

Spatial Distribution of Soil Water Content, Soil Salinity and Root Length Density in a Drip Irrigated Nectarine Orchard under Plastic-Mulched and Bare Soils

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ABSTRACT

This study characterizes the spatial distribution of Gravimetric soil Water Content (GWC), soil saturation extract Electrical Conductivity (ECe) and Root Length Density (RLD) in the wetted area by the emitter in a drip irrigated nectarine orchard cultivated in bare and plastic-mulched soils. To this aim, 150 soil cores were sampled in a 0.25 m by 0.25 m grid spacing at three soil depths in one m² area with an emitter located in the center and a tree in a corner of the area in the bare and plastic-mulched soils. The 0-60 cm soil profile mean GWC was 15% higher and the mean ECe 42% lower in the mulched than in the bare soil, whereas the mean RLD was similar in both treatments. Root growth was preponderant at the 0-20 cm soil depth, where RLD accounted for 66% of the total RLD. The root weighed GWC (GWC_{r,w}) was somewhat higher and the root weighed ECe (ECe_{r,w}) somewhat lower than their arithmetic means, indicating that root growth was preponderant in regions with higher moisture and lower salinity. This conclusion was supported by the positive RLD-GWC correlation, and the RLD-ECe upper boundary line analysis showed that root growth decreased above a threshold ECe of about 4 dS m⁻¹. Overall, plastic mulching benefited water conservation and soil salinity control, but did not promote nectarine root growth.

Keywords: Contour maps, Drip irrigation, Root growth, Soil mulching.

INTRODUCTION

Soil mulching is an agronomic practice frequently used in horticultural crops because it accelerates crop development in cool climates, assists in weed control, reduces soil erosion and evaporation losses from the soil surface, and benefits the conservation of water and the control of soil salinity (Allen *et al.*, 1998; Aragües *et al.*, 2014a). In particular, plastic mulches are most effective for evaporation control and may reduce evaporation losses by 50-80% over bare soils (Allen *et al.*, 1998; Zribi *et al.*, 2015). Some of these mulching benefits would be most relevant in high-frequency drip irrigation systems where the soil surface close to the

emitter remains wetted for longer periods of time and therefore soil evaporation is exacerbated.

Soil mulching could affect the growth and distribution of plant roots depending on climate, mode of mulch application, quality and quantity of mulch material and rate of decomposition. Thus, Gale *et al.* (1993) concluded that mulching with inorganic materials such as plastic film; gravel and sand tend to increase soil moisture and soil temperature, and could promote root growth.

Characterization of the spatial distribution of the root system is essential because it largely determines the absorption of water and nutrients by plants. In fruit trees, this distribution depends on the species (cultivar

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and rootstock), age of the plant, environmental conditions, soil physical and chemical properties (Klepper, 1992), tree spacing and cultivation practices (Mitchell and Black, 1971), and type of irrigation system and its management (Clothier and Green, 1997). Thus, Neilsen *et al.* (1997) found that daily drip irrigations in five-year apple trees resulted in shallow and visibly concentrated roots near the emitters.

Long, dry and high-temperature summer seasons typical in the Mediterranean region may enhance root-zone salinity and restrain root water uptake and the performance of fast-growing fruit trees like peach (Tattini, 1990). When root zone salinity is highly heterogeneous as in drip irrigation, where it increases with the distance to emitters (Stevens and Douglas, 1994; Aragiús *et al.*, 2014a, b), plants preferentially take up the less saline soil solution as long as the zone with minimum salinity contains enough water to satisfy the evaporative demand (Shalhevet, 1994). The arithmetic mean soil salinity in these heterogeneous profiles could give a disproportionate weighing to soil salinity in regions of the soil profile where root growth is low; suggesting that the root weighed soil salinity would be a more sensible parameter for the assessment of the response of crops to soil salinity (FAO, 1985; Stevens and Douglas, 1994). This “root-weighed” approach is not documented in drip-irrigated nectarine subject to bare and plastic mulched soils.

The objectives of this work are: (1) To characterize and compare the spatial distribution of soil water content, soil salinity and root length density in the area of influence of an emitter next to a nectarine tree in bare and plastic-mulched soils, and (2) To assess potential relationships between these variables and particularly, the effects of soil water content and salinity on root length density.

MATERIALS AND METHODS

Experimental Orchard

The work was conducted in a 0.4 ha nectarine orchard located in the

AFRUCCAS experimental farm in Caspe (Zaragoza, Spain) (41° 18' 56" N, 0° 4' 56" E). Early-maturing nectarine (*Prunus persica* (L.) Batsch cv. Big Top) trees grafted on peach x almond hybrid rootstock GF677 (*P. dulcis* x *P. persica*) were trained in a Y system with trees spaced 6×2 m. The trees were planted in 2005 in a 1.1 m deep sandy-loam soil (calcic haploxerept, fine loamy, mixed, thermic). The gypsum content was relatively low in the 0-60 cm soil layer and very high in the 60-90 cm soil layer. The average gravimetric soil water contents at saturation, field capacity and permanent wilting percentage were 36, 27 and 12%, respectively.

The nectarine trees, managed according to the usual cultural practices in the farm, were daily irrigated by an automated drip system with two laterals per tree row located at 0.5m from the row with 1m spaced self compensating emitters of 4 l h⁻¹ flow rate. With this lateral disposition each tree was positioned in the center of a 1 m² area with the four emitters located in the vertices. Two trees were selected in two mulching treatments: Bare soil and plastic-mulched soil, where the 2-m wide plastic strip was installed on February 22nd 2010 above the irrigation laterals.

The orchard was irrigated at 100% of gross irrigation requirements estimated by the farmer according to the recommendations of the Irrigation Advisory System of Aragón for a peach or nectarine orchard cultivated in bare soil. The calculated annual nectarine evapotranspiration in the bare soil was 925 mm. The same seasonal irrigation depth of 645 mm was applied in the bare and plastic-mulched nectarine trees of the experimental orchard during the 2011 irrigation season. The 2011 mean EC of the irrigation water was 1.2 dS m⁻¹. Rainfall during the irrigation season of the nectarine orchard amounted to 252 mm.

The experimental plot was flat in the tree row direction (X axis direction in Figure 1) but had a 6% slope perpendicular to the tree rows (i.e., decreasing ground elevation with

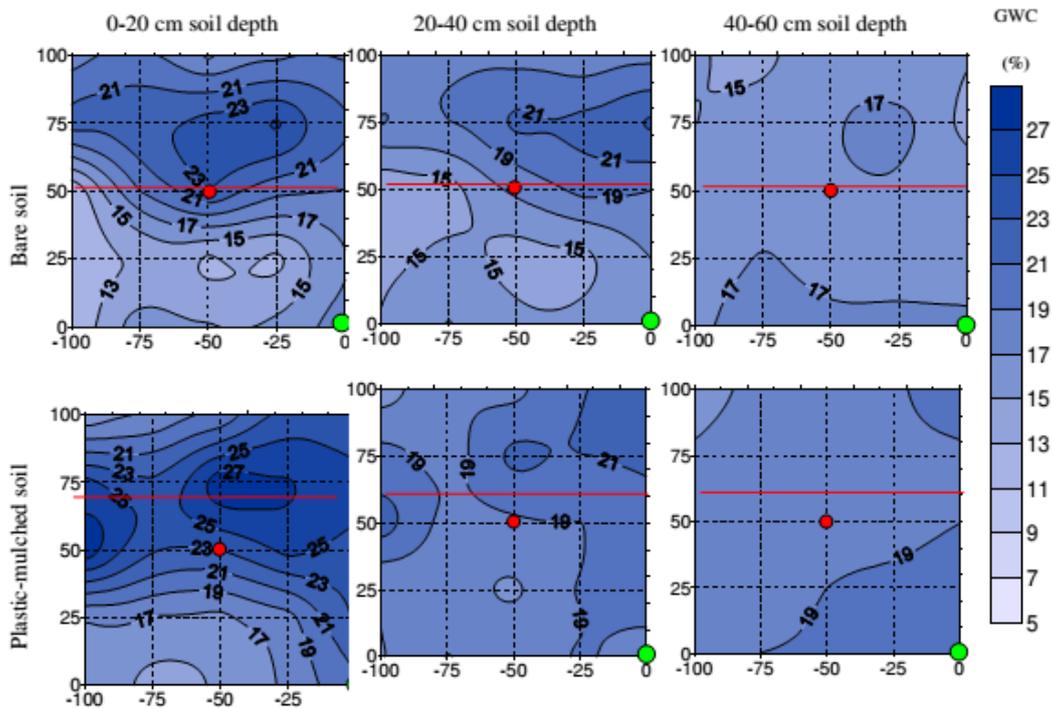


Figure 1. Gravimetric soil Water Content (GWC): Contour maps of GWC measured in the wetted area of the emitter in bare and plastic-mulched soil treatments in soil samples taken at 0-20, 20-40 and 40-60 cm soil depths on a 25×25 cm grid of a 1 m² square area with the emitter (red dot) located in the center (X= -50 cm, Y= 50 cm) and the nectarine tree trunk (green dot) located in a corner of the area (X= 0 cm, Y= 0 cm). The horizontal red line represents the irrigation lateral.

increasing Y values in Figure 1). Hence, to prevent water runoff the irrigation laterals were sited in small furrows about 6 cm deep dug in parallel at both sides of the tree row.

Soil Sampling and Analysis

Soil cores were taken on July 14th 2011 before irrigation with a 5 cm diameter soil auger at three depths (0-20, 20-40 and 40-60 cm) in a 0.25×0.25-m grid of a 1 m² area in the bare soil and the plastic-mulched soil. Thus, a total of 75 soil samples were taken in each mulching treatment. An emitter was located at the center and the tree at a corner of each sampled area (Figures 1-3). This sampling methodology is time-consuming but it is very accurate for the determination of the vertical and horizontal distribution of water, salinity and roots in the soil.

Each soil sample was homogenized and split into three subsamples. The first subsample was analyzed for its Gravimetric Water Content (GWC). The second subsample was analyzed for its saturation extract Electrical Conductivity (ECe) after being air-dried, ground and sieved (< 2 mm). Both analyses were performed according to Page *et al.* (1982). The third 150 g subsample was used to measure Root Length Density (RLD) according to Tennant (1975), a common parameter that quantifies root mass expressed by the total length of active roots in a given volume of soil (Klepper, 1992).

Based on the GWC, ECe and RLD values measured in each soil sample, the root weighed GWC (GWC_{rw}) and ECe (ECe_{rw})

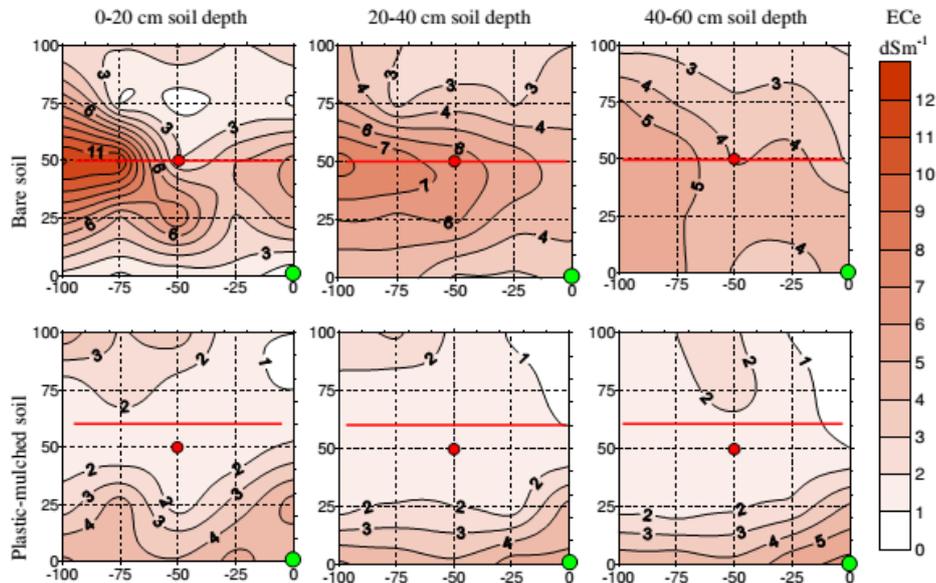


Figure 2. Soil salinity (ECe): Contour maps of ECe measured in the wetted area of the emitter in bare and plastic-mulched soil treatments in soil samples taken at 0-20, 20-40 and 40-60 cm soil depths on a 25×25 cm grid of a 1 m² square area with the emitter (red dot) located in the center (X= -50 cm, Y= 50 cm) and the nectarine tree trunk (green dot) located in a corner of the area (X= 0 cm, Y= 0 cm). The horizontal red line represents the irrigation lateral.

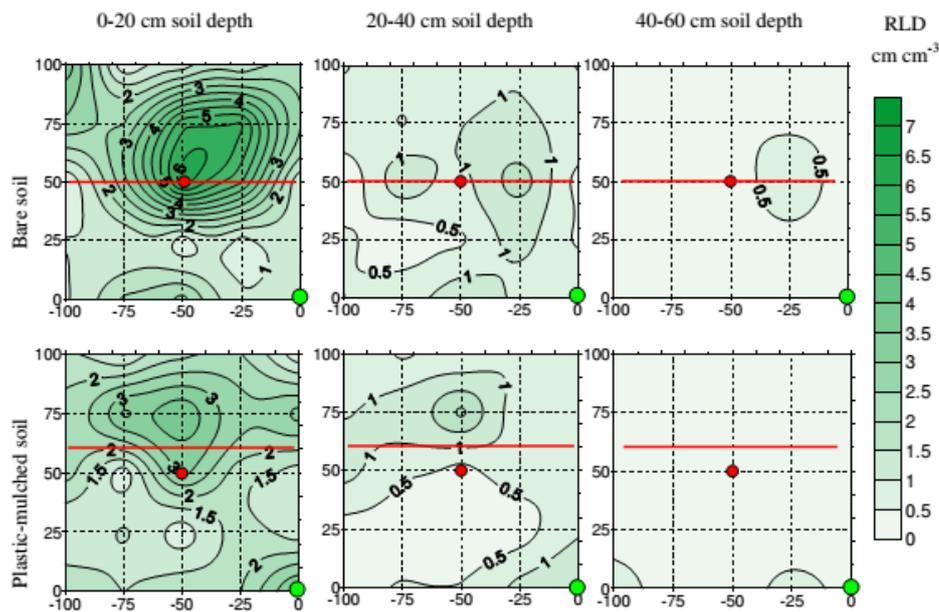


Figure 3. Root Length Density (RLD): Contour maps of RLD measured in the wetted area of the emitter in bare and plastic-mulched soil treatments in soil samples taken at 0-20, 20-40 and 40-60 cm soil depths on a 25×25 cm grid of a 1 m² square area with the emitter (red dot) located in the center (X= -50 cm, Y= 50 cm) and the nectarine tree trunk (green dot) located in a corner of the area (X= 0 cm, Y= 0 cm). The horizontal red line represents the irrigation lateral.

values for a given number of soil samples (n) were calculated as:

$$X_{rw} = \frac{\sum_{i=1}^n X_i RLD_i}{\sum_{i=1}^n RLD_i} \quad (1)$$

Where, X is GWC or ECe.

Statistical Analysis

A Student's *t*-test was performed with the data of GWC, ECe and RLD in the bare and plastic mulched soil for comparison purposes (SAS Institute, 2004). Relationships between variables were established by regression analysis with SAS 9.1 software (SAS Institute, 2004). Unless otherwise stated, the significance level was $P= 0.05$. The GWC, ECe and RLD contour maps were plotted using Surfer 8.2 (Golden Software Inc., Golden, CO, USA) and the Kriging method for spatial interpolation.

RESULTS AND DISCUSSION

Gravimetric Soil Water Content (GWC)

All the GWC values of a given soil depth were higher (with one exception) in the plastic-mulched than in the bare soil (Table 1). Thus, the mean GWC was 20% (at 0-20

cm soil depth) and 15% (for the 0-60 cm integrated soil depth) higher in the plastic-mulched soil. Since irrigation intervals and depths were the same in both treatments, the higher GWC values in the plastic-mulched soil were attributed to its lower evaporation. The mean GWC decreased slightly with soil depth (Table 1), reflecting the position of the emitter at the soil surface and the increase in the cumulative ETC with increasing soil depths. The variability of the mean GWC was relatively low and similar in both treatments, although higher for the shallower [Coefficient of Variation (CV) of about 22%] than for the deeper (CV of about 6%) soil depth.

The root weighed GWC (GWC_{rw}) at 0-20 cm soil depth was 12 (bare soil) and 4% (plastic mulched soil) higher than the arithmetic mean GWC (Table 1). At other soil depths, the GWC_{rw} values were also higher than the GWC values (with one exception), but the differences were small. These results suggest that at 0-20 cm soil depth, the roots tended to accumulate in the areas with higher GWC, particularly in the bare soil. This behavior was not apparent at deeper soil depths probably because GWC was quite uniform and the RLD values were much lower.

Figure 1 shows that the GWC contour lines did not follow the expected radial distribution centered around the emitters typical in drip irrigation systems (Hanson,

Table 1. Gravimetric soil Water Content (GWC) measured in the wetted area of the emitter in the bare and plastic-mulched soils at four soil depths (0-20, 20-40, 40-60 and 0-60 cm).^a

	Gravimetric soil Water Content (GWC, %)							
	Bare soil				Plastic-mulched soil			
	Soil depth (cm)				Soil depth (cm)			
	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
Maximum GWC	25.3	23.4	17.9	22.2	28.5	22.2	20.6	23.8
Minimum GWC	11.1	13.3	14.4	12.9	14.5	16.0	16.4	15.6
Mean GWC	17.7	17.4	16.3	17.1	21.3	19.1	18.6	19.7
CV of mean GWC (%)	23	15	6	17	21	9	5	15
Root weighted GWC (GWC_{rw})	19.8	17.5	16.3	17.9	22.2	19.6	18.8	20.2
(% Over mean GWC)	(12%)	(1%)	(0%)	(5%)	(4%)	(3%)	(1%)	(2%)

^a The number of soil samples taken at each depth was 25. CV is the Coefficient of Variation of the mean. The root-weighted GWC (GWC_{rw}) and its percent over the mean GWC are given in the last row.



2012) because the applied water flooded the already mentioned small furrows practiced to prevent water run-off, giving rise to a line-source rather than a point-source shape with the contour lines fairly parallel to the laterals. This figure also shows that the GWC values were higher at lower ground elevations (Y values between 50 and 100 cm) than at higher (Y values between 0 and 50 cm) ones in both treatments at 0-20 and 20-40 cm depths. Thus, water delivery and soil infiltration rate as well as soil topography played a major role in the GWC distribution observed at the shallower soil depth.

Soil Saturation Extract Electrical Conductivity (ECe)

The maximum, minimum and mean ECe values at each soil depth were lower in the plastic-mulched than in the bare soil (Table 2). Thus, the mean ECe for the 0-60 cm integrated soil depth was 42% lower in the mulched soil due to its lower evaporation and salt evapo-concentration rates. The mean ECe was about 10% higher at shallower than at deeper soil depths. The variability (CV) of the mean ECe was high and relatively similar in both treatments, but decreased with soil depth in the bare soil and increased with soil depth in the plastic-mulched soil. Overall, these results show the high efficiency of plastic mulching for soil salinity control.

The root weighed ECe (ECe_{rw}) was similar or lower than the mean ECe in the mulched and bare soils (Table 2). The maximum differences between ECe_{rw} and ECe were obtained in the bare soil at 0-20 cm soil depth (ECe_{rw} 14% lower than ECe) and in the plastic-mulched soil at 20-40 and 40-60 cm soil depths (ECe_{rw} 13% lower than ECe). These results indicate that the roots tended to accumulate in the areas with lower salinity values at the shallower soil depth in the bare soil and at somewhat deeper depths in the plastic-mulched soil.

Table 2. Soil saturation extract Electrical Conductivity (ECe) measured in the wetted area of the emitter in the bare and plastic-mulched soils at four soil depths (0-20, 20-40, 40-60 and 0-60 cm).^a

	Soil saturation extract Electrical Conductivity (ECe, dS m ⁻¹)											
	Bare soil						Plastic-mulched soil					
	0-20		20-40		40-60		0-20		20-40		40-60	
Maximum ECe	12.2	8.5	6.0	8.9	5.6	6.4	5.6	5.6	5.6	6.4	5.9	
Minimum ECe	1.1	1.4	1.9	1.5	1.0	0.8	0.8	0.8	0.8	0.8	0.9	
Mean ECe	4.4	4.4	4.0	4.3	2.7	2.4	2.4	2.4	2.4	2.4	2.5	
CV of mean ECe (%)	69	38	31	49	59	65	65	65	65	70	64	
Root-weighted ECe (ECe_{rw})	3.8	4.4	3.9	3.9	2.5	2.1	2.1	2.5	2.1	2.1	2.2	
(% Over mean ECe)	(-14%)	(0%)	(-1%)	(-9%)	(-7%)	(-13%)	(-13%)	(-7%)	(-13%)	(-13%)	(-12%)	

^a The number of soil samples taken at each depth was 25. CV is the coefficient of variation of the mean. The root-weighted ECe (ECe_{rw}) and its percent over the mean ECe are given in the last row.

The $EC_{e_{rw}}$ values of 3.9 (bare soil) and 2.2 $dS\ m^{-1}$ (plastic-mulched soil) for the integrated 0-60 cm soil depth will imply that nectarine yields will be slightly (bare soil) or not affected (plastic-mulched soil) by soil salinity according to the FAO threshold EC_e of 3.7 $dS\ m^{-1}$ for peach (no data for nectarine) in soils with gypsum (FAO, 1985). In contrast, the arithmetic mean EC_e values of 4.3 (bare soil) and 2.5 $dS\ m^{-1}$ (plastic mulched soil) will imply that nectarine yields will not be affected by soil salinity in the plastic-mulched soil, but will decrease by 14% in the bare soil. Since fruit yields measured in the bare and plastic mulched soils (data not given) were similar and comparable to those recorded in other peach and nectarine farms of the Caspe County without salinity problems, these results suggest that the $EC_{e_{rw}}$ i.e., the water uptake weighed mean salinity of the root zone) would be more reliable than the arithmetic mean EC_e in terms of the response of these nectarine trees to soil salinity. Similar results were obtained by Zekri and Parsons (1990) in sour orange and Stevens and Douglas (1994) in grapevine.

Figure 2 shows that, as for the GWC, the EC_e contour lines did not follow the expected radial distribution typical in drip irrigation systems. For unknown reasons, a very high EC_e region with values up to 12 $dS\ m^{-1}$ was observed in the bare soil at 0-20 cm soil depth close to the irrigation lateral and at a distance of 25 to 50 cm from the emitter ($X < -75$ cm), and this high EC_e region was also visible at 20-40 cm soil depth, although with lower EC_e values. In the plastic-mulched soil the contour lines were quite parallel to the irrigation lateral at the high elevation area ($Y = 0$ to 50 cm) and with higher EC_e values than at the low elevation area ($Y > 50$ cm). Thus, the shape of the GWC and EC_e contour lines were fairly similar, with higher water contents and corresponding lower soil salinities (i.e., higher gravity-induced salt leaching) at lower than at higher ground elevations.

Root Length Density (RLD)

The maximum, minimum and mean RLD values at each soil depth were similar in the bare and plastic-mulched soils (except the maximum RLD at 0-20 cm soil depth that was higher in the bare soil). Thus, the mean RLD values for the 0-60 cm integrated soil depth were 1.1 and 1.0 $cm\ cm^{-3}$ in the bare and plastic-mulched soils, respectively ($P > 0.05$). These RLD values are similar to those measured in four-year old peach trees by Abrisqueta *et al.* (2008). The variability of the mean RLD was very high, particularly in the bare soil at 0-20 cm soil depth ($CV = 74\%$). Overall, these results show that the nectarine RLD was not significantly affected by soil mulching, in contrast with other works given in the introduction section showing that plastic mulching increased soil temperature and enhanced root growth in other annual plant species. This apparent contradiction could be explained because the 2011 mean soil temperature was only 1°C higher in the plastic-mulched than in the bare soil, and because the roots of these six-year old nectarine trees were exposed to plastic mulching only during sixteen months.

Root growth was preponderant at the shallower 0-20 cm soil depth, with RLD values that were about 66% of the total RLD in both treatments, whereas only 10% of the total RLD was present at the deeper 40-60 cm soil depth (Table 3). These RLD profiles are typical in surface drip irrigation systems where roots accumulate in the vicinity of emitters and decrease with soil depth (Stevens and Douglas, 1994; Kang *et al.*, 2002; Abrisqueta *et al.*, 2008).

Figure 3 shows that in the bare soil the maximum RLD value at 0-20 cm soil depth was in the emitter's position, although the highest RLD contour lines were displaced towards the lower ground elevation area. In the plastic-mulched soil, the highest RLD contour lines were also preponderant at the lower elevation area, although the roots also concentrated close to the position of the

**Table 3.** Root Length Density (RLD) measured in the wetted area of the emitter in the bare and plastic-mulched soils at four soil depths (0-20, 20-40, 40-60 and 0-60 cm).^a

	Root Length Density (RLD, cm cm ⁻³)							
	Bare soil				Plastic-mulched soil			
	Soil depth (cm)				Soil depth (cm)			
	0-20	20-40	40-60	0-60	0-20	20-40	40-60	0-60
Maximum RLD	6.3	1.8	0.9	3.0	4.0	2.1	0.9	2.3
Minimum RLD	0.5	0.1	0.1	0.2	0.6	0.2	0.,1	0.3
Mean RLD	2.3	0.8	0.3	1.1	2.0	0.8	0.3	1.0
(% Of total RLD)	(68%)	(23%)	(9%)	-	(64%)	(26%)	(10%)	-
CV of mean RLD (%)	74	53	55	117	47	63	65	94

^a The number of soil samples taken at each depth was 25. CV is the Coefficient of Variation of the mean. The percent of total RLD measured at each soil depth is also given.

nectarine tree with RLD values of about 3 cm cm⁻³ at the shallower soil depth.

GWC, ECe and RLD Profiles under the Irrigation Lateral

Even though the horizontal spatial distributions of GWC, ECe and RLD did not follow in general the typical radial configuration observed in drip irrigation systems due primarily to the uneven topography of the plot, the vertical spatial distribution or contour line profiles under the irrigation lateral (Y= 50 cm, X= -100 to 0 cm in Figures 1-3) followed this radial distribution closely, particularly in the bare soil (Figure 4). Thus, the maximum GWC and RLD and the minimum ECe values were centered on the emitter's position, the GWC and RLD values decreased and the ECe values increased radially with increasing distances to emitters.

Figure 4 also shows that: (i) In the bare soil, the region of highest salinity matched the region of lowest water content (0-30 cm soil depth at a distance of -25 to -50 cm to the emitter) suggesting that soil evaporation was the driving mechanism for soil salinization, (ii) In the plastic-mulched soil, salinity under the lateral was quite uniform and similar to the irrigation water salinity

(Mean EC = 1.2 dS m⁻¹), indicating that salt leaching was very high, and (iii) The proliferation of roots close to the emitter was much higher in the bare than in the plastic mulched soil, although in both treatments it was negligible (RLD ≤ 0.5 cm cm⁻³) at soil depths greater than 40 cm.

RLD-GWC-ECe Relationships

GWC and ECe measured in all the individual soil samples taken in the bare and plastic-mulched soils were significantly (P < 0.001) and inversely correlated through a power regression equation, showing that the increases in soil salinity were due to nectarine's EvapoTranspiration (ETc) and concomitant decreases in GWC. Therefore, ETc was a significant driving mechanism for root zone soil salinization in both mulching treatments, although the low coefficient of determination (R² = 0.219) of this equation indicates that other factors such as the dissolution of gypsum present in some soil samples would also contribute to these ECe increases. Aragüés *et al.* (2014c) in drip-irrigated peach also found an inverse power regression correlation between soil salinity and soil water content, indicating that at low GWC values small changes in water content

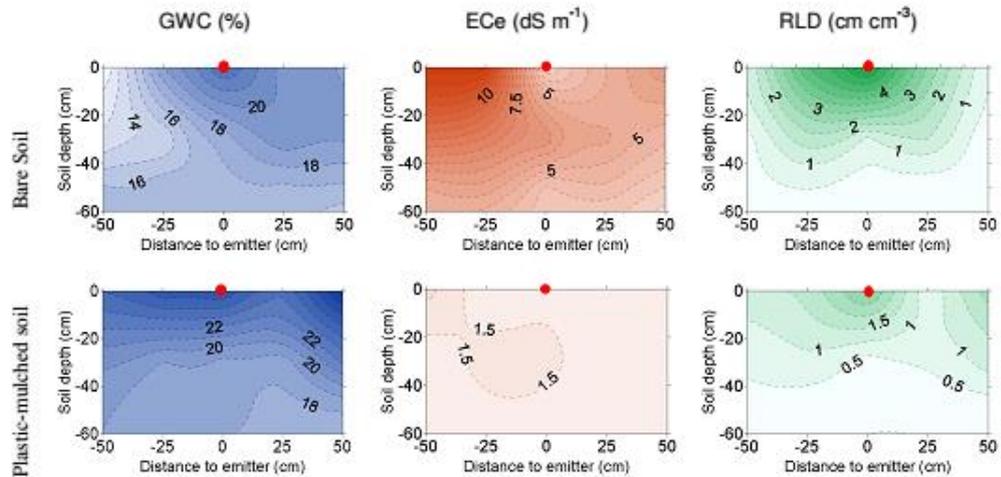


Figure 4. Gravimetric soil Water Content (GWC), soil salinity (ECe) and Root Length Density (RLD) contour lines of the bare and plastic-mulched soil treatments delineated for the 0-60 cm soil depth under the irrigation lateral. The soil samples were taken at three soil depths (0-20, 20-40 and 40-60 cm) in five points located at 25 cm increments along a 1-m segment of the lateral with the emitter (red dot) positioned in the center.

could bring about considerable changes in soil salinity.

RLD and GWC were significantly ($P < 0.001$) and positively correlated through a linear regression equation, showing that root growth was preponderant in regions with higher GWC values (i.e., hydrotropism dominated geotropism). This positive relationship between RLD and GWC has been also observed by Machado and Oliveira (2005) in tomato, and by Izzi *et al.* (2008) in wheat. However, the determination coefficient of this equation was low ($R^2 = 0.233$), indicating that other variables also affected RLD.

RLD and ECe were not linearly correlated, but the upper boundary line (Webb, 1972) fitted the observations reasonably well (Figure 5). However, the large number of observations located below the upper boundary lines represents sites where other factors besides salinity will limit root growth. According to this eye-fitting upper envelope approach, RLD will be independent of soil salinity up to a threshold ECe close to 4 dS m^{-1} , above which RLD would decrease linearly with increases in

ECe at a rate of about 25%. Although these values should be taken with caution because

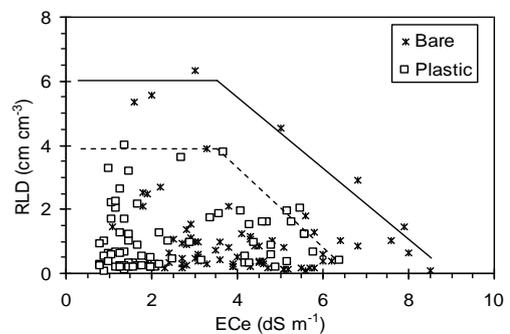


Figure 5. Relationship between Root Length Density (RLD) and soil saturation extract Electrical Conductivity (ECe) measured in the bare and plastic mulched soils in 148 samples taken at 0-20, 20-40 and 40-60 cm soil depths in a $25 \times 25 \text{ cm}$ grid of a 1 m^2 square area with the emitter in its center. Two outliers with $\text{ECe} > 12 \text{ dS m}^{-1}$ were deleted. The eye-fitted upper boundary lines for the bare and plastic-mulched soil treatments are given for comparison purposes.



of the large data scattering, they agree with the FAO (1985) threshold EC_e of 3.7 dS m^{-1} and slope of 21% for shoot growth and fruit yield of peach trees in soils with gypsum, suggesting that root and shoot growth would have similar salinity tolerances.

CONCLUSIONS

Soil mulching with plastic tended to decrease evaporation compared to the bare soil, promoted water conservation (i.e., higher GWC values) and salinity control (i.e., lower EC_e values). The inverse correlation between GWC and EC_e showed that the nectarine's EvapoTranspiration (ET_c) was a significant driving mechanism for root zone soil salinization, particularly in the bare soil where soil salinity was 72% higher than in the plastic-mulched soil.

Root growth in both bare and plastic-mulched soils was much higher at shallower than at deeper soil depths following, in terms of percent of total RLD, a 66-24-10% pattern for the three thirds of the root zone. This pattern implies that soil salinity should be preferentially controlled in the shallower soil through appropriate management strategies such as high frequency irrigation that will continuously leach the salts towards the deeper soil, and through soil mulching that will prevent soil evaporation and the accumulation of salts at the soil surface.

The root weighed GRW ($GWC_{r,w}$) was higher and the root weighed EC_e ($EC_{e,r,w}$) was lower than the corresponding arithmetic means, suggesting that root growth was preponderant in regions with higher humidity and lower salinity. This conclusion was supported by the positive RLD-GWC correlation and the RLD- EC_e upper boundary line analysis showing that root growth in nectarine tended to decrease above a threshold EC_e of about 4 dS m^{-1} , similar to the FAO (1985) threshold EC_e for shoot growth and fruit yield in soils with gypsum. This conclusion should be further supported because of the large data scattering which indicates that root growth

was also affected by other unidentified variables.

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REFERENCES

1. Abrisqueta, J. M., Mounzer, O., Alvarez, S., Conejero, W., Garcia-Orellana, Y., Tapia, L. M., Vera, J., Abrisqueta, I. and Ruiz-Sánchez, M. C. 2008. Root Dynamics of Peach Trees Submitted to Partial Rootzone Drying and Continuous Deficit Irrigation. *Agric. Water. Manage.*, **95**: 959–967.
2. Allen, R. G., Pereira, L. S., Rais, D. and Smith, M. 1998. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*. Irrig. Drain. Paper No **56**, FAO, Rome, Italy, 300 PP.
3. Aragüés, R., Medina, E. T. and Clavería, I. 2014a. Effectiveness of Inorganic and Organic Mulching for Soil Salinity and Sodicity Control in a Grapevine Orchard Drip-Irrigated with Moderately Saline Waters. *Span. J. Agric. Res.*, **12(2)**: 501-508.
4. Aragüés, R., Medina, E. T., Clavería, I., Martínez-Cob, A. and Faci, J. 2014b. Regulated Deficit Irrigation, Soil Salinization and Soil Sodification in a Table Grape Vineyard Drip-Irrigated with Moderately Saline Waters. *Agric. Water. Manage.*, **134**: 84–93.
5. Aragüés, R., Medina, E. T., Martínez-Cob, A. and Faci, J. 2014c. Deficit Irrigation Strategies, Soil Salinization and Soil Sodification in a Semiarid Drip-Irrigated Peach Orchard. *Agric. Water. Manage.*, **142**: 1-9
6. Clothier, B. E. and Green, S. R. 1997. Roots: The Big Movers of Water and Chemical in Soil. *Soil. Sci.*, **162**: 534–543.
7. FAO. 1985. *Water Quality for Agriculture*. FAO Irrig. Drain. Paper 29 (Rev. 1), (Eds.): Ayers, R. S. and Westcot, D. W. Food and

- Agriculture Organization of the United Nations, Rome, Italy, 174 PP.
8. Gale, W. J., McColl, R. W. and Frang, X., 1993. Sandy Fields Traditional Farming Water Conservation in China. *Soil. Water. Conserv.*, **48**: 474–477.
 9. Hanson, B. 2012. Drip Irrigation and Salinity. 17. Manuals and Reports on Engineering Practice No. 71. In: “*Agricultural Salinity Assessment and Management*”, (Eds.): Wallender, W. W. and Tanji, K. K. Second Edition, American Society of Civil Engineers, Reston, VI, PP. 539–560.
 10. Izzi, G., Farahani, H. J., Bruggeman, A., and Oweis, T. Y. 2008. In-Season Wheat Root Growth and Soil Water Extraction in the Mediterranean Environment of Northern Syria. *Agric. Water. Manage.*, **95**: 259–270.
 11. Kang, S., Hu, X., Li, Z., and Jerie, P. 2002. Soil Water Distribution, Water Use and Yield Response to Partial Root Zone Drying under Shallow Groundwater Conditions in a Pear Orchard. *Scientia Hort.*, **92**:277–291
 12. Klepper, B. 1992. Development and Growth of Crop Root Systems. In: “*Limitations to Plant Root Growth*”, (Eds.): Hatfield, J. L. and Stewart, B. A. Springer-Verlag, Berlin, Germany, PP. 265–286.
 13. Machado, R. M. A. and Oliveira, M. R. G. 2005. Tomato Root Distribution, Yield and Fruit Quality under Different Subsurface Drip Irrigation Regimes and Depths. *Irrig. Sci.*, **24**: 15–24.
 14. Mitchell, P. D. and Black, J. D. F. 1971. The Response of Replant Peach Trees to Weedicide, Daily irrigation, Nitrogen and Phosphorus. *Aus. J. Exp. Agric. Anim. Husb.*, **11**: 699–704.
 15. Neilsen, G. H., Parchomchuk, P., Berard, R. and Neilsen, D. 1997. Irrigation Frequency and Quantity Affect Root and Top Growth of Fertigated McIntosh Apple on M9, M26 and M7 Rootstock. *Canad. J. Plant. Sci.*, **77**: 133–139.
 16. Page, A. L., Miller, R. H., and Keeney, D. R. 1982. *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties.* 2nd Edition, *Amer. Soc. of Agron.*, **9**(Part 2) in the Agronomy Series ASA, SSSA Madison, 1159 PP.
 17. SAS Institute. 2004. *SAS/STAT User's Guide Release 9.0.* Statistical Analysis Institute, Cary, NC.
 18. Shalhevet, J. 1994. Using Water of Marginal Quality for Crop Production: Major Issues. *Agric. Water. Manage.*, **25**: 233–269.
 19. Stevens, R. M. and Douglas, T. 1994. Distribution of Grapevine Roots and Soil Salt under Drip and Full-Cover Microjet Irrigation System. *Irrig. Sci.*, **15**: 147–152.
 20. Tattini, M. 1990. Effect of Increasing Nutrient Concentration on Growth and Nitrogen Uptake of Container-Grown Peach and Olive. In: “*Plant Nutrition: Physiology and Applications*” (Ed.): van Beusichem, M. L., Kluwer, Dordrecht, pp. 515–518.
 21. Tennant, D. 1975. A Test of a Modified Line Integral Method of Estimating Root Length. *J. Appl. Ecol.*, **63**: 995-1001.
 22. Webb, R. A. 1972. Use of the Boundary Line in the Analysis of Biological Data. *J. Hort. Sci.*, **47**: 309– 319.
 23. Zekri, M. and Parsons, L. R. 1990. Response of Split-Root Sour Orange Seedlings to NaCl and Polyethylene-Glycol Stresses. *J. Exp. Bot.*, **41**: 35–40.
 24. Zribi, W., Aragüés, R., Medina, E. and Faci, J.M. 2015. Efficiency of Inorganic and Organic Mulching Materials for Soil Evaporation Control. *Soil Till. Res.*, **148**: 40-45.



توزیع فضایی محتوای آب خاک، شوری خاک و تراکم طول ریشه در باغ هلو آبیاری شده با سیستم قطره ای در زیرمالچ پلاستیکی و خاک های برهنه

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چکیده

این مطالعه توزیع فضایی محتوای رطوبت خاک (gravimetric) (GWC)، هدایت الکتریکی عصاره اشباع خاک (ECE) و تراکم طول ریشه (RLD) در منطقه مرطوب توسط emitter در باغ هلو آبیاری شده با سیستم قطره ای کشت شده خاک لخت و خاک پلاستیک-مالچ را مشخص نمود. برای این هدف، ۱۵۰ هسته خاک در شبکه ۰.۲۵ متر در ۰.۲۵ متر، در سه عمق خاک یک متر مربعی با یک emitter واقع در مرکز و درخت در یک گوشه ای از این منطقه و در شرایط خاک لخت و خاک پلاستیک-مالچ، نمونه برداری شدند. میانگین GWC در پروفیل ۰-۶۰ سانتی متری خاک، ۱۵ درصد بالاتر بود و میانگین ECE ۴۲ درصد در خاک پلاستیک-مالچ کمتر از خاک لخت بود، در صورتیکه میانگین RLD در هر دو تیمار یکسان بود. جایی که RLD برای ۶۶ درصد RLD کل محاسبه شد، رشد ریشه در عمق ۰-۲۰ سانتی متر خاک غالب بود. GWC وزن ریشه (GWC_{rw}) در بعضی مناطق بالاتر بود و ECE وزن ریشه در بعضی مناطق کمتر از میانگین های محاسباتی آن بود که نشان می دهد که رشد ریشه در مناطق با رطوبت بالاتر و شوری کمتر غالب است. این نتیجه گیری از طریق همبستگی مثبت RLD-GWC و تجزیه و تحلیل خط مرزی بالایی RLD-ECE نشان داد که رشد ریشه در بالاتر از آستانه ECE حدود ۴ ds m⁻¹ کاهش می یابد. به طور کلی، مالچ پلاستیک نقش محافظت از هدر رفت آب و کنترل شوری خاک دارد اما منجر به بهبود رشد ریشه نمی شود.