



Effects of combination of tillage with olive mill wastewater on soil organic carbon groups in arid soils

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Abstract

Soil fertility in arid areas is poor due to the climatic conditions, weak natural biomass and inappropriate agricultural practices. Soil fertility can be determined by assess the chemical composition of soil organic carbon (SOC) and soil organic matter (SOM) quantity in different systems of soil management. To identify efficient field management practices for enhanced soil fertility in arid regions, the impact of combination tillage with olive mill wastewater as compared to native vegetation were studied for more than 20 years of field experiment. Soil samples were collected from three field management treatments and three replicates for each treatment localized in Chaâl area in southern Tunisia. Field experiment includes uncultivated soil (NC) for more than 80 years (since 1936), with native vegetation, cultivated and tilled soil (CT1) and tilled soil with addition of 5 l.m⁻² of olive mill wastewater (CT2). Soil properties were assessed and principal component analysis (PCA) was executed. In addition, structural functional carbon groups were investigated using MIR spectroscopy. The results showed that NC had the highest significant values of moisture content, soil organic matter, and exchangeable cations. This is likely to be due to the role of humified organic matter with colloidal properties. Significant reduction in pH and cation exchange capacity values were found in CT2 conversely to CT1. Olive mill wastewater mineralization provided soluble ions increasing electrical conductivity. MIR analyzes determined higher absorbance of aromatic/aliphatic C in NC and CT2 more than in CT1. Long-term using olive mill wastewater application improved soil carbon groups, which lead to the SOC stabilization for long-term sequestration in arid climates.

Keywords Soil quality · Tillage · Olive mill wastewater · MIR spectroscopy · Arid regions

Introduction

Soil fertility is an important aspect of soil productivity and combines biological, chemical, and physical soil properties that affect nutrient availability (Moral et al. 2017). It is related to soil organic matter (SOM) and to chemical composition of soil organic carbon (SOC). In fact, SOC amounts are the result of the balance between carbon input from plant residues and

organic waste added to soil and loss of carbon through SOM decomposition. In arid regions soils have a very low nutrient availability and low SOM less than 1% (Yaakoubi et al. 2010). This low SOM is considered as a serious problem for agriculture in those regions where high temperatures and droughts can accelerate its decomposition (Conant et al. 2011). In addition, to the weather conditions, the decline of SOM in cultivated soil is exacerbated due to the tillage intensification (Giongo et al. 2011). Indeed, tillage accelerates oxidation of SOM by soil microorganisms through changes of soil water, aeration and temperature regimes, aggregation, and nutritional environment (Doran and Smith 1987). Therefore, tilled soils contain less SOC than untilled ones especially on the soil surface (Tomas et al. 2007). Tillage intensification decreases also chemical composition of SOC (aliphatic, aromatic, and other functional organic groups). Several researchers such as Tivet et al. (2013) investigated the effect of tillage on soil organic carbon groups in arid climates. They demonstrated a significant increase of aliphatic C1 and aromatic C1 groups in

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the top soil (0–20 cm) under native vegetation and no-tillage system that is more than soil with conventional tillage. Therefore, native vegetation residues accumulated on soil surface can improve SOM and chemical compositions of SOC. Indeed, the application of fertilizer and plant residue input on soil increases SOC (Limin et al. 2015; Mori and Hojito 2015; Poeplau and Don 2015). Moreover, while adding manure, the organic fertilizer increases the amount of nutrients and SOM (Moussadek et al. 2014). No tillage also had positive effects on SOC (Jarecki and Lal 2003; Christopher and Lal 2007). In Spain, Alvaro Fuentes et al. (2008) showed that no tillage increases SOC stock in the soil compared to cultivated land. However, no tillage is hard to be applied in arid climates with high water scarcity for enhancing soil fertility. Indeed, in these areas, water scarcity is the major limiting factor and long drought is faced every year during 4 to 6 months. During this period any competition to water with cultivated crop is avoided by tillage and, due to lack of water, it is hard to maintain cover crops. Thus, among the possible solutions were reduced tillage, and using the combination tillage with organic waste to enhance soil quality for crop production in agricultural land. Indeed, the impacts of a combination of tillage with fertilizer type as compared to plant residue input on SOC rates were studied in northern Japan (Koga 2017). This study reported that the combination tillage with organic waste (green manure and compost of cattle manure) and plant residues enhances SOC amounts conversely to the reducing tillage which does not enhance SOC rates. However, Koga (2017) limited their work to quantitative evolution of SOC with no information on qualitative aspects.

In arid regions, the low soil fertility and the need for water scarcity lead farmers to use olive mill wastewater (OMW) as an adopted management strategy that enhances soil quality. Indeed, more than 30 million m³ of OMW are produced annually in Mediterranean basin (D'Annibale et al. 2004) by three phases olive oil extraction plant. Some countries, like Italy and Tunisia, adopted OMW spreading in agricultural land as a solution. Spain shifted to two-phase system without generation of OMW. When OMW was produced, it caused a serious environmental problem because it is characterized by large volumes, low pH, salinity, and high amount of organic matter, and phenolic compounds (Federici et al. 2009; Piotrowska et al. 2011). However, OMW is considered as an organic amendment as it is rich with organic matter and nutrients. Therefore, arid soils could benefit from OMW application (Paraskeva and Diamadopoulos 2006). In fact, many researchers (Chaari et al. 2013; Gargouri et al. 2014) showed that applying OMW on arid soil for short-term and long-term decreases soil pH and increases electrical conductivity (EC), SOM, and mineral status. OMW application can also promote plant growth in the short-term (Mekki et al. 2013; Rusan et al. 2016). Spreading OMW under long-term increases soil bulk density (Mohawesh et al. 2014) and aggregates stability (Levy

et al. 2018). Nevertheless, Mollaei et al. (2010) reported the inhibition of the multiplication of soil microorganisms after OMW application by the toxicity of phenolic compounds. Most of these studies were performed, at small scales, to assess the impact of the direct application of OMW on the fertility of bare soils and on the chemical and physical properties and plant performance (Mekki et al. 2006). OMW spreading on soil improves SOM content and soil fertility (Chen et al. 2010; Gotosa et al. 2011). It also may constitute a valuable approach for SOC rates (García et al. 2011). Therefore, more emphasis needs to be placed on the qualitative changes on SOC in arid environment. SOC quality can be determined by the functional organic carbon groups on soil. Nevertheless, to the best of our knowledge, the impact of the combination tillage with OMW for the long-term on SOC quality in arid soils has never been studied. The impact on soil organic carbon groups is highly important since the aromatic, aliphatic groups, and other functional groups have been responsible for SOM preservation (Gomez et al. 2017). These functional organic groups increase during organic matter decomposition indicating the increase of humification degree as demonstrated during composting process (AitBaddi et al. 2004). Spectroscopic techniques MIR are reliable to assess the SOC changes with regard to chemical and structural characteristics due to the different types of management (Laudicina et al. 2015; Blanco-Moure et al. 2016). In fact, MIR is efficient for the detection of aliphatic, carboxyl-functional groups, and for different levels of complexity's compound such as polysaccharides, aromatic, and phenolic compounds due to specific bands (Bornemann et al. 2010; Calderon et al. 2013).

This study aims to understand how combination tillage with OMW application influence a range of functional soil properties on the long-term in arid agro-ecosystems of south-eastern Tunisia, and to assess changes of functional organic carbon groups using MIR spectroscopy under uncultivated soil and two contrasting cultivated soils in arid climates.

Materials and methods

Description of experimental site

The study area is located in Sfax-Tunisia and called Chaâl (34°51'63", 10°06'43"). This organic agricultural area has a surface of 18,000 ha and is composed of more than 12 farms. The majority of the soil texture in this area is sandy (Soil texture data provided by the Chaâl farm station 2016). Different soil managements were identified in studied area: cultivated soils planted with olive trees for long and short-term periods, one uncultivated soil in the long-term with native vegetation (Natural soil). Planting density is the common density used in the region corresponding to 17 trees/ha with a

squared grid of 24 m. The climate of the region is an arid Mediterranean climate. At the study period, the mean temperature was 23 °C and the average annual rainfall was 143 mm of studied area (Climatic data provided by the Chaâl farm station 2016).

Study design and trial management

The experimental field was a site covering a whole surface of 80 ha. Within this site three treatments corresponding to different soil management practices. Each treatment was composed from three parcels. Thus, three parcels were considered as replicates for each treatment. The first treatment (NC) has been an uncultivated soil for more than 80 years (since 1936) covering 20 ha. The NC treatment has been soil colonized by native arid vegetation since 1934. In treatment NC three parcels were considered separated by at least 200 m and covering each 2 ha. It was considered as a control soil without any amendment and farming practices.

The second treatment was a cultivated soil with frequent soil tillage and without amendment for the last 80 years (CT1) covering 40 ha. Within CT1 treatment three parcels were considered separated by at least 200 m and covering each 6 ha. The third and last treatment was a tilled plot with yearly addition of 5 l.m⁻² of OMW for 20 years (CT2) covering 20 ha. During the olive mill operation (from early November to late December) OMW was spread, since 1996 until 2016 yearly, homogeneously on the soil covering the entire surface between trees. Within CT2 treatment three parcels were considered separated by at least 200 m and covering each 2 ha.

CT1 and CT2 treatments were tilled to depths varying between 5 and 25 cm five times a year using tractor driven cultivator. These soils were tilled five times a year i.e., twice before blooming during winter and early spring (for weed control, aeration of soil ...), one more in late spring (for weed control), one very superficial during summer to destroy capillarity channels and reduce evaporation and one reaching the depth of 20 to 25 cm during autumn to break compaction according to the local agricultural management practices. In fact, in this arid region, farmers' practices to mitigate high temperatures and low rainfall aim to avoid any competition for water by eliminating any natural vegetation and reduce evaporation through tillage.

Physical and chemical analyzes of the OMW are presented in Table 1.

Fresh OMW was taken from an olive oil extraction plant located in Chaâl Sfax, Tunisia. In General, there is low variability of the composition of OMWs between seasons and within the same season. In fact, The OMW's characteristics depend on the olive variety, climate conditions, and cultivation practices as well as on the oil extraction process. In our study, since 1996 the used OMW has been produced in the olive mill of Chaâl farm from fruits and trees of same variety

Table 1 Chemical characteristics of fresh Olive mill wastewater from Chaâl Sfax, Tunisia (average values of three replications ± SD for each sample)

Parameters analyzed	Values
pH	4.56 ± 0.28
Electrical conductivity (mS /cm)	22.35 ± 0.42
Organic carbon(%)/DM	42.71 ± 0.11
Organic matter (%)/DM	86.8 ± 0.23
Total nitrogen %/DM	1.57 ± 0.01
C/N	27.20 ± 0.06
Calcium (mg /kg)	5700 ± 0.12
Potassium (mg/kg)	33,600 ± 0.22
Sodium (mg/kg)	22,000 ± 0.21

(Chemlali) belonging to the same farm, under the same climatic conditions, and cultural practices. Compositions of OMW were in agreement with others reported by Gargouri et al. (2014) who worked in the same field.

Soil sampling

Fifteen soil samples were collected randomly using soil auger from every treatment. In fact, five soil samples were taken from each parcel. Samples were taken from the superficial layer to a depth of 20 cm. All soil samples were air dried and sieved on a sieve with a 2 mm mesh prior to analytical analysis.

Soil analysis

Particle size distribution was determined by the Robinson pipette's method and the texture were determined from the particle size analyzes using the texture diagram (Gee and Bauder 1986). Soil moisture content was measured immediately after sampling (soil samples were placed in sealed plastic bags and isolated container during the transport to the laboratory 40 min) by drying samples at 105 °C until weight constancy for 48 h. The pH was measured in water suspensions (1:5 w/v) using a pH meter (type Mettler Toledo MP 225). The electrical conductivity (EC) was determined on the liquid extract of the saturated paste after 4 h of rest and measured by a conductivity meter AME type 123 at 25 °C. The chloride (Cl⁻) concentration was measured by silver nitrate titration (Pauwels et al. 1992). The carbon content was determined by the dichromate oxidation technique as described in the Walkley and Black method (Pauwels et al. 1992). The amount of organic matter (OM) in the soil was indirectly determined through carbon content determination using a multiplication factor of 1.72 (Pauwels et al. 1992). Cation exchanges were first extracted by stirring 5 g of soil with 100 ml ammonium acetate (0.1 N) during 60 min followed by filtration. The filtrate was then

analyzed by atomic absorption spectrophotometry (Pauwels et al. 1992).

The cation exchange capacity (CEC) was determined after saturation of the adsorption sites by a 1 N ammonium acetate solution and the desorption of NH_4^+ by K^+ was performed using 1 N KCl. The CEC was estimated by the amount of desorbed K^+ (Pauwels et al. 1992).

Physical and chemical analyzes were performed in triplicate for each soil sample.

MIR spectral data acquisition

Diffuse reflection Mid-infrared spectroscopy data were acquired using a Fourier transform MIR-spectrometer equipped with a high throughput HTS accessory (Bruker Optics, Ettlingen, Germany). Soil samples are loaded into shallow wells in multiplate accessory with 96 wells using a micro spatula. Samples are replicated four times. The MIR spectra ($4000\text{--}400\text{ cm}^{-1}$) were acquired at a resolution of 4 cm^{-1} and with a co-addition of 64 scans. For MIR analysis all soil samples were analyzed. Forty-five soil samples were analyzed. The reported spectrum is the mean spectrum for each treatment.

7Data analysis

Descriptive analysis of the data sets was performed by classical statistics, determining minimum, maximum mean values, and the skewness. The mean value was calculated on the basis of 15 soil samples collected from each plot. The data were submitted to variance analysis using SPSS 13.0 for windows. The mean values of the treatments were compared using the Tukey's range tests at 5% level of significance ($p = 0.05$).

Principal component analysis (PCA) was applied based on the correlation matrix between the components and standardized variables using XLSTAT.2014. PCA was used to cluster patterns of 45 soil samples collected from three different agricultural plots based on their physical and chemical analysis.

Results

Soil properties

Particle size distribution of the soils indicated that studied soils have coarse soil texture with low clay content, high sand content in CT1 and NC and high silt in CT2. Thus, NC and CT1 had sandy loam texture. Conversely CT2 had silt loam texture. Analyzes of moisture content showed that NC had a higher significant value ($3.18\% \pm 0.84$). The low significant values ($1.06\% \pm 0.94$ and $1.34\% \pm 0.84$) were recorded in both plots CT1 and CT2. Soils NC and CT1 were alkaline and soil CT2 was

acid. The mean highest EC was found in CT2 followed by NC and the lowest value was recorded in CT1. A decrease of soil chloride content was recorded in CT1 as compared to NC. On the other hand, chloride concentration had not decreased in CT2. This plot had higher chloride content as compared to CT1 and NC plots.

Significant difference of SOM concentration was determined between CT1, NC, and CT2. The low amount ($0.82\% \pm 0.45$) was recorded in CT1 soil while it reached $1.87\% \pm 0.35$ in CT2 and $3.19\% \pm 0.93$ in NC soil.

The highest mean CEC was observed in NC, followed by CT1 soil, and the lowest under CT2, despite CT2 with OMW, the NC stayed always with the highest CEC content. Exchangeable cation values (calcium, sodium, and potassium) in soil NC were higher than those in soil CT1 and CT2. There is not a large difference between exchangeable cation values if one compares CT2 with NC (Table 2).

Principal component analysis

The principal component analysis (PCA) showed the correlation between soil properties under each treatment. PCA analysis for NC treatment showed that the pH was correlated positively with EC, CEC, moisture content, Cl^- and potassium according to factor 1 (Fig. 1a). On the other hand, the pH variation was opposite to SOM 1. It was correlated negatively with calcium and sodium. SOM was correlated to calcium and sodium negatively according to factor 1 (Fig. 1a).

The CT1 treatment and PCA analysis found that the pH, SOM and group included CEC, EC, and Cl^- , and moisture

Table 2 Soil properties under conventional tillage (CT1), no-tillage with native vegetation (NT), and conventional tillage combined with OMW application (CT 2). (Means with different letters indicate a significant difference at $P = 0.05$)

Soil property	Cultivation practices		
	CT1	NC	CT2
Clay (%)	0.17	0.23	0.36
Silts (%)	37.07	33.46	70.69
Sand (%)	62.75	66.30	28.94
Moisture content(%)	1.06 ± 0.94^b	3.18 ± 0.84^a	1.34 ± 0.79^b
pH	9.17 ± 0.76^a	8.34 ± 0.68^b	6.78 ± 0.64^c
EC (mS/cm)	0.48 ± 0.17^b	0.54 ± 0.40^b	1.44 ± 0.44^a
Chloride (meq/l)	25.8 ± 0.19^c	236.94 ± 0.87^b	481.46 ± 0.97^a
Organic matter (%)	0.82 ± 0.45^c	3.19 ± 0.93^a	1.87 ± 0.35^b
CEC (cmolc/kg)	4.91 ± 0.85^a	5.96 ± 0.93^a	2.95 ± 0.96^b
Calcium (%)	3100 ± 0.28^b	4500 ± 0.25^a	4700 ± 0.17^a
Potassium (%)	100 ± 0.01^b	700 ± 0.08^a	800 ± 0.08^a
Sodium (%)	500 ± 0.02^b	100 ± 0.02^a	100 ± 0.04^a

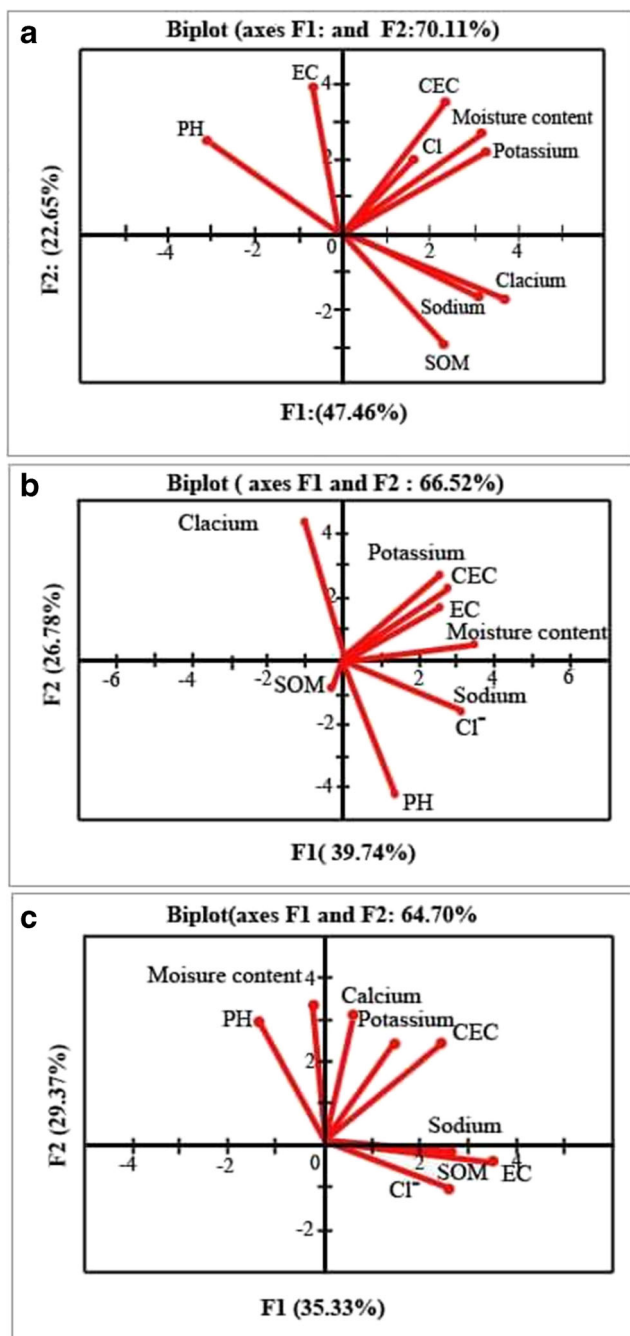


Fig. 1 Biplot of a correlative scaling of the principal component analysis (PCA) of soil properties in uncultivated soil (NC) since 1936 with arid native vegetation (A); soil properties in cultivated and tilled soil (CT1) for more than 80 years (B); soil properties after application olive mill wastewater with tillage for more than 20 years (C)

content and potassium were correlated positively according to factor 1. On the other side, the pH was correlated negatively with calcium according to factor 1 (Fig. 1b).

PCA analysis for the CT2 treatment (Fig. 1c), pH and moisture content were correlated positively according to factor 1. CEC, calcium, and potassium were also correlated positively according to factor 1. SOM, EC, Cl⁻ and sodium were

correlated positively according to factor 2. The pH correlated negatively with CEC, potassium, and calcium according to factor 1 (Fig. 1c).

MIR spectroscopy

Qualitative analysis and signals of MIR spectroscopy are presented in Fig. 2 and Table 3 respectively. The occurrence of absorbance bands in the vicinity of 3622, 3392 and 3388 cm⁻¹ indicated the presence of the kaolinite and gibbsite in soil samples. Signals centered around 2922 cm⁻¹ and 2852 cm⁻¹ were termed aliphatic C2 (Tivet et al. 2013). These bands were only observed in the spectra of samples from NC and CT2 plots. In addition, the spectra showed a band around 2230 cm⁻¹, more intense in spectra of samples from CT2 plots, that may be due to organic molecules (-CH2, -CH3, and -NH3), SiOH bonds, cation OH bonds in phyllosilicate minerals (kaolinite, montmorillonite) (Conforti et al. 2015). The signals around 1630 cm⁻¹ are characteristics of aromatic C=C vibrations and asymmetrical stretching C=O of COO (Tivet et al. 2013). The signal of aromatic C=C vibrations was higher in spectra of samples issued from NC and CT2 plots than CT1 plot. Bands in the signal around 1462 and 1423 cm⁻¹ characteristic of axial deformation in phenolic O-H group, with aliphatic C1, H₂O, and amine (Carra et al. 2017) cannot be clearly observed in spectra of samples issued from CT1 plots. In contrast, these groups were present in spectra of samples from CT2 and NC plots. In addition, peaks at 1100, 800, and 700 cm⁻¹ are possibly due to Si-O stretching and bending or OH bending vibrations (Madejova 2003).

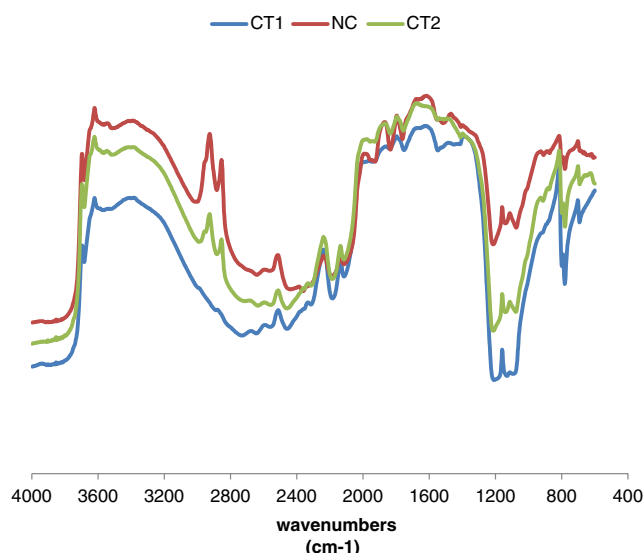


Fig. 2 MIR spectra of soil samples (0–20 cm) from a cultivated and tilled soil for more than 80 years (CT1), tilled and treated soil over 20 years with olive mill wastewater (OMW) and uncultivated soil for more than 80 years with arid native vegetation (NC)

Table 3 Fundamental vibration and functional group of major MIR bands observed in soil samples

Wavenumbers (cm ⁻¹)	Vibration and functional Group	Reference
3392	O-H stretching of kaolinite	Brinatti et al. 2010
3622	O-H stretching of kaolinite	Carra et al. 2017
3388	O-H stretching of gibbsite	Brinatti et al. 2010; Balan et al. 2006
2922	C-H Aliphatic groups stretching	Tivet et al. 2013
2852	C-H Aliphatic groups	Tivet et al. 2013
2230	SiOH bonds, cation O-H bonds in phyllosilicate mineral stretch	Conforti et al. 2015
1630	C-C Aromatic groups and C-O stretching of carboxylic acid anions	Cocozza et al. 2003
1462	deformation of C-H -CH ₂ and -CH ₃ groups	Carra et al. 2017
1423	Deformations of O-H phenolic groups and aliphatic group	Carra et al. 2017
1100, 800, 700	Si-O stretching and O-H bending absorptions	Madejova 2003

Discussion

Change soil properties with tillage and OMW application

Soil texture is the most fundamental quantitative soil physical property that influences most of the other properties and processes of the soil (Fisher and Binkley 2000). Thus, soil capacity for carbon storage depends on the distribution of their particle size (Arrouays et al. 2006). Thus, in coarser soil textures, the potential carbon sequestration is small, near zero, while the carbon storage potential is high in fine soil textures (clay soils). Indeed, Najmuldeen et al. (2010) assess the effects of soil texture of six textural classes (sandy loam, loamy sand, silty loam, silty clay loam, clay loam, and loam) on chemical compositions and carbon mineralization in soil. They found that carbon mineralization in fine soil textures (clay loam, loam, and silty clay loam), is significantly ($p \leq 0.01$) higher than coarser soil textures (silty loam, loamy sand and, sandy loam). They did not found differences between sandy loam and silty loam textures. Studied treatment (NC, CT1, CT2) have poor structure and low SOC storage.

The highest values of moisture content found in NC have indicated that uncultivated plots have higher moisture content. Therefore, it can be said that tillage reduced moisture content. This higher moisture content could be attributed to the minimum soil disturbance with little exposure of the soil surface to the atmospheric demand and with consequent reduction of water in soil. Our results were in accordance with Kargas et al. (2012), whom reported that untilled plots retain more water than tilled plots. Indeed, higher moisture content was registered in topsoil (0–10 cm) under no tillage (McVay et al. 2006). The increase of moisture content in CT2 as compared to CT1 can be due to the effect of OMW application given that tillage reduces soil moisture content. Indeed, where the content of SOM is greater, more water can be stored especially in topsoil (Bot and Benites 2005). This is can be confirmed also

by OMW's application during 20 years with tillage which led to an increase in soil moisture content in soil CT2. It has been suggested that continuous application of OMW increases soil water retention capacity (Mohawesh et al. 2014). In fact, the higher organic matter and salts content on OMW blocked large sized pores thus, OMW reduced large soil pore and improve soil water holding capacity (Mahmoud et al. 2010). Thus, OMW's application seemed to improve soil water holding capacity. Tillage with OMW's application could be a means for water storage in particularly arid climates and semi-arid countries.

The lower value of soil pH in NC as compared to CT1 can be attributed to the higher concentration of organic matter accumulated on soil surface which cause an increase in the concentration of electrolytes and pH reduction (Rahman et al. 2008). However, tillage reduces SOM, and therefore, the soil's ability to resist changes in soil pH. The lower value of soil pH in CT2 may be due to the low pH of OMW and their higher content inorganic matter since organic acids are also produced as a result of OM decomposition (Bot and Benites 2005). OMW's application on soil had a significant decrease on the pH soils (Lopez-Pineiro et al. 2006). The low soil pH improves the solubility and availability of certain nutrients (P, Fe, Mn, Zn, B, and Cu) in soils (Mohammad and Mazahreh 2003). OMW's application on soil for long-term can be efficient to reduce soil alkalinity and to improve the availability of nutrients for crops. Indeed, in most cases, a pH range of 6.0–7.5 is optimum for the adequate availability of nutrients in the soil (BARC 2005).

The highest mean EC value determined in CT2 as compared to NC and CT1 may be due to the high mineral content of the effluent (Gargouri et al. 2014). This increase may be explained by the mineralization and transformation of organic matter on soil. Indeed, EC's increase after OMW's application was also described in other studies (Lopez-Pineiro et al. 2006) following short- and long-term field and greenhouse studies. Thus, the spread of OMW leads to increase in soil salinity.

The decrease of soil Cl^- in CT1 may be due to the downward movement of chloride with water infiltration into deeper layers. In addition, chloride is highly soluble and remains in the soil solution (Abyaneh et al. 2004). The highest concentration of Cl^- in amended and tilled plots could be due to its concentration in OMW (Mollaei et al. 2010). In fact, the OMW has the highest value of Cl^- (Bouknana et al. 2014). This high Cl^- content is due to OMW wealth from fruits and used water in extraction process. Indeed, chlorides are important inorganic anions contained in varying concentrations in the OMW (Bouknana et al. 2014).

The highest levels of SOM in NC were due to the accumulation of native vegetation in soil surface. This confirmed that with no tillage system, plant residues left on the soil surface enhance the SOM concentration in top soil (Conceição et al. 2013). Low SOM concentration in CT1 can be explained by the effect of tillage. Tillage reduced the production of natural biomass and revolved the top soil enhancing exposure of organic matter to degradation. Indeed, tillage, when combined to aridity, avoided quasi totally natural biomass production. Moreover, aridity and organic matter exposure to oxidation by tillage accelerated the SOM degradation and mineralization. In fact, many studies reported that the SOM content in soils of Chaâl area is very low (less than 1%) (Gargouri et al. 2014).

The higher amounts of SOM in CT2 can be attributed to OMW which is rich in organic compounds. Thus, OMW's application in the long-term can be used to enhance SOM in soils. Zenjari and Nejmeddine (2001) confirmed that OMW's application induces an increase of SOM concentrations in soil surface. Thus, OMW's application is a good strategy to restore SOM in arid areas mainly after removal of their phenolic compounds (Piotrowska et al. 2011). Using combination tillage with OMW's application for long-term helps build SOM and improves nutrients in the soil surface which enhanced soil fertility.

The significant difference between CEC concentration in NC and CT1 may be an indication that tillage and cultivation reduce soil CEC. Tarkalson et al. (2006) reported greater CEC under no-tillage due to the increased potential of conserving plant nutrients. Yet, low CEC could be due to low clay and organic matter concentration in CT1, since this plot had a low content in SOM of $0.82\% \pm 0.45$, and clay content of 0.17%. Low CEC concentration in CT2 can be explained by the effect of OMW's application on soil pH. There is a strong relationship between the CEC and the pH of the soil, since the soil pH increases with the increasing of CEC concentrations. In fact, in this treatment with the lowest pH, CEC was lower. Indeed, acid soils have a low CEC (Baligar and Bennett 1986). These results are consistent with those reported by Munawar and Wanti (2016) whom observed a decrease of CEC with decreasing pH when adding humic acids (HA). This can be explained by the incorporation of HA in soil aggregate

reducing their contact with soil solution causing at the same time less adsorption of H^+ and pH decrease and lower CEC.

Exchangeable bases (calcium, potassium, and sodium) were lowered in CT1 except sodium due to the decline of SOC in mechanically tilled plot due to rapid break. In fact, long-term tillage reduced the concentration of soil exchangeable cations. Rahman et al. (2008) found that exchangeable cations were significantly higher in the surface soil under no-tillage compared to the plowed soil. OMW's application for the long term increased exchangeable cation. This is due to the high amounts of soluble salts in OMW, mainly potassium. Some studies reported that OMW contains high amounts of nutrients and other compounds that might be beneficial to soil fertility and productivity (Belaqziz et al. 2008; Lopez-Pineiro et al. 2011). Thus, combination of tillage with OMW's addition can be useful alternative solutions for arid soil where the soil is characterized by low nutrient availability and productivity.

Correlation between soil properties

The positive correlation determined with pH and properties (CEC, moisture content, EC, Cl^- , and potassium) in NC with soil properties (CEC, EC, moisture content, Cl^- and SOM) in CT1 and with moisture content in CT2 was justified by the role of humified organic matter with colloidal properties. Indeed, this organic fraction improves soil structure and enhances soil water holding capacity and CEC too. Thus, soil moisture and cation wealth were improved. Consequently, in these conditions, soil fertility was improved. The opposite relationship between pH and SOM in NC were maybe related to the relationship between soil pH and SOM, especially when regarding that the soil pH decreased with the increasing of SOM concentrations. The negative correlation between pH and groups of CEC, calcium and potassium in CT2, pH and calcium in CT1, pH and calcium and sodium in NC may be related to the relationship between soil pH and CEC, since the soil pH increases with increasing CEC concentration. The increase of EC, Cl^- content and sodium content in CT2 were related to the mineralization of OMW that provides soluble ions increasing EC among them is chloride.

Change organic carbon functional groups after tillage and OMW application

The higher signals for aliphatic C2 compounds around 2922 cm^{-1} and 2852 cm^{-1} and observed just in NC and CT2 were more evident in the spectrum of soil samples having higher organic carbon concentrations (Madari et al. 2006). The fact that these groups did not appear in CT1 may be caused by the using of tillage. In fact, Tivet et al. (2013) reported that tillage can reduce aliphatic groups. The groups of aliphatic C1 cannot be clearly observed in CT1 and were

observed clearly in CT2 and NC; they can indicate that conventional tillage reduces aliphatic structures. These results are similar to results conducted in sub-tropical and tropical Brazilian environments by Tivet et al. (2013) and Carra et al. (2017). Moreover, lower aliphatic-C1 groups in soil were observed under conventional plow-based tillage as compared to native vegetation and no-till systems. Aliphatic groups appearing in soil CT2 were attributed to the effect of OMW's application in the long-term. It has been reported that aliphatic groups increase during the decomposition of organic matter (AitBaddi et al. 2004). The higher signal of aromatic groups (C=C) in NC and CT2 as compared to CT1 can indicate that conventional tillage reduces aromatic compounds. In addition, the increasing of aromatic-C was also observed in the surface layers (0–20 cm) under native vegetation as compared to conventional plow-based tillage (Tivet et al. 2013). Soil spectrum in CT2 contained a higher signal of C=C vibration as compared to CT1. This is may be due to the decomposition of OMW in soils in the way of humification and more processed forms of carbon (Calderón et al. 2006). Thus, the incorporation of OMW in soil CT2 can lead to an increase both of aromatic and aliphatic structures. This is may be attributed to OMW especially because it is rich in phenols and organic compounds. The higher peak of aromatic-C and aliphatic-C in CT2 has a positive impact on soil aggregation through organo-mineral interactions, and because aliphatic-C acts as a binding agent between micro-aggregates. This function is essential for the stabilization of SOC within aggregates, and for long-term sequestration (Tivet et al. 2013). It is true that in coarse soils potential carbon sequestration is small, near zero, while the carbon storage potential is high in clay soils. Moreover, application of OMW on coarse soils induced an increase of functional aromatic /aliphatic C groups. Thus, coarse soils in arid climate can stabilize SOC when a combination of tillage with OMW is used in the long-term. Applied no tillage in arid regions is hardly to be applied, combination OMW application with tillage may be useful management to increase the soil structural stability, soil quality by increasing the quantity of soil humic acids (HAs) with enhancing humification degree and aromatic structures formation in arid soils.

Conclusion

Conventional tillage and addition of olive mill wastewater (OMW) for more than 20 years led to a change of soil fertility as compared to an uncultivated soil for more than 80 years. Application of tillage without amendment (CT1) for more than 80 years reduced functional organic carbon groups and affected soil fertility. Condensations of organic carbon functional groups as well as a higher amount of SOM, exchangeable cations, CEC, and humidity content were higher in both uncultivated soil (NC) and cultivated soil with addition of

OMW (CT2) as compared to cultivated soil without amendment (CT1). In addition, SOM, exchangeable cations, aromatic, and aliphatic structures increased after application 5 l.m^{-2} for more than 20 years in CT2. No tillage is hardly useful in arid regions. Therefore, combination of tillage with OMW's application (5 l.m^{-2}) was considered as the best solution to remediate soil fertility in terms of restoring soil carbon, enhancing sustainability of agro ecosystems and reducing environmental problems in arid climates. However, it is necessary to assess leaching risks of OMW components.

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