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Influence of Water Application Systems on Avocado Root Distribution

Darwish, W. M. B. [1]; M. A. El-Howeity[1] and M. I. Ghazy[2*]

[1] Environmental Studies and Research Inst., U., of Sadat City
[2] Faculty of Agric., Mansoura University.

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ABSTRACT

This study was conducted on the farm of Pico Agricultural Company in Badr Center, Behira Governorate, Egypt (30.5766º N, 30.7155º E). The Pinkerton avocado trees were used in this study. The study aims to demonstrate the effect of water addition using drip irrigation, micro-sprinkler, and (drip irrigation and micro-sprinkler together) on the active root distribution of avocado trees. Active roots were recorded per square centimeter during the spring season of each year within 200 cm of the avocado tree stem from the four surrounding trees under each of the three irrigation systems. The results showed that the best distribution of active roots/cm^2 was achieved under the drip and micro-sprinkler systems together, followed by micro-sprinkler irrigation, and finally drip irrigation. The distribution of active roots /cm^2 for both drip irrigation and micro-sprinkler irrigation together and drip irrigation to a distance of 90 cm from the avocado tree trunk from the four different sides was equaled, followed by micro-sprinkler irrigation. On the other hand, there are no active roots in the distance from 120 cm to 200 cm of the trunk under drip irrigation in the direction of east and west of the trunk of avocado trees. Finally, the best distribution of the active roots of the avocado trees was under the combination of the drip and micro-sprinkler irrigation systems together, which positively affected the productivity of avocado trees compared to both drip irrigation and micro-sprinkler irrigation alone.

Keywords: Drip irrigation – Micro-sprinkler irrigation –Root distribution – Avocado tree

INTRODUCTION

Avocado fruit production (Persea Americana Mill) is a major agribusiness in a number of countries, including Mexico, Indonesia, the United States of America, the Dominican Republic, Colombia, Chile, and Peru. (FAOSTAT, 2019). Avocado farming requires a lot of water (above 150 L/ day) (Lahav and Whiley, 2002). Water plays a role in the physiological mechanisms that affect how long and how intense growth flushes last (Silva et al, 2017). The patterns of avocado root dispersion and the elements that define them are not well understood. Avocado root distribution is likely to be affected by factors that affect other tree species, such as variety, soil type, watering method, and season, among others. Micro-sprinklers (typically one or two per tree) concentrate roots in a larger wet bulb, generally positioned between the trees and inside the row, while drip irrigation concentrates roots in as many wet bulbs as there are emitters (Cantuarias *et al.*, 1995), (Meyer *et al.*, 1992). The location of the best air/water balance for root growth of various species, including avocado trees, is determined by the water holding capacity of the soil, which interacts with the irrigation method and scheduling factors (Watson and Kelsey, 2006; Gaertig *et al.*, 2002). For avocado plantations, studies comparing drip irrigation and micro-sprinkler systems have yielded inconsistent results. Plants planted using micro-sprinklers produced more root growth than plants grown with drip irrigation, according to Marsh *et al.* (1978), however this differed by season and year. For different types of soil textures, such as fine and coarse textured soils, Salgado and Cautin (2008) found that avocado tree under drip irrigation developed 25% more roots on average than avocado trees under micro-sprinkler systems. When the distance to the trunk was taken into account, drip watering treatments created more consistent and uniform root distribution systems. The majority of the roots were located 20-25 cm on either side of the drip irrigation emitter, indicating a consistent flow, but this result fluctuated seasonally. Moreover, in the summer, drip irrigation was found to increase root formation in fine-textured topsoil profiles compared to fine-textured micro-sprinkler treatments. Regardless of irrigation system or soil type, overall root production was higher in the autumn than in the spring and summer (Salgado and Cautin, 2008). This was a surprising result because, according to (Lahav and Kalmar,1977) root numbers and length should be higher during the active summer season. (Atucha *et al.* 2013) also discovered that root dispersion follows phenology, implying that the type of irrigation system is less significant than irrigation frequency, which should be adjusted periodically to match crop demands. When compared to micro-sprinkler systems, drip irrigation systems may deliver more DU during periods of significant drought stress and high heat. Roots are important because they connect the plant to the soil and the soil to the atmosphere. Above-ground plant growth and development are tightly linked to root morphology and physiology because they rely on the uptake of soil nutrients and water (Ju *et al.*, 2015).

(Darwish and Elmetwalli, 2019) selected the optimum irrigation method and fertilization type for the production of two avocado cultivars (Hass and Ettinger). The results indicated that the combined of micro-sprinkler and drip irrigation encouraged avocado yield and quality including fruit yield, number of fruits per tree, export ratio and water use efficiency. Moreover, the combination between micro-

[*] Corresponding author.
E-mail address: mohamed_ghazy@mans.edu.eg
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sprinkler and drip irrigation to have greater root size and distribution that enhance various nutrients uptake and other root activities. Most irrigation systems are designed to deliver enough water to keep soils at field capacity while also allowing them to drain adequately during dry seasons or low precipitation (Meyer, 2014). Drip and micro-sprinkler irrigation methods are the most common in avocado plantations, and irrigation frequency is frequently determined by the amount of soil volume wetted to prevent yield reduction (Shalhevet, 2006). The amount of water held in the root zone is referred to as the specific soil volume wetted (Zur, 1996), and to guarantee that irrigation is given directly to roots, irrigation emitters must be placed and spaced within the root dimensions of the plant. The kind of soil and crop root distribution influence whether a producer uses drip or micro-sprinkler irrigation (Zur, 1996). Irrigation technology advancements were a vital element in avocado plantation expansion into the Mediterranean, semi-arid, and dry regions where irrigation is critical (Carr 2013; Lahav *et al.* 2013). In vast orchards, determining the right location of equipment to monitor soil water levels inside the zones where roots are actively growing so that adequate irrigation-scheduling decisions may be made is a common difficulty. The need for irrigation is determined by the amount of available water in the soil profile at any particular time. Several sensors, such as tensiometers, TDR, and neutron or resonance probes, can be used to detect soil moisture under uniform soil conditions. The most common field circumstances, however, include substantial heterogeneity in root distribution and frequency, both inside the orchard and around the tree. This root zone variability can have an impact on the accuracy and representativeness of field soil moisture measurements (Gong *et al.*, 2006). Consequently, our objective was to evaluate avocado root frequency and distribution patterns, using trees grown in sandy soil types, with either drip, micro-sprinkler, or a combination of drip and micro-sprinkler irrigation systems.

MATERIALS AND METHODS

A research study was conducted over two seasons in 2019 and 2020 on six-year-old Pinkerton avocado (Persea Americana Mill.). The experiment took place at Bader City, South AlTahrir, Al-Beharia Governate, Egypt (30.5766º N, 30.7155º E), at the experimental farm (ElFath), reclamation areas. Avocado trees were planted in sandy soil and irrigated with three different irrigation systems. The fruit burden was medium-to-high (9.5–16.6 Mg/ ha), accounting for annual yield changes that aren't influenced by the alternating bearing. Plot A was a 1 ha orchard with a micro-sprinkler irrigation system, plot B was a 1 ha orchard with a drip irrigation system, and plot C was a 1.4 ha orchard with a combination of drip and micro-sprinkler irrigation systems. The soil in all plots was classed as sandy soil with a bulk density of 1.26 g/cm^3. The soil particle sizes for the first 0.3m of the soil profile were 91% sand, 3% silt, and 6% clay. Organic matter accounts for 0.38 percent of the total. Table (1) shows the chemical analysis of the soil. Using a pressure membrane, the volumetric water content values at saturated, field capacity, and wilting points were 19, 22, and 11 %, respectively. Table (2) shows the chemical analysis of the irrigation water, which was Nile water (FAO, 1970; Page *et al.*, 1992).

Table 1. Some chemical properties of the cultivated soil

EC (dS. m^{-1})	pH	Soluble cations (meq.L^{-1})				Soluble anions (meq.L^{-1})				SAR
		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	Co_3^{-2}	HCo_3^{-1}	Cl^{-1}	SO_4^{-1}	
2.8	7.9	10.8	7.2	9	1	0.8	6.8	18.7	1.7	3

Table 2. Some Chemical analysis of water used in the study

EC (dS. m^{-1})	pH	Soluble cations (meq.L^{-1})				Soluble anions (meq.L^{-1})				SAR
		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	Co_3^{-2}	$H\,Co_3^{-1}$	Cl^{-1}	SO_4^{-1}	
0.37	7.6	0.8	1.6	1	0.3	1	0.00	2.3	0.4	0.91

All plots of trees had been planted at a density of 4 m x 7 m. In plot A, trees were irrigated with two micro-sprinklers per tree (120 L/h each with a 5 m wet diameter), each located 2 m from the tree on either side of the planting line. In plot B, trees, were irrigated with 24 GR drippers per tree (4 L/h each) in three drip lines, 0.5 m from the trees on either side of the planting line, with drippers spaced at 0.5 m apart, and in plot C, trees were irrigated with one micro-sprinkler (120 L/h each with a 5 m wet diameter and 2 m from the tree on either side of the planting line) and 24 GR drippers (0.5 m from the trees on either side of the planting line, with drippers at 0.5 m apart) as shown in Fig. (1). Irrigation methods were applied on all plots since plantation. Early in the winter of each growing period, we calibrated all of the emitters and micro-sprinklers used in the study for all plots.

Drip irrigation system

The drip irrigation system included a 20 m^3/h electrical centrifugal pump with a 200 KPa operating pressure that lifted water from an open channel and delivered it to a 50 mm diameter PE main pipe via a control head with media and screen filters, a 3/4-inch venturi fertiliser injector, valves, and pressure gauges. PE laterals with a diameter of 16 mm. Each tree had three 25-meter-long laterals with a 0.5 m space between them. GR drippers (4 L/h) were spaced 0.5 m apart along the lateral line on each lateral.

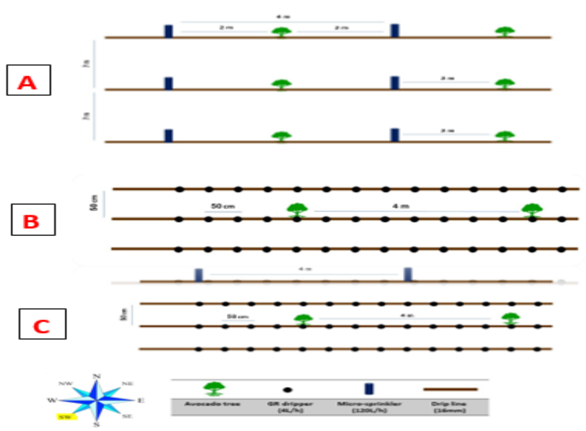

Figure 1. Avocado trees and experimental sites with micro-sprinkler, drip, and mixed drip and micro-sprinkler irrigation systems

Micro-sprinkler irrigation system

Other centrifugal pump (3-inch inlet and outlet diameters, 30 m^3/h nominal discharges), backflow prevention device, pressure gauges, flowmeter, control valves, mainline, sub-main lines, laterals, and micro-sprinklers, all powered by a 3.75kW internal combustion engine, were all included in the micro-sprinkler irrigation system under investigation. The mainline underground was 75 mm of PVC pipes, the sub-main lines underground were 50 mm PVC pipes connected to the mainline by 32 mm control valves, and the lateral lines were 16 mm PE pipes connected to the micro-sprinkler (120 L/h) with an 8 mm outer diameter spaghetti tube and a 90 cm stake height.

Micro-sprinkler and drip irrigation system distribution uniformity

Burt *et al.* (1997) addresses the various definitions of irrigation system efficiency and distribution uniformity. Because irrigation system efficiency is dependent on management and design, it is difficult to assess. In micro-sprinkler and drip irrigation systems, low quarter distribution uniformity is frequently employed to assess the performance of the system.

$$DU_{lq} = \frac{V_{lq}}{V} \quad \text{................(1)}$$

where:

DU_{lq} is the low quarter distribution uniformity, V_{lq} is the average volume caught in the lowest 25% of volumes collected, and V is the overall average of volumes collected. If the system is effectively, distribution homogeneity indicates potential efficiency. That is to say, efficiency is unlikely to outperform distribution homogeneity. The emitters and micro-sprinklers utilised in this investigation for all plots were calibrated early in the winter of each growing season. Plot A has 20 micro-sprinklers, plot B has 240 drippers, and plot C has 10 micro-sprinklers and 240 drippers. 120 catch cans were used to collect water under micro-sprinklers and drippers which were distributed according to (ASAE standard, 2006). The micro-sprinkler discharge was tested for 30 minutes. For drippers, discharge was monitored using a graded glass at each emitter around the tree for 1 minute. The uniformity coefficients were approximately 90 and 82% for drip and micro-sprinkler, respectively, in all plots.

Roots distribution of avocado trees

For the purposes of this study, active roots were characterised as white roots with a diameter of 2 mm or less. Throughout the growing season, root density measurements (number of roots/cm^2) were taken from three trees in each plot. On the wall of a radial trench excavated toward the trunk of each tree, white roots with a diameter of less than 2 mm were counted (50 x 30 x 200 cm). To count the roots, a sample of the complete wall (50 x 200 cm) was taken, with 30 squares of 4 cm^2 each chosen at random on a clear squared of paper. Root distribution isolines were created using an average of three trees per irrigation type category (Salgado and Cautin, 2008).

Water Requirements

To determine the irrigation time and calculate the amount of water applied for the complete irrigation regime, the FAO CROPWAT program v.8 was utilized (100 percent ETc). Using the modified FAO Penman-Monteith equation given by Allen *et al.* (1998), this software calculates the reference evapotranspiration (ETo). The ETo in mm day^{-1} was estimated using the several daily environmental indicators gathered from the nearest meteorological station (Table 1). Relative humidity data obtained were used to alter the potato crop coefficient (Kc) the ETc to ETo ratio. The following calculation was used to compute the water required for the 100 % ETc treatment using the ETo and Kc values:

$$\mathbf{ETc = ETo \times Kc.} \qquad \mathbf{(2)}$$

After calculating the water consumption of the crop, it is multiplied by the reciprocal of the efficiency according to the irrigation system used as presented in table (3).

A total of 14925 m^3/ ha (combination of micro-sprinkler and drip), 10375 m^3/ ha (drip), and 11234 m^3/ ha (micro-sprinkler) of irrigation water was applied to the corresponding avocado trees depending on the table (3) as shown in fig (2) and numbers of irrigation per month as shown in table (4) below.

Water application was adjusted based on moisture meter type (HH2) readings (50 cm deep) as shown in fig. (3).

Table 3. Average climatological data, reference crop evapotranspiration (ETo) and crop coefficient (Kc) for avocado trees used to compute irrigation requirement (ETc)

Average Months	Temp. Max C^0	Temp. Min C^0	Temp. average C^0	Relative humidity (%)	Rain fall (mm)	ETo mm/day	Kc*
January	19.9	8.4	14.15	64.2	5.9	2.5	0.5
February	24.4	7.89	16.15	60.4	4.5	2.5	0.5
March	26.5	9.9	18.2	60.52	3.2	4	0.8
April	26	12.5	19.25	55	1.6	5.5	0.8
May	30.5	15.4	22.95	56	1.2	6.5	0.68
June	32.7	18.2	25.45	56.1	0.00	7	0.68
July	33.5	19.1	26.3	57.7	0.00	8	0.68
August	34.2	22	28.1	59.7	0.00	8.5	0.68
September	32.6	20.1	26.35	63.1	0.5	6.5	0.68
October	28	17	23	63	0.7	4.5	0.68
November	23	10.8	16.9	66.2	11	3.5	0.5
December	20.6	9.1	14.85	65	10.5	2.5	0.5

Source: https://dacom.farm/apps/dacom_online/weather_data/page/ , and Kc from Kiggundu *et al.*, (2012)

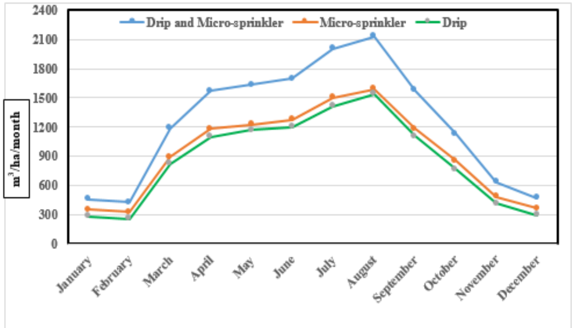

Figure 2. Average monthly water applied with a combination of drip and micro-sprinkler, micro-sprinkler, and drip irrigation systems during the studied seasons

Table 4. Numbers of irrigation per month for avocado trees

Months	Numbers of irrigation/ month		
	Drip	Micro-sprinkler	Combined of drip and micro-sprinkler
January	10	15	10
February	10	15	10
March	10	15	10
April	15	30	15
May	15	31	15
June	15	30	15
July	15	31	15
August	15	31	15
September	15	30	15
October	10	31	10
November	10	15	10
December	10	15	10

Figure 3. Moisture meter instrument type (HH2)

RESULTS AND DISCUSSIONS

Monitoring of soil water content

Figure (4) and figure (5) show the distribution of moisture content at 20 cm depth by using moisture meter (HH2) in the soil of avocado trees before irrigation and one hour after irrigation, respectively, for both the drip irrigation system, micro-sprinkler irrigation, and drip irrigation and micro-sprinkler irrigation together for the surface layer (20 cm) of the soil up to 2 m from the avocado tree trunk. It is noticeable from the two figures that there is a convergence of the three irrigation systems in the moisture content before irrigation and an hour after irrigation until a distance of 90 cm from the avocado tree trunk. In addition to the above, it was also found from the two figures that the moisture content before irrigation and one hour after irrigation in the distance from 150cm to 200cm from the avocado tree trunk was higher in the combined system (drip irrigation and micro-sprinkler irrigation) compared to both the drip irrigation system and the micro-sprinkler irrigation system alone. Moreover, also notice at that distance mentioned earlier that the moisture content after irrigation for an hour was twice the moisture content before irrigation. To explained that micro-sprinkler irrigation, which works well on sandy soils, and drip irrigation, is one of the greatest approaches from a technical standpoint because it saves water. In a study of irrigation scheduling literature, (Du Plessis, 1991),(Kourgialas, 2018) and Karam *et al.* (2019) strongly suggested the use of soil moisture sensors in avocado plantations to enhance irrigation management and offer farmers sustainable irrigation guidance.

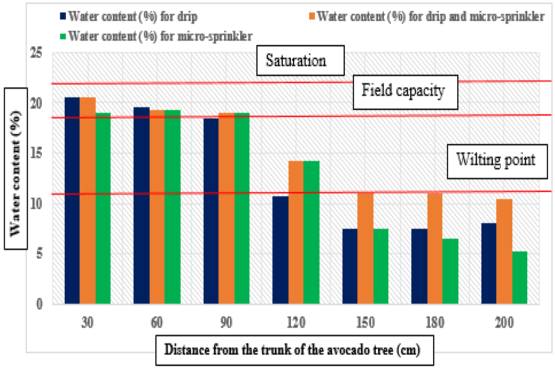

Figure 4. Water content (%) at 20 cm before irrigation for avocado trees by using drip, micro-sprinkler, or (drip and micro-sprinkler together)

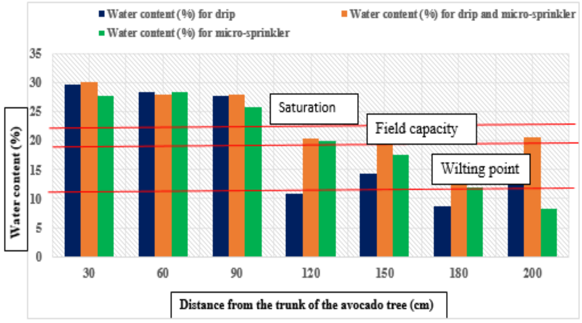

Figure 5. Water content (%) at 20 cm after one hour of irrigation for avocado trees by using drip, micro-sprinkler, and (drip and micro-sprinkler together)

Table (4) below illustrates the distribution of average active roots/cm^2 in avocado trees irrigated with drip, micro-sprinkler, and a combination of drip and micro-sprinkler irrigation methods across the seasons investigated. The effect of irrigation systems on the distribution of active roots of avocado trees will be demonstrated by the accompanying drawings, which will be accompanied by field images.

Table 4. Distribution of average values of active roots/cm^2 of avocado trees under drip, micro-sprinkler, and drip/ micro-sprinkler irrigation systems

Distance from trunk of tree (cm)	Number of active roots /cm^2											
	Micro-sprinkler irrigation				Combined of the drip and micro-sprinkler				Drip irrigation			
	North direction	East direction	South direction	West direction	North direction	East direction	South direction	West direction	North direction	East direction	South direction	West direction
30	8	7	8	7	10	9	11	8	10	9	11	8
60	9	6	10	6	12	10	10	11	12	10	10	11
90	6	7	9	7	8	10	9	10	8	10	9	10
120	8	7	5	2	8	7	4	8	8	0	4	0
150	7	8	5	3	9	8	7	5	9	0	7	0
180	4	2	2	3	6	4	5	4	6	0	5	0
200	2	1	3	4	9	8	9	8	9	0	9	0

The average of root frequency of avocado trees under drip irrigation during the study seasons was shown in fig. (6). The active root values were concentrated in the first 90 cm from the trunk in all directions, with values of around 10/cm^2. In addition, the values of the active roots were close to zero in the range of more than 90 cm to 200 cm west and east of the avocado tree's stem. This may be due to the concentration of roots spreading around the circle of wet points of the drip irrigation system. Finally, observations revealed that the areas with the highest active root concentration under drip irrigation were only 90 cm from the avocado tree's trunk, whereas the areas between 120 cm and 200 cm from the avocado tree's trunk had zero active roots. Michelakis et al. (1993) and (Salgado and Cautin, 2008) both came to the same conclusion.

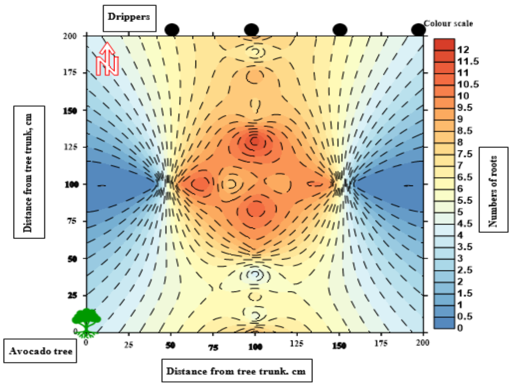

Figure 6. Average root frequencies of avocado trees under drip irrigation during the seasons under consideration

The average root frequencies of avocado trees under micro-sprinkler watering during the study seasons are shown in Fig. (7). The active root values concentrated 90 cm from the trunk in all directions surrounded the avocado tree trunk, with values of around 8/cm^2). In addition, the active root values were reduced in the space surrounding the avocado tree's trunk from 120 cm to 200 cm in all directions. This was due to the micro-sprinkler irrigation system assisting the roots to spreading deeper into surface layer. Finally, observations revealed that the areas with the highest active root concentration under the micro-sprinkler watering system were only 90 cm from the avocado tree's trunk, whereas the active root concentration in the areas between 120 cm and 200 cm from the avocado tree's trunk had decreased. The same conclusions were reached by (Salazar-Garcia and Cortes-Flores, 1986).

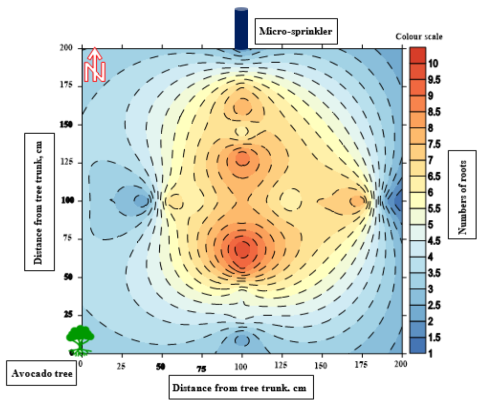

Figure 7. Average root frequencies of avocado trees under micro-sprinkler irrigation during the seasons under consideration

The average root frequencies of the avocado tree under drip and micro-sprinkler irrigation together during the study seasons are shown in Fig. (8). The active root values concentrated in the 90 cm from the trunk in all directions surrounded the avocado tree trunk, with values of around 10/cm^2). Additionally, the active root values were somewhat reduced in the space surrounding the avocado tree's trunk from 120 cm to 200 cm in all directions. This result may occur due to the incorporation of the advantages of drip irrigation in terms of spreading the roots around the drippers in a deep vertical manner, as well as the advantages of micro-sprinkler irrigation through the dense spread of the roots in the surface layer. Finally, it was discovered that combining drip irrigation with micro-sprinkler irrigation systems resulted in better dispersion of avocado tree active roots, which was reflected in avocado tree growth and productivity. The same findings were obtained by (Salgado and Cautin, 2008) and (Darwish and Elmetwalli, 2019).

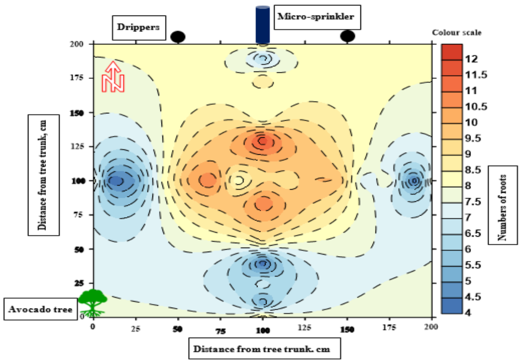

Figure 8. Average of root frequency of avocado trees under combination of drip and micro-sprinkler irrigation during the seasons under consideration

CONCLUSIONS

In general, for avocado production, a mixture of two irrigation systems was recommended: a) micro-sprinkler irrigation, which works well on sandy soils, and b) drip irrigation, which is one of the best techniques from a technical standpoint owing to water savings. In avocado cultivation, soil moisture sensor networks, in addition to a competent irrigation system, are strongly suggested to optimise irrigation management and enhance the sustainable use of water in severe climatic circumstances by increasing wetted soil volume. Finally, variations in both the number of roots and the location of the active root zone should be expected as a result of different watering methods, particularly when using a combination of drip and micro-sprinkler irrigation systems, both around the tree and within the soil layers. In addition, the watering method utilised affects the amount and position of roots. Nonetheless, the most appropriate irrigation method, according to our findings, was a combination of drip and micro-sprinkler irrigation.

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تأثير أنظمة تطبيق المياه على توزيع جذور الأفوكادو

وليد محمد بسيونى درويش[1] ، محمد أحمد الحويطى[1] و محمد إبراهيم غازى[2]

[1] معهد الدراسات والبحوث البيئية جامعة مدينة السادات

[2]قسم الهندسة الزراعية ـ كلية الزراعة ـ جامعة المنصورة

أجري هذا البحث بمزرعة شركة بيكو الزراعية بمركز بدر محافظة البحيرة, مصر. استخدمت أشجار الافوكادو صنف بنكيرتون. هدف البحث إلى بيان تأثير إضافة المياه باستخدام نظم الرى بالتنقيط ،الرش الدقيق ،الرى بالتنقيط والرش الدقيق معا على إنتشار الجذور النشطة لأشجار الأفوكادو. سجلت اعداد الجذور النشطة لكل سم^2 خلال موسم الربيع من كل عام لمسافة 200سم من جذع شجر الافوكادو من الجهات الاربع المحيطة بالأشجار تحت كل نظام من نظم الرى الثلاثة. أظهرت النتائج أن أعلى إنتشار للجذور النشطة لكل سم ^{2} تحقق تحت نظام الرى بالتنقيط والرش الدقيق معا ، تلاه الرى بالرش الدقيق ، وأخيرا الرى بالتنقيط . أيضا تساوى إنتشار الجذور النشطة لكل سم^{2}لكل من (الرى بالتنقيط والرش الدقيق معا) والرى بالتنقيط حتى مسافة 90 سم من جذع شجر الأفوكادو من الجهات الاربع المختلفة تلاه الرى بالرش الدقيق. ومن جهة أخرى تبين عدم وجود جذور نشطة فى المسافة من 120سم وحتى 200سم من الجذع تحت نظام الرى بالتنقيط فى اتجاهى الشرق والغرب من جذع شجر الافوكادو. أخيرا تبين أن دمج نظامى الرى بالتنقيط والرى بالرش الدقيق معا أدى إلى إنتشار أفضل للجذور النشطة لأشجار الافوكادو الامر الذى سوف ينعكس بالتبعية على نمو وإنتاجية أشجار الافوكادو. لذلك يوصى بدمج نظامى الرى بالتنقيط والرى بالرش الدقيق عند زراعة أشجار الافوكادو صنف بنكيرتون للحصول على إنتشار أفضل للجذور ونمو وإنتاجية أفضل.

الكلمات المفتاحية: الرى بالتنقيط – الرى بالرش الدقيق – توزيع الجذور – أشجار الافوكادو.