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SOIL MOISTURE AND ROOT DISTRIBUTION IN AN APPLE ORCHARD IRRIGATED BY TRICKLERS

by I. LEVIN*, R. ASSAF* and B. BRAVDO**

KEY WORDS

Apple trees Drainage water loss Pulsed irrigation Root distribution Soil moisture distribution Trickler irrigation

SUMMARY

The soil moisture distribution at different distances from the water source in a high-yielding apple orchard planted on a 60-cm-deep heavy basalt soil underlined with gravel was studied. The soil water content was determined in three irrigation treatments which differed in discharge rates, distances between the tricklers on the lateral, and frequency of application of an equal amount of water. The determinations were made several times during the wetting and drying processes in one irrigation cycle of each treatment. The roots of the trees perpendicular to and along the trickler line were counted in the soil profile. The results showed that the soil moisture and root system distribution covered a wider area when irrigated twice a week with 8 l/h tricklers rather than by irrigating every day or once a week with 4 l/h tricklers. Every day compared with once a week irrigation caused an appreciably narrower soil moisture distribution but a quite similar root distribution pattern. The soil-moisture-saturated level in the soil profile in all treatments, in the area under the trickler, caused water loss by drainage while irrigation continued. The loss was estimated to be 17% of the water applied. A pulsed irrigation was assumed to decrease this drainage loss by trying to supply the water in pace of the plant consumption.

INTRODUCTION

The use of trickle irrigation systems in apple orchards in Israel has increased considerably in the last 10 years. The main advantages of this method are the low cost of establishing permanent irrigation in the orchard, low water pressure requirement in the pipe system, and maintenance of high water availability to the roots for most of the time between irrigations, without interfering with the usual cultivation practices. Although the soil volume wetted is limited, no reduction in tree growth or yield has been observed so far, and even an increase in yield was apparent in some cases. It is still not certain whether this irrigation method enables a reduction in the seasonal amount of water applied.

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** The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, Israel.

Research on the distribution pattern of the water discharged from a point source and its dependence on some soil parameters was analyzed theoretically and has been tested in the laboratory and also to some extent under field conditions[3,4]. Water distribution under tricklers in vegetable and field crops growing in several soil types has also been investigated[6,9]. Limited observations and preliminary reports of experiments on the distribution of water discharged from tricklers in fruit orchards have been published[1,2,7]. Simulation of soil water distribution under the tricklers in orchards is complicated, due to the concomitant water uptake by the roots.

In this paper we report on soil moisture and root distribution in an apple orchard on a shallow soil profile subjected to different trickle irrigation treatments. The possibility of more efficient use of the water applied is discussed.

MATERIALS AND METHODS

Three trickle irrigation treatments were applied in the 1972 and 1973 summer seasons to an apple orchard with four varieties on Hashabi selected local rootstock: Jonathan, Grand (Calville de St. Sauveur), Golden Delicious and Red Delicious. The trees were planted 2 × 4.5 m apart in 1969, in the southern Hula Valley of Israel. The orchard was sod cultivated and trained in a special irregular palmetta hedgerow without pruning and with continuous shoot bending. A total amount of 360 kg/ha N and 400 kg/ha K was applied through the irrigation system mainly during the period 15/III–1/VI, in weekly intervals. Five applications totaling 4 kg/ha EDTHA as H-138 sequestrene were given through the irrigation system and five neutrazinc sprays were applied during the summer season. The experimental site was located 70 m above sea level, with an average annual precipitation (limited to the winter) of 400 mm, and an average daily temperature in the summer (May to September) of 24°C. The soil was 60 cm deep, brown grumusol, uniform throughout the profile, underlined by basaltic and lime gravel stones. The pH was 6.7–7.0; the $CaCO_3$ content is 1–2%; and the mechanical composition was 69% clay and 21% silt. The bulk density was 1.23 g/cm^3, the field capacity (FC) 39% and the wilting point (WP) 26% by weight. The saturated hydraulic conductivity – (K) was 1.0 cm/h at soil moisture content of 48% (by weight) using the constant head method[4]. The ground water table was below 4 m depth throughout the summer.

The irrigation water was applied using 'Netafilm' trickle lines placed on one side of each tree row, 20 cm from the trunks. For the determination of soil water content by the neutron scattering method (Troxler, USA), four rows of access tubes were driven into the soil at four distances from the tricklers, normal to the tree row in each treatment. The daily water application rate was 9–10 mm (1.0 coefficient to the relevant Class A pan evaporation rate) from mid June to the harvest, and half that rate for the rest of the season – calculated on the basis of the whole area.

The treatments were: T_1 – daily irrigation; T_2 – weekly irrigation, both using 4 l/h tricklers placed 1.25m apart on the lateral; and T_3 – twice-a-week irrigation using 8-l/h tricklers placed 2 m apart on the lateral*.

Soil water content measurements were made frequently in July 1973 in order to establish the distribution pattern throughout one irrigation cycle in all treatments. The average soil water content of the entire 60 cm deep profile was calculated for the different distances from the tricklers. Pulses of

* Each treatment was applied to a plot of 4–6 trees with two border trees on each side replicated six times in the four apple varieties. Treatment 3 did not include the Grand variety.

half an hour on and one hour off irrigation were applied in July in T_1 to follow the soil moisture content fluctuation under the trickler.

At the end of the season two 2 m long trenches were dug perpendicular to the tree row, and one 6 meter long trench parallel to the row was dug 20 cm from the trees. The trenches, one in each variety and in each treatment, were 1 meter deep. The walls of the trenches were flushed with water and the visible roots were counted in each square (20 × 20 cm) formed by attaching a net to the trench walls.

RESULTS

Despite the unusually shallow soil profile, the yields obtained were relatively high and early (Table 1). The rate of soil moisture increase (wetting) in the T_1

Table 1. Sum of the yield (t/ha) of four varieties of apples during three years, 1973–1975 (3–5 years after planting), in the different treatments

Variety	Treatment			
	T_1	T_2	T_3	± S.E.
Grand	254	223		3.2
Golden Delicious	242	248	289	10.7
Jonathan	211	171	216	6.8
Red Delicious	78	75	86	N.S.

daily irrigation treatment was very rapid at the zero and 30 cm distances from the tricklers, during the first hour after the start of irrigation (Fig. 1). It slowed down during the next hour, afterwards reaching a plateau at the zero distance and increasing at a slow rate at 30 cm. At 60 cm distance a very small increase was apparent throughout the irrigation period (Fig. 1). The high level of 45–60% Pw of the soil moisture was reached at zero distance after two hours, whereas at 30 cm the maximum was 44% after 14 hours of irrigation. At 60 cm the increase in soil moisture content was small and Pw was always lower than F.C. (Fig. 1). The moisture depletion within 1.5 hours after termination of the irrigation was 3% at the zero distance, somewhat slower at 30 cm, and unchanged at 60 cm distances from the trickler.

In T_2 the duration of the irrigation period was 70 hours and the furthest point wetted was 117 cm from the trickler (about twice that in T_1) (Fig. 2). Under the emitters F.C. was reached within half an hour and the maximum moisture content after 22 hours. At 45 and 60 cm distance the rate of wetting was slow and F.C. was reached only after 20 hours of irrigation. At 117 cm, only a small

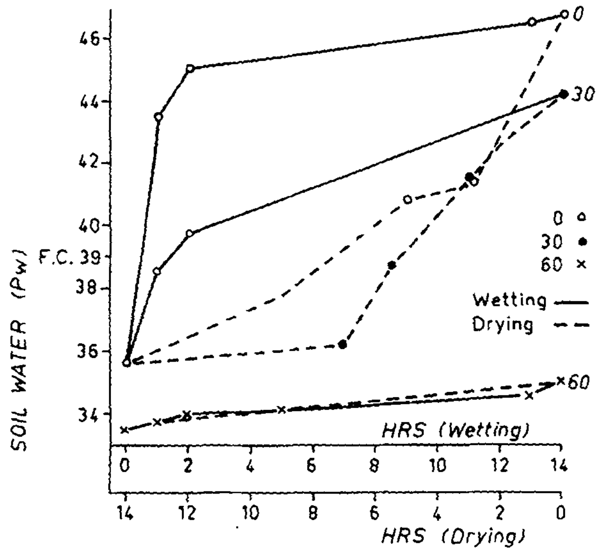

Fig. 1. Soil moisture content for the 0-60-cm profile at different distances from trickler (0, 30, 60 cm) as a function of time from the beginning (wetting) or terminating (drying) of the irrigation in treatment 1.

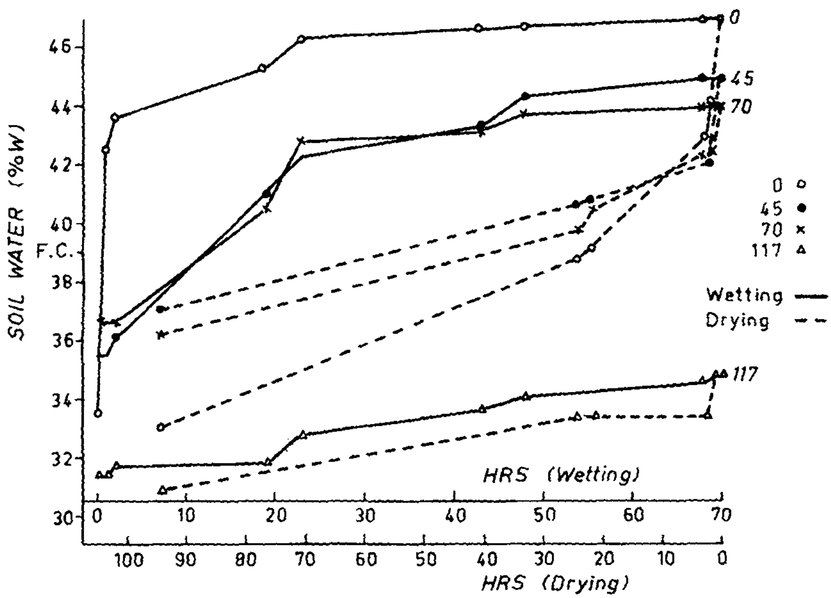

Fig. 2. Soil moisture content for the 0–60-cm profile at different distances from the tricklers (0, 45, 70 and 117 cm) as a function of time from the beginning (wetting) or terminating (drying) of the irrigation in treatment 2.

increase in soil moisture content was apparent throughout the 70 hours of irrigation. The soil water depletion during the first 1.5 hours after terminating the irrigation was 3%, 2.3% and 1.3% at 0, 45 and 70 cm distances, respectively. The rate of water depletion decreased afterwards at all three distances, the highest rate being under the emitters.

By the twice-weekly irrigation with 8 l/h tricklers (T_3), the maximum level at the zero distance was reached after two hours – similar to T_1 (Fig. 3). The moisture distribution from 8 l/h tricklers after 40 hours was similar to that obtained after 70 hours of irrigation by 4 l/h tricklers with small moisture content increase at 110 cm from the trickler. The rate of water depletion was slower than the initial rate of wetting at all distances from the tricklers except 110 cm, where both rates were low and similar.

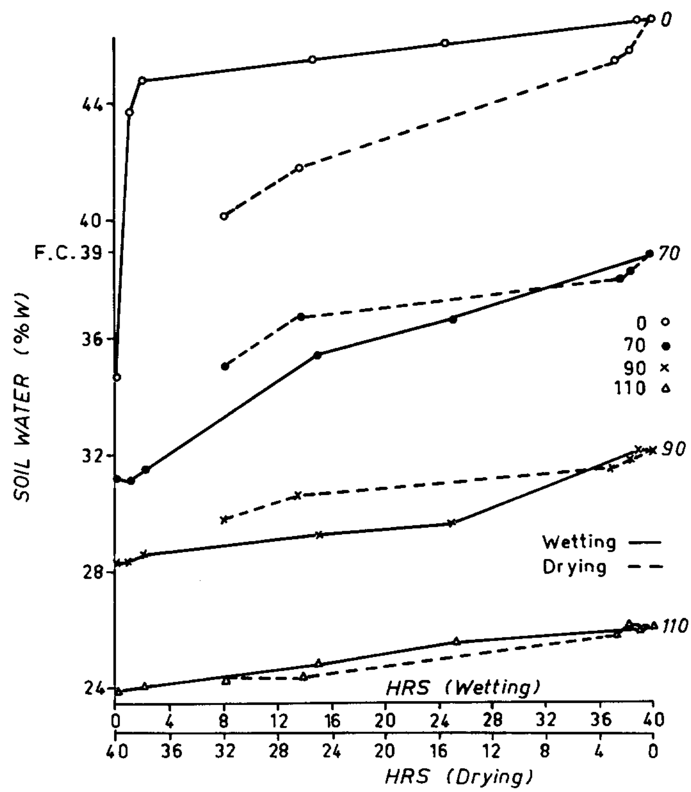

Fig. 3. Soil moisture for the 0–60-cm profile at different distances from the trickler (0, 70, 90 and 110 cm) as a function of time from the beginning (wetting) or terminating (drying) of the irrigation in treatment 3.

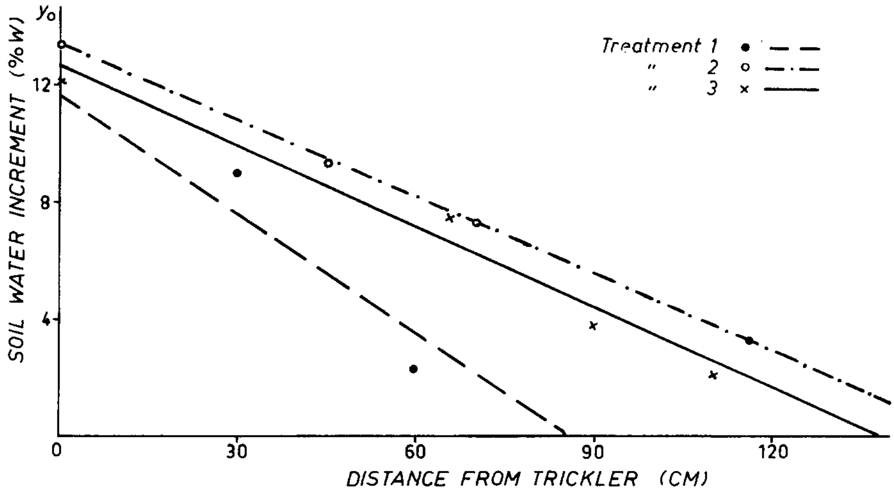

Fig. 4. Increments of soil moisture content (Pw) at the end of the irrigation at several distances from the tricklers.

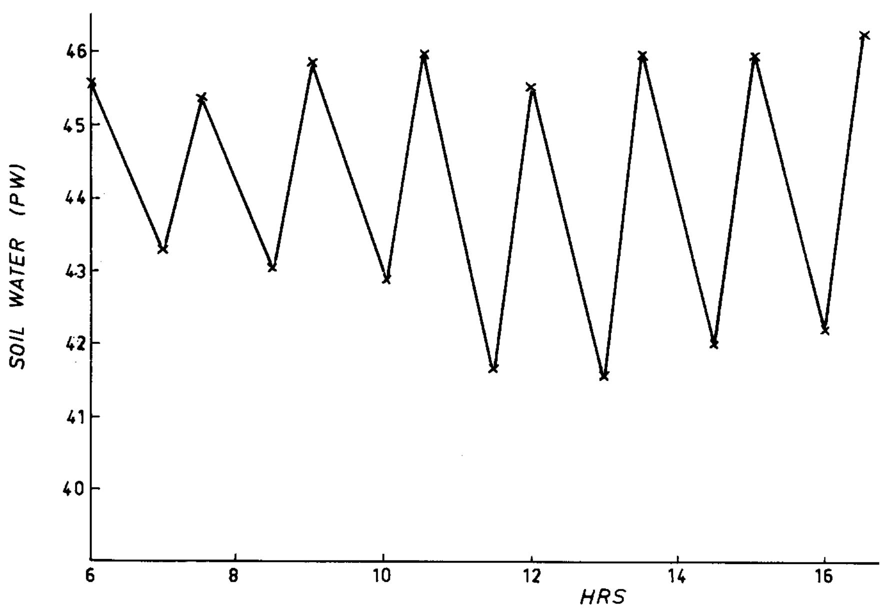

Fig. 5. Soil moisture content of the 0–60-cm profile under the trickler during half an hour on and one hour off irrigation.

The differences in soil water content between the beginning and termination of irrigation (the increments of Pw) at the different distances from the emitters in the three treatments, are presented in Fig. 4. The increments declined linearly along the distance from the water source and approached zero at the end of the wetted radius.

The fluctuation of the soil moisture content caused by the pulsed irrigation of half-an-hour-on and one-hour-off-water application presented in Fig. 5 shows higher depletion rates in the midday hours compared with the morning and afternoon hours. However, in all cases after the half-hour irrigation, the soil moisture content reached the saturation level of 45–46% Pw in the 60 cm soil profile.

The root concentrations declined steeply in the direction normal to tree row in Treatments 1 and 2, and vanished at 1.7 m distance from the tree row. In Treatment 3 a lower concentration of roots than in the rest of the treatments was found close to the tree row but the roots extended as far as the middle of tree rows – 2.25 m (Fig. 6). Along the tree row the root concentrations were quite uniform in each treatment, but differed in their concentration levels with the lowest level in Treatment 3. (Fig. 7). In Treatment 2 was the highest concentration of roots near to the trees normal to and along the row compared to the rest of the treatments (Figs. 6, 7).

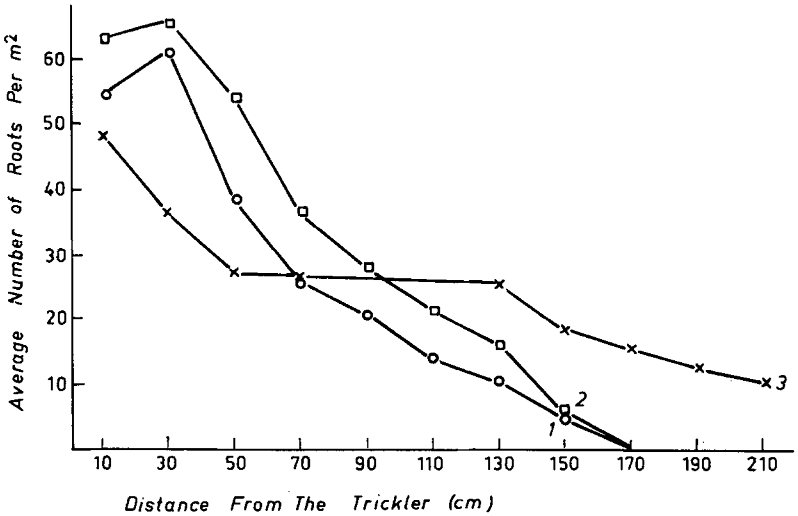

Fig. 6. Root distribution normal to the tree row in the different treatments.

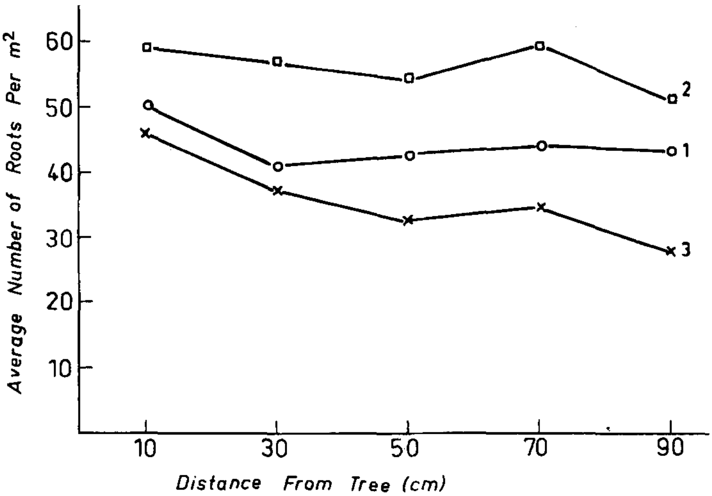

Fig. 7. Root distribution along the tree row in the different treatments.

DISCUSSION

The main feature that characterizes the trickler irrigation system is the limited horizontal distribution of water in the area between the trees. Consequently, the roots of the trees adapt themselves to the relatively small soil volume wetted by the tricklers. Beyond the wetted soil volume no water is available to the tree during the summer season. Calculations based on the areas wetted by the tricklers in the different treatments according to the length of the wetted radius (Fig. 4), showed that only 35–65% of the total area of the orchard was wetted during the summer. The soil water distribution volume was directly dependent on both the discharge rate of the tricklers and the duration of the irrigation. This is in accordance with theoretical considerations[2]. By applying the same total amount of water in T_3 as in T_2, but with a 8 l/h discharge rate, 2 m distances between tricklers and irrigating twice per week – T_3 showed a quite similar moisture distribution normal to the tree row (Fig. 4). However, an appreciable difference occurred in the distribution pattern of the roots between T_3 and T_2, *viz.* a considerably wider distribution was obtained with T_3, and the root concentration from 1 m outwards was also significantly higher. The reason for this is probably the long interval between successive irrigations (7 days) in T_2 which in turn caused soil-water stress at the greater distances from the water source for longer periods than in T_3. Because of a stronger development of roots in T_3 from 1 m distance outwards from the tree rows (and a weeker development up to 1 meter distance) compared to the other treatments, the root system of T_3 can be considered to be more evenly developed and therefore better balanced. The long periods of water-saturated conditions under the emitter in the entire shallow 60 cm profile underlined with basalt gravel cause water losses due to the drainage of water under the root zone. It is difficult to calculate the exact amount of the drainage loss. However, it is assumed that drainage under the 60 cm soil profile occurs only when all of the soil profile under the water source is fully saturated (water would not drain from the clay down to the gravel before the saturation level would be reached). In T_1 after the second hour of irrigation the soil profile was continuously saturated for 10 hours (Fig. 1). As the water content was measured by a neutron scattering device, the radius measured varied with the soil moisture content. Taking into account an average value of 15 cm distance (about 700 cm^2 area) and the K_{sat} of 1 cm/h, the calculated drainage loss is estimated as 0.7 l/h or $0.7/4.0 = 17.5\%$ of the discharge rate. In all treatments the wetting rate was much greater than the drying rate during the first two hours after the start or termination of the irrigation. This also proves that the water supply at both discharge rates is more rapid than the water depletion which occurs simultaneously during daytime, and suggests that water loss occurs after the profile under the water source reaches full saturation. By reducing the time of full saturation of the profile and using the same amount of water, one can expect that the water which in a usual system of irrigation would drain under the root zone, would move laterally due to the matrix suction force of the soil, widening the wetted area. Evidence of a similar trend was found under laboratory conditions[8].

Our results seem to indicate that on-and-off trickling pulses of about 1 or 2 hours may wet the same volume of soil, as with continuous irrigation, with perhaps less water. If such pulses were applied after an initial continuous trickling (the duration of which still has to be determined), lateral movement should continue due to the near-saturation level of soil water near the trickler, and downward drainage could be reduced – due to the 'off' periods. Water availability to the roots might even increase, since the total duration of each irrigation would be longer. The results of the observation with the pulsed irrigation show that despite the 1 hour interval after the termination of irrigation, another half an hour of water application seems to be enough to cover the trees' water consumption (Fig. 5). It is impossible to make a water balance of the amount of water applied and depleted in the soil volume and to compare these results with the results obtained in the treatments, because of the change of the wetted area under the trickler. However, the system of intermittent water application (pulses) by lengthening the duration of the irrigation time, approaches the comsumptive use (pace) rate of the trees, thus probably reducing the loss of drainage under the root zone in the area below the water source. Additional field experiments in this direction are now under investigation using specially built automatic control devices.

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