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ESTIMATING ROOT ACTIVITY OF A DRIP-IRRIGATED PEACH ORCHARD UNDER THE SOIL AND CLIMATE CONDITIONS OF A SEMI-ARID REGION

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Abstract

Irrigation is a very important link in fruit growing of semi-arid regions. Dynamics of soil water content was studied in such a region, Dobrogea, Romania, during more irrigation cycles. The biological material studied was peach, 'Cardinal' variety, grafted on franc rootstock in a 4 x 3 m layout, with a trained spindle bush canopy shape. Soil management system was represented by clean cultivation both between tree rows and in the row. It was found that the main root activity of the peach orchard occurred in the 0-80 cm soil layer, and this finding could be used for both irrigation planning and scheduling.

Key words: *soil water content, root activity, matric potential, depletion cycle, Prunus persica.*

INTRODUCTION

For the last decades, the competition for water has increased mainly due to global changes and population growth, but due to the large crop land area worldwide the pressure upon water resources has mainly occurred in agriculture. Crop transpiration and evaporation are, alongside soil internal drainage and surface runoff, the principal components of the crop water consumption in the field. All these processes consistently influence the dynamics of soil water content (SWC), either in fully irrigated orchards or in water stressed plantations.

Many soil and plant parameters, e.g. physical soil properties, SWC dynamics, plant rooting depth and density or root activity, are important to establish fruit tree plantations and irrigation methods in order to use more efficiently irrigation water in orchards.

Dynamics of SWC in orchards is caused by a complex interaction between climatic factors (reference evapotranspiration ETo and, implicitly, crop evapotranspiration ETc and precipitation), technological factors (e.g. irrigation technological parameters, soil management) and plant characteristics (root thickness, volume and density, and leaf area index), etc.

Cockroft and Wallbrink (1966) were among the first scientists reporting root distribution of peach orchard trees in the soil and said that roots growth was as close to the actual ground surface as was allowed by such factors as cultivation depth, competition, and soil temperature.

More recently, Olsson and Rose (1988) studied the patterns of water withdrawal beneath an irrigated peach orchard on a red-brown earth where the hydraulic properties varied with depth. They found that when drying, water uptake by roots was well correlated with root concentration over the profile but, over time, water uptake was redistributed over the root system.

Mata et al. (1999) studied SWC variation in daily drip irrigated peach orchard on a sandy-loam soil lysimeter in USA and reported a relatively shallow SWC change depth (76 cm). Schwankl et al. (1999) also investigated the pattern of soil wetting-drying cycle in an almond tree grafted on peach rootstock orchard irrigated as surface drip, subsurface drip and microsprinklers and found various soil wetted volumes as a function of irrigation method used.

Girona *et al.* (2002) have reported that in monitoring the available soil water content for irrigation timing in high frequency irrigation methods, more than one plant and soil property is particularly important, e.g.: variable tree responses, wetting patterns, soil depth and root exploration. In the same context, Mounzer et al. (2008) reported comparative data on the soil water content distribution in two irrigation treatments and its effect on the physiological response of young peach trees during growing season, while Abrisqueta et al. (2008) studied the Root dynamics of peach trees submitted to partial rootzone drying and continuous deficit irrigation.

Rooting depth of fruit trees were previously reported in the study region for mature peach trees grown in fertile soils by Indreias (1997), who found values of 60-80 cm, but there is no more information with regard to the root spatial distribution within the soil in the region.

Data on daily SWC dynamics during depletion cycles showing daylight versus night and morning versus afternoon in an irrigated peach orchard under various soil water regimes has been recently reported by Paltineanu et al. (2013). However, little has been done with regard to SWC dynamics over the entire soil profile in drip irrigated peach orchards under the specific soil and climate conditions of Black Sea coastal area in Romania.

The purpose of this paper is to find out the SWC pattern during water infiltration and depletion cycles within soil layers from a chernozem in a young peach orchard, when applying usual water depths by drippers under a fully irrigated regime in order to use in irrigation design and scheduling; another objective is to emphasize the depth of normal activity of the tree roots.

MATERIALS AND METHODS

The experiment was performed in the summer of 2013, at the Research Station for Fruit Growing Constanta, Agigea Farm, in the village of Agigea located on the Black Sea coastal area in the eastern part of Dobrogea region, Romania, at the latitude of 44º 05' North and longitude of 28º 37' East. The average altitude of the field is 30 m.

Climate and soil conditions

The temperate climate of the experimentation site has a continental character with mild Black Sea influence. The climate conditions are characterized by mean annual values of temperature and precipitation of 10.7 °C and 409 mm, respectively, and precipitation is not uniformly distributed across the year, with about 60% during the growing season; for the whole year the reference evapotranspiration ETo is 778 mm, with an average of 122, 133 and 118 mm $month^{-1}$ during summer months: June, July and August, respectively (Paltineanu et al., 2007).

For the site of experiment and period of study, the climatic data were recorded by an automatic weather station (Watch Dog Weather Station 2000, Spectrum Technologies, Aurora, Illinois, USA) possessing mowed sod as reference cover. The data consisted of solar radiation (Rs), air temperature (T), relative air humidity (RH), wind speed at the height of 2 m (U) and precipitation (P) were recorded by a 30-min step and averaged for 1-h intervals. These data were periodically transferred by wire to a laptop and processed as diurnal means and used in calculations. ETo was calculated using the combined equation of Penman-Monteith (Allen et al., 1998) based on daily climate data and grass reference.

For the period of study (May 10 through July 14, 2013, i.e. day of year, DoY, 130 to 195) and the whole agronomic year before these months, the climatic elements are presented in Table 1. One can note the fact that the mean temperature was positive along the winter, and total precipitation till July (303.1 mm) were much lower than total ETo (695.8 mm), resulting in a real need to irrigate. During the experiment, the rainfall recorded a total of 107 mm in more than one event, as further shown in graphs.

The soil is a Calcaro-Calcic Chernozem (Sistemul Român de Taxonomie a Solurilor, Florea and Munteanu, 2012; World Reference Base for Soil Resources, 2006) or Entic Haplustolls (Soil Survey Staff, 1999) with a loamy texture and alkaline pH in topsoil, which has a proper soil structure and fertility. Land slope is between 2.0 and 2.5%.

There is the following sequence of soil layers within the soil profile: Am, about 45 cm deep with two sub-horizons, then an A/C layer ca. 18 cm deep, after which a C/A of 23 cm, and there are more horizons (Cca symbol) deeper containing lots of calcium carbonate (more than 12%) down to 1.2 m.

Table 1. The monthly means of the climatic conditions of Agigea Farm for the 2012-2013 agronomic year (period October - July)

Monthly Values	Temperature (ºC)			RH	Solar rad.	Wind speed	Rain	ETo
	Mean	Max.	Min.	%	(W/m^2)	(km/h)	(mm)	(mm)
October	15.5	20.7	10.1	76.0	123.9	4.2	28.9	47.7
November	8.9	13.0	5.0	85.8	71.4	4.3	17.2	19.8
December	2.1	6.4	-2.2	81.3	49.5	6.2	62.1	9.3
January	1.2	4.9	-2.5	83.2	57.1	5.8	29.6	12.4
February	3.6	7.2	-0.1	84.2	62.5	5.8	12.1	16.8
March	5.4	9.4	1.3	72.4	124.7	6.5	9.5	46.5
April	11.3	16.5	6.1	72.5	265.5	6.9	11.9	102.0
May	18.3	23.7	12.8	76.4	306.8	4.2	34.9	139.5
June	20.7	27.0	14.2	70.8	316.6	3.5	66.7	153.0
July	22.1	27.6	16.5	66.9	301.5	3.1	30.2	148.8

Sum of rainfall = 303.1 mm, sum of ETo = 695.8 mm

The main SWC indexes — permanent wilting point (WP), field capacity (FC), management allowed deficit (MAD) and total soil water capacity (TC) on the soil entire profile down to 1.2 m depth — were previously determined for the studied site and shown in the following graphs, as either mean values for the entire soil profiles or for each soil layer. A specific characteristic of the soils is that there is a large range between FC and TC where water can infiltrate without waterlogging or air deficits.

Experimental design and irrigation application

One of the most representative fruit tree for the region is peach tree (*Prunus persica* (L) Batsch). The 5-year old orchard consisting of Cardinal variety grafted on generative franc rootstock was established in the autumn of 2008 in a 4 m x 3 m layout. The canopy shape was trained as a spindle bush with a height of about 2.5 m, and the soil management system was clean cultivation (bare soil) both between tree rows and in the row. The canopies were flattened in the row to enhance technological traffic, and fruit tree volumes occupied all the space in the row as a fence, with a mean canopy tree diameter of ca. 2.7 – 3.0 m. The studied field parcel comprised three adjacent fruit tree rows in a 50 m long plot, with the central row containing two trees for measurements, while the other trees were guard trees.

For this region, irrigation usually completes the lack of precipitation, and scheduling is based on both water balance method and soil water sensing devices. Five irrigation applications were carried out during the experiment in DoYs: 134, 156, 163, 177 and 187. The 200 m^3/ha water of each irrigation application was usually carried out when SWC had values around MAD (half of the available soil water holding capacity), i.e. there was a fully irrigation regime until harvest and a rain-fed regime afterwards. The time of each application was 24 h. The 2-l/h discharge drippers were located 0.6 m apart on the single lateral line along the tree rows. After irrigation application the fruit tree rows showed a wetted bulb about 1 m wide at the soil surface, and the water depth was considered to be equivalent to 800 m^3/ha for the tree rows, because only one fourth of the orchard area received irrigation water.

Soil water content measurements

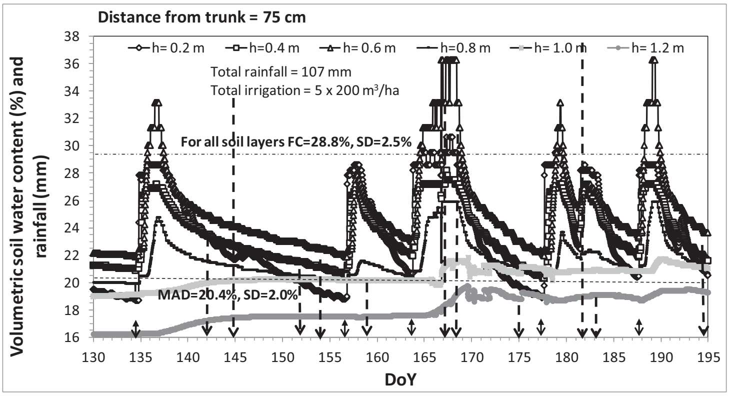
More than one infiltration and depletion cycles were investigated after irrigation application and rainfall events in the reference plots to notice the SWC variation, i.e. crop evapotranspiration, redistribution and deep percolation combined, in order to emphasize the pattern of soil wetting and drying in the orchard.

Soil water matric potential was measured continuously with Watermark resistance blocks (6450 Watermark Soil Moisture Sensor, Spectrum Technologies) installed in two replicates for each of two representative fruit trees at six depths: 20, 40, 60, 80, 100 and 120 cm, and for two distances from the tree trunk: 75 cm and 150 cm (1/4 and 1/2 of distance between fruit trees on the row), respectively. These data were recorded by WatchDog dataloggers (WatchDog Model 1650 Data Logger, Spectrum Technologies) and downloaded periodically by a laptop. The relationships between soil water matric potential measured with the Watermark sensors and SWC measured gravimetrically were previously determined from field data (Paltineanu et al., 2011); these relationships were then used to transform soil water matric potential readings into SWC values during the experiment.

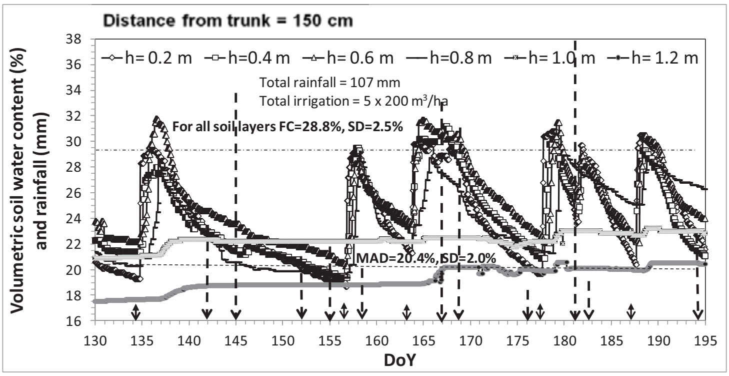
RESULTS AND DISCUSSIONS

Dynamics of soil water content

For the five irrigation / rainfall events, SWC dynamics of six soil layers: 0.2; 0.4; 0.6; 0.8; 1.0 and 1.2 m depth during the 130 – 195 days of year (DoY) is depicted in figure 1. This variation is shown for both distances from the tree trunk: 75 and 150 cm, respectively, and these places are between two consecutive drippers. In the graph, there are also shown the moments of irrigation application and rainfall amounts.



a)



b)

Figure 1. Dynamics of soil water content on six soil layers: 0.2; 0.4; 0.6; 0.8; 1.0 and 1.2 m depth during the irrigation period, days of year (DoY) 130 – 195, Agigea, for two distances from the tree trunk: a) 75 and b) 150 cm respectively; equal small-sized double arrows represent the moment of irrigation application and the other up-down arrows represent rainfall at the scale; each point in the graph is the result of two replicates.

Field capacity (FC) and MAD as average values for the soil layers over the soil profile are also shown. One can note that the first four soil layers mainly show an intense SWC dynamics by participating to wetting – drying cycles between FC and MAD. The other two soil layers, i.e. at 1.0 and 1.2 m depth, which show lower SWC values, near MAD due to a particularly droughty year, show a different shape, generally increasing with time. This is true even if the irrigation and rainfall water has reached their depths, because these layers have been slightly wetted, and SWC has not shown a real decrease afterwards. This means that SWC has been mainly up-taken by the fruit tree roots found in the first 80 cm of soil, and the possible existing roots were not active.

Mean variation of SWC

The mean variation of SWC between the moments of irrigation application and 2-3 days after internal drainage and redistribution on the six soil layers studied during the irrigation period is illustrated in figure 2 for both trunk distances studied.

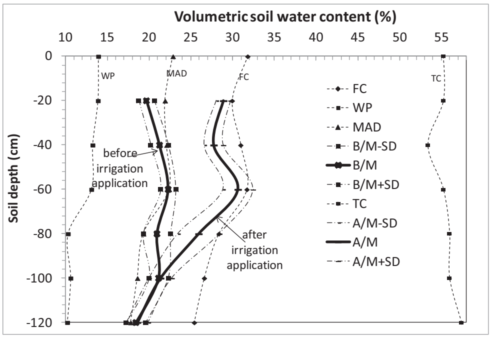


Figure 2. Mean variation of SWC between the moment of irrigation application and 2-3 days after water redistribution on the six soil layers studied during the irrigation period; symbols used: FC, MAD, WP and TC are explained in the text, M = mean, SD = standard deviation, A and B are the situations after and before irrigation application, respectively

For all irrigation – rainfall events, SWC has been averaged in time for all soil layers studied both just before (B) water application and after (A) its redistribution in order to emphasize SWC range during the most active root water uptake (RWU) period, the summer time.

As a rule, it can be noted that the highest SWC variation has occurred within the first 60 cm soil depth, and this fact can be explained by the existence of the biggest root mass and volume there, as previously reported by Indreias (1997). However, there has also been a SWC variation deeper in the soil. Thus, as this figure shows, the intersection between these two curves (and their accompanying standard deviation curves) occurs at a soil depth of 80-100 cm, showing this way the most intense root activity depth in such fertile deep soils where fruit tree roots of this kind of generative rootstock can easily penetrate.

Irrigation applications and soil water stored

Figure 3 shows the five irrigation applications and soil water stored in the first 80 cm depth for both distances analyzed here, i.e. 75 cm and 150 cm from the tree trunk, respectively, after internal drainage and redistribution; otherwise this can be seen as being actually irrigation efficiency for this depth.

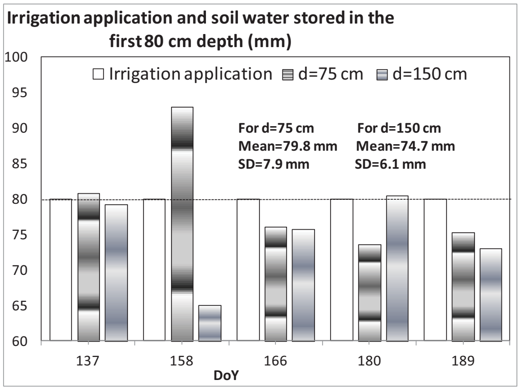


Figure 3. The five irrigation applications and soil water stored in the first 80 cm depth for both distances analyzed, 75 cm and 150 cm from the tree trunk, respectively, after 2-3 days of internal drainage and redistribution; SWC stored mean and standard deviations are specified in the figure for the five occasions (DoY 137-189)

For the soil surface layer the water stored in soil was estimated according to the 20 cm depth Watermark sensor. SWC stored and standard deviations specified in the figure for the five occasions during DoYs 137 and 189 show that most of the irrigation water, i.e. 75

– 80 mm, was retained homogeneously within the first 80 cm soil depth, with a SD of 6 – 8 mm. Even if this calculation has not the accuracy of a weighing lysimeter and has used some SWC estimated values (at 0 cm depth), the results indicate a proper way of wetting-drying cycle for drip irrigation in young peach orchards.

Discussions

The pattern of wetting-drying cycles from above took into consideration the soil layers and root system of the peach tree rows between two consecutive drippers, for two distances from the tree trunk. The distance of 75 cm characterizes the vicinity of plant, whereas the distance of 150 cm is specific for the mid-interval between two consecutive trees. Hence, the root system as well as the canopy projection over the soil surface is covered by these two-distance determinations. Consequently, it is different from the pattern of other irrigation methods ,like sprinkler or furrow irrigation, where water is spread over almost all area.

Working in a daily drip irrigated peach orchard on a sandy-loam soil lysimeter, Mata et al. (1999) found a 76-cm root activity depth shown by SWC change; they considered that shallow extraction of water as being induced mainly by the high frequency irrigation application regime. The results obtained in our experiment showed a bigger SWC change depth, about 80 to 100 cm, due to both low frequency irrigation application regime and finer soil texture. The authors also reported that, since there had been presumably denser rooting closer to the tree trunks, soil water in that area would have been extracted at a greater rate than in the vicinity of soil water monitoring instruments, which had been located some distance from the trunks. This assumption was also probably true in our case, but the results were not significantly different for the two trunk distances used.

On the other hand, experimenting on course-textured soils with low water-holding capacity Schwankl et al. (1999) studied the pattern of soil wetting-drying cycle in an almond tree grafted on peach rootstock irrigated orchard as surface drip, subsurface drip and microsprinklers, with the drip systems operated daily and the microsprinklers about once every 3 days. The climate of the region was similar concerning the precipitation amount (375 mm annually). The authors found a SWC change depth of about 90-120 cm. According to these authors, the trees initially withdrew soil water from zones close to the tree, especially at shallow depths, and as that soil moisture was depleted, the trees withdrew water from zones farther away from the tree and from deeper depths.

More recently, Mounzer et al. (2008), studied drip irrigation scheduling of peach trees by continuous measurement of soil water status on calcareous, rocky and shallow clay-loam texture and low organic matter soils with about 90 mm m^{-1} available SWC. The climate conditions were more arid there than in our experiment, with about 1100 mm of Penman-Monteith reference evapotranspiration and 440 mm of annual precipitation. However, the authors monitored soil moisture only down to 50 cm where they found SWC changes and intense root activity.

CONCLUSIONS

It has been found that the first four soil layers mainly show an intense soil water content dynamics by participating to wetting – drying cycles between field capacity and management allowed deficit, meaning that the soil water has been mainly up-taken by the fruit tree roots found in the first 80 cm of soil, and the possible existing roots were not active.

This fact can be explained by the existence of the biggest root mass and volume there, and most of the irrigation water was retained homogeneously within the first 80 cm soil depth.

More instruments should be installed at more distances from the trunk in order to find more accurate conclusions for SWC change and root activity in peach orchards. This is particularly true because the high spatial variability of the root distribution in such soil.

The results obtained in this study on fertile and medium-textured chernozems can be used by irrigation designers and planners, as well as in irrigation scheduling, to improve water management and conservation in semiarid regions with similar environmental conditions, by taking into account the architecture of root system and the intense fruit trees activity that should be considered when calculating irrigation depth and timing, as well as dripper discharge and density.

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