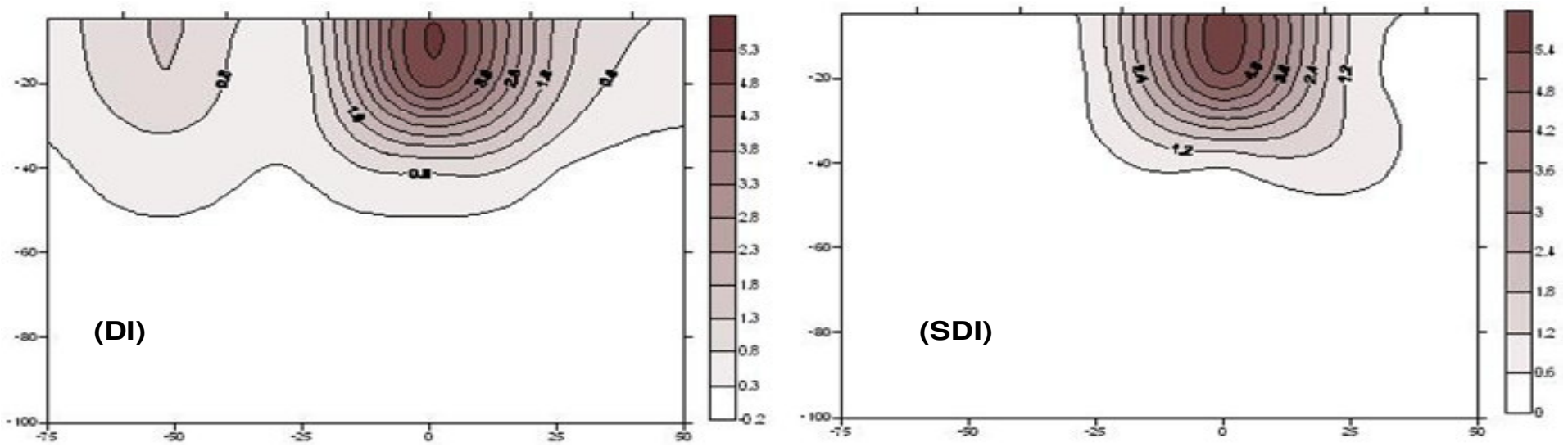

Figure 3. Total spatial root distribution of Williams Pride cv. trees irrigated by different methods with a depth (0 - 100 cm) and width (0 - 75) cm for direction of between roots (BR) and 0 - 50 cm for direction of on roots (OR), mg cm^{-3}.

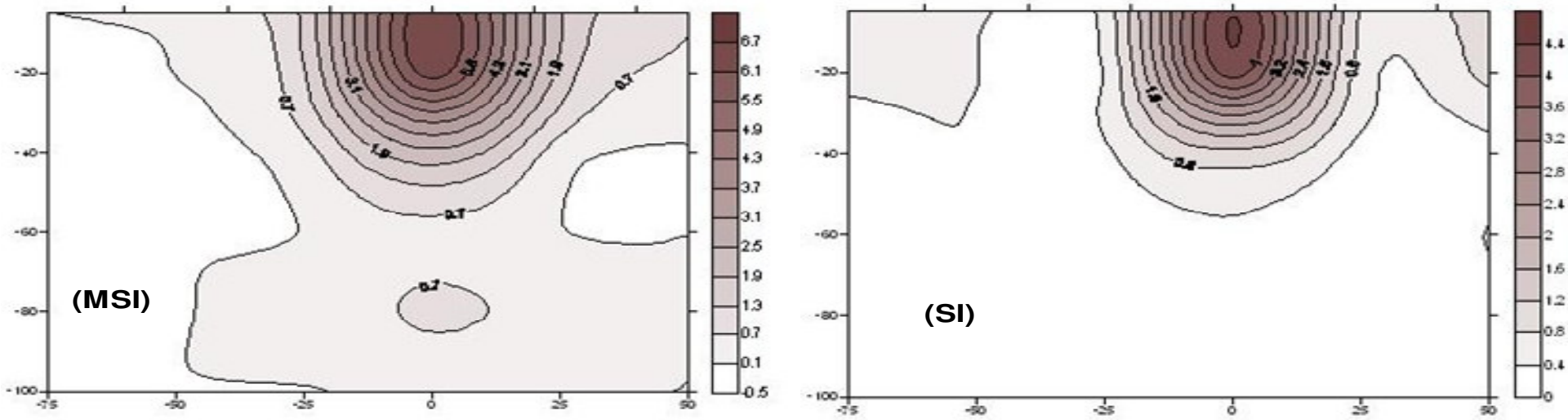

Figure 3. Continued.

Table 3. Accumulated root distributions on the different soil profile.

Soil profile	DI		SDI		MSI		SI	
	mg cm^{-3}	%	mg cm^{-3}	%	mg cm^{-3}	%	mg cm^{-3}	%
Jersey Mac cv.								
0 - 20	7.2	63.0	8.9	74.0	8.4	74.1	6.9	71.3
0 - 40	9.1	80.0	10.7	88.8	10.8	94.8	8.1	84.0
0 - 60	10.1	88.5	11.1	92.4	11.1	97.2	9.0	93.0
0 - 80	11.0	97.0	11.8	98.1	11.3	99.2	9.3	96.5
0 - 100	11.4	100.0	12.0	100.0	11.4	100.0	9.6	100.0
Williams Pride cv.								
0 - 20	10.1	72.5	8.6	69.7	10.8	62.6	7.5	61.1
0 - 40	11.8	85.0	10.7	87.1	13.6	78.6	9.6	77.6
0 - 60	12.6	90.8	11.6	94.3	14.3	82.9	10.9	88.2
0 - 80	13.4	96.2	12.0	97.9	16.8	97.7	11.7	94.8
0 - 100	13.9	100.0	12.3	100.0	17.2	100.0	12.3	100.0

Table 4. Root distributions at tree's bottom (TB), on the row (OR) and between rows (BR).

Apple cultivars	Irrigation method	BR		TB		OR		Total (mg cm^{-3})
		mg cm^{-3}	%	mg cm^{-3}	%	mg cm^{-3}	%	
Jersey Mac	DI	4.2	36.6	3.3	29.3	3.9	34.0	11.4
	SDI	2.2	18.3	7.9	65.6	1.9	16.1	12.0
	MSI	2.9	25.1	5.7	50.3	2.8	24.6	11.4
	SI	3.7	38.1	3.9	40.3	2.1	21.7	9.6
Williams Pride	DI	2.5	17.9	7.3	52.7	4.1	29.4	13.9
	SDI	3.1	25.5	6.7	54.8	4.4	19.8	12.3
	MSI	3.6	20.6	11.2	64.7	2.5	14.7	17.2
	SI	2.7	22.2	6.3	51.4	3.3	26.5	12.3

bution, mainly the amount of root of Williams Pride cv. (12.3 - 17.2 mg cm^{-3}) and was found higher than root distribution of Jersey Mac cv. (9.6 - 12.0 mg cm^{-3}). This difference showed that the amount of root of rootstocks was affected by varieties. As a known issue, roots of M9 rootstocks are surface distributed and fragile. Thus, it is hard to grow without any supplementary trench. It was observed that the varieties had effects on roots of rootstock. So, it can be said that M9 rootstock was dominant to both varieties and similarly, Williams Pride cv. was dominant to the Jersey Mac Cv.

For all of the treatments, roots axial distribution for the tree center axe was found higher at the nearest point (29.3 - 65.6%, mean value 51.1%) to the center. This value was found higher than the directions between rows (17.9 - 36.6%; mean, 25.5%) and on rows (14.7 - 34.0%; mean, 23.4%). It was determined that; (i) Most of the root distribution mainly occurred on tree center and showed a vertical distribution as a shape of bowl with the dimensions of 0.5 m diameter and 0.4 m depth, (ii) root distribution decreased while the soil depth and the distance from the tree increased, (iii) all the irrigation treatments showed no difference on root distribution. In other words, irrigation methods showed similar results by means of root distribution. Furthermore, since root distribution of Jersey Mac cv. resulted more on the rows than between the rows, root distribution of Williams Pride showed no difference for these directions.

Roots of three years M9 rootstock were observed as surface based and their amounts were decreased within the direction of distance from the tree while the distance from soil surface was increased. However, it was found that the above mentioned situation was not related to the irrigation treatments; in other words, irrigation methods showed similar results by the means of root distribution.

Goldberg et al. (1976) observed that effective root development with relatively higher water content occurred at upper levels of soil layer since in arid conditions, root development occurred in deeper soil layers and was concentrated at a small portion of soil volume surrounding the emitter location. However, Adato and Levinson (1988) stated that at near emitter locations, root development system was limited by lack of soil aeration, salt accumulation on the irrigated soil surface and limited portion of participated soil volume. Levin et al. (1979) observed that root distribution showed a correlation with

Table 5. Effective root depths, cm.

Years	Jersey Mac cv.				Williams Pride cv.			
	DI	SDI	MSI	SI	DI	SDI	MSI	SI
2006	29.0	28.4	36.3	35.3	29.7	29.8	36.6	35.8
2007	32.3	33.5	41.5	39.5	34.7	36.5	41.8	40.2
2008	37.7	38.1	44.7	43.8	39.7	37.1	45.2	44.4

soil water content of the soils through the laterals on apple trees. Researchers indicated that dripper flow and irrigation frequency affected soil water content and root distribution took place in a larger soil surface area by using 8.1 l h^{-1} flow rate twice in a week instead of 4.0 l h^{-1} flow rate daily or once in a week. Carmi et al. (1993) showed that root development was slower and root dry matter contents were decreased significantly by increasing soil depth from the surface. Researchers related this information as a stress symptom for the research location and showed that root development of cotton plants was affected by irrigation regime and total amount of irrigation for vegetation period. Kanber (1977) reported that irrigation treatments of shorter periods instead of irrigation at infrequent intervals increased both water consumption at the level of soil layers and root development. Similarly, Kanber et al. (1999) found that root distribution was increased by increasing water irrigation; more of 80% of roots occurred at the first 60 cm distance from soil surface; root distribution decreased significantly by both increasing the distance from the tree and the distance from soil surface, and this occurred in a ratio of 90 - 94% on the lateral side and 83 - 89% on the other side. Tanasescu and Paltineanu (2004) reported that the 43 and 28% of root distribution occurred at 0 - 20 and 20 - 40 cm of soil depth, respectively, on the roots of MM106 and Golden Delicious apple varieties. Besides, Bielorai (1985) investigated the effects of different irrigation methods (drip irrigation and sprinkler) on the root distribution of grapefruit trees. They found root distribution was identical in sprinkler irrigation; most of the root distribution occurred nearby location to the plant and almost 85% of root distribution was at first 60 cm of soil layer. Kanber et al. (1996) showed that similar root distribution of young orange trees was decreased by both distances from plant and from soil layer. They found that root intensity was higher on the location close to the laterals and first layers of the field soil when drip irrigation was used. However, they concluded that root distribution was identical in sprinkler irrigation.

The findings and determinations from literature cited here supported that the bias of rural apple growers in Isparta as drip irrigation method had negative effects on root development. However, most of the above mentioned researchers also agreed that root development of a plant was highly dependent on irrigation program.

In this study, values of drip irrigation treatments showed similar results with the literature cited. Our research showed that irrigation treatments had identical effects on distribution. It can be concluded that the above statements were due to the identical amount of irrigation (same total amount of irrigation and same irrigation frequency).

Surface irrigation treatment showed the highest values of effective root depth than the other treatments (Table 5). By the means of effective root depth, while undertree micro sprinkler was a second best treatment, drip irrigation and subsurface drip irrigation treatments showed the lowest values. Although drip irrigation showed lower effective root depth values, it is a well known fact that conduction of water content in tree root cross sectional area to the upper and side dry areas by capillarity is higher than the other treatments. So, plant roots could absorb most of the required water from top soil layers. However, there should be adequate water content in tree root area to establish this transport. Thus, wetting soil depth by irrigation should not be changed by changing the irrigation method.

As a result, we mention that for irrigation of the dwarf varieties subjected to this research, effective root depths were 40-45 cm until trees were 3 years aged. Doorenbos and Kassam (1979) concluded that effective root depth of field crops and vegetables could be 60 - 90 cm; for fruit trees, 120 cm; and the other kinds of plants that have surface roots, this value could be 30-60 cm. Many researchers have used this information on their studies in the world and also in Turkey. But there is no information on effective root depth of dwarf apple trees in literature yet. Therefore, using the findings of this study of dwarf apple varieties by dwarf apple growers and researchers is recommended.

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