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Soil management and compost effects on salinity and seasonal water storage in a Mediterranean drought-affected olive tree area

Nektarios N. Kourgialas, Georgios Doupis, Georgios Psarras, Chrysi Sergentani, Nektaria Digalaki, Georgios C. Koubouris*

Institute for Olive Tree, Subtropical Crops & Viticulture, Hellenic Agricultural Organization "Demeter" (ex. NAGREF), Agrokipion, 73100, Chania, Greece, Tel. +30 28210 83431; Fax: +30 28210 93963; email: koubouris@nagref-cha.gr (G.C. Koubouris)

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ABSTRACT

In this 4-year study, the effects of (a) sustainable soil management with weed mowing during spring and addition of compost without tillage (SUST) and (b) intensive management with soil tillage and use of herbicides (INT) on soil properties related to water storage and salinity were determined in a drip-irrigated olive orchard in Crete, Greece. Higher annual levels of soil moisture were observed in SUST (+12%) as compared with INT, as well as in the rainy period (October–March) (+40%) as compared with the irrigation period (April–September). Mean soil moisture content was increasing by soil depth. Soil pH was unaffected while increased electrical conductivity was observed in the superficial soil layer (0–10 cm), as compared with deeper soil layers as well as in SUST, as compared with INT. The present study describes a sustainable olive orchard management system that reduces soil erosion risk, enhances water storage in the root zone and, through mineral nutrient recovery at the local scale, contributes to energy savings by reducing use of chemical fertilizers.

Keywords: Climate change; *Olea europaea* L.; Olive mill waste; Recycling; Soil depth

1. Introduction

Olive (*Olea europaea* L.) is one of the most important crops in the Mediterranean basin. It is considered as one of the best adapted species to the semi-arid environment [1–3]. Specifically, tolerance to drought and salinity makes olive tree the most characteristic perennial crop in the Mediterranean region, providing economical benefits to farmers, minimizing at the same time soil erosion and desertification risks [4,5]. Under the Mediterranean environment, with limited availability of irrigation water, prolonged dry periods and heavy rainfall incidents, olive tree can still be a profitable crop under current and future climate conditions [6–8]. Based on the above, olive tree has traditionally been grown under rainfed conditions, although, in areas such as Chania Prefecture (Crete, Greece), where irrigation water availability has been increased during the past decades, irrigation of olive orchards has been adopted, since it can significantly improve the fruit yield potential both on an annual and bi-annual basis [9]. Improving key soil properties in olive orchards is essential for reducing water losses, including water erosion, and improving water management for agricultural purposes at watershed scale [10–12].

Apart from water supply and proper irrigation management, the quality and the quantity of olive fruit depends upon cultural practices adopted in the field, such as fertilization [13,14]. In recent years, valorizing of locally available agricultural wastes through composting provides an alternative source of fertilizer that can provide both nutrients for plant growth and improve soil characteristics over time [15–17]. However, compost application may affect soil

* Corresponding author.

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pH proportionally with compost application rates at the surface soil layer [18]. A risk of pH increase was observed due to the production and downward transport of OH^- ions and the release of cations [19]. In addition, due to the release and solubilization of ions during compost incorporation, the soil electrical conductivity (EC) may increase considerably immediately after its incorporation into the soil [19–21]. Subsequently, gradual decline of EC is commonly observed due to leaching, nutrient uptake by the crop as well as cation adsorption in soil organic matter colloids [16,22]. These two indicators should be carefully monitored since olive trees grow poorly on soils with EC (dS/m) or pH values above 5 and 8.5, respectively [23,24].

On this basis, it is very important for olive tree cultivation to maintain soil moisture, pH and EC levels at desired levels for optimal agricultural productivity. This would ensure an adequate quality and quantity of yield. Moreover, knowing that soil moisture is related to carbon, energy and mass fluxes between the soil–olive tree interface and the atmosphere, monitoring of soil moisture status is necessary [25]. Up to now, few studies have addressed soil moisture dynamics in olive orchards and the effect of composted olive mill byproducts on soil pH and EC under field conditions [26,27]. Continuous measurements of soil moisture, pH and EC in different soil depths are time consuming, labour intensive and need to be repeated for many years and under different field conditions in order to ensure valid results [28]. Various soil moisture measurement methods such as gravimetric analysis of soil samples, weighing lysimeters, capacitance probes and time domain reflectometry tensiometers have been used for determining optimal irrigation schedules, minimizing water losses and monitoring leaching process [29,12]. Capacitance probe method has been developed and used increasingly during the recent years, since it provides (depending on the applied sensing technology) automatic acquisition of data at short time interval, enhancement of depth resolution and minimal soil disturbance or influence from soil salinity [30].

Most studies on recycling of organic materials such as compost focus at quantification of nutrient release for crop nutrition. The aim of this 4-year field experiment was to determine soil moisture dynamics, pH and EC at the soil profile (four different soil depths 10, 20, 30, and 40 cm) of an irrigated olive orchard, under two different soil management systems (a) all year-round weed-free soil through tillage and herbicides, (b) natural soil cover by weeds during winter, followed by mowing during spring and addition of compost without soil tillage. The research hypothesis was that spatial allocation and temporal storage of rain and irrigation water in the soil can be optimized through proper soil management and locally increased availability of organic material.

2. Materials and methods

2.1. Experimental site and treatments

The study was performed from 2013 until 2016 in a 40-year-old olive plantation (*Olea europaea* L., cv. Kalamata; trees planted at 7 × 7 m distances) located in Chania, Crete island, Southern Greece (35°28′34,85″N, 24°02′33,23″E). Based on the meteorological data of the station Agrokipio (35°29′37,50″N, 24°02′43,80″E) located close to the experimental field (1.5 km distance), mean annual air temperature for the past 20 years was 18°C, mean relative humidity was 64%, and mean annual rainfall was 700 mm. Irrigation was implemented weekly from May to September according to the calculated evapotranspiration (ETc) losses, through drippers (five per tree) each with a discharge rate of 4 L h^{-1} and wetting a 1.0 m wide strip along the tree row (Water pH = 7.14, EC = 35 μs cm^{-1}, [Na] = 20.67 mg L^{-1}, [K] = 5.00 mg L^{-1}, [Ca] = 60.30 mg L^{-1}, [Mg] = 12.37 mg L^{-1}). The ETc was calculated by multiplying the reference evapotranspiration (ETo) by the empirical olive tree coefficient (Kc), [11]. The ETo was computed based on FAO Penman-Monteith method, using the appropriate meteorological data from Agrokipio station.

Two treatments, performed according to a completely randomized design, with three replicates per treatment (n = 3, for a total of six plots; each plot included four olive trees, covering about 200 m^2 of soil), were considered:

- "SUST." Sustainable soil management with weed mowing during spring and addition of compost without tillage. The compost used for the experiment was a commercial product consisting of recycled olive mill byproducts and was added to the soil without tillage in February 2013, March 2014, March 2015 and June 2016 at an average rate of 10.5 t ha^{-1}. The compost properties are presented in Table 1.
- "INT." Control consisted of intensive management (soil tillage and use of herbicides) and no addition of organic material.

2.2. Soil physicochemical properties

Before the onset of treatments, in autumn of 2012, one composite soil sample formed by 10 subsamples pooled on site was collected at the depth of 0–40 cm to depict basic soil properties of the study site. In autumn 2016, two composite soil samples were collected from each plot at each of the following depths: 0–10, 10–20, 20–30 and 30–40 cm (n = 6) and analyzed for EC and pH. Each composite sample was formed from two subsamples pooled on site. Soil samples were air-dried at room temperature, disaggregated in a ceramic pestle and mortar and sieved through a 2 mm sieve.

Table 1
Basic properties of the compost consisted of recycled olive mill byproducts used for the experiment according to the manufacturer

Parameter	Value
Moisture content (%)	45.65
Bulk density (kg m^{-3})	645
Water holding capacity (%)(w/w)	249
pH	7.8
CEC (meq/100g)	52
Total organic C (%)(w/w, on dry matter basis)	49.76
Total N (%) (w/w)	2.77
Total P (%) (w/w)	0.18
Total K (%) (w/w)	2.26
C/N ratio	17.97

The <2 mm fraction of the soil was used for all soil analyses. Electrical conductivity and soil pH were measured in a 1:2.5 soil/distilled water (w/v) suspension. The exchangeable cations (Ca, K and Mg) were determined by initial extraction of soil samples in 1 N ammonium acetate and then measurement of cation concentration by Inductively Coupled Plasma (ICP-OES, Optima 8300, PerkinElmer). Nitrate (NO_3-N) was extracted with 1 M KCl for 1 h and measured spectrophotometrically by the Cd reduction method [31]. Soil organic matter was determined by the Walkley–Black procedure [32]. Free calcium carbonate was measured by the Bernard calcimeter method [33]. Soil available P was determined according to the Olsen method [34].

2.3. Soil moisture measurements

Volumetric soil moisture content was assessed at each of the following depths: 0–10, 10–20, 20–30 and 30–40 cm using a commercial profile probe system (PR2, Delta-T, UK). The PR2 was combined with an HH2 readout unit which enables a single probe to be used at different locations of the study area. It is also crucial to mention that the sensing technology of the device used is slightly influenced by soil salinity [35]. Soil moisture was recorded from May 2013 up to September 2016 at 20–30 d intervals in order to capture the variability of soil moisture content under different meteorological conditions. During the irrigation season (April to September), measurements took place in the mid-time between two successive irrigation events.

2.4. Statistical analysis

Data were analyzed using SPSS (SPSS Inc., Chicago, USA) and were subjected to three-way analysis of variance using the GLM (General Linear Model) procedure, with soil management treatment, season of the year and soil depth as factors at three levels of significance (0.05, 0.01 and 0.001). Subsequently, due to significant complex interactions observed (Treatment × Soil depth, Soil depth × Season, Treatment × Soil depth × Season), data were analysed separately for each soil depth and season. For data presented in figures, significantly different means were statistically separated by Student's t-test at two levels (0.05 and 0.01). The number of replicates (n) for each measured parameter is specified in the figure captions (soil moisture n = 42, soil EC and pH n = 6). For comparison of rainfall and soil moisture data mean values for each of the following periods were used: (a) rainy period from October to March and (b) irrigation period from April to September.

3. Results and discussion

In this study, the effects of (a) sustainable soil management with weed mowing in spring and addition of compost without tillage (SUST) and (b) intensive management with soil tillage and herbicides (INT), on soil properties related to water storage and salinity were determined. An olive orchard with typical soil properties for the semi-arid Mediterranean areas was employed so that results could be of interest to a wide audience of stakeholders. The main features of this soil were the very low organic matter content and mineral nutrient availability, as well as the low content in clay (Table 2). Annual rainfall levels as well as its seasonal distribution also corresponded to typical Mediterranean climate. Indeed, according to Agrokipio meteorological station, average annual rainfall for the 3 years of the study was 535 mm while the 89.5% was allocated between October and March and only 56 mm in average were available through rainfall from April to September (Fig. 1). Moreover, the average air

Table 2
Soil properties at a depth of 0–40 cm before the onset of treatment application

Parameter	Value
Clay (%)	6.8
Silt (%)	28.0
Sand (%)	65.2
pH	7.2
EC (μS/cm)	114
Total $CaCO_3$ (%)	3.52
Soil organic matter (%)	0.67
NO_3-N (mg kg^{-1})	7.24
P (mg kg^{-1})	8.53
K (mg kg^{-1})	72
Ca (mg kg^{-1})	501
Mg (mg kg^{-1})	75

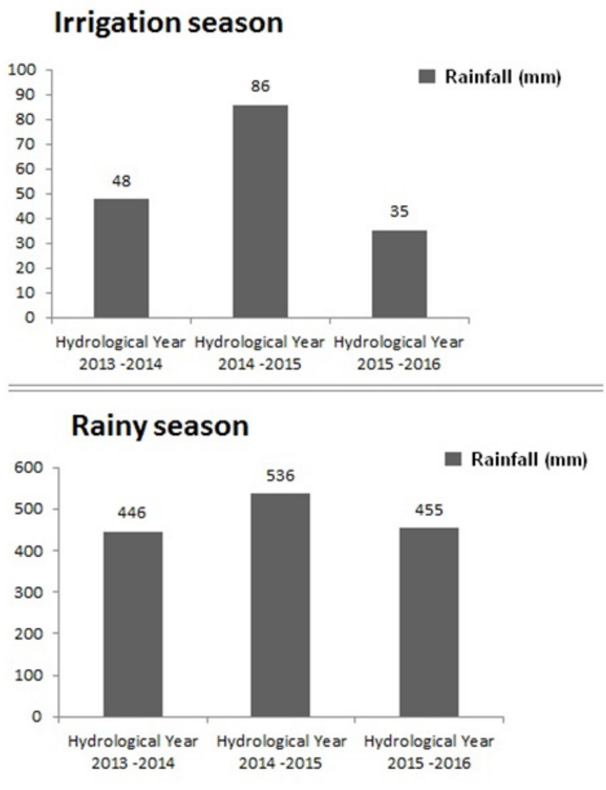

Fig. 1. Seasonal rainfall data for the studied olive grove [Irrigation season (April to September) and rainy season (October to March), period 2013–2016].

temperature for the experimental time period was 23°C and 15°C for irrigation and rainy season, respectively. The variation of temperature and especially precipitation is crucial for organic matter oxidation in Mediterranean soils [36]. Under these circumstances, the adoption of subsequent practices to increase soil organic matter should be combined with no tillage to protect soil aggregates [37].

In the present study, soil moisture was significantly affected by soil management, soil depth and season (Table 3). Higher annual values were observed in SUST (+12%) as compared with INT, as well as in the rainy period (October–March) (+40%) as compared with the irrigation period (April–September). Mean soil moisture content was increasing by soil depth. This finding is very important for irrigation management because farmers commonly supply water based on empirical indicators such as visual inspection of soil. In fact, soil may look dry on the surface, however, holding adequate amount of water in deeper layers. On the other hand, heavily compressed soils may be saturated with water in the surface layer while lower soil moisture levels may be observed in deeper layers due to poor infiltration and drainage. Sustainable soil management resulted in significantly higher (+25%) soil moisture at 20 cm depth during the rainy period as well as (+88%) in 30 cm depth during the irrigation period (Fig. 2). Significant Treatment × Soil Depth, Season × Soil Depth and Treatment × Soil Depth × Season interactions were observed (Table 3). This appears to be a very important aspect for irrigation management, especially taking into consideration that the highest proportion of fibrous roots for olive trees is concentrated in the top 30 cm of soil under the canopy and decreases with soil depth. Specifically, for olive trees the maximum root water uptake is realized within the soil layer 10–50 cm [38,39].

Even though irrigation was available during summer, soil moisture in the upper soil layers (0–10 and 10–20 cm) was significantly lower compared with the respective values of the rainy period. However, in the deeper soil layers (20–30 and 30–40 cm) irrigation successfully recovered soil moisture losses through evapotranspiration especially in SUST. Olive trees have the ability to mobilize and exploit water stored in deeper soil through longer roots and meet high transpiration demands in spite of water deficit in superficial soil [27]. This is true for most of the traditional olive orchards. However, in modern super-high density hedgerow plantations the root system of olive trees explores small soil volumes and may be unable to use water stored in the deeper layers [40]. Soil mulching with plant residues or organic amendments such as described in the present study would contribute to higher water retention in the superficial soil being available even for short rooted plants or trees in the early stage of plantation. Consequently, savings in irrigation water and pumping energy will be achieved and crops will grow and produce better yields in periods of limited precipitation. Recycling olive mill waste and use as organic soil amendments has the potential of additional energy savings (reduction of chemical fertilizer manufacture) given that proper methods are applied [41].

Soil management, season of the year and soil depth had no effects on soil pH while no interactions among different

Table 3
Effects of soil management (sustainable, SUST or intensive, INT), season of the year (rainy season from October until March or irrigation season from April until September), soil depth and their interactions on soil moisture, pH and electrical conductivity (EC)

Source of variance		Parameter		
		Soil moisture	pH	EC
Treatment	SUST	23.675 ± 0.975^{a}	6.993 ± 0.08	191.075 ± 13.32^{a}
	INT	21.143 ± 0.926^{b}	6.949 ± 0.07	146.525 ± 5.32^{b}
Soil depth	10 cm	8.486 ± 0.535^{d}	7.017 ± 0.08	218.125 ± 20.08^{a}
	20 cm	14.001 ± 0.734^{c}	6.863 ± 0.12	153.767 ± 10.46^{b}
	30 cm	25.886 ± 1.084^{b}	6.947 ± 0.13	155.567 ± 11.99^{b}
	40 cm	39.371 ± 1.327^{a}	7.059 ± 0.09	147.742 ± 9.32^{b}
Season	Rainy	25.303 ± 0.791^{a}		
	Irrigation	18.136 ± 1.129^{b}		
$F_{(Treatment)}$		5.991*	0.161^{ns}	19.063***
$F_{(Soil\ depth)}$		213.183***	0.594^{ns}	10.493***
$F_{(Season)}$		64.335***		
$F_{(Treatment \times Soil\ depth)}$		4.856**	0.724^{ns}	6.492**
$F_{(Treatment \times Season)}$		1.577^{ns}		
$F_{(Soil\ depth \times Season)}$		3.155*		
$F_{(Treatment \times Soil\ depth \times Season)}$		2.750*		

[a]GLM model. Values of F: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; NS: no significant differences.
[b]Soil moisture in %, EC in μS cm^{-1}.
[c]Mean values for each measured parameter within factors, with the same letter are not significantly different ($p < 0.05$) LSD test.

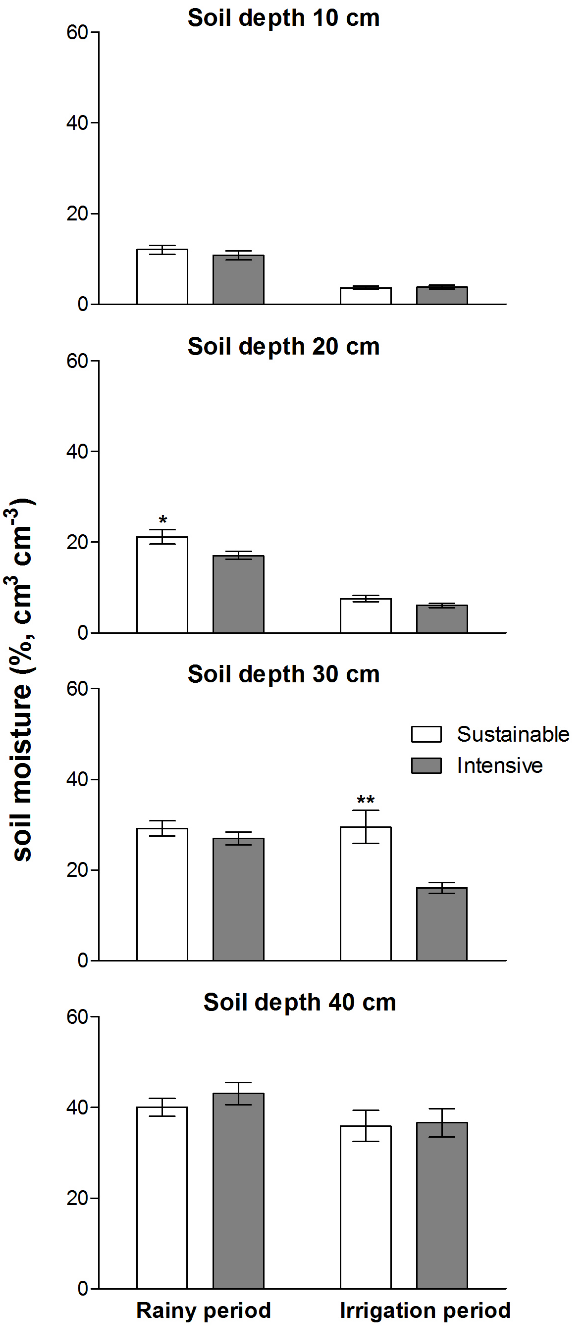

Fig. 2. Soil moisture in four soil depths and two seasons of the year (rainy season from October until March or irrigation season from April until September) as affected by soil management (sustainable, SUST or intensive, INT). Three-year Mean ± S.E.M. per each treatment is presented (n = 42). Significant differences between SUST and INT are marked with one asterisk ($p < 0.05$) or two asterisks ($p < 0.01$) (Student's t-test).

factors were observed (Table 3; Fig. 3). Soil pH is considered an indicator of salinity and when it exceeds 8.5 the soil is more likely to be saline/alkaline [42]. In the present study, pH remained in the initial levels after 4 years of different soil management systems indicating balanced cation–anion supply and efficient soil buffering capacity.

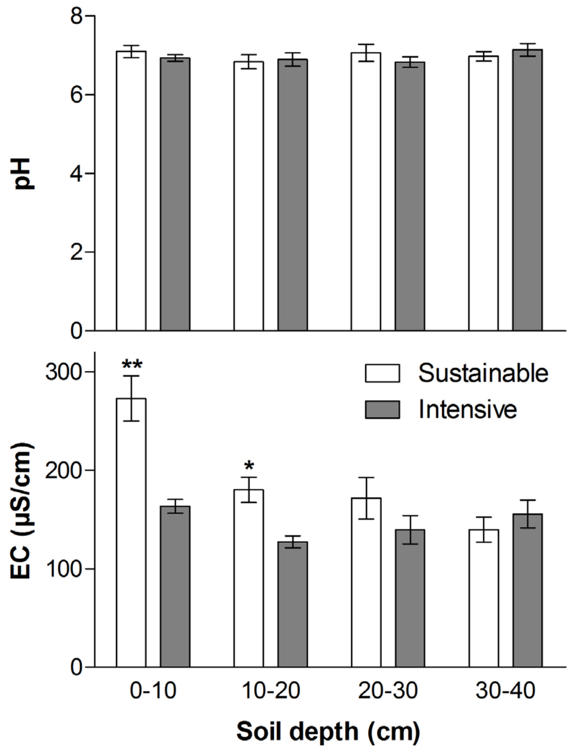

Fig. 3. Soil pH and electrical conductivity in four soil depths as affected by 4 years of soil management (sustainable, SUST or intensive, INT). Mean ± S.E.M. per each treatment is presented (n = 6). Significant differences between SUST and INT are marked with one asterisk ($p < 0.05$) or two asterisks ($p < 0.01$), (Student's t-test).

However, EC was significantly affected by soil management and soil depth (Table 3). Indeed, increased EC was observed in the superficial soil layer (0–10 cm) compared with the deeper soil as well as in SUST compared with INT. Marked increase of EC was apparent in layers 0–10 cm (+67%) and 10–20 cm (+42%) following sustainable soil management (Fig. 3). Significant Treatment × Soil depth interaction was observed for soil EC (Table 3). Since soil EC increased only in the superficial soil, this can be attributed mainly to soil management and addition of compost rather than salt transportation from parent material or groundwater. Similarly, it would not derive from salt accumulation through irrigation water, since both management systems received water of the exact quantity and quality. Soil received SUST remained in the "non-saline" category (EC values between 0 and 2 dSm^{-1}) according to [43] implying that increase of EC was not a direct threat to soil quality. Despite the statistical differences observed when only the superficial layer (0–10 cm) was considered, increase of EC, in absolute values, was not considered as important (<50 µS cm^{-1} between SUST and INT) and was far away for being considered as a threat for plant growth, even in the case that this was due to toxic ions such as Na^+ and Cl^-. However, long-term application of soil amendments as well as irrigation with reclaimed wastewater requires attention since they occasionally may increase soil pH, EC and other salinity indicators [44]. Soil characterization as well as appropriate quantification of land spreading would contribute to protection of soils and water bodies from degradation and pollution [45].

4. Conclusion

Exploring soil water dynamics would contribute to the optimization of irrigation performance in olive plantations and to integrated water management at basin scale [30,46]. In addition, the effect of crop management practices on soil quality should be carefully studied in the Mediterranean region which stands out at European level in terms of soil salinization, especially taking into consideration the foreseen climate warming which is expected to result in the expansion of affected areas [42]. Under good agricultural practices that protect the environment, recycling rural waste is recommended for nutrients recovery at the local scale and energy savings through reduced manufacture and long distance transportation of industrial fertilizers. Adaptation of the whole process of rural waste treatment and application to local conditions is necessary for it to be cost-efficient and environmentally sustainable in the long term.

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References

[1] C. Gimenez, E. Fereres, C. Ruz, F. Orgaz, Water relations and gas exchange of olive trees: diurnal and seasonal patterns of leaf water potential, photosynthesis and stomatal conductance, Acta Hortic., 449 (1997) 411–416.

[2] G.C. Koubouris, N. Tzortzakis, N. Kourgialas, M. Darioti, I.T. Metzidakis, Growth, photosynthesis and pollen performance in saline water treated olive (*Olea europaea* L.) plants under high temperature, Int. J. Plant Biol., 6 (2015) 28–32.

[3] G.C. Koubouris, N. Kavroulakis, I.T. Metzidakis, M.D. Vasilakakis, A. Sofo, Ultraviolet-B radiation or heat cause changes in photosynthesis, antioxidant enzyme activities and pollen performance in olive tree, Photosynthetica, 53 (2015) 279–287.

[4] A. Diaz-Espejo, A.S. Walcroft, J.E. Fernandez, B. Hafidi, M.J. Palomo, I.F. Giron, Modeling photosynthesis in olive leaves under drought conditions, Tree Physiol., 26 (2006) 1445–1456.

[5] G.C. Koubouris, I.T. Metzidakis, M.D. Vasilakakis, Impact of temperature on olive (*Olea europaea* L.) pollen performance in relation to relative humidity and genotype, Environ. Exp. Bot., 67 (2009) 209–214.

[6] J.A. Gómez, T.A. Sobrinho, J.V. Giráldez, E. Fereres, Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain, Soil Tillage Res., 102 (2009) 5–13.

[7] N.N. Kourgialas, G.C. Koubouris, G.P. Karatzas, I. Metzidakis, Assessing water erosion in Mediterranean tree crops using GIS techniques and field measurements: the effect of climate change, Nat. Hazard., 83 (2016) 65–81.

[8] F. Viola, D. Caracciolo, D. Pumo, L.V. Noto, G.L. Loggia, Future climate forcings and olive yield in a Mediterranean orchard, Water, 6 (2014) 1562–1580.

[9] J.C. Melgar, Y. Mohamed, C. Navarro, M.A. Parra, M. Benlloch, R. Fernandez-Escobar, Long-term growth and yield responses of olive trees to different irrigation regimes, Agric. Water Manage., 95 (2008) 968–972.

[10] G. Martínez, K. Vanderlinden, J.V. Giráldez. A.J. Espejo, J.L. Muriel, Field-scale soil moisture pattern mapping using electromagnetic induction, Vadose Zone J., 9 (2010) 871–881.

[11] N.N. Kourgialas, G.P. Karatzas, G. Morianou, Water management plan for olive orchards in a semi-mountainous area of Crete, Greece, Global Nest J., 17 (2014) 72–81.

[12] A.J. Espejo-Pérez, L. Brocca, T. Moramarco, J.V. Giráldez, J. Triantafilis, K. Vanderlinden, Analysis of soil moisture dynamics beneath olive trees, Hydrol. Process., 30 (2016) 4339–4352.

[13] M. Patumi, R. d'Andria, G. Fontanazza, G. Morelli, P. Giorio, G. Sorrentino, Yield and oil quality of intensively trained trees of three cultivars of olive (*Olea europaea* L.) under different irrigation regimes, J. Hortic. Sci. Biotechnol., 74 (1999) 729–737.

[14] F. Viola, L. Valerio Noto, M. Cannarozzo, G.L. Loggia, A. Porporato, Olive yield as a function of soil moisture dynamics, Ecohydrology, 5 (2012) 99–107.

[15] M. Ozores-Hampton, P.A. Stansly, T.P. Salame, Soil chemical, physical, and biological properties of a sandy soil subjected to long-term organic amendments, J. Sustain. Agric., 35 (2011) 243–269.

[16] M.T. Barral, R. Paradelo, Trace elements in compost regulation: the case of Spain, Waste Manage., 31 (2011) 407–410.

[17] G. Giannakis, N.N. Kourgialas, N.V. Paranychianakis, N.P. Nikolaidis, N. Kalogerakis, Effects of municipal solid waste compost on soil properties and vegetables growth, Compost Sci. Util., 22 (2014) 1–16.

[18] A. Yaakoubi, A. Chahlaoui, M. Rahmani, M. Elyachioui, I. Nejdi, Effect of olive mill wastewater spreading on the physicochemical characteristics of soil, Desal. Wat. Treat., 16 (2010) 194–200.

[19] M.S. Mkhabela, P.R. Warman, The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash Sandy Loam Soil in Nova Scotia, Agric., Ecosyst. Environ. 106 (2005) 57–67.

[20] M. Irshad, T. Honna, S. Yamamoto, A.E. Eneji, N. Yamasaki, Nitrogen mineralization under saline conditions, Commun. Soil Sci. Plant Anal., 36 (2005) 1681–1689.

[21] I. Walter, F. Martinez, G. Cuevas, Plant and soil responses to the application of composted MSW in a degraded, semiarid shrubland in Central Spain, Compost Sci. Util., 14 (2006) 147–154.

[22] A. Fernández-Hernández, A. Roig, N. Serramiá, C.G.-O. Civantos, M.A. Sánchez-Monedero, Application of compost of two-phase olive mill waste on olive grove: effects on soil, olive fruit and olive oil quality, Waste Manage., 34 (2014) 1139–1147.

[23] K.S. Chartzoulakis, Salinity and olive: growth, salt tolerance, photosynthesis and yield, Agric. Water Manage., 78 (2005) 108–121.

[24] L. Nasini, G. Gigliotti, M.A. Balduccini, E. Federici, G. Cenci, P. Proietti, Effect of solid olive-mill waste amendment on soil fertility and olive (*Olea europaea* L.) tree activity, Agric. Ecosyst. Environ., 164 (2013) 292–297,

[25] R.D. Koster, Z. Guo, P.A. Dirmeyer, R. Yang, K. Mitchell, M.J. Puma, On the nature of soil moisture in land surface models, J. Climate, 22 (2009) 4322–4335.

[26] R. Fernández-Escobar, G. Beltrán, M.A. Sánchez-Zamora, J. Garciá-Novelo, M.P. Aguilera, M. Uceda, Olive oil quality decreases with nitrogen over-fertilization, HortScience, 41 (2006) 215–219.

[27] N. Nadezhdina, M.I. Ferreira, N. Conceiçao, C.A. Pacheco, M. Häusler, T.S. David, Water uptake and hydraulic redistribution under a seasonal climate: long-term study in a rainfed olive orchard, Ecohydrology, 8 (2014) 387–397.

[28] M.A. Palecki, J.E. Bell, U.S. climate reference network soil moisture observations with triple redundancy: measurement variability, Vadose Zone J., 12 (2013) DOI:10.2136/vzj2012.0158.

[29] S.R. Evett, R.C. Schwartz, J.J. Casanova, L.K. Heng, Review: soil water sensing for water balance ET and WUE, Agric. Water Manage., 104 (2012) 1–9.

[30] N.N. Kourgialas, G. Doupis, A. Papafilippaki, G. Psarras, G.C. Koubouris, Seasonal variation of soil moisture in irrigated olive trees, Procedia Eng., 162 (2016) 471–475.

[31] A.L. Page, R.H. Miller, D.R. Keeney, Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties, 2nd ed., ASA and SSSA, Madison, Wisconsin, 1982.

[32] D.W. Nelson, L.E. Sommers, Total Carbon, Organic Carbon and Organic Matter, A.L. Page, R.H. Miller, D.R. Keeney, Eds., Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties, American Society of Agronomy, Soil Science Society of America, 1982, pp. 539–579.
[33] J.H. Horton, D.W. Newsom, A rapid gas evolution method for calcium carbonate equivalent in liming materials, Soil Sci. Soc. Am. Proc., 17 (1953) 414–415.
[34] S.R. Olsen, C.V. Cole, F.S. Watanabe, L.A. Dean, Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. (U.S. Department of Agriculture Circular 939) U.S. Government Printing Office, Washington D.C., 1954.
[35] Delta-T, Delta-T Devices – Soil Moisture Sensors, 2005. Available at: http://www.delta-t.co.uk.
[36] J. Albaladejo, R. Ortiz, N. Garcia-Franco, A.R. Navarro, M. Almagro, J.G. Pintado, M. Martinez-Mena, Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain, J. Soils Sediments, 13 (2013) 265–277.
[37] P. Merante, C. Dibari, R. Ferrise, B. Sánchez, A. Iglesias, J.P. Lesschen, P. Kuikman, J. Yeluripati, P. Smith, M. Bindi, Adopting soil organic carbon management practices in soils of varying quality: implications and perspectives in Europe, Soil Tillage Res., 165 (2017) 95–106.
[38] P.S. Searles, D.A. Saravia, M.C. Rousseaux, Root length density and soil water distribution in drip-irrigated olive orchards in Argentina under arid conditions, Crop Pasture Sci., 60 (2009) 280–288.
[39] S. Besharat, A.H. Nazemi, A.A. Sadraddini, Parametric modeling of root length density and root water uptake in unsaturated soil, Turk. J. Agric. For., 34 (2010) 439–449.
[40] A. Diaz-Espejo, T.N. Buckley, J.S. Sperry, M.V. Cuevas, A. de Cires, S. Elsayed-Farag, M.J. Martin-Palomo, J.L. Muriel, A. Perez-Martin, C.M. Rodriguez-Dominguez, A.E. Rubio-Casal, J.M. Torres-Ruiz, J.E. Fernández, Steps toward an improvement in process-based models of water use by fruit trees: a case study in olive, Agric. Water Manage., 114 (2012) 37–49.
[41] P. Proietti, R. Calisti, G. Gigliotti, L. Nasini, L. Regni, A. Marchini, Composting optimization: integrating cost analysis with the physical-chemical properties of materials to be composted, J. Cleaner Prod., 137 (2016) 1086–1099.
[42] I.N. Daliakopoulos, I.K. Tsanis, A. Koutroulis, N.N. Kourgialas, A.E. Varouchakis, G.P. Karatzas, C.J. Ritsema, The threat of soil salinity: a European scale review, Sci. Total Environ., 573 (2016) 727–739.
[43] L.A. Richards, Diagnosis and improvement of saline and alkali soils, Soil Sci., 78 (1954) 154.
[44] S. Ayoub, S. Al-Shdiefat, H. Rawashdeh, I. Bashabsheh, Utilization of reclaimed wastewater for olive irrigation: effect on soil properties, tree growth, yield and oil content, Agric. Water Manage., 176 (2016) 163–169.
[45] M.K. Doula, A. Sarris, A. Hliaoutakis, A. Kydonakis, N.S. Papadopoulos, L. Argyriou, Building a strategy for soil protection at local and regional scale—the case of agricultural wastes land spreading, Environ. Monit. Assess., 188 (2016) 141,
[46] G. Egea, A. Diaz-Espejo, J.E. Fernández, Soil moisture dynamics in a hedgerow olive orchard under well-watered and deficit irrigation regimes: assessment, prediction and scenario analysis, Agric. Water Manage., 164 (2016) 197–211.