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RESEARCH ARTICLE

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Use of organic mulch to enhance water-use efficiency and peach production under limiting soil conditions in a three-year-old orchard

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Abstract

Mulching techniques have emerged in recent years to overcome soil constraints and improve fruit tree productivity. The object of this study was to evaluate the effects of a low-cost organic mulch application in a newly planted peach orchard under a ridge planting system. Three treatments were performed in 12 elementary plots using a randomized complete block design. The orchard was drip-irrigated. Mulch was applied in two treatments, which differed in fertigation (none *vs*. multi-nutrient fertigation), while the third treatment did not include either mulch or fertigation and served as the control. Treatments were compared in terms of their effects on the physical properties of the soil, crop response, and water-use efficiency. Mulch treatments did not alter the soil bulk density. However, the mulch significantly (p=0.0004) increased the water infiltration rate (2.21 mm/h *vs*. 121 mm/h), which is a key issue when working in high frequency irrigation systems under soil limiting conditions. Similarly, mulched treatments showed a more favorable water status both in the second and the third year, which was translated in a better crop response. Thus, mulched treatments recorded higher yields both in the second (+155%, p=0.0005) and the third year (+53%, p=0.0007) of the experiment. Water use efficiency (WUE_{agr}) was higher in the mulch treatments (+50% in average, p=0.0007) than in the control in the third year of the study. On the basis of our results, we propose that organic-mulching techniques should be considered as a beneficial practice to apply in fruit-trees production under limiting soil conditions.

Additional key words: *Prunus persica*; compost; irrigation water use efficiency; limiting soil, salinity.

Abbreviations used: C (control treatment); CL (crop load); DI (drip irrigation); DMC (fruit dry matter concentration); EC_{e} (electrical conductivity); EMM (estimated marginal means); ETc (crop evapotranspiration); ETo (reference evapotranspiration); FF (fruit flesh firmness); FW (average fruit weight); Kc (crop coefficient); M (mulch treatment); MF (mulch plus fertigation treatment); SWP (stem water potential); THSD (Tukey honestly significant difference test); TSS (total soluble solids concentration); WUE (water-use efficiency); WUE_{agr} (agronomical water-use efficiency).

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Introduction

There is a global need to increase food production while minimizing the amount of irrigation needed. In this regard, the improvement of water-use efficiency (WUE) in arid and semi-arid agricultural regions of the world is of particular importance. In recent decades, drip irrigation (DI) systems have allowed a considerable increase in irrigation efficiency. Irrigation uniformity is one of the major indicators for the evaluation of DI systems, and soil water distribution homogeneity is the ultimate expression of irrigation uniformity (Burt *et al*., 1997). Thus, guaranteeing the correct infiltration of irrigation water and its distribution within the soil is crucial to increase DI efficiency.

Fruit tree plantations are increasing in the Mediterranean Basin, sometimes at the expense of marginal lands. Consequently, limiting soils are now being used for crop production. Such soils are considerably constrained in terms of infiltration, retention, and transmission of water, and also regarding the salinity and/or nutrient content. A number of agronomical techniques can be used to improve soil productivity for agricultural purposes; however, many of them are ineffective or unsustainable. Mulching techniques have emerged in recent years to address these soil constraints yielding positive results in a variety of scenarios. An early study by Kumar *et al*. (1985) and other more recent studies (Kar & Kumar, 2007; Mubarak *et al*., 2009; Okonkwo *et al*., 2011; García-Moreno, 2013; López *et al*., 2014; Zribi *et al*., 2015) reported the positive effects of mulches and organic amendments on soil physical properties, such as increased water retention and decreased soil evaporation.

Organic mulches are of particular interest for the purposes of organic crop production since they offer a means not only to improve physical properties of soil but also its nutrient content. Thus, mulch may serve to ameliorate soils with limiting conditions, thus allowing crop production. The object of this study was to assess the effects of organic mulch and fertigation in a commercial peach orchard on soil physical properties and crop response. The hypothesis was that using compost as mulch may improve water use efficiency in peach trees cultivated on limiting soils.

Material and methods

Experimental site

The trial was conducted in a commercial orchard of peach (*Prunus persica* (L.) Batsch. cv. Ryan Sun) grafted onto GF-677 and planted in 2010 in a ridge planting system, spaced 5 m × 2.5 m, in the region of Los Monegros (Huesca, Spain; 41º42’58’’ N, 0º0’53’’ E). Ridges were molded using soil already present in the orchard by means of a rear v-blade attached to a tractor. Ridges were 1.5 m (bottom) and 1 m (top) wide and 0.8 m high. The climate is semi-arid Mediterranean, with an average annual rainfall of 350 mm. Irrigation water, characterized by a low salt, sodium, and nitrate content, is taken from the Cinca irrigation canal. The soil is a Xeric Torriorthent (Soil Survey Staff, 1999) developed from calcareous siltstones with a silt loam texture (USDA; 23.1% sand, 50.7% silt and 26.2% clay). The soil is slightly saline (saturated soil-paste extract, EC_e=2.46 dS/m at 25ºC), with a pH of 8.9 and an organic matter content of 7.7 g/kg (0-0.3 m soil depth).

Experimental design and treatments applied

We evaluated the following three treatments: no mulch and no fertigation (C); with mulch and no fertigation (M); and with mulch and fertigation (MF). The treatments were applied during 2010 and 2011. In order to study crop recovery, in 2012 (the third and final year of the trial) all the treatments received the same amount of mulch and fertigation. The experiment was organized in a randomized complete block design with four replications and 12 elementary plots. Each elementary plot had six trees, from which the two central ones were monitored in order to avoid edge effects. An automated drip fertigation system with auto-compensated emitters was implemented to supply the water requirements of the trees. Drip emitters supplying 0.97 mm/h were spaced 0.33 m apart (7.6 emitters/tree). Irrigation scheduling was based on a simple water budget that was calculated from readings taken from Alcolea de Cinca meteorological station located in Huesca (Spain; 41º43’25’’ N, 0º06’45’’ E), on a weekly basis, using FAO methodology (Allen *et al*., 1998) and by using the crop coefficient values (K_c) proposed Doorenbos & Pruitt (1977) for peach crop. Final applied water resulted from ET_c calculations (ET_o*K_c), subtracting the weekly rainfall and divided by the irrigation system efficiency (0.95 for drip irrigation). Meteorological data were acquired using an automatic weather station – property of the regional meteorological service– located 7.5 km from the experimental orchard. Fertigation was supplied during the whole crop cycle by applying a multi-nutrient solution, achieving a dose of 106 kg N/ha/year, 68 kg P_2O_5/ha/year and 170 kg K_2O/ha/year at the end of the crop season.

For the mulch treatments (M and MF) organic compost (Table 1) was applied on the ridge surface at an application dose of 10 Mg/ha/year on mid-January in 2010, 2011 and 2012. The organic compost application supposed an additional water supply of approximately 0.4 mm/year (as estimated from application dose and compost properties from Table 1), which was considered as negligible since the compost was provided on mid-January.

Measurements

Soil bulk density was determined by the excavation method (Blake & Hartge, 1986), performing one measurement per plot for the C and M treatments, from the surface to a depth of 0.2 m. The mulch layer was removed in order to measure the soil bulk density. Water infiltration rate was measured at the ridge surface (0.2 m from drip emitter) using the single ring infiltrometer

Table 1. Main physical and chemical characteristics of the compost used in the experiment.

Variable	Unit	Value	Method
Humidity	%	41.0	
Dry weight (d.w.)	%	59.0	
pH		7.8	
Electrical conductivity	dS/m	6.4	
Organic matter	g/kg dw	433	Muffle furnace (450°C)
Organic carbon	g/kg dw	217	–
Total organic nitrogen	g/kg dw	16.7	Kjeldahl
C/N ratio		13.0	
Ammoniacal nitrogen (NH_4)	g/kg dw	3.3	
Phosphorus (P_2O_5)	g/kg dw	71.5	
Potassium (K_2O)	g/kg dw	10.4	
Chrome (Cr)	mg/kg	45.1	ICP-Plasma
Cadmium (Cd)	mg/kg	0.71	ICP-Plasma
Lead (Pb)	mg/kg	20.4	ICP-Plasma
Copper (Cu)	mg/kg	119	ICP-Plasma
Zinc (Zn)	mg/kg	316	ICP-Plasma
Mercury (Hg)	mg/kg	0.66	ICP-Plasma
Nickel (Ni)	mg/kg	36.5	ICP-Plasma
Plastic materials	% dw	0.33	
Salmonella sp.	UFC/g	none	ISO 16140
Escherichia coli	UFC/g	none	UNE-EN ISO 9308-1:2001

method (Pla, 1983). Rings 0.25 m in diameter and 0.4 high were inserted into the soil at a depth of 0.15 m in order to prevent lateral seepage loss. Furthermore, a small soil dam was built around the cylinder. Water infiltration rate was measured in winter time once per plot during 2 hours-test (first hour for stabilization, the second hour for measuring). Soil electrical conductivity (EC_e) was measured in a sample taken at a depth of 0.2 m at a range of emitter distances (0, 0.8 and 1 m radius) at the beginning of the irrigation period (mid-May), performing one measurement per plot. Soil physical measurements were performed once at the end of the second year (Winter 2011/12).

Tree growth was assessed by measuring the trunk diameter of two controlled trees per plot at the end of the season (at 2011 and 2012). To evaluate tree water status, midday stem water potential (SWP) was determined at midday at the end of development stage III (end of July at 2011 and 2012). For this purpose, we used a pressure chamber (model 3005; Soil Moisture Equipment Corp., Santa Barbara, CA, USA) and followed the methods described by Shackel *et al*. (1997). The measurements were performed by taking one leaf per tree in two controlled trees per plot.

A composite leaf sample was taken randomly from each plot on 19th July. Each sample contained 50 newly but fully developed mid-terminal leaves from current year shoots at a height of 1.5 m in the tree canopy. All samples were cleaned, oven-dried at 65 ºC, and ground. Nitrogen (N) concentration was analyzed using the Kjeldahl procedure. Phosphorous (P) and potassium (K) concentrations were determined using an inductively coupled plasma mass spectrograph (IPC-MS; Agilent 7700X, Agilent Technologies, Santa Clara, CA, USA).

To determine yield and fruit quality variables, two trees per plot were manually harvested on July 19th (2011) and August 21st (2012). Fruit yield (kg/tree), crop load (CL; number of fruits per tree) and average fruit weight (FW; g/fruit) were determined. Quality variables such as fruit flesh firmness (FF, in N) and total soluble solids concentration (TSS, in ºBrix) were determined in a sample of four fruits per tree using a manual penetrometer (Penefel, Agro Technologie, France) and a thermo-compensated refractometer (Atago Bussan Co., Tokyo, Japan), respectively. The fruit dry matter concentration (DMC, in %) was measured in a sample of two fruits per tree using a forced-draft oven at 68ºC.

Agricultural WUE index (WUE_{agr}; kg/m^3) as defined by García Tejero *et al.* (2011) was determined as the ratio between economic yield (kg/ha) and total water (irrigation+rainfall) applied (m^3/ha):

$$WUE_{agr}\ (kg/m^3) = Yield\ (economic) / (Irrigation + Rainfall)$$

A linear mixed model for analysis of estimated marginal means (EMM) was built to separate treatment effects. The Tukey Honestly Significant Difference (THSD) post hoc test was used to compare soil physical properties and crop response data across treatments. The treatment effects on the average fruit weight were evaluated by means of analysis of covariance (ANCOVA) using number of fruits per tree as a covariate. Statistical significance was set at p=0.05.

Results

Soil properties

Differences in soil physical properties between M and C treatments were observed (Table 2). The infiltration rate (mm/h) was 50 times higher in the mulch treatment than it was in the control treatment (2.21 *vs.* 121 mm/h; p=0.0004). As for the soil bulk density (0-0.2 m depth) no significant differences (p>0.05) between treatments were found, suggesting that the mulch did not alter the soil bulk density. The average soil bulk density varied between 1.79 Mg/m^3 for the control treatment and 1.66 Mg/m^3 for the mulch treatment.

No significant differences (p>0.05) between the M and C treatments regarding the EC_e at any distance to the emitter (0, 0.8 and 1 m) were observed. However, there were significant differences between emitter distances regardless of the applied treatment. Soil EC ranged from 0.74 to 25.2 dS/m in C treatment and from 0.80 to 30.8 dS/m in the M treatment (0 and 1 m emitter distance). Soil salinity increased by more than 30 times within one-meter emitter distance.

Tree growth and yield response affected by soil and nutrient treatments

The total amount of water supplied in 2012 was 817 mm; 560 mm were supplied through irrigation, 257 mm were provided by rainfall events. Irrigation season in 2012 started on March 6th and finished on October 20th. These data was used to calculate the WUE_{agr} for 2012 season (Table 3).

The analysis of variance revealed differences among treatments with respect to vegetative growth, plant water status, and yield response (Table 3). Differences in trunk diameter growth were observed in all the treatments in 2011 (p<0.0001) and 2012 (p=0.0016) seasons. The control treatment recorded the lowest values of trunk diameter in 2011 (40.5 mm) and 2012 (65.6 mm) seasons while the greatest values were observed in the MF treatment (mulch plus fertigation) for both seasons (57.6 and 81.8 mm in 2011 and 2012 seasons, respectively). Significant differences of trunk diameter growth were observed between M and MF treatments for both seasons. Figure S1 (online supplement), shows the growth difference between control and mulched trees on 16th April 2010, during the first development stages.

There were significant differences between treatments regarding SWP before harvest in 2011 (p<0.0001) and 2012 (p<0.0001). The lowest values of midday SWP were observed in the control treatment for both seasons (-1.21 and -0.63 MPa). Regarding yield, significant differences were observed between treatments in 2011 (p=0.0005) and 2012 (p=0.0007) seasons. While the MF treatment recorded the highest yield in 2011 (2.9 kg/tree) we did not observe significant differences between the control and the M treatment. However, it is important to mention that overall, the yield values can be considered to be commercially low for all the treatments in 2011 (less than 2,500 kg/ha). In 2012, significant yield differences were observed between the control and the mulched treatments (p=0.0007, Tukey HSD test). The mulched treatments (M and MF) recorded the highest yield values with no

Table 2. Mean values of soil bulk density (ρb), soil infiltration rate (vi), and saturated soil paste-extract electrical conductivity (EC_e) at a depth of 0.2 m at various emitter distances (0, 0.8 and 1 m).

Treatment	ρ_b 0-0.2 m (Mg/m^3)	v_i at surface (mm/h)	EC_e0 m (dS/m)	EC_e 0.8 m (dS/m)	EC_e 1 m (dS/m)
C	1.79	2.21 b	0.74	1.6	25.2
M	1.66	121 a	0.80	1.6	30.8
Prob>F	ns	0.0004	ns	ns	ns

Values followed by different letters indicate significant differences according to the Tukey HSD test (p-value 0.05).

Table 3. Mean values of trunk diameter (TD), midday stem water potential (SWP) before harvest and yield in 2011 and 2012, and water-use efficiency (WUE) in 2012.

Treatment	TD (mm)		SWP (MPa)		Yield (kg/tree)		WUE$_{agr}$ (kg/m^3) 2012
	2011	2012	2011	2012	2011	2012	
C	40.5 c	65.6 c	-1.21 c	-0.63 c	0.9 b	18.7 b	1.91 b
M	53.1 b	73.9 b	-0.86 a	-0.59 b	1.7 b	26.6 a	2.72 a
MF	57.6 a	81.8 a	-1.05 b	-0.54 a	2.9 a	30.8 a	3.14 a
Prob>F	<0.0001	0.0016	<0.0001	<0.0001	0.0005	0.0007	0.0007

Values followed by different letters indicate significant differences according to the Tukey HSD test (*p*-value 0.05).

Table 4. Mean values of nutrient content in peach leaves in the second experimental year (July 2011).

Nutrient	Treatment			
	C	M	MF	Prob > F
N (%)	1.79 b	2.17 b	3.03 a	0.001
P (%)	0.11 b	0.17 a	0.19 a	0.0006
K (%)	1.41 b	1.96 a	2.12 a	0.0095

Values followed by different letters indicate significant differences according to the Tukey HSD test (*p*-value 0.05).

significant differences between them regardless the fertigation. In 2012, the mulched treatments increased the yield by 55% in average as compared to the control treatment (from 18.7 to 28.2 kg/tree). There were significant differences between treatments regarding the agricultural water use efficiency (*p*=0.0007). The WUE$_{agr}$ in the MF treatment was 64% higher than in the control treatment.

Significant differences between treatments were observed regarding leaf nutrient content (Table 4). While the MF treatment recorded the highest leaf nutrient (N, P and K) content, the lowest values were observed in the control treatment. Significant differences were observed for N concentration between M and MF treatments (*p*=0.001, THSD test). There were significant differences for P and K content between the control and both the mulched treatments.

We observed significant differences between treatments for many quality variables measured both in 2011 and 2012 seasons (Table 5). While dry matter concentration was found to be the highest in the control treatment (*p*=0.0042, Tukey HSD test) we did not observe significant differences between treatments regarding this variable in 2012. The MF treatment recorded the lowest values of TSS among all the treatments both in 2011 and 2012 seasons (*p*<0.0001 and *p*=0.0002, respectively). In 2011, the control treatment recorded 16 ºBrix, 2.5 ºBrix more in average than the MF treatment. In 2012 such difference was reduced by 1.2 ºBrix. We observed significant differences between the control and the mulched treatments regarding the fruit firmness both in 2011 and 2012. While we observed that the lowest values of FF in 2011 were found in the control treatment, the next season the same treatment recorded the highest FF values (*p*=0.0003).

The mean values for the average fruit weight (in g/fruit) and the average number of fruits per tree (crop load) for the different treatments can be observed in Table 6 (seasons 2011 and 2012). We observed significant differences between treatments regarding the crop load for both seasons (2011 and 2012). While the MF treatment recorded the greatest values of CL,

Table 5. Mean values of dry matter concentration of the fruit (DMC), total soluble solids content (TSS) and fruit flesh firmness (FF) values for the 2011 and 2012 crop production.

Treatment	2011			2012		
	DMC (%)	TSS (ºBrix)	FF (N)	DMC (%)	TSS (ºBrix)	FF (N)
C	20.4 a	16 a	48.7 b	13.6	13.1 a	58.7 a
M	17.5 b	14.1 b	72.0 a	13.8	12.6 a	54.7 b
MF	16.9 b	13.5 b	71.5 a	13.1	11.9 b	54.6 b
Prob>F	0.0042	<0.0001	<0.0001	ns	0.0002	0.0003

Values followed by different letters indicate significant differences according to the Tukey HSD test (*p*-value 0.05).

Table 6. Mean values of crop load and average fruit weight for 2011 and 2012 crop production.

Treatment	Crop load		Average fruit weight (g/fruit)	
	2011	2012	2011	2012
C	6 b	111 b	162	169 b
M	10 b	155 a	179	172 ab
MF	15 a	177 a	189	175 a
Prob>F	0.0018	0.0035	ns	0.0283

Values followed by different letters indicate significant differences according to the Tukey HSD test (*p*-value 0.05). Average fruit weight (FW) data was evaluated by means of analysis of covariance (ANCOVA) using number of fruits per tree as a covariate. Note: Covariate for average fruit weight in 2011 was found non-significant; covariate for average fruit weight in 2012 was found significant (Prob>F=0.0106).

the control treatment had the lowest values, both in 2011 (*p*=0.0018, THSD test) and 2012 season (*p*=0.0283, THSD test). There were no significant differences between treatments regarding the average fruit weight in 2011. However, fruit weight differences were significant in 2012 (*p*=0.0283). Regarding the CL variable in 2012, we observed an increase of 60% of fruits per tree in average when both mulch and chemical fertigation was applied (C *vs*. MF treatment).

Discussion

Physical properties of the soil

While topsoil bulk density (0–0.2 m) was similar among treatments, the water infiltration rate differed. Although the mulch covered the whole ridge surface, it affected only the first millimeters of the soil, preventing soil crust formation and deterioration of topsoil structure. These results indicate that mulch did not affect the soil bulk density, although the water infiltration rate improved considerably (2.21 *vs*. 121.04 mm/h), thereby pointing to a better water distribution. Similarly, Merwin *et al*. (1994) reported significant differences in the hydraulic properties of soil in various groundcover management systems. After a 6-year trial, those authors found that both the cumulative infiltration of soil water and water sorptivity were enhanced after organic mulch treatment, while the soil bulk density remained unaltered. It therefore appears that the hydraulic properties of soil could be modified, depending on factors such as soil type, mulching material, or mulch application rate.

Recent decades have witnessed the conversion of marginal areas into agricultural land in the Mediterranean Basin. This change has brought about drastic changes in crop management and soil tillage techniques, as well as mechanical land conditioning. Soil adequacy techniques lead to a considerable deterioration of the physical properties of soil, which in turn triggers soil degradation and erosion (Nacci, 2001). Here we show that the application of organic mulch impeded both soil crusting and soil sealing, which in turn enhanced the water infiltration rate and consequently reduced surface runoff and ridge soil degradation.

Many studies performed with ridge planting systems have reported enhanced soil physical properties, resulting in improved performance in many crops (Roth *et al*., 2005; Lordan *et al*., 2013). We found that soil salinity around the drip-wetted area was considerably lower than that at the outer area of the ridge (in M treatment, EC_e at 0 m=0.8 dS/m *vs*. EC_e at 0.8 m=30.8 dS/m) (Table 2). However, no differences were found between treatments, with a suitable non-saline environment being available in the root zone of all the treatments. Ridge systems provide a better root environment, reduce water logging, and increase irrigation efficiency (Khan *et al*., 2010). However, they clearly reduce the drip infiltration surface. We observed that this variable was reduced by 80% compared with a non-ridge system ($0.33\ m^2$/dripper *vs*. $1.65\ m^2$/dripper). This reduction may pose an irrigation management issue when working with drip irrigation systems in which water is applied at high frequency. As Currie (2007) reported, these phenomena may lead to high soil degradation and ultimately to low irrigation efficiency, especially in limiting soil conditions. Ridge planting systems may facilitate crop production under such conditions, although the system itself may reduce the drip infiltration surface, leading to soil degradation problems and low irrigation efficiencies. Under these conditions, mulch techniques may provide an effective remedy since its application causes a decrease in soil crusting and sealing and a notably improvement in the hydraulic properties of soil.

Crop response

Trees under the M treatment showed greater growth compared to the C treatment, with an increase of 37% and 13% in 2011 and 2012, respectively. Trees under the MF treatment achieved the greatest growth among all the treatments, with an increase of 9% and 11% compared to the M treatment in 2011 and 2012, respectively. As shown in the 2011 results, mulch was responsible for the greater part of increase in tree growth, although chemical fertigation contributed, as reflected by a growth difference between the M and MF treatments. According to the leaf nutrient analysis (Table 4), fertigation led to an increase in N uptake since leaf N content in the MF treatment (3.3%) was greater than that of the M and C treatments (2.2 and 1.8%, respectively). N content values below 2.4% in a peach crop may be indicative of N deficiency (Johnson, 2008), while values around 2.5 and above are found to be normal in late peach cultivars under temperate conditions (Rufat & DeJong, 2001). Leaf P and K content were greater in the M and MF treatments than in C. In the latter treatment, these concentrations (0.11 and 1.41% for P and K, respectively) were in a deficiency range for a peach crop (Johnson, 2008). In 2012 all the treatments received the same amount of mulch and fertigation. We observed a partial tree growth recovery for the C treatment. However, after two years of differential treatment (2010 and 2011), differences were still apparent.

SWP before harvest is a good indicator of crop water status (Shackel *et al*., 1997). Both in 2011 and 2012, trees in the M and MF treatments showed a more favorable water status (Table 3) since they had higher water potential values than those not receiving mulch (C treatment). Furthermore, the SWP values in 2011 were slightly lower than those in 2012, suggesting that the crop was under a more favorable water status in the last year. In 2012 mulch and fertigation were applied on all treatments, nevertheless the differences between them although were minimal (if compared to 2011 season) could be explained by carry over effects on tree growth. In addition the SWP values in all treatments were in a non-stress range according to Girona & Fereres (2012).

The physical properties of ridges may improve progressively, year by year, as a result of periodical organic mulch applications (10 Mg/ha/year), crop root activity, and irrigation management. Similarly, Rubauskis *et al*. (2004) and Yin *et al*. (2012) found that mulch application improved tree water status of apple and sweet cherry crops, respectively. Under our experimental conditions, mulch enhanced crop growth and water status.

Similarly, Merwin *et al*. (1994) and Okonkwo *et al*. (2011) showed that mulch applications improved soil water retention and infiltration, which in turn enhanced crop response. Mulch application at a rate of 10 Mg/ha/year may allow an ammoniacal N supply of 20 kg/ha/year (estimated from Table 1 data). Since mulch is applied on the soil surface and most of the nitrogen is in an ammoniacal form, much of it may be lost by volatization (Teira Esmatges, 1998). Under these agronomic conditions, crop N requirements might be around 60 and 120 kg N/ha/year (Rufat *et al.,* 2010). Therefore an N supply of 20 kg/ha/year, as best-case scenario, would not cover total crop needs. Mineralization of the compost organic matter may provide an additional supply of this nutrient, although it could be considered a long-term supply since rate of mineralization is slow under semiarid conditions (Teira Esmatges, 1998). For instance, Merwin & Stiles (1994) demonstrated that organic mulch applications improve tree growth and yield. However, those authors reported that, under their experimental conditions, supplemental fertilizers were required to provide essential elements.

Regarding production variables (Table 3), trees in the MF treatment gave the highest yield in 2011. The difference between the yield in the MF treatment with respect to the M and C treatment was attributed to the number of fruits since average fruit weight was similar among treatments (Table 6). Average fruit weight was not affected by average number of fruits per tree since the number of fruits per tree as a covariate was found to be non-significant by ANCOVA. However, it is important to consider that in 2011 the overall fruit production was low for all treatments. In 2012 the recovery in yield attributed to mulch application and fertigation was notable since there were no significant differences between MF and M treatments. However, the lowest yield was obtained in the C treatment. In 2012, yield differences were attributed to the number of fruits per tree and average fruit weight, which were greater in M and MF treatments (Table 6). However, in 2012, the average fruit weight was affected by crop load, as it was found to be significant in the ANCOVA test (p=0.0220). The average fruit weight in 2012 was less variable among treatments (FW_{2012}=172.4±5.9 g/fruit *vs*. FW_{2011}=176.3±24.0 g/fruit). Crop yield was notably improved by mulch and fertigation.

Fruit quality variables differed among treatments. Fruit dry matter concentration for the C treatment was greater than that of M and MF treatments, suggesting that in 2011 fruits from the C treatment were partially dehydrated (Table 5). This finding is consistent with other studies that reported increases in peach dry matter content under high water stress conditions (Marsal *et al*., 2006; Lopez *et al*., 2007). Furthermore, fruits from the C treatment presented a higher total soluble solids concentration and lower flesh firmness values than fruits treated with mulch in 2011. These lower flesh firmness values could be attributed to water stress (Table 3), as previous studies have reported accelerated fruit maturation under deficit irrigation (Gelly *et al*., 2004; Naor, 2006). In addition, high values of total soluble solids concentration under the C treatment could be related to water stress during the final stages of fruit development (stage II and III) or may be caused by a lower individual fruit weight and a higher dry matter concentration, as proposed by Rufat *et al*. (2010).

In 2012 there were differences in total soluble solids and fruit firmness, although dry matter content was similar among all the treatments, suggesting that water status did not show great differences between treatments. However, the soil in the C treatment still had a worse water status than that of the other treatments (Table 2). This may have affected the total soluble solids in the fruit. The fruit firmness registered in the C treatment was higher than that of fruit from the M and MF treatment, although the values of this variable varied in a narrow range, from 58.7 N (C treatment) to 54.7 and 54.6 N (M and MF treatments). We conclude that in 2012 all the treatments were under mild water stress (Table 3), which may have affected various quality attributes (TSS and FF), although it did not affect fruit dry matter content.

Regarding irrigation efficiency, mulch treatments (M and MF) showed the highest agricultural WUE values (kg/m^3). These values were significantly greater than those obtained in the C treatment (WUE_{agr} C=1.91 *vs*. WUE_{agr} M=2.72 *vs*. WUE_{agr} MF=3.14). Agricultural WUE was calculated for the third experimental year since it was considered to be the first year at full fruit production. The average WUE_{agr} for all treatments (2.6) was low compared to other related studies (García Tejero *et al*., 2011) although it should be considered normal in a peach orchard in third year's production. Differences were evident in spite of the three treatments receiving the same amount of fertilizer and mulch in the third year. These differences in WUE could be attributed to the fact that during the two first years the fruit yield potential differed between treatments, consequently affecting fruit yield and WUE in the third year. However, our results demonstrate that mulch enhanced both fruit yield and irrigation efficiency, as reported in other crops (Mukherjee *et al*., 2012; Zhao *et al*., 2012).

Our findings support the use of the ridge planting system for crop production under limiting soil conditions. Many producers in the Mediterranean area are shifting to this system. However, ridge planting techniques reduce the drip infiltration potential. On the basis of our results, we propose that mulching techniques can provide an effective solution to this drawback. Such techniques were observed to significantly improve the physical properties of the topsoil, which in turn enhanced the hydraulic properties of the matrix and improved crop response. Mulch improved crop growth, fruit yield, and also WUE. Moreover, mulch had a greater effect on crop response than fertigation. This observation highlights the relevance of soil factors on crop performance. In addition, our results reveal the importance of an early application of mulch techniques, preferably during crop establishment. As shown in this study, mulch techniques enhanced crop precocity, as mulched trees reached maturity earlier.

This work advocates that there is a need to find more efficient and soil sustainable crop production techniques to apply under limiting soil conditions and encourages further research concerning this issue.

References

Allen RG, Pereira LS, Raes D, Smith M, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. Irrig Drain No. 56, FAO, Rome.

Blake GR, Hartge KH, 1986. Bulk density. In: Methods of soil analysis. Part I. Physical and mineralogical methods; Klute A (ed.). pp: 363-376. Am Soil Sci Soc Inc., Madison, WI, USA.

Burt CM, Clemmens AJ, Strelkoff TS, Solomon KH, Bliesner RD, Hardy LA, Howell TA, Eisenhauer DE, 1997. Irrigation performance measures: efficiency and uniformity. J Irrig Drain Eng 123(6): 423-442. http://dx.doi.org/10.1061/(ASCE)0733-9437(1997)123:6(423)

Currie DR, 2007. Soil physical degradation due to drip irrigation in vineyards: evidence and implications. Doctoral thesis. University of Adelaide, Australia.

Doorenbos J, Pruitt W, 1977. Crop water requirements. Irrig Drain Paper No. 24. FAO, Rome.

García-Moreno J, Gordillo-Rivero ÁJ, Zavala LM, Jordán A, Pereira P, 2013. Mulch application in fruit orchards increases the persistence of soil water repellency during a 15-years period. Soil Till Res 130: 62-68. http://dx.doi.org/10.1016/j.still.2013.02.004

García Tejero I, Durán Zuazo VH, Jiménez Bocanegra JA, Muriel Fernández JL, 2011. Improved water-use efficiency by deficit-irrigation programmes: Implications for saving water in citrus orchards. J Sci Hortic 128: 274-282. http://dx.doi.org/10.1016/j.scienta.2011.01.035

Gelly M, Recasens I, Girona J, Mata M, Arbones A, Rufat J, Marsal J, 2004. Effects of stage II and postharvest deficit irrigation on peach quality during maturation and after cold storage. J Sci Food Agric 84: 561-568. http://dx.doi.org/10.1002/jsfa.1686

Girona J, Fereres E, 2012. Crop yield response to water: peach. Irrig Drain Paper No. 66; Steduto P, Hsiao TC, Fereres E, Raes D (eds). FAO, Rome.

Johnson RS, 2008. Nutrient and water requirements of peach trees. In: The Peach: botany, production and uses; Layne

DR, Bassi D (eds). pp: 303-321. CAB Intnal, Oxfordshire, UK. http://dx.doi.org/10.1079/9781845933869.0303

Kar G, Kumar A, 2007. Effects of irrigation and straw mulch on water use and tuber yield of potato in eastern India. Agr Water Manage 94: 109-116. http://dx.doi.org/10.1016/j.agwat.2007.08.004

Khan MJ, Jan MT, Khan AU, Arif M, Shafi M, 2010. Management of saline sodic soils through cultural practices and gypsum. Pak J Bot 42(6): 4143-4155.

Kumar S, Malik RS, Dahiya, IS, 1985. Influence of different organic wastes upon water retention, transmission and contact characteristics of a sandy soil. Aust J Soil Res 23: 131-136. http://dx.doi.org/10.1071/SR9850131

Lopez G, Girona J, Del Campo J, Marsal J, 2007. Effects of relative source-sink position within peach trees on fruit growth under water stress conditions. J Hortic Sci Biotech 82: 140-148.

López R, Burgos P, Hermoso JM, Hormaza JI, González-Fernández JJ, 2014. Long term changes in soil properties and enzyme activities after almond shell mulching in avocado organic production. Soil Till Res 143: 155-163. http://dx.doi.org/10.1016/j.still.2014.06.004

Lordan J, Pascual M, Fonseca F, Villar JM, Rufat J, 2013. Use of rice husk to enhance peach tree performance in soils with limiting physical properties. Soil Till Res 129: 19-22. http://dx.doi.org/10.1016/j.still.2013.01.002

Marsal J, Lopez G, Mata M, Girona J, 2006. Branch removal and defruiting for the amelioration of water stress effects on fruit growth during Stage III of peach fruit development. J Sci Hortic 108: 55-60. http://dx.doi.org/10.1016/j.scienta.2006.01.008

Merwin IA, Stiles WC, 1994. Orchard groundcover management impacts on apple tree growth and yield, and nutrient availability and uptake. J Am Soc Hortic Sci 119: 209-215.

Merwin IA, Stiles WC, Vanes HM, 1994. Orchard groundcover management impacts on soil physical properties. J Am Soc Hortic Sci 119: 216-222.

Mubarak AR, Ragab OE, Ali AA, Hamed NE, 2009. Short-term studies on use of organic amendments for amelioration of a sandy soil. Afr J Agric Res 4: 621-627.

Mukherjee A, Sarkar S, Chakraborty PK, 2012. Marginal analysis of water productivity function of tomato crop grown under different irrigation regimes and mulch managements. Agric Water Manage 104: 121-127. http://dx.doi.org/10.1016/j.agwat.2011.12.006

Nacci S, 2001. Alteraciones en el regimen hídrico del suelo asociadas a la sistematización y cambios en el manejo de tierras con viña de secano en el Anoia-Penedès. Doctoral thesis. Universitat de Lleida, Spain.

Naor A, 2006. Irrigation scheduling and evaluation of tree water status in deciduous orchards. Hortic Rev 32: 111-165. http://dx.doi.org/10.1002/9780470767986.ch3

Okonkwo CI, Mbagwu JSC, Egwu SO, Mbah CN, 2011. Effect of decomposed rice husk dust on soil properties and yield maize. J Agr Biol Sci 2: 129-135.

Pla I, 1983. Metodología para la caracterización física con fines de diagnóstico de problemas de manejo y conservación de los suelos en condiciones tropicales. Alcance 32. Rev. UCV, Maracay (Venezuela).

Roth CH, Fischer RA, Piggin C, Meyer W, 2005. Evaluation and performance of permanent raised bed systems in Asia, Mexico and Australia: A synopsis. ACIAR Proc. Nº 121; Roth CH, Fischer RA, Meisner CA (eds). Griffith, Australia, pp: 200-207.

Rubauskis E, Skrivele M, Dimza I, Berlands V, 2004. The influence of rootstock B 9 on apple growing and yields, as influenced by mulching and fertigation.Proc. 1st Int. Symp. on Rootstocks for Deciduous Fruit Tree Species, Vols 1 and 2 (Sanchez MA, Webster AD, eds.). Int. Soc. Hortic. Sci., Leuven, Belgium, pp: 251-256. http://dx.doi.org/10.17660/actahortic.2004.658.35

Rufat J, DeJong TM, 2001. Estimating seasonal nitrogen dynamics in peach trees in response to nitrogen availability. Tree Physiol 21: 1133-1140. http://dx.doi.org/10.1093/treephys/21.15.1133

Rufat J, Domingo X, Arbonés A, Pascual M, Villar JM, 2010. Interaction between water and nitrogen management in peaches for processing. Irrigation Sci 29: 321-329. http://dx.doi.org/10.1007/s00271-010-0234-4

Shackel K, Ahmadi H, Biasi W, Buchner R, Goldhamer D, Gurusinghe S, Hasey J, Kester D, Krueger B, Lampinen B et al., 1997. Plant water status as an index of irrigation need in deciduous fruit trees. HortTechnology 7: 23-29.

Soil Survey Staff, 1999. Keys to Soil Taxonomy, 2nd ed. USDA-Natural Resources Conservation Service, Washington, DC.

Teira Esmatges MR, 1998. Emission of NH3 and N20 from irrigated semi-arid calcareous Spanish soils. Doctoral thesis. University of Gent, Belgium.

Yin XH, Long LE, Huang XL, Jaja N, Bai JH, Seavert CF, le Roux J, 2012. Transitional effects of double-lateral drip irrigation and straw mulch on irrigation water consumption, mineral nutrition, yield, and storability of sweet cherry. HortTechnology 22: 484-492.

Zhao H, Xiong YC, Li FM, Wang RY, Qiang SC, Yao TF, Mo F, 2012. Plastic film mulch for half growing-season maximized WUE and yield of potato via moisture-temperature improvement in a semi-arid agroecosystem. Agr Water Manage 104: 68-78. http://dx.doi.org/10.1016/j.agwat.2011.11.016

Zribi W, Aragüés R, Medina E, Faci JM, 2015. Efficiency of inorganic and organic mulching materials for soil evaporation control. Soil Till Res 148: 40-45. http://dx.doi.org/10.1016/j.still.2014.12.003