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# The impact of agricultural management on selected soil properties in citrus orchards in Eastern Spain: A comparison between conventional and organic citrus orchards with drip and flood irrigation

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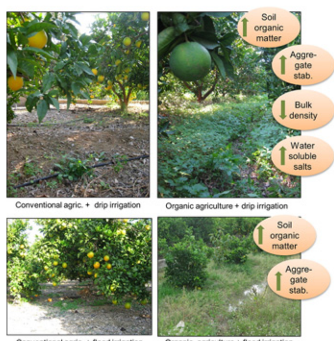
## HIGHLIGHTS

- Agricultural management with irrigation type has influences on soil parameters.
- Aggregate stability and the amount of SOM were higher under organic farming.
- Organic soils with drip irrigation were more favorable for bulk density and nutrients.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The agricultural management of citrus orchards is changing from flood irrigated managed orchards to drip irrigated organic managed orchards. Eastern Spain is the oldest and largest European producer of citrus, and is representative of the environmental changes triggered by innovations in orchard management. In order to determine the impact of land management on different soil quality parameters, twelve citrus orchards sites were selected with different land and irrigation management techniques. Soil samples were taken at two depths, 0–2 cm and 5–10 cm for studying soil quality parameters under the different treatments. Half of the studied orchards were organically managed and the other six were conventionally managed, and for each of these six study sites three fields were flood irrigated plots and the other three drip irrigated systems. The outcome of the studied parameters was that soil organic matter (SOM) and aggregate stability were higher for organic farms. Bulk density and pH were only significantly different for organic farms when drip irrigation was applied in comparison with flooded plots. C/N ratio did not vary significantly for the four treatments. Although there are some points of discussion, this research shows that a combination of different management decisions leads to improvement of a couple of soil quality parameters. Organic management practices were found to be beneficial for soil quality, compared to conventional management for soils with comparable textures and applied irrigation water.


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## 1. Introduction

Soils provide a variety of important ecosystem services, such as food production (Tilman et al., 2002), buffering and filtering of ground water (Keesstra et al., 2012), soil carbon storage and climate mitigation (De Vries et al., 2012; Montanarella, 2015; Keesstra et al., 2016a, 2016b). Therefore, it is important to preserve or even improve the quality of soils after millennia of abuse of soil resources resulting in declining ecosystem services. To maintain or improve soil quality transdisciplinary approaches are needed, incorporating input from different science fields such as soil science, ecology, hydrology, and geomorphology in combination with management expertise (Brevik et al., 2015).

Currently, a transition in agricultural soil management of citrus orchards is occurring all over the world as a consequence of the increasing use of drip irrigation. The area of Valencia is representative of this change due to private, national and European policies that subsidise the development of highly mechanized, drip-irrigated, chemically and computer-managed orchards. However also socioeconomic changes played a role. Valencia is the region that produces two thirds of the Spanish oranges and it is the oldest and the largest European producer of citrus. Conventional managed orchards with flood irrigation (currently <50%) changed to drip-irrigation over the last 30 years. The ageing of the farmer population, or farmers that cannot take care of the flood irrigation system, the low prices for oranges, and the need for agricultural mechanization to be more competitive, all have their impact on land and irrigation management. Due to changes in irrigation type, differences in soil quality are expected to occur, which consequently also will affect the soil moisture regime. Drip irrigation moistens only 20% of the soil, but continuously throughout the growing season. Meanwhile flood irrigation moistens all soil every 15–30 days in summer in three to six controlled flooding events. The soil wetting patterns resulting from of the two irrigation methods are different, and also the use of chemicals is different as the drip irrigation is more regular at low dose (once per day, usually for 30 to 120 min), in contrast to the higher short fluxes under controlled floods. Consequently, SOM content and the bulk density should change as a result of the changed spatio-temporal distribution of soil moisture (Cassel Sharmasarkar et al., 2001; Wang et al., 2006).

Another fast change in the citrus agriculture in the world is the development of organic farming strategies to supply a high quality product to the markets of developed countries. Organic farming is more than a fashion and is well established. Right now, 3% of the Valencia citrus production is under organic farming rules, and no-tillage, reduction of pesticide application, use of machinery to weed, and mulching with chipped pruned branches is widespread among non-organic farmers to avoid expenses, labour and to increase subsidies.

Research has been conducted to compare organically managed farms and conventional farms (Marriott and Wander, 2006; Gómez et al., 2009; Cerdà et al., 2016; Keesstra et al., 2016a, 2016b; Prosdocimi et al., 2016) as well as for different irrigation systems (drip versus flood irrigation) (e.g. Swietlik, 1992; Nelson et al., 2011). However, the combined effect of organic or conventional farming in combination with different irrigation types is not studied yet.

Soriano et al. (2014) studied the shift from conventional to organically managed orchards in olive groves. Their conclusion was that some soil properties, such as texture, pH, C/N ratio, cation exchange capacity (CEC) and exchangeable potassium were equal in conventional and organically managed systems. However, organic C and N, saturated hydraulic conductivity and available water-holding capacity (AWC) of the soil improved in olive groves under organic farming strategies. Glover et al. (2000) made a comparison between conventional, organic and integrated systems (a combination of both systems) in apple orchards and applied a soil quality index. Some chemical, biological and physical soil properties were shown to be of higher quality in organic systems if compared to conventional. Also, Bulluck et al. (2002) found higher crop yields for organic farming systems in the second year of harvest of vegetables. Soybean yields were found to be similar for organic and conventional farms (Liebhardt et al., 1989). However, a long-term experiment by Mäder et al. (2002) showed a 20% decrease of crop yield for organic practices over a period of 21 years, for fields with crop rotation. Van Leeuwen et al. (2015) found no improvement in chemical and physical parameters for organic farms in comparison with conventional farms. Still organic farming is recommended due to a decrease in energy consumption and fertilizer utilization (Mäder et al., 2002) as well as by the improvement of biological parameters (Van Leeuwen et al., 2015). Soil organic matter (SOM) is another important indicator of soil quality, which is correlated with the degree of soil aggregation (Marriott and Wander, 2006). Marriott and Wander (2006) also found an increase of total and labile SOM concentrations in surface soils at organic farms in comparison to conventionally managed farms. However, there is still an ongoing debate about the question whether organic farming management is enhancing the carbon storage in the soil (Gattinger et al., 2012; Leifeld et al., 2013).

Another key issue is whether drip irrigation will affect soil quality. Studies have been focusing on the differences of drip and flood irrigated practices in agroecosystems (Swietlik, 1992; Nelson et al., 2011). Various studies found positive responses of different crop and soil types to drip irrigation, with no reduction or even a higher crop yields due to drip irrigation in comparison with flood irrigation (Swietlik, 1992; Cassel Sharmasarkar et al., 2001; Wang et al., 2006; Nelson et al., 2011). Furthermore, flood irrigation does not saturate the soil fully due to the sudden application of a large amount of water. The irrigated water will partly be lost to the groundwater due to preferential flow in macro pores making it unavailable to crops. In general, flood irrigation is recharging aquifers, but this is not of profit for the farmers where the irrigation takes place, although others will be benefit of the increased groundwater downstream (Zhang et al., 2014). This is not the case with drip irrigation (Cassel Sharmasarkar et al., 2001), where the watering takes place daily, while the saturation of the soil and the flow in macro-pores is avoided. Another advantage of drip-applied water systems compared to flood irrigation is that it has been found to be water saving as less water is evaporated (Uckoo et al., 2005; Deng et al., 2006). Bryla et al. (2005) showed that young peach trees grew taller and had higher yields under drip irrigation. Geleta et al. (1994) stated that total nitrogen ($N_t$) and nitrate ($NO_3^-$) losses were reduced when drip irrigation was applied. Although much attention has been paid to effects of irrigation in the context of water management, relatively little is known about how they affect soil quality.

The combined effects of management (organic or chemical) and irrigation (drip or flooding) are not yet studied in combination, and little is known about the effect on soil quality in citrus orchards. Therefore, the objective of this research is to get a better understanding of managing citrus orchards in relation to the chosen soil quality parameters, irrigation systems and the presumable benefits of a better soil quality under organic agriculture. Our hypothesis is that out of the four different managed orchard types the organically managed orchards with a drip irrigation system have the highest score on the studied soil quality parameters. For conventional orchard with flood irrigation we expect the opposite. We think that the research findings can contribute to an improved management of citrus orchard on Mediterranean type of soils under Mediterranean climatic conditions.

## 2. Materials and methods

### 2.1. Study site

The research area is located in Eastern Spain, in the province of Valencia (39°04′46″N, 0°25′44″W and 38°58′16″N, 0°35′06″W). The area has a Mediterranean climate, which implies an annual rainfall ranging from 498 to 715 mm year$^{-1}$ and 3 to 5 months of summer drought, with an average annual temperature of 14.2 °C. Frost is unusual in this area. The actual evapotranspiration for mature orange trees has been measured by Castel et al. (1987) and was between 660 and 750 mm $year^{-1}$ $tree^{-1}$. The soils in this area are developed in recent Quaternary, alluvial sediments (IGME, 2015). The soils of orchard 1 and 2 were classified as Cambisols and the soils of the other orchards were determined as Fluvisols (IUSS Working Group WRB, 2015). The selected orchards were studied as paired plots on neighbouring farms, to reduce the impact of spatial heterogeneity. Moreover, all orchards had non-sloping surfaces, which made them more comparable, and they have been ploughed and used for millennia. The only differences now are the contrasting management and irrigation strategies. The tree density of the orchard was similar for all orchards, on average about 500 trees $ha^{-1}$. The sampling was carried out in November 2014, a couple of weeks before the orange harvest.

In the conventional farms, both on the drip- or in the flood-irrigated orchards, Glyphosate (N-(phosphonomethyl)glycine) is applied in April, June, July and early September to keep the soil surface bare. NPK 15% (1.1 Mg $ha^{-1}$ yr) is applied as fertilizer and iron chelates plus zinc and manganese are added to the irrigation water (5 kg $ha^{-1}$) for conventionally managed orchards. The pruned branches are removed from the field and burned. Organic farms apply chipped pruned branches and weeds to the soil surface, as well as composted manure from sheep at a doses of 10 Mg $ha^{-1}$ and which contains 0.075% N, 0.031% P2O5, and 0.095% K2O. The manure is spread in winter on the soil surface of the flood-irrigated orchards and on the drips in the drip-irrigated farms. In organic farming orchards pests were controlled with an organic pesticide called Neem. However different chemical treatments (4 per year) were applied in the conventional farms. These included Chlorpyrifos (*O,O*-diethyl *O*-3,5,6-trichloropyridin-2-yl phosphorothioate) for a decade and currently Diflubenzuron. More details about the different orchards are given in Table 1.

### 2.2. Experimental design and soil sampling

Twelve orchards were selected as sampling sites. Soil samples were taken at two depths, 0–2 cm and 5–10 cm (Cerdà, 1999). Drip irrigated (DRP) plots were sampled 6 times for both soil depths and flood irrigated (FLD) plots were sampled only 3 times at the same two depths for each orchard, as the spatial variability is lower on the flood irrigated land (Cerdà et al., 2009a, 2009b; Cerdà and Jurgensen, 2011). Half of the studied orchards were organically managed (OR) and the other six were conventionally managed (CO), and for each of these six study sites three fields were flood irrigated (FLD) plots and the other three drip irrigated (DRP) systems. Three sampling point beneath the DRP system were chosen (WET), as well as three sampling points 1 m away from the DRP system (DRY). The irrigation system is characterised by two tubes that run along the row of trees. Each pipe is having a drip every meter. Undisturbed soil core samples were taken to determine dry bulk density at each chosen orchard using a cylindrical core sampler for a soil depth of 0–10 cm (Blake and Hartge, 1986).

**Table 1**
Division of the different orchards with size, number of years with drip irrigation and type of cultivar.

| Orchard # | CO/OR | DRP/FLD | Size (ha) | Switch to OR (years) | Period under DRP (years) | Type of cultivar |
|---|---|---|---|---|---|---|
| 1 | CO | DRP | 0.32 | – | 12 | *Orange navaline* |
| 2 | OR | DRP | 0.43 | 10 | 12 | *Orange navaline* |
| 3 | CO | DRP | 0.45 | – | 15 | *Orange navaline* |
| 4 | OR | DRP | 0.42 | 20 (always) | 20 | *Orange navaline* |
| 5 | OR | DRP | 0.42 | 20 (always) | 20 | *Orange navaline* |
| 6 | CO | DRP | 0.45 | – | 20 | *Orange navaline* |
| 7 | CO | FLD | 0.56 | – | – | *Orange navaline* |
| 8 | OR | FLD | 0.57 | 10 | – | *Orange navaline* |
| 9 | OR | FLD | 0.57 | 2 | – | *Orange navaline* |
| 10 | CO | FLD | 0.36 | – | – | *Orange navaline* |
| 11 | CO | FLD | 0.36 | – | – | *Diospyros kaki* |
| 12 | OR | FLD | 0.57 | 10 | – | *Orange navaline* |

CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation. Dark grey: CO+DRP; Lighter grey: OR+DRP; light grey: CO+FLD; blank: OR+FLD.

### 2.3. Soil and water analysis

The shear strength was measured in situ at each site by a pocket penetrometer (Amacher and O'Neill, 2004). The soil samples were air dried and sieved over 3 different sieves (2 mm, 4 mm and 4.8 mm) to obtain the aggregates with a size between 4.0 mm and 4.8 mm and the fine earth fraction (<2 mm). The texture of the fine earth material, was determined by dry sieving over sieves with a mesh of 1 mm, 0.5 mm and 0.2 mm. The fraction smaller than 0.2 mm was further analysed utilizing a Sedigraph 5100 to determine the fine sand, silt and clay fractions.

Aggregate stability was tested on the aggregates of 4 to 4.8 mm with the Counted Number of Drops (CND) test (Imeson and Vis, 1984).

The soil organic matter (SOM) was determined using the loss-on-ignition (LOI) method (Heiri et al., 2001). The concentrations of total C (Ct), total N (Nt) and total S (St) were measured by a CNS-analyzer (Elementar vario ElCube). $CaCO_3$ content was determined by the method of Wesemael (1955), which is based on weight loss by dissolution of $CaCO_3$, and from which the total inorganic carbon (TIC) was calculated. Soil organic carbon (SOC) was determined by subtracting TIC from Ct. The water extracts obtained after the pre-treatment for wet analysis with distilled water (1:10 soil-water) were analysed by the Inductively Coupled Plasma Mass Spectrometry (ICP-MS), IPC-OES OPTIMA 8000DV, and an Auto-Analyser (AA) Skalar SAN++ Segmented Flow Analyzer, fitted with a 1074 Autosampler. All properties, including electrical conductivity ($EC_{25}$) and pH ($H_2O$), were measured of the water extracts. ICP-MS measured the following elements and nutrients: total sulfur (St), total potassium (Pt), iron ($Fe^{2+}$), sodium ($Na^+$), calcium ($Ca^{2+}$), potassium ($K^+$), magnesium ($Mg^{2+}$), aluminium ($Al^{3+}$). Auto-Analyser (AA) measured the following elements and nutrients: ammonium ($NH^{4+}$), nitrate ($NO^{3-}$), nitrite ($NO^{2-}$), phosphate ($PO_4^{3-}$), sulfate ($SO_4^{3-}$), dissolved organic nitrogen (DON), total nitrogen ($N_t$) and chloride ($Cl^-$). The pH and $EC_{25}$ of the water used in the orchards for either drip or flood irrigation, were measured in the field and in the lab. Three different water sources were sampled: one spring

**Table 2**
Texture soil parameters for four different management types (weighed average 0–10 cm).

| Treatment | Classification | Bd (g $cm^{-3}$) | Sand >63 μm (%) | Silt 63–2 μm (%) | Clay <2 μm (%) |
|---|---|---|---|---|---|
| CO + DRP Mean (Std. Dev.) | Sandy Loam | $1.12^a \pm 0.46$ | 70.1 ± 15.7 | 27.5 ± 14.5 | 2.4 ± 1.9 |
| OR + DRP Mean (Std. Dev.) | Sandy Loam | $0.99^a \pm 0.15$ | 65.1 ± 8.0 | 32.9 ± 8.1 | 1.9 ± 0.5 |
| CO + FLD Mean (Std. Dev.) | Sandy Loam | $1.67^b \pm 0.03$ | 63.0 ± 7.8 | 34.7 ± 8.0 | 2.4 ± 0.4 |
| OR + FLD Mean (Std. Dev.) | Sandy Loam | $1.67^b \pm 0.02$ | 66.8 ± 3.6 | 30.6 ± 3.5 | 2.6 ± 0.7 |

Std. Dev: standard deviation; Bd: bulk density; CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation. Dark grey: CO+DRP; Lighter grey: OR+DRP; light grey: CO+FLD; blank: OR+FLD. However, the vertical grey line is only a seperation line.

**Table 3**
Average values with standard deviation of chemical soil properties ($EC_{25}$, pH, soluble salts and $CaCO_3$ content) for four different treatments (weighed average 0–10 cm). Values with different letters are significantly different at $p < 0.05$, for SOM at $p < 0.001$.

| Soil property | Treatment | | | |
|---|---|---|---|---|
| | CO + DRP | OR + DRP | CO + FLD | OR + FLD |
| pH ($H_2O$) | $7.65^a \pm 0.16$ | $7.48^b \pm 0.13$ | $7.52^a \pm 0.50$ | $7.75^a \pm 0.29$ |
| $EC_{25}$ (μS $cm^{-1}$) | $172^a \pm 114$ | $297^b \pm 114$ | $262^b \pm 140$ | $228^c \pm 96$ |
| Calcium carbonate (% of dry soil weight) | $20.98^a \pm 20.13$ | $24.81^a \pm 13.84$ | $50.65^a \pm 8.03$ | $4701^a \pm 1.16$ |
| SOM (% of dry soil weight) | $3.50^a \pm 1.30$ | $10.57^b \pm 4.48$ | $2.03^a \pm 0.31$ | $3.05^a \pm 1.41$ |
| Total soluble salts (meq 100 $g^{-1}$) | $1759^a \pm 573$ | $2917^b \pm 897$ | $2365^b \pm 829$ | $2278^c \pm 982$ |

SOM: soil organic matter; CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation. Dark grey: CO+DRP; Lighter grey: OR+DRP; light grey: CO+FLD; blank: OR+FLD.

and two wells, although all of them are coming from the same aquifer and the wells and spring are 2 Km apart. Orchard number 1 and 2 got irrigation water from the same source, a well. Orchard number 3 until 6 were irrigated by the same water basin from a well 1Km apart from the previous one. Orchard 7 until 12 were irrigated by water from the same stream, coming from a spring from the same aquifer as the previous orchards. The samples were analysed for iron ($Fe^{2+}$), sodium ($Na^+$), calcium ($Ca^{2+}$), potassium ($K^+$), magnesium ($Mg^{2+}$) and for ammonium ($NH_4^+$), nitrate ($NO_3^-$), nitrite ($NO_2^-$), phosphate ($PO_4^3$), sulfite ($SO_3^{2-}$) and chloride ($Cl^-$). using the same instruments as for the soil extracts. The SAR values were calculated.

### 2.4. Statistical analysis

We sampled 0–2 cm and 5–10 cm and measured the different parameters. To compare the different layers we did a statistical analysis for the separate layers and also for the whole top soil layer (0–10 cm). The average values of the whole layer 10 cm upper soil were estimated by using the weighted average concentration for each layer: 1/5 ∗ conc 0–2 cm + 3 / 10 ∗ conc 3–5 cm + 1/2 ∗ conc 5–10 cm. We estimated the concentration values of the layer of 3–5 cm from the mean of the over- and underlying layer. The values of the average concentrations of the layer of 0–10 cm are displayed in Tables 2, 3 and 4.

Boxplots and histograms were made for each parameter to understand the distribution characteristics. For all the parameters the Kruskal-Wallis tests was performed to determine if the groups differed significantly, because all parameters were not normally distributed. If significant, a multi-comparison test (Post Hoc) was conducted to verify which groups differ significantly from each other. The relationships between the variation of each parameter were explored using Spearman's correlations (rho).

**Table 4**
Average values with standard deviation of chemical soil properties (total C, N, S, Total Organic C, C/N ratio, DON, N—$NH^{4+}$, N—$NO^{3-}$, $P_t$, P—$PO4^{3-}$, $S_t$, S—$SO4^{3-}$) for four different treatments (weighed average 0–10 cm).

| Treatment | $N_t$ (%) | $C_t$ (%) | $S_t$ (%) | TOC | C/N (m/m) | $N_t$ (μg $g^{-1}$ soil) | DON (μg $g^{-1}$ soil) | N–$NH^{4+}$ (μg $g^{-1}$ soil) | N–$NO_3^-$ (μg $g^{-1}$ soil) | $P_t$ (μg $g^{-1}$ soil) | P–$PO_4^{3-}$ (μg $g^{-1}$ soil) | $S_t$ (μg $g^{-1}$ soil) | S–$SO_4^{2-}$ (μg $g^{-1}$ soil) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO + DRP | | | | | | | | | | | | | |
| Mean | $0.18^a$ | $4.72^a$ | $0.09^a$ | $3.12^a$ | 11.23 | 37.8 | $10.6^a$ | 2.8 | 33.2 | 8.1 | 5.3 | 43.1 | 35.5 |
| St.Dev. | 0.06 | 2.97 | 0.04 | 2.71 | 1.65 | 20.3 | 2.9 | 1.2 | 26.9 | 3.9 | 2.9 | 73.7 | 81.1 |
| OR + DRP | | | | | | | | | | | | | |
| Mean | $0.59^a$ | $9.15^a$ | $0.13^a$ | $5.89^b$ | 11.52 | 126.1 | 38.1 | 11.7 | 96.0 | 27.7 | 19.3 | 68.4 | 48.4 |
| St.Dev. | 0.25 | 4.45 | 0.04 | 2.23 | 4.39 | 71.4 | 12.6 | 3.6 | 75.6 | 9.2 | 7 | 71.4 | 62.5 |
| CO + FLD | | | | | | | | | | | | | |
| Mean | $0.17^a$ | $7.56^a$ | $0.05^a$ | $1.44^a$ | 6.94 | 70.9 | $8.6^a$ | 1.8 | 85.9 | 7.4 | 4.9 | 75.0 | 64.0 |
| St.Dev. | 0.03 | 0.62 | 0.02 | 0.49 | 0.16 | 75.2 | 2.3 | 0.0 | 107.7 | 3.4 | 2.6 | 51.4 | 48.7 |
| OR + FLD | | | | | | | | | | | | | |
| Mean | $0.29^a$ | $8.63^a$ | $0.08^a$ | $3.93^a$ | 6.56 | 98.5 | $21.5^a$ | 4.1 | 100.7 | 17.8 | 12.0 | 53.1 | 37.8 |
| St.Dev. | 0.16 | 1.30 | 0.04 | 1.15 | 4.27 | 86.2 | 11.5 | 1.7 | 113.6 | 12.0 | 8.6 | 39.0 | 29.7 |

Std. Dev: standard deviation CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation. Dark grey: CO+DRP; Lighter grey: OR+DRP; light grey: CO+FLD; blank: OR+FLD. However, the vertical line of grey is only a seperation line.

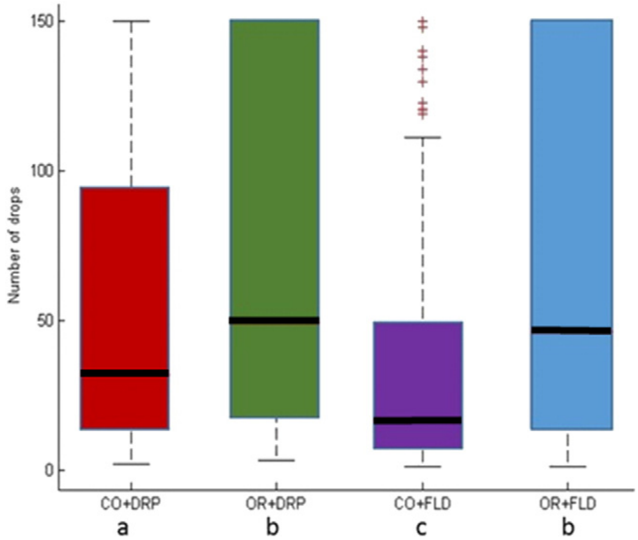


**Fig. 1.** Boxplot of counted number of drops for aggregate stability for four different treatments, with group indication (a, b or c), who are significantly different from each other (weighed average 0–10 cm). CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation.

## 3. Results

### 3.1. Physical soil properties

The analysis showed that OR had a higher aggregate stability in comparison with CO (Fig. 1). For OR no difference was found for the two irrigation types (DRP or FLD). However, when comparing the conventionally managed orchards it did make a difference which irrigation type was being applied. FLD irrigation had lower aggregate stability than DRP. As shown in Table 2, the grain size distribution analysis had the same soil texture classes for the four studied practices. These values were obtained by combining the orchards for the four treatments with both the surface and subsurface layer values. The bulk density of FLD irrigated orchards was significantly higher in comparison with DRP irrigated orchards (Table 2).

### 3.2. Chemical soil and water properties

The pH values were a bit above neutral (between pH 7.4 and 7.7 on average, Table 2) and OR + DRP was significant different from the other treatments ($p < 0.05$). The electrical conductivity ($EC_{25}$) values of the orchard's soils were between 183 and 294 ($\mu S\ cm^{-1}$) on average with a variation of around 100 $\mu S\ cm^{-1}$. The lowest average $EC_{25}$ value was of CO + DRP and the highest was of OR + FLD. The level of water soluble salts was found to be the highest for OR + DRP (2917 meq 100 $g^{-1}$), and the lowest for CO + DRP (1759 meq 100 $g^{-1}$), however this treatment showed a high variation. The values of soluble salts of both FLD irrigated (OR and CO) were similar (respectively 2278 meq 100 $g^{-1}$ and 2365 meq 100 $g^{-1}$). Calcium carbonate ($CaCO_3$) content was higher in FLD (ca. 50%) than in DRP irrigated orchards (ca. 22%) (Table 2). However, the carbonate content was not significantly different for the groups with different management treatments.

OR + DRP had the highest values of soil organic matter (SOM) with approximately 12% and was significantly different from the rest of the treatments, however this treatment showed a big range of the values (Fig. 2). The surface layer (0–2 cm) was higher in SOM content than the subsurface layer (5–10 cm) for all the 4 management types. This difference was the clearest visible for organic with drip irrigation (OR + DRP). The correlation between SOM and TOC was 0.98 ($p < 0.05$). SOM was positively correlated with the with DON 0.88 ($p < 0.05$).

Table 3 shows the average percentages for the $C_t$, $N_t$, $S_t$ content and C/N ratio. OR + DRP had the highest total nitrogen ($N_t$), total carbon ($C_t$) and total sulfur (St) concentrations and they were significantly different from the other treatments. FLD had lower values for the C/N ratio than DRP in combination with the two land management types and the differences were significant ($p < 0.05$). The variation of the sulfate ($SO_4^{2-}$) contents was very high. The total N ($N_t$) contents included the dissolved organic nitrogen (DON), ammonium ($NH^{4+}$), nitrite ($NO_2^-$) and nitrate ($NO_3^-$). It can be stated that OR + DRP had significantly the highest portion of DON of the total N ($p < 0.05$). 60% of $N_t$ was DON in comparison with around 20% of the other treatments. Other treatments had the highest share of nitrate ($NO_3^-$) in relation to $N_t$ (approx. 65%) and this difference was significant ($p < 0.05$). Additional correlations were found for the upper 2 cm of the soil in comparison with the subsurface layer (Table 5). The irrigation water properties (Table 6) were compared. pH was close to neutral for all samples. The SAR value was calculated for the three different irrigation water samples and was low.

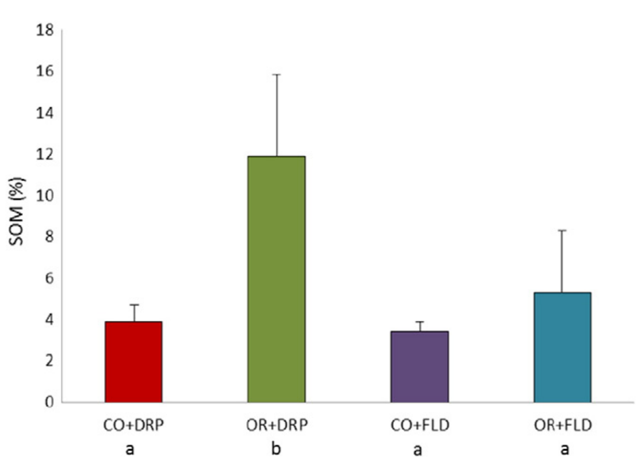


**Fig. 2.** Mean SOM with standard deviation for four treatments (weighed average 0–10 cm). CO: conventional; OR: organic; DRP: drip irrigation; FLD: flood irrigation.

## 4. Discussion

### 4.1. Physical soil properties

Previous research found that soil structure, biological and chemical processes and physical forces, like shrinkage and swelling (Allison, 1968; Oades, 1993; Pulido Moncada et al., 2015) is influenced by aggregate formation and stabilization. Cammeraat and Imeson (1998), Cerdà (1998) and Boix-Fayos et al. (2001) looked at aggregates in the Mediterranean and concluded that especially aggregates are an important indicator for soil quality. They also found that the clay and organic matter are the key factors on the aggregate stability. Land management can result in changes in organic matter (e.g. van Wesemael et al., 2010). This applies worldwide, as for other continents and regions, under different climatic conditions, many authors found that organic matter is the key factor to explain aggregate formation and aggregate stability (Stanchi et al., 2015; Aksakal et al., 2016; Gelaw et al., 2015; Luna et al., 2016).

Our results showed that organically (OR) managed orchards had a higher aggregate stability than conventionally (CO) managed orchards. This outcome is in line with the results of Mäder et al. (2002). In their research a 10 to 60% higher aggregate stability was found in organic plots, in comparison with the conventionally managed plots. Previous research states that aggregate stability is highly dependent on SOM content (e.g. Six et al., 2004). Cerdà (1998) found a positive correlation between SOC and aggregate stability in undisturbed forest soils in the Mediterranean. We found significant moderate to good positive correlations between SOM and aggregate stability only for the upper two cm of the soil (DRP: $r = 0.75$, $p < 0.00033$; FLD: $r = 0.77$, $p < 0.015$) for

**Table 5**
Correlations between different parameters in the surface layer (0–2 cm) and subsurface layer (5–10 cm) with $p < 0.05$.

| First variable | Second variable | 0–2 cm | 5–10 cm |
|---|---|---|---|
| St (%) | SOM | 0.8531 | – |
| Clay | SOM | −0.8182 | – |
| Pt(μg $g^{-1}$ soil) | SOM | 0.9021 | – |
| TOC | $N_t$ (%) | 0.9021 | – |
| TOC | Pt (μg $g^{-1}$ soil) | 0.8811 | – |
| TOC | P—$PO_4^3$ (μg $g^{-1}$ soil) | 0.8811 | – |
| TOC | N—$NO_3^-$ (μg $g^{-1}$ soil) | 0.9371 | – |
| N—$NO_3^-$ (μg $g^{-1}$ soil) | SOM | 0.9441 | – |
| N—$NO_3^-$ (μg $g^{-1}$ soil) | St (μg $g^{-1}$ soil) | 0.8811 | – |

SOM: soil organic matter; TOC: total organic carbon.

organically managed orchards, irrespective of irrigation type, and no correlation for the conventionally managed soils. For the subsoil (5–10 cm) no correlation existed. This difference can be explained by both the direct extra organic material input organic to the organically managed soil surfaces. Apparently the organic management does not yet have an impact on the subsoil, probably due to limited period of organic management.

Literature showed that the interactions between the clay and silt fractions and soil organic matter are other properties that influence the degree of soil aggregation (Boix-Fayos et al., 2001). Similar findings were found by Cerdà (2000) in Bolivia, where management was the key factor to explain soil aggregate stability and soil quality. However, in our research no significant correlation could be found between the amount of clay or silt present in the soil in relation with SOM or soil aggregation, as the variability of the soil texture properties was negligible as the soils are from the same type. Boix-Fayos et al. (2001) developed their research along a climatological gradient were soil properties were different due to different pedogenesis processes that resulted in clay rich soils in the wettest site, and where soil aggregation was higher. Bronick and Lal (2005) stated in a review that aggregation is positively influenced by an increasing amount of calcium carbonates, however our research did not confirm this. Soil aggregation and SOM are dynamic properties that react quickly to land use management, but especially soil texture will need more time to be affected by land management. This is relevant on soils were crusting is present and were the grain size and (lack of) organic matter are determining the formation of crusts (Arjmand Sajjadi and Mahmoodabadi, 2015; Gümüs and Şeker, 2015). Calcium carbonate contents will change depending on the water quality of irrigation water, and other sources of $CaCO_3$ such as fertilization and atmospheric dust deposition, as well as the temporal dynamics in water balance properties, such as percolation, rainfall, irrigation and evapotranspiration rates (Bast et al., 2015; Wang et al., 2016).

**Table 6**
$Mg^{2+}$, $K^+$, $Ca^{2+}$, $Na^+$, $SO_4^{2-}$, $Cl^-$ values and pH, $EC_{25}$ and sodium absorption ratio values for three irrigation water samples.

| Sample # (meq $L^{-1}$) | $Mg^{2+}$ | $K^+$ | $Ca^{2+}$ | $Na^+$ | $SO_4^{2-}$ | $Cl^-$ | pH | $EC_{25}$ (μS/cm) | SAR |
|---|---|---|---|---|---|---|---|---|---|
| 1 (orchard 1 + 2) | 1.93 | 1.9 | 5.14 | 0.84 | 1.99 | 0.63 | 7.27 | 635 | 0.45 |
| 2 (orchard 3 to 6) | 2.63 | 0.09 | 4.91 | 2.48 | 2.75 | 1.33 | 7.40 | 755 | 1.28 |
| 3 (orchard 7 to 12) | 3.01 | 0.07 | 4.26 | 2.16 | 2.80 | 1.33 | 7.57 | 680 | 1.13 |

SAR: sodium absorption ratio. The vertical grey line is only a seperation line.

The type of irrigation system in the orchards also has an impact on soil properties. Our result from the conventionally managed citrus orchard showed no difference in aggregate stability between drip-irrigated patches and non-irrigated patches. Meek et al. (1992) measured the influence of drip and flood irrigation and found that bulk density was higher for FLD irrigated plots, when the soil experiences slaking and compaction, which resulted in a loss of soil structure. In our research, the bulk density of FLD irrigated orchards was indeed higher than orchards with DRP irrigation. Moreover, Bulluck et al. (2002) found a lower bulk density for organic soil (OR) practices. Looking at our data, this is only the case if the organic practices are combined with drip irrigation (OR + DRP). It appeared that FLD irrigation overruled the benefits of organic management for this soil property. In our study a negative and significant correlation ($R^2 = -0.59$, $p < 0.05$) was found between bulk density (Bd) and SOM. This negative relationship is related to the fact that a) SOM has a lower density than the mineral phase, also taking into account that the texture and origin of the soil was the same for all orchards; and b) organic matter will enhance soil biological activity and hence macro-pore development. This will result in a fast decrease in the bulk density (Table 2), as organic managed soils also are not affected by biocides. Previous researchers found this negative relationship between organic matter and soil bulk density under different types of soils and managements (Arvidsson, 1998; O'Sullivan, 1992; Jakšík et al., 2015; Laudicina et al., 2015).

### *4.2. Chemical soil properties*

The sodium absorption ratio (SAR) values indicated the suitability of the applied irrigation water (Table 6). For all sources, the water samples were classified as suitable based on salinity and sodium hazard index based on Richards (1954). As we found comparable chemical properties of water, we can contribute the observed changes in soil properties to other factors than water quality. Several researchers (Reganold, 1988; Drinkwater et al., 1995; Mäder et al., 2002) reported higher pH values in organically managed fields than in conventional plots, but this was in soils with low pH, whereas the soils of the citrus plantations had a pH > 7. We only found lower pH's if OR was combined with DRP, however the differences were small. $CaCO_3$ present in our soils function as a buffer for the deprotonation of SOM. The soil's calcium carbonate content for flood irrigated orchards was nearly twice as much as that for drip irrigated orchards (Table 3). It can be concluded that due to flooding a larger amount of $CaCO_3$-containing water is added to the soil in comparison with DRP irrigation.

Many researchers found increased total SOM concentrations of surface soils at organic farms in comparison with conventionally managed farms at different climatic conditions (Drinkwater et al., 1998; Bulluck et al., 2002; Edmeades, 2003; Marriott and Wander, 2006). We also measured a higher level of SOM for organic farms, however the difference was even more profound for the organic farms that utilized drip (DRP) irrigation (Fig. 2). Geleta et al. (1994) stated that $N_t$ and $NO_3^-$ losses are reduced due to drip irrigation. Moreover, Liebhardt et al. (1989) stated that soils in organic production systems lose less $N_t$ into the water system in comparison with conventional management, but this is most likely due to the fact that the N applied in conventional farms is not coming from manure but from artificial fertilizers. Marinari et al. (2006) found a remarkably higher $N_t$ content in organic fields in comparison with conventional fields. In our study, all N-containing compounds were the highest for organically managed orchards with drip irrigation (OR + DRP), followed up by organic farms with flood irrigation (OR + FLD) (Table 4). Even though the conventional orchards had application of nitrogen during six months of the year these orchards were still lower in $NH_4^+$, $NO_3^-$, and $N_t$. The cleaning step of the tubes of DRP irrigation by nitric acid ($HNO_3^-$) could have an effect on the nitrate content. However, the nitrate values of CO + DRP were the lowest, so the influence of the cleaning step can be neglected.

Thus, the positive effects for N containing compounds of organic management are enhanced by the combination of DRP irrigation, which is in line with previous research.

The C/N ratio is an indicator of the decomposition processes of plant residues in the soil. A high C/N ratio > 60 indicates a relatively slow decomposition and slow SOM turn-over, which is characteristic for forest litter decomposition (Adams and Attiwill, 1982) and a low C/N ratio of 10–20 indicates a fast decomposition, which was found by e.g. García-Gil et al. (2004) in agroecosystems in the Mediterranean with a C/N ration between 5 and 16. In our research we found values of C/N ratios of around 10, which indicate fast decomposition rates. Drip irrigated farms, either with CO or OR, had the highest C/N ratios, thus the slowest decomposition rate. This could be explained by the fact that more recalcitrant organic matter is present. However, it would be expected that flooded soils would have slower decomposition rates, because the soils have temporarily anaerobic conditions after the application of water (Davidson and Janssens, 2006). Our findings could indicate that the drip systems are experiencing water stress due to a lower moisture content and this would mean that the decomposition is triggered by moisture content. Previous work (e.g. Reganold, 1988; Mäder et al., 2002; Marinari et al., 2006) found higher microbial biomass content and activity in organic fields than in soils of conventionally cropped fields. This could be resulting in higher decomposition rates and thus lower C/N ratios for different land management types. The higher microbial activity in organic fields, reported by Marinari et al. (2006), was found after a period of at least seven years of organic management. However, in our research differences were small and not significant between C/N ratios for different treatments, which correspond with the findings of Soriano et al. (2014) for soils in olive groves.

The most apparent correlations in our study were found in the surface layer (Table 5). This could be explained by the fact that the management choices effect initially the first few centimetres of the soil. Other effects of different management treatments were also found for certain parameters. It would be interesting to investigate the mechanisms and dynamic processes behind these parameters more profoundly in cultivated soils. Another recommendation for further research is to investigate the quality of SOM, as this could tell us more about the soil quality. The quality of SOM, as well as its accessibility, could change the conclusions about the soil conditions for different management treatments.

The sampling of the soil and water samples was conducted in November. However, some soil quality indicators, such as the transformation and decomposition of organic material, could vary by season. A bigger dataset of sampling periods and more years could improve the conclusions drawn in this research. More sampling periods could also tell us more about the fluxes of nutrients and changes in parameters during transition from different management practices.

## 5. Conclusion

The aim of this research was to find differences in the selected soil quality parameters between different management treatments. Organic management practices were found to be beneficial for the chosen soil quality parameters, compared to conventional management for soils with comparable textures and applied irrigation water. Aggregate stability was found higher for organic farming and the amount of SOM was higher for OR farms. The SOM content and N-containing compounds were found to be even more elevated when the soils with organic treatment were combined with drip irrigation. When comparing drip and flood irrigation the stabilizing effect of aggregates was not significantly different. Bulk density was lower for drip irrigation. Although there are some points of discussion, like the number of sampling periods and the amount of years, we conclude that the differences in chemical and physical soil parameters showed that agricultural land management together with irrigation management had an important influence on the different soil quality parameters. It is therefore recommended for farms to consider a switch from flood-irrigated, conventionally managed farms to drip-irrigated, organic agriculture to reach and improve soil quality in citrus orchards.

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