International Soil and Water Conservation Research 9 (2021) 26–36

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Mulching as best management practice to reduce surface runoff and erosion in steep clayey olive groves

Giuseppe Bombino [a], Pietro Denisi [a, *], José Alfonso Gómez [b], Demetrio Antonio Zema [a]

[a] *Mediterranea University of Reggio Calabria, Department "Agraria" Località Feo di Vito, I-89122, Reggio Calabria, Italy*
[b] *Institute for Sustainable Agriculture (IAS-CSIC), Agronomy Department, Avenida Menéndez Pidal s/n, E-14004, Córdoba, Spain*

ARTICLE INFO

Article history:
Received 7 July 2020
Received in revised form
9 October 2020
Accepted 14 October 2020
Available online 20 October 2020

Keywords:
Pruning residues
Tillage
Soil loss
Vegetal cover
Organic matter
Soil hydraulic conductivity

ABSTRACT

No-tillage and soil mulching with pruning residues, applied in olive groves of the semi-arid Mediterranean environment, as erosion control practices still practice not fully studied. This study has evaluated the saturated hydraulic conductivity (Ksat), surface runoff (SR) and soil erosion (SL) under rainfall at plot scale throughout two years in four different management practices, total soil cover with a net (SP), mechanical tillage (MT) and mulching by vegetal residues at $3{,}5 \cdot 10^3$ and $17{,}5 \cdot 10^3$ kg ha^{-1} of dry matter (NTR350 and NTR1750), in an olive grove of Southern Italy. K_{sat} varied between 1.6 (MT) and 25.1 (NTR1750) mm/h. A clear reduction in runoff and soil losses was detected for the mulch-based practices when compared to MT, from 20 to 32% in the runoff coefficient and 75–80% in SL, with higher reductions in the NTR1750. This reduction in SL can be mainly explained by the reduction in SR and rain-splash, interrill and rill erosion, due to protection by mulch residues, which increased the vegetal cover and organic matter content of mulched plots. The vegetal cover was on average higher in SP (33%), NTR1750 (25%) and NTR350 (22%), and lower in MT (12%). The mean organic matter content of soil was 2.01%, 1.69%,1.34% and 0.82% for NTR1750, NTR350, SP and MT respectively.

Overall, the results quantify the impact of soil mulching with pruning residues at different doses, which will provide guidelines to control and mitigate the hydrological response of clayey and steep soils in Mediterranean olive groves, analysing the associated environmental and economic benefits.

1. Introduction

In Mediterranean areas, olive is often cultivated on steep hill slopes (Beaufoy, 2002; Gomez et al., 2003, 2011; Ibañez et al., 2014), taking advantage of the capacity of this tree to grow on sloping areas in a condition of water shortage. These areas are particularly prone to high runoff and soil loss rates, due to the intrinsic climatic conditions, heavy and infrequent storms with intense and often destructive floods (Fortugno et al., 2017; Zema et al., 2018). Furthermore, when olive growing is cultivated in soils with high clay content (where other crops cannot grow or grow with difficulty), the runoff and erosion rates may be unsustainable. This leads to negative on-site (e.g., loss of cultivated land and productivity) and off-site (e.g., offsite contamination, damage to infrastructures, etc.) effects generating severe environmental concerns on olive cultivation (Gomez, 2017). These impacts can be even aggravated by inadequate soil management practices (hereinafter indicated as "SMPs"), only focused on increasing crop productivity.

The most common soil management practice in the Mediterranean croplands is still being mechanical tillage (Gomez et al, 2014a, 2017, 2018; Beaufoy, 2002; Xiloyannis et al., 2008), which is used to improve nutrient (by incorporating fertilizer and OM into the soil) and soil water balance (by reducing the soil evaporation), as well as to facilitate harvest. However, this SMP, if intensively done, may results in rapid oxidation to CO_2 and loss to the atmosphere (Kassam et al., 2009), worsening the soil structure and thus its hydrological response with increased runoff and erosion rates, particularly in the wetter periods when the runoff and erosion risks are higher (Sastre et al., 2018). This can be explained because tillage decreases soil organic matter content through increasing mineralization rates and CO_2 loss to the atmosphere (García-Díaz et al., 2016; García-Ruiz, 2010; Kassam et al., 2009). Tillage also reduces infiltration capacity due to soil structure degradation (Palese et al., 2014), and destroys olive roots in the plough layer reducing the tree

* Corresponding author.
E-mail address: pietro.denisi@unirc.it (P. Denisi).

https://doi.org/10.1016/j.iswcr.2020.10.002

water uptake capacity (Sastre et al., 2018).

To reduce erosion and improve water storage and physical properties of soils in olive orchards, several studies during the last five decades have demonstrated the possibility of substituting conventional tillage for less impacting agricultural practices, such as temporary cover crops (Gómez et al., 2014a; Sastre et al., 2017) or mulching with pruning residues (Repullo et al., 2012). These alternative management methods are inspired by the conservation agriculture paradigm, a system of principles and practices capable of building sustainability into the agricultural production system, which has been proposed for decades, in order to protect soil, water quality and biological resources. Conservation agriculture also includes environmental-friendly SMPs, aiming at, ideally: a) maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop; b) minimizing the soil disturbance by tillage and if possible seeding directly into untilled soil, c) diversifying crop rotations, sequences and associations, adapted to local environmental conditions (Kassam et al., 2009). The presence of dead or living vegetation (i) shields the soil from raindrops impact (reducing splash erosion), (ii) reduces soil surface sealing (e.g. Francia et al., 2000; Gomez, 2017; Lopez-Vicente et al., 2016), (iii) enhances water infiltration in soil by the increase in organic matter and soil roughness that slows down the overland flow, and (iv) maintain soil roughness, which reduces the velocity of overland flow (Franzluebbers, 2002; Pikul & Zuzel, 1994). Moreover, in the Mediterranean semi-arid environment, these conservation practices can improve the infiltration capacity of the soil, thus increasing the water availability for crops which might reduce the risk of water competition between this main crop and the cover crops (Bombino et al., 2019). In the Mediterranean olive groves, cover crops are usually temporary, emerging in fall or winter (mostly from spontaneous vegetation) growing up between the rows allowing soil protection when the rainfall has a higher erosion potential. Afterward, this cover crop is chemical or mechanically killed, in late winter or early spring creating a mulch that does not compete with the main crop (Gomez, 2017).

Besides these hydrological benefits, the vegetal cover of soils increases carbon storage (in the form of organic matter) and reduces CO_2 emissions (Qingren et al., 2010; Repullo et al., 2012). In olive groves, as well as in other tree crops of the Mediterranean semi-arid environment, for successful adoption by farmers, SMPs should be targeted at increasing the vegetal cover of the soil. At the same time, the main agronomic goals of common practices should be maintained in order to balance soil conservation and water availability on one side and crop production and efficient harvesting on the other side.

To our knowledge, many researchers have studied the hydrological effects of the SMPs aimed at increasing the vegetal cover of soils (e.g. Hernandez et al., 2005; Milgroom et al., 2007) often in comparison to mechanical tillage or no-tillage combined with herbicide use. To summarise, the results of these studies have highlighted that vegetal cover in the rainy season, when properly implanted, often limits the soil loss to tolerable rates compared to the bare soil and plays beneficial effects on biodiversity (Gomez, 2017; Gomez et al., 2011). For instance, it has been demonstrated through field measurements or modelling approaches that runoff volumes and soil losses, particularly soil losses, are up to 50 times higher on bare soils than on covered soils (Sastre et al., 2017). In olive groves cultivated over steep areas, reduction in erosion rates between 50% and 80% has been observed compared to conventional SMPs based on bare soil (e.g., Francia et al., 2000; Gomez et al., 2014; Sastre et al., 2017; 2018). However, in different conditions, particularly in rain-fed plantations, cover crops, even if temporary, might compete for water and nutrients with trees, introducing risk of decreasing yields (Gomez et al., 2014; Repullo et al., 2012). This hampers the introduction of BMPs based on cover crops in the most water-limited environments such where some of the Mediterranean olive orchards are.

To enhance the adoption of these BMPs it is necessary to properly document the hydrological impacts of soil mulching with pruning residues, particularly the effect of different amounts of dry matter.

Quantitative information based on experimental activities is currently very limited in this regard, especially in soils with low permeability and high slope gradient (Prats et al., 2015; Moreno-García et al., 2018). To our knowledge, only Bombino et al. (2019) has addressed this topic. These authors determined in a clayey and steep olive groves soil of Calabria (Southern Italy) cover by pruning residues, the runoff generation.

Giving continuity to the above-mentioned research, the present study evaluates the hydrological effects of different SMPs (of which two are based on soil mulching with pruning residues) in a Mediterranean olive orchard with steep and clayey soil. For this, surface runoff and soil loss were measured during 2.5 years in four plots managed with four different SMPs (standard protection, mechanical tillage, cover with pruning residues at two dry matter rates). The initial hypothesis is that mulching with pruning residues, together with a grass cover naturally growing under the mulch layer, will significantly reduce runoff and erosion as compared to the traditional practice of conventional tillage, obtaining a reduction close to a full cover by synthetic material. If this hypothesis is confirmed, a suitable BMPs model can be proposed to olive farmers for supporting soil conservation issues providing an alternative, or a compliment, to cover crop-based strategies.

2. Materials and methods

2.1. Study area

The experimental site was located in an olive grove close to Locri (38.2671° N, 16.1872° E, Southern Calabria, Italy) at a mean altitude of 114 m a.s.l. (Fig. 1a). The olive grove, about 10–12 years old at the start of the experiment, was planted in 2006 with trees of *Olea europea* (cultivar *Geracese*) at 6 m × 6 m spacing (Fig. 1b).

The climate of the area is typically semi-arid Hot-summer Mediterranean climate, Csa class, according to Koppen, classification. Winter is mild and rainy, while summer is dry and warm. The annual average rainfall and minimum/maximum temperatures are 1350 mm and 11/28 °C, respectively (historical observations of 1923–2017).

The soil of the olive grove, with a slope of 20%, is a Eutric cambisol (FAO, 2006). Its texture is mostly clayey (28% of sand, 28% of silt and 44% of clay, w/w) without rock fragments over 2 mm. The soil depth is about 0.8 m across all horizons (Ap, BW1 and BW2). An impervious nearly uniform layer appears at a depth of 1.15–1.2 m. The soil quickly saturates also after moderate intensity rainfall events.

Spontaneous grass cover the soil of the olive grove. This cover is usually mowed twice a year, in April and August, while the olive trees are pruned each year. After mowing and pruning operations, the residues (around $1 \cdot 10^3$ and $1.8 \cdot 10^3$ kg ha^{-1} yr^{-1} of dry matter for chopped vegetation and pruning residues respectively) are left on the surface of the whole plot under the tree canopy and in the inter-row areas as mulching cover.

2.2. Experimental site and design

In 2015, four plots (each one of 42-m long and 6-m wide, covering an area of 252 m^2) were hydraulically isolated, using 0.3-

m high metallic sheets inserted up to 0.1 m below the ground surface, in order to avoid the inflow of water (Fig. 2). The bottom side of each plot was equipped with a transverse channel, intercepting the flows of water and sediments, which were collected through a pipe into a 1000-litre tank. The four plots were subjected to the following SMPs: (i) Standard Protection of soil (hereinafter indicated as SP); (ii) Mechanical Tillage (MT); (iii) and (iv) No-Tillage and Retention of pruning residues at dry matter doses of 350 g/m^2 (NTR 350) and 1750 g/m^2 (NTR 1750).

For the SMP SP, which was assumed as the control practice, the plot was covered by a horizontal net (mesh of 1 mm^2), placed 10 cm over the ground. This practice represents the optimum soil protection, since the plot cover shadows soil from the direct raindrop impact (thus reducing the splash erosion) and intercepts a share of the precipitation. In this SMP, living vegetation, mainly composed of grass and short shrubs, grows under the net.

The MT, carried out in autumn and spring by a rotary tiller, is the reference practice, since this is the most common SMP adopted by the farmers of Southern Italy, who, however, complain about high soil losses in their olive groves. To respond to these farmers' needs, a soil cover with pruning residues of olive groves were simulated in NTR 350 and NTR 1750 plots as soil conservation model. Under these SMPs, the vegetal residues were distributed as mulching cover at a dose of $3.5 \cdot 10^3$ and $17.5 \cdot 10^3$ kg ha^{-1} in NTR350 (in spring) and NTR1750 (in spring and autumn) plots.

2.3. Hydrological measurements

Hydrological measures started one-year after implementing SMPs, lasting from January 2016 to June 2018. Rainfall depth and intensity were measured at the gauging station of Antonimina (327 m a.s.l.), 1-km far from the experimental site. The rain gauging station provided the sub-hourly data, which we totaled in daily precipitation. In this observation period of about 2.5 years, the annual rainfall was between 815 and 1275 mm yr^{-1}, and the maximum daily precipitation was 183 mm. Twenty-six rainfalls were recorded in the monitoring period with depths between 16.6 mm (March 25, 2018) and 183 mm (November 25, 2016). All these rainfalls were classified as erosive events (that is, with depth over 13 mm), according to Wischmeier and Smith (1978).

Saturated hydraulic conductivity of the soil (hereinafter "K_{sat}") was measured immediately after each precipitation, by a double-cylinder infiltrometer, consisting of two coaxial cylinders having inner and outer diameters of 0.32 and 0.57 m, respectively, and height of 0.30 m, and driven into the soil to a depth of 150 mm.

The K_{sat} was measured following the NRCS Survey NRCS Soil survey manual (2017). Before each measurement, the soil was completely saturated, filling up the infiltrometer several times until an apparent steady infiltration rate was reached. After this, the infiltration test measured the time needed for the infiltration of 20 mm of water in the cylinders filled with 50–70 mm of water. The ratio between the water depth of 20 mm and the time recorded for water infiltration gave the K_{sat}. The timing of each measurement ranged between 20 and 40 min, and the water head was 150 mm.

For each of the twenty-six measurements over time, K_{sat} measurements was performed in three points per plot dividing the plot in three sections: upper, medium and lower part. Within each section measurement points were randomly selected in the lane area (that is outside the olive canopy projection) avoiding measurements in points that appear disturbed by previous measurements and calculated the mean value among the three measurements. Since the plot surface characteristics were quite uniform, a single point per transverse transect was considered for each part (usually in the plot centre). Soil samples with cracks or pebbles or previously disturbed, which could lead to unrealistic measurements, were excluded. The mulch cover was left on the soil during the infiltration measurements and removed only inside the cylinder border to avoid preferential water flow paths.

The surface runoff and sediment produced by the monitored rainfalls described above were measured. After each storm, runoff samples were collected by mixing the water in the tank and collecting three successive samples, totalling about 0.5 L. The samples were brought to the laboratory, where they were dried in oven at 105 °C for 24 h. The dried sediment was weighted and referred to the sample volume, in order to measure the sediment concentration (Lucas-Borja et al., 2019). The latter was multiplied by the runoff volume to estimate the soil loss and thus the erosion after each precipitation event. The runoff coefficients were calculated as the ratio of runoff to rainfall.

2.4. Measurements of the vegetal cover and organic matter of soil

The vegetation cover (VC) and soil content of organic matter (OM) were measured each month and every three months, respectively, in the four plots throughout the monitoring period. For VC, the grid method was applied (Vogel & Masters, 2001), using a 0.75 × 0.75-m grid square on three sampling areas (upstream, in the middle part and downstream of each plot) per plot. The vegetal species detected in the sampling areas were classified according to Raunkier's life forms, in order to evaluate their adaption to the environment (Raunkiaer, 1934). For each the vegetal species, vegetal cover was estimated using the central value of the six cover classes in the abundance-dominance scale of Braun-Blanquet.

OM was measured in the inter-row areas (out of the canopy projection), collecting every three months samples of soil in the top, middle and bottom parts of the plots; each sample was taken at three depths (5, 10 and 30 cm). To avoid soil disturbance in repeated soil sampling throughout the experiment, the OM samples were not collected in the same point over time, but in points very close (40–50 cm) to the previous sampling point. OM content of the samples was measured using the Loss-On-Ignition (LOI) method (Cambardella et al., 2001). By LOI method, the soil sample was burned for 2 h at steps of temperature of 300, 360, 400, 500 and 550 °C and its weight loss was finally measured. The soil content of OM was calculated in percentage by Schulte & Hopkins equation (Schulte and Hopkins, 1996). Moreover, SOM stratification index has been calculated from soil properties (i.e. SOM percentage) between 0 -5 and 10–20 cm soil depth.

2.5. Data analysis

The statistical significance of differences in the hydrological variables (K_{sat}, surface runoff and soil loss) among the different SMPs was analysed for the 25 monitored rainfall events using Kruskal-Wallis test (a non-parametric alternative to the analysis of variance) with pairwise comparisons (at p-level < 0.05) using Dunn's procedure with Bonferroni's correction for the significance level. The statistical analysis was carried out by the XLSTAT software package (release 2019.2).

3. Results

3.1. Soil hydraulic conductivity

The initial values of K_{sat} at the start of the experiment were on average 4 mm/h. During the monitoring period, the values of K_{sat} varied between 1.6 and 25.1 mm/h (the latter value occurring in the SMP NTR1750). The lowest K_{sat} (3.59 mm/h) was measured for the MT plot, while the highest value (7.82 mm/h) for the NTR1750 plot. The mean values of K_{sat} under SP (control) and NTR350 were

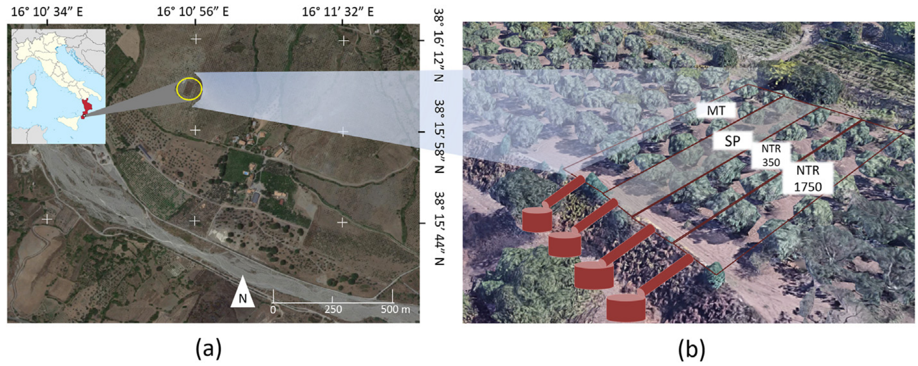

Fig. 1. Geographical location (a) and aerial view (b) of the experimental plots (Locri, Southern Italy).

intermediate with 6.47 and 4.82 mm/h, respectively, (Figs. 3a and 4a and Table 1). According to the classification reported in NRCS Survey NRCS Soil Survey Manual (2017), the measured values can be considered as "moderately high". Compared to the control practice SP, the differences in K_{sat} were not statistically significant ($p > 0.05$) for the MT and NTR350 treatments, but they were significant ($p < 0.05$) for NTR 1750 (Fig. 4a and Table 1). The low correlation between K_{sat} and rainfall ($r^2 < 0.45$, $p < 0.05$, for an exponential function, Fig. 5a) shows that the precipitation did not affect water infiltration capacity of soil.

3.2. Surface runoff

The 26 erosive events generated runoff volumes in the range from 7.4 mm (March 25, 2018, after 16.6 mm of rainfall) to 146 mm (November 25, 2016 rainfall depth 183 mm), both recorded values under the MT treatment (Figs. 3b and 4b and Table 1). On the average, the runoff produced in the NTR1750 treatment was not significantly different from the corresponding values of the control SP and NTR350 treatments, but significantly lower than MT, the traditional SMP (Fig. 4b and Table 1). For all the SMPs, surface runoff ($r^2 > 0.95$, $p < 0.05$) and soil loss ($r^2 > 0.58$, $p < 0.05$) were significantly correlated with rainfall (Fig. 5b).

On the average, the NTR1750 treatment presented the smallest runoff coefficient RC (about 42%), while the largest value (approximately 62%) was recorded for MT. The runoff coefficient of NTR1750 was statistically similar as that of NTR350 and significantly different of those of MT and SP (Fig. 4c and Table 1).

3.3. Soil erosion

Sediment concentration of the runoff collected in the plots was in the range of 0–165 g/L. On the average, the concentration measured in the MT treatment was higher than that of the other SMPs, 39 g/L against 14.4 g/L for SP, 12.8 g/L for NTR1750 and 14.7 g/L for NTR750 (Fig. 4d, and Table 1), but these differences were not statistically significant ($p > 0.05$) (Table 1). Sediment concentration was not correlated with rainfall ($r^2 < 0.49$, $p < 0.05$), surface runoff ($r^2 < 0.15$, $p < 0.05$) and soil loss ($r^2 < 0.16$, $p < 0.05$) (data not shown).

The maximum soil loss produced by the erosive events varied from 0.04 (NTR1750) to 190 (MT) kg ha-1 (Figs. 3c and 4e and Table 1). The mean values, ranging from 9 (NTR1750) to 45 (MT) kg ha-1, were significantly different ($p < 0.05$) only between the MT, which was higher, and the SP, NTR350 and NTR1750 treatments (Fig. 4e and Table 1). Soil loss was noticeably correlated with the precipitation for all SMPs (r^2 from 0.65, MT, to 0.86, SP, $p < 0.05$) (Fig. 5c).

3.4. Soil cover and organic matter dynamics

At the start of the experiment, the vegetal cover of soil was between 18 and 20%. During the monitoring period, the vegetal cover was generally higher in spring and autumn, when the rainfall input increased, and lower in winter. The vegetation, mowed in April and August (except in MT plots), re-grew very quickly in spring. In late summer, the vegetal growth was much slower, due to

Fig. 2. The experimental plots with the water and sediment collection equipment (Locri, Southern Italy).

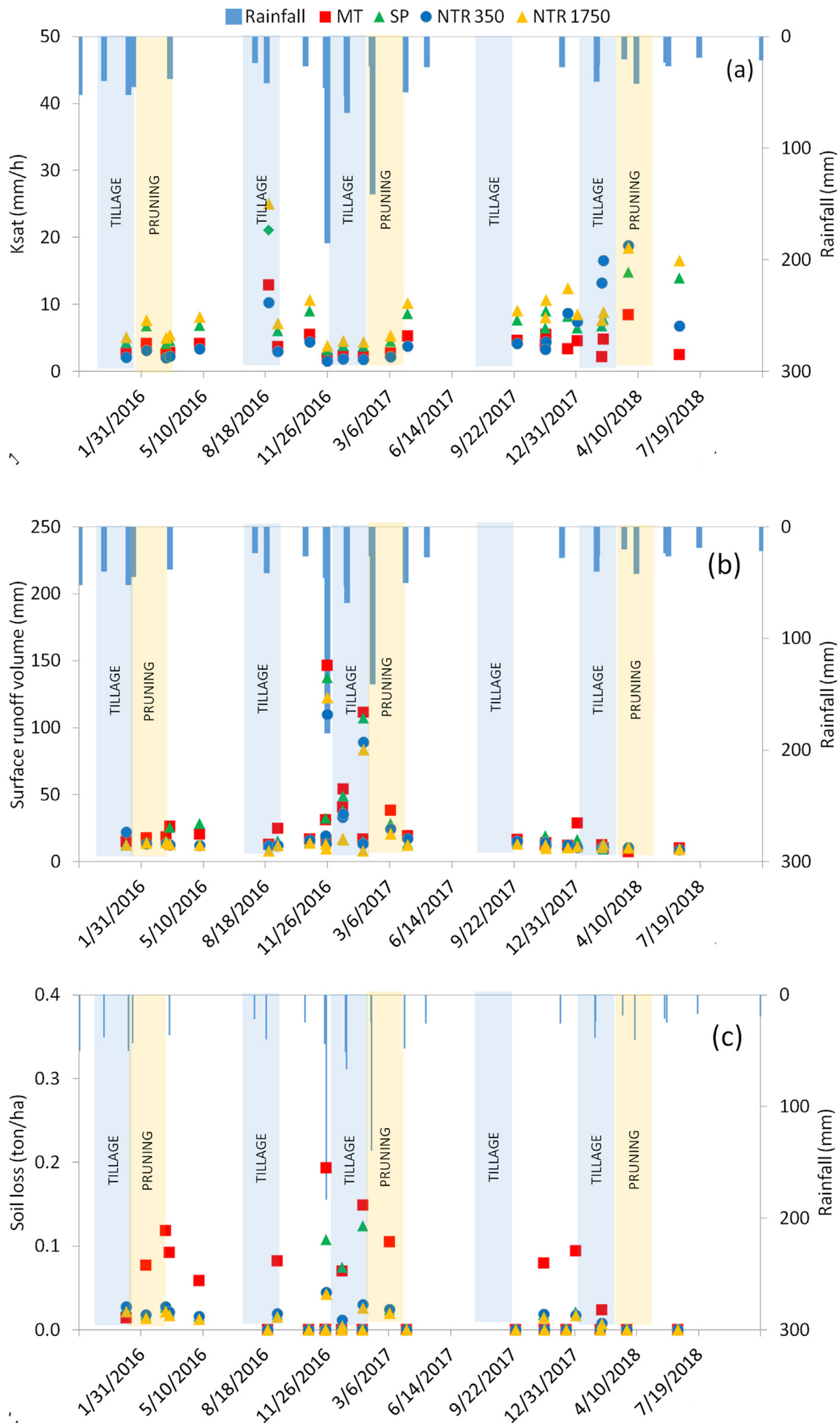

Fig. 3. Mean soil hydraulic conductivity (a), surface runoff volume (b) and soil loss (c) measured after natural rainfalls in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

the water shortage in the dry season (Fig. 6). The vegetal cover was lower in the MT plots and higher in SP treatment, except for a few survey dates. Although the two NTRs treatments were mulched with pruning residues, some living vegetation grew up. Compared to SP (mean vegetal cover of 33.4%), the average vegetal cover was lower in NTR1750 (average of 25.3%, not significantly different compared to SP, $p > 0.05$) and NTR350 plots (average of 21.7%, significantly different compared to SP, $p < 0.05$). The lowest vegetal

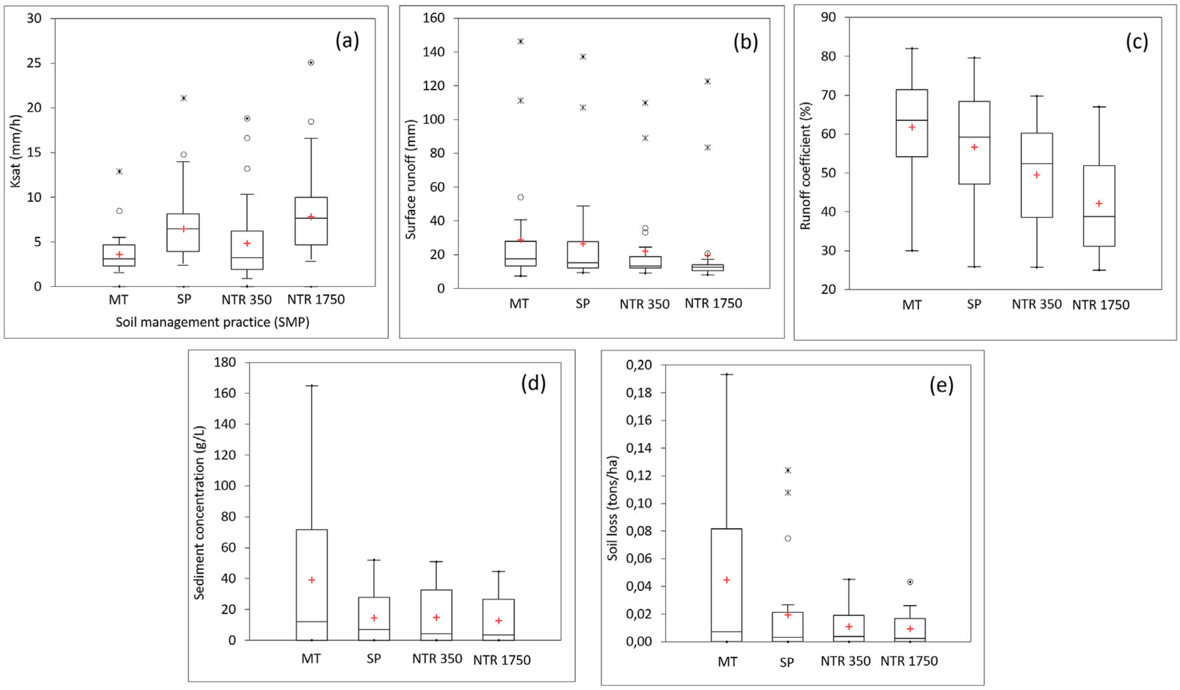

Fig. 4. - Statistics of soil hydraulic conductivity (a, K_{sat}), surface runoff volume (b), runoff coefficient (c), sediment concentration (d) and soil loss (e) measured after natural rainfalls in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

Table 1
Statistics (mean ± standard deviation) of the variables measured in the plots subjected to four soil management practices (Locri, Southern Italy).

SMP	Measured variable						
	Soil hydraulic conductivity (mm/h)	Surface runoff (mm)	*Runoff coefficient (−)*	Sediment concentration (g/l)	*Soil loss (t/ha)*	*Soil vegetal cover (%)*	*Soil organic matter (%)*
MT	3.58 ± 2.75 b	28.8 ± 31.7 a	61.8 ± 15.4 a	39.0 ± 50.7 a	0.045 ± 0.056 a	11.5 ± 7.3 b	0.82 ± 0.18 b
SP	6.47 ± 4.79 ab	26.5 ± 30.1 ab	56.7 ± 15.0 ab	14.4 ± 16.6 a	0.019 ± 0.033 a	33.4 ± 13.2 a	1.34 ± 0.28 a
NTR 350	4.82 ± 4.99 b	22.1 ± 23.9 ab	49.6 ± 13.7 bc	14.7 ± 17.8 a	0.011 ± 0.013 a	21.7 ± 8.9 c	1.69 ± 0.30 a
NTR 1750	7.82 ± 5.81 a	19.4 ± 25.4 b	42.2 ± 12.7 c	12.8 ± 15.7 a	0.009 ± 0.011 b	25.3 ± 9.8 ac	2.00 ± 0.78 a

Notes: Soil Management Practices (SMP): SP = Standard Protection of soil; MT = Mechanical Tillage; NTR 350 = No Tillage and Retention of vegetal residues at dry matter dose of 350 g/m^2; NTR 1750 = No Tillage and Retention of vegetal residues at dry matter dose of 1750 g/m^2; different letters indicate statistically significant differences after Kruskal-Wallis test (at p level < 0.05).

cover was measured in MT soils (average of 11.5%) and this value was significantly different ($p < 0.05$) compared to both SP and NTR treatments (Fig. 8a and Table 1). The correlations between hydrological parameters (sections 3.1, 3.2 and 3.3 above) and the monitored vegetal cover of soil did not generally explain clear trends. Moreover, the vegetal cover was not correlated with surface runoff and soil loss ($r^2 < 0.05$, $p < 0.05$), data not shown.

The NTR350 treatment showed a vegetal cover that was lower, by 14%, than NTR1750, presumably limited by the low OM content of the soil in NTR350 plot (Fig. 8a and Table 1). The vegetation of plots mainly consisted of scapose therophytes (*Amaranthus* sp., *Solanum* sp., *Chenopodium* sp., *Sonchus* sp.) and cespitose hemicryptophytes (*Hedysarum* sp., *Lolium* sp., *Vulpia* sp.).

The soil OM content generally did not follow the meteorological input, but seasonal variations were observed, with expected decreases in spring and summer and increases during the wet season (Fig. 7 and Table 1). The initial value of OM content of soil was, on average, 1.10% during the monitoring period, the mean content of NTR1750 (2.00%) and NTR350 (1.69%) treatments were higher compared to the soil in SP (1.34%), but not significantly. The soils subjected to MT showed an OM content significantly different ($p < 0.05$) from that of the NTR treatments, but statistically similar ($p > 0.05$) to SP (Fig. 8b and Table 1).

The topsoil (0–5 cm) was the layer with highest OM (on the average 1.64%) compared to deeper layers (5–10 cm, 1.46%, and 10–30 cm, 1.32%, in average). The decrease of OM content with depth was more noticeable in the MT and SP compared to NTR treatments (Fig. 8b). The average stratification index of SOM varied from 0.82 (MT) to 1.20 (NTR1750). The index increased with decreasing mean annual precipitation, and decreased with increasing mean annual temperature. The stratification ratio had lowest value in MT compared with SP but the difference among SMPs were higher between MT and NTR1750 and lower between SP and NTR350.

4. Discussion

4.1. Water infiltration and runoff generation

For the experimental soil and climate conditions, it is clear that surface runoff volumes were linearly correlated to the precipitation for all the investigated SMPs ($r^2 > 0.93$, $p < 0.05$). This indicates that

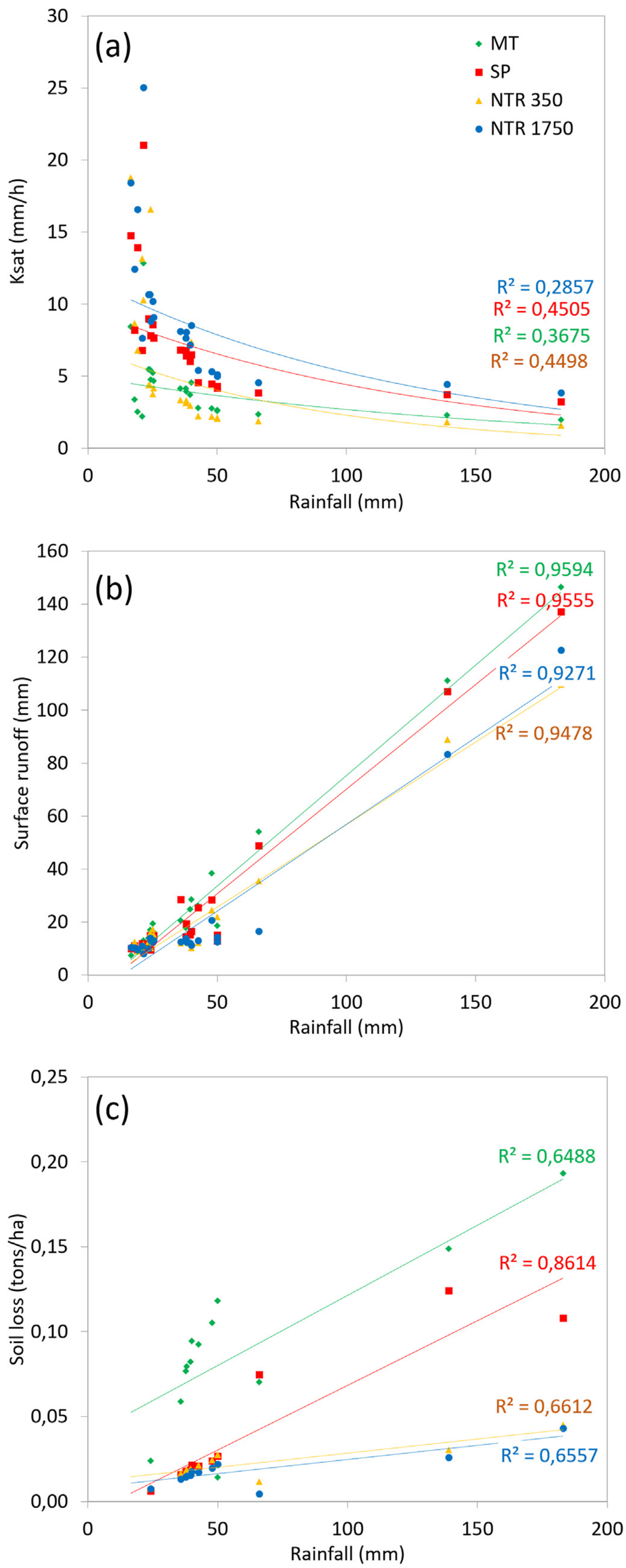

Fig. 5. Correlation between the soil hydraulic conductivity (K_{sat}) (a), surface runoff (b), soil loss (c) and rainfall in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

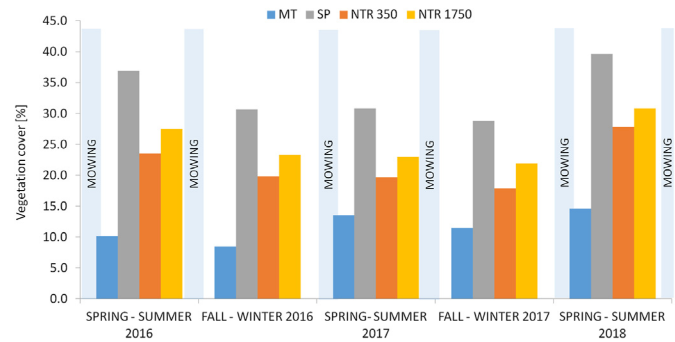

Fig. 6. Vegetal cover [%] surveyed in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

the hydrological response of the soil is based on Hortonian flow type, and showed to be strongly dependent on daily precipitation in the four SMPs evaluated. This might be predicted using relatively simple, but well tested, hydrological models, such as the SCS-Curve Number method, successfully validated for olive orchards previously (Gómez et al., 2009).

As expected, the tilled treatment (MT) presented the highest runoff and erosion rates, since the soil is left without vegetal cover and tillage has worsened some of the soil physical properties (e.g., aggregate stability and infiltrability). Compared to MT, the runoff volume produced under the other SMPs treatments was lower (on average −33.6% in NRT1750, -23.5% in NTR350 and -8.1% for SP, although not significantly different between SP and NTR 350). A temporary increased infiltration after tillage can be expected, but the soil was subject to a very quick compaction few weeks after MT, due to its clayey texture and low OM content, and this compaction may have worsened its hydrological response. Covering the soil surface with the highest dose of pruning residues (NTR1750) resulted in the lowest runoff rate, significantly lower than MT. This reduction can be attributable to higher infiltration rates, as reflected by changes in K_{sat} as compared to MT or SP, although in all cases these rates remained relatively low (Zhu et al., 2019), because of the clayey texture of the experimental soils. The lowest K_{sat} was measured in MT, while the maximum K_{sat} was measured in SP and NTR1750 treatments. The differences in K_{sat} were statistically significant only between NTR1750, and NTR350 and MT. It is well known that K_{sat} is influenced by the root system of plants that creates preferential pathways for water infiltration (Cui et al., 2019; Ghestem et al., 2011). Besides, the higher OM content in the soil, the larger the K_{sat}, increase because the aggregate stability - and therefore the equilibrium between micro and macropores - improves (Atkinson et al., 2010; Jordan et al., 2010). Therefore, the variations of K_{sat} measured among the SMPs can be linked to these variables, explaining why the NTR350, NTR1750 and SP, treatments, where the vegetal cover and OM of soil were significantly higher compared to MT, showed a higher K_{sat}. The highest K_{sat} (+20%, although this difference was not significant) of NTR1750 plot (where the vegetal cover is lower, −24%) compared to SP soil can be explained by the increase (+44%, although not significant) of the soil OM, due to the decomposition of the chopped pruning residues. Gomez et al. (2009), who measured in no-tilled clayey soil with cover crops infiltration values very close to those measured in the NTR1750 treatment, highlighted the positive correlation between organic matter and mean infiltration rate. The significant K_{sat} increase in the NTR1750 plot, where the highest dose of pruning residues has been supplied to the soil, is in accordance with other authors (e.g. Bissett & O'Leary, 1996; Murphy et al., 1993). They have shown how the retention of vegetal residues on soil leads to an

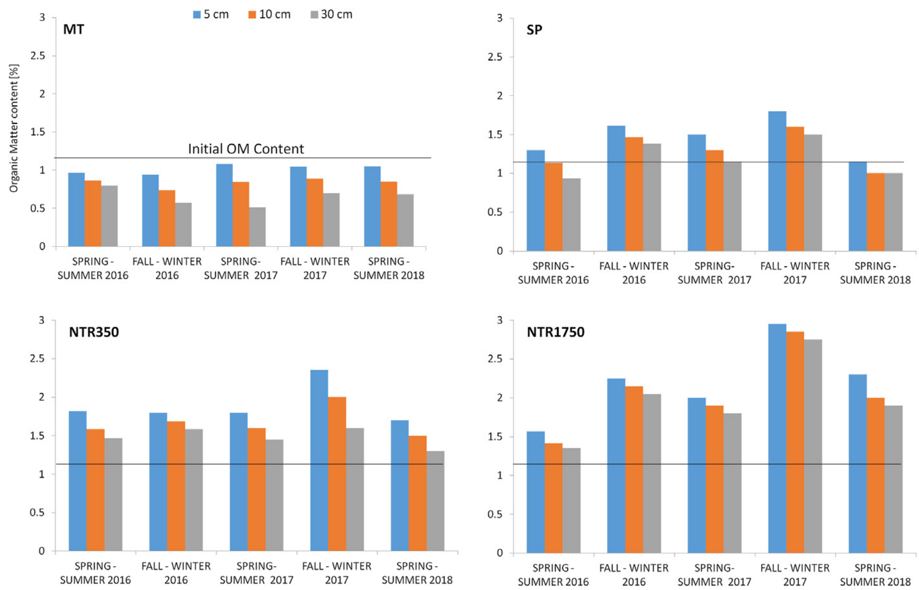

Fig. 7. Organic matter content [%]of the soil surveyed in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

increase in infiltration rates by about five times, compared to conventional farming practices, because of soil structure modification at high experimented dose.

In the NTR350 treatment, where the vegetal cover was lower than in SP (−35%, not a significant difference) the soil OM content, as compared to SP (+26%, but not significantly), is presumably in an insufficient amount to achieve a K_{sat} similar to that of SP. Moreover, the lower K_{sat} of NTR350 was presumably due to lower improvement of soil properties and protection against soil sealing and compaction due to the lower mulch cover (Li et al., 2018). It is possible that in the soil type of our experiment (Eutric Cambisols with clay-rich A horizon), the absence of tillage and the subsequent soil sealing and compaction might counteract the protective effect of a moderate mulch and vegetation cover, as in NTR350, as compared to NTR1750 and SP.

In our study, a variability of the infiltration rate was observed between the wet season, and spring and summer of each year, when K_{sat} was generally higher. K_{sat} increased from spring to summer with peaks in the late dry season thanks to the plant seasonal cycle and management practices, and also partially to increase of soil water potential as the soil dries up. During summer many species complete their life cycle, and the returning dry matter provides organic matter to the soil to improve also soil physics characteristics (Thompson et al., 2010). Furthermore, the pruning residues generated in spring and left on the soil decompose in the dry season, adding residues to the top layer. This variability is presumably due to the changes in soil characteristics (i.e., roots of spontaneous vegetation, improvement in soil structure, increase in its macro-porosity etc.).

Several authors report that surface runoff generation, besides the K_{sat} variations, is more affected by the vegetal cover and secondarily by OM content of soil (Gomez et al., 2009; Pagenkemper et al., 2014). Over time, the vegetal residues gradually decomposein the top layer, allowing increases in infiltration, but the presence of organic matter stabilizes the soil properties after many years (Zhang et al., 2007). This trend was not evident in this study, probably because the 2.5-year duration of the experiment did not provide enough time for that process to become relevant.

Although being a major factor, the K_{sat} increase in the NTR350 and NTR1750 plots was not the only reason for the runoff reduction compared to the other SMPs of this study. Other beneficial effects of soil cover contributing to the reduction in runoff volumes found in SP, NTR350 and NTR1750 is the interception of precipitation and increased surface roughness, which simultaneously increased surface storage and reduces overland flow velocity allowing for an increase in infiltration (Gholami et al., 2013; Gomez et al., 2009, 2011). The presence of the intricate mesh of wood sticks branches and grass on the ground in the NTR350 and NTR1750 plots (absent in SP) probably created a higher surface roughness maximizing the impact of these processes (Díaz-Raviña et al., 2012).

This can explain the highest reduction in runoff coefficient rate for the NTR1750 treatment as compared to the other SMPs, which are reduced by 32%, 26%, and 15%, compared to MT, SP, and NTR350, respectively.

4.2. Erosion

As expected, the soil losses measured in the three plots with an additional ground cover were significantly lower (−57% for SP, −75% for NTR350 and -80% for NTR1750) compared to the MT treatment. The lack of statistical significance of differences in sediment concentration suggests that the reduction in soil losses detected among the SMPs is mainly linked to the general reduction of surface runoff as compared to MT. Nevertheless, the large variability in sediment concentration among events might mask statistical detection of an overall trend to reduced sediment concentration for mulched treatments (SP, NTR350 and NTR1750), (Table 1 and Fig. 4d). We hypothesize that a reduction of splash, rill and interrill erosion might be also an important reason for the general reductions of the measured erosion rates in SP, NTR350 and NTR1750. This can be due to the soil protection by the different synthetic and organic materials as well as living vegetation, which prevented surface sealing observed after intense rainfalls in the MT treatment (Gholami et al., 2013).

Sediment concentration was not correlated with soil loss; although soil loss results from the product of runoff by sediment concentration, the first component is much higher compared to the second. Therefore, high soil loss can be generated by high runoff also when sediment concentration is limited.

OM has a great influence on sediment concentration and soil loss (e.g. Wang et al., 2007) and it is also positively correlated with increasing vegetation and mulch covers. This explains why the

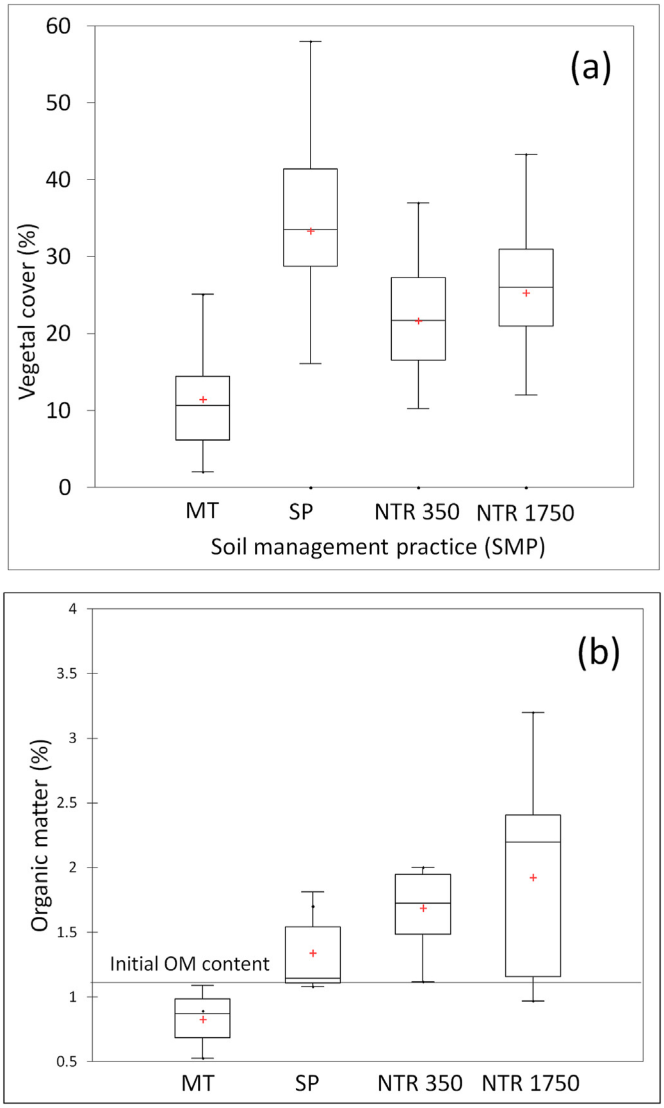

Fig. 8. - Statistics of vegetal cover (a) and organic matter content (b), averaged among sampling depths) of the soil in the experimental plots subjected to four soil management practices (Locri, Southern Italy).

plots with higher OM compared to MT soil (SMPs SP, NTR350 and NTR1750) were less prone to erosion. Moreover, in soil with a cover of pruning residues (NTR350 and NTR1750), the high density of grass with thick and high stems (which was lower in SP plot, due to the presence of the net) prevented the complete and spontaneous burying of the pruning residues, due to the weather agents. Unburied residues limit the soil loss in the early stage of the runoff process.

4.3. Vegetation cover and organic matter content

The advantages of the soil cover with pruning residues and living vegetation, were also evident not only because these SMPs help to reduce runoff generation, but also because the two NTR SMPs, at the rates tested, increased the vegetation cover and OM content of the soil as compared to MT. Subsequently, its physical-chemical properties linked to the OM dynamics (e.g., the aggregate stability and fertility, González-Rosado et al., 2020) were improved. Pruning residues slowly decompose and humificate the soil thanks to their high content of cellulose and lignin, medium to low content of moisture and a high C/N ratio, which makes it possible to ensure long-lasting soil protection (Repullo et al., 2012). This is particularly beneficial for the Mediterranean soils, whose OM content can be low and variable among seasons (Waldrop & Firestone, 2006), particularly for bare soil managements like MT, and the use of pruning residues can address those two issues. Olive grove soils generally have a low content of organic matter, up to 50% less compared to natural areas of vegetation (Alvarez et al., 2007). Cover crop and mulch with organic residues allow an increase in OM along with the soil profile, although the OM content tends to be stratified and concentrated in the top centimetres of the soil profile (Franzluebber, 2002). This increase in soil OM allows an increase in fertility of the rhizosphere, which can improve the growth dynamics of surface roots of olives trees, the soil structure and water storage in the topsoil (Sastre et al., 2018). In our study, mulching with pruning residues at a moderate rate (NTR350) facilitates the maintenance of some green vegetation, particularly in the drier seasons, when vegetation is desiccated due to the water shortage and hot temperature in Mediterranean areas. The combination of mulching with better conditions for the growth of vegetation thanks to the cover of pruning residues at a moderate rate (NTR350) reduces erosion in spring and autumn when rainfalls have a higher intensity. In fact, all plots (except for MT) were mainly populated by scapose hemicryptophytes, which usually provide efficient soil protection and sediment yield reduction in Mediterranean conditions since their epigean parts are present in autumn/winter (Taguas et al., 2015).

5. Conclusions

The hydrological monitoring of mulched plots in comparison with tilled soils has shown that, the use of mulching residues at a moderate amount combined with temporary cover crops, seem to be the best strategy to protect clayey soils in olive groves in steep areas and water limiting conditions. In the experimental study, this practice significantly improved water infiltration and OM content of the soil as well as reduced surface runoff and erosion. It also allows the maintenance of some green vegetation, which has a positive effect on the provision of other ecosystem services. Our study clearly demonstrates the need to minimize as much as possible tillage operations, which occasionally might be necessary for agronomic purposes.

Our study also shows clearly how a higher amount of mulching, increasing the amount of pruning residues, results in higher benefits in terms of reduction of runoff / soil losses and enhancement of soil properties. Therefore, our initial hypothesis – no-tillage and soil mulching with pruning residues over the soil may significantly reduce runoff and water erosion losses and improving topsoil properties as compared to the conventional tillage - has been confirmed. The experimented SMPs (particularly the one at the lower rate) can be suggested to local farmers as a viable cultivation model supporting soil conservation while preserving the yields expectations. Nevertheless, an open question might be the evaluation of the maximum slope length, at which pruning residues remain effective against erosion, before being washed away due to runoff concentration downslope. Future researches may answer this question, preferably on clayey olive orchards with different profile slopes and mulching doses and rates, in order to identify the optimal doses using the pruning residues produced by the orchard without external sources.

Funding

This study was funded by the Italian minister of education and research in the framework of the project PON “Modelli Sostenibili e

Nuove tecnologie per la Valorizzazione delle Olive e dell'Olio Extravergine di Oliva Prodotto in Calabria". Grant ID.: PON03 PE 00090_2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Alvarez, S., Soriano, M. A., Landa, B. B., & Gómez, J. A. (2007). Soil properties in organic olive groves compared with that in natural areas in a mountainous landscape in southern Spain. *Soil Use & Management, 23*(4), 404–416. https://doi.org/10.1111/j.1475-2743.2007.00104.x

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant and Soil, 337*, 1–18.

Beaufoy, G. (2002). The environmental impact of the olive oil production in the European union: Practical options for improving the environmental impact. http://www.ec.europa.eu/environment/agriculture/pdf/oliveoil. pdf. (Accessed 11 March 2019).

Bissett, M. J., & O'Leary, G. J. (1996). Effects of conservation tillage and rotation on water infiltration in two soils in south-eastern Australia. *Australian Journal of Soil Research, 34*, 299–308. https://doi.org/10.1071/SR9960299

Bombino, G., Denisi, P., Gómez, J. A., & Zema, D. A. (2019). Water infiltration and surface runoff in steep clayey soils of olive groves under different management practices. *Water, 11*(2), 240. https://doi.org/10.3390/w11020240

Cambardella, C. A., Gajda, A. M., Doran, J. W., Wienhold, B. J., Kettler, T. A., & Lal, R. (2001). Estimation of particulate and total organic matter by weight loss-on-ignition. *Assessment Methods for Soil Carbon*, 349–359.

Cui, Z., Wu, G. L., Huang, Z., & Liu, Y. (2019). Fine roots determine soil infiltration potential than soil water content in semi-arid grassland soils. *Journal of Hydrology, 578*, 124023.

Díaz-Raviña, M., Martín, A., Barreiro, A., Lombao, A., Iglesias, L., Díaz-Fierros, F., & Carballas, T. (2012). Mulching and seeding treatments for post-fire soil stabilisation in NW Spain: Short-term effects and effectiveness. *Geoderma, 191*, 31–39.

FAO. (2006). *Guidelines for soil description*. Rome: Food and Agriculture Organisation of the United States.

Fortugno, D., Boix-Fayos, C., Bombino, G., Denisi, P., Quiñonero Rubio, J. M., Tamburino, V., & Zema, D. A. (2017). Adjustments in channel morphology due to land-use changes and check dam installation in mountain torrents of Calabria (southern Italy). *Earth Surface Processes and Landforms, 42*(14), 2469–2483. https://doi.org/10.1002/esp.4197

Francia, J. R., Martinez, A., & Ruiz, S. (2000). Erosion en suelos de olivar en Fuertes pendientes. Comportamientos de distintos manejos de suelo (Soil erosion in olive groove on steep slopes. Behaviors of different soil management). *Edafologia, 7*, 147–155.

Franzluebbers, A. J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research, 66*(2), 197–205. https://doi.org/10.1016/S0167-1987(02)00027-2

García-Díaz, A., Bienes, R., Gristina, L., Cerdà, A., Pereira, P., & Novara, A. (2016). Carbon input threshold for soil carbon budget optimization in eroding vineyards. *Geoderma, 271*, 144–149. https://doi.org/10.1016/j.geoderma.2016.02.020

García-Ruiz, J. M. (2010). The effects of land uses on soil erosion in Spain: A review. *Catena, 81*, 1–11. https://doi.org/10.1016/j.catena.2010.01.001

Ghestem, M., Sidle, R. C., & Stokes, A. (2011). The influence of plant root systems on subsurface flow: Implications for slope stability. *BioScience, 61*(11), 869–879. https://doi.org/10.1525/bio.2011.61.11.6

Gholami, L., Sadeghi, S. H., & Homaee, M. (2013). Straw mulching effect on splash erosion, runoff, and sediment yield from eroded plots. *Soil Science Society of America Journal, 77*(1), 268–278.

Gomez, J. A. (2017). Sustainability using cover crops in Mediterranean tree crops, olives and vines — challenges and current knowledge. *Hungarian Geographical Bulletin, 66*(1), 13–28. https://10.15201/hungeobull.66.1.2.

Gomez, J. A., Battany, M., Renschler, C. S., & Fereres, E. (2003). Evaluating the impact of soil management on soil loss in olive orchards. *Soil Use & Management, 19*, 127–134. https://doi.org/10.1111/j.1475-2743.2003.tb00292.x

Gomez, J. A., Campos, M., Guzmán, G., Castillo-Llanque, F., Van Walleghem, T., Lora, A., & Giráldez, J. V. (2018). Soil erosion control, plant diversity, and arthropod communities under heterogeneous cover crops in an olive orchard. *Environmental Science and Pollution Research, 25*, 977–989. https://doi.org/10.1007/s11356-016-8339-9, 2018.

Gómez, J. A., Infante-Amate, J., González de Molina, M., Vanwalleghem, T., Taguas, E. V., & Lorite, I. (2014a). Olive cultivation, its impact on soil erosion and its progression into yield impacts in Southern Spain in the past as a key to a future of increasing climate uncertainty. *Agriculture, 4*, 170–198. https://doi.org/10.3390/agriculture4020170

Gómez, J. A., Llewellyn, C., Basch, G., Sutton, P. B., Dyson, J. S., & Jones, C. A. (2011). The effects of cover crops and conventional tillage on soil and runoff loss in vineyards and olive groves in several Mediterranean countries. *Soil Use & Management, 27*(4), 502–514. https://doi.org/10.1111/j.1475-2743.2011.00367.x

Gomez, J. A., Sobrinho, T. A., Giraldez, J. V., & Fereres, E. (2009). Soil management effects on runoff, erosion and soil properties in an olive grove of southern Spain. *Soil and Tillage Research, 102*, 5–13. https://doi.org/10.1016/j.still.2008.05.005

González-Rosado, M., Parras-Alcántara, L., Aguilera-Huertas, J., Benítez, C., & Lozano-García, B. (2020). Effects of land management change on soil aggregates and organic carbon in Mediterranean olive groves. *Catena, 195*, 104840.

Hernández, A. J., Lacasta, C., & Pastor, J. (2005). Effects of different soil management practices on soil conservation and soil water in a rainfed olive orchard. *Agricultural Water Management, 77*, 232–248. https://doi.org/10.1016/j.agwat.2004.09.030

Ibáñez, J., Martínez-Valderrama, J., Taguas, E. V., & Gómez, J. A. (2014). Long-term implications of water erosion in olive-growing areas in southern Spain arising from a model-based integrated assessment at hillside scale. *Agricultural Systems, 127*, 70–80. https://doi.org/10.1016/j.agsy.2014.01.006

Jordan, A., Zavala, L. M., & Gil, J. (2010). Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena, 81*, 77–85.

Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability, 7*(4), 292–320. https://doi.org/10.3763/ijas.2009.0477

Li, H., Zhao, X., Gao, X., Ren, K., & Wu, P. (2018). Effects of water collection and mulching combinations on water infiltration and consumption in a semiarid rainfed orchard. *Journal of Hydrology, 558*, 432–441.

López-Vicente, M., García-Ruiz, R., Guzmán, G., Vicente-Vicente, J. L., VanWesemael, B., & Gómez, J. A. (2016). Temporal stability and patterns of runoff and runon with different cover crops in an olive orchard (SW Andalusia, Spain). *Catena, 147*, 125–137. https://doi.org/10.1016/j.catena.2016.07.002

Lucas-Borja, M. E., Plaza-Álvarez, P. A., Gonzalez-Romero, J., Sagra, J., Alfaro-Sánchez, R., Zema, D. A., Moya, D., & de Las Heras, J. (2019). Short-term effects of prescribed burning in Mediterranean pine plantations on surface runoff, soil erosion and water quality of runoff. *The Science of the Total Environment, 674*, 615–622.

Milgroom, J., Soriano, M. A., Garrido, J. M., Gómez, J. A., & Fereres, E. (2007). The influence of a shift from conventional to organic olive farming on soil management and erosion risk in southern Spain. *Renewable Agriculture and Food Systems, 22*(1), 1–10. https://doi.org/10.1017/S1742170507001500

Moreno-García, M., Repullo-Ruibérrizde Torres, M. A., Carbonell-Bojollo, R. M., & Ordóñez-Fernández, R. (2018). Management of pruning residues for soil protection in olive orchards. *Land Degradation & Development, 29*, 2975–2984. https://doi.org/10.1002/ldr.3054

Murphy, B. W., Koen, T. B., Jones, B. A., & Huxedurp, L. M. (1993). Temporal variation of hydraulic properties for some soils with fragile structure. *Australian Journal of Soil Research, 31*(2), 179–197. https://doi.org/10.1071/SR9930179

NRCS Soil Survey Manual. (2017). In C. Ditzler, K. Scheffe, & H. C. Monger (Eds.), *USDA handbook 18*. Washington, D.C: Government Printing Office.

Pagenkemper, S. K., Puschmann, D. U., Peth, S., & Horn, R. (2014). Investigation of time dependent development of soil structure and formation of macropore networks as affected by various precrop species. *International Soil and Water Conservation Research, 2*(2), 51–66.

Palese, A. M., Vignozzi, N., Celano, G., Agnelli, A. E., Pagliai, M., & Xiloyannis, C. (2014). Influence of soil management on soil physical characteristics and water storage in a mature rainfed olive orchard. *Soil and Tillage Research, 144*, 96–109.

Pikul, J. L., & Zuzel, J. F. (1994). Soil crusting and water infiltration affected by long-term tillage and residue management. *Soil Science Society of America Journal, 58*(5), 1524–1530. https://doi.org/10.2136/sssaj1994.03615995005800050036x

Prats, S. A., Abrantes, J. R. C. B., Crema, I. P., Keizer, J. J., & De Lima, J. L. M. P. (2015). Testing the effectiveness of three forest residue mulch application schemes for reducing post-fire runoff and soil erosion using indoor simulated rain. *FLAMMA, 6*(3), 113–116.

Qingren, W., Youncong, L., & Ashock, A. (2010). Cropping system to imptrove carbon sequestartion for mitigation of climate change. *Journal of Environmental Protection, 1*, 207–2015. http://doi: 10.4236/jep.2010.13025.

Raunkiaer, C. (1934). *The life forms of plants and statistical plant geography*. Oxford: Oxford University Press.

Repullo, M. A., Carbonell, R., Hidalgo, J., Rodrıguez-Lizana, A., & Ordonez, R. (2012). Using olive pruning residues to cover soil and improve fertility. *Soil and Tillage Research, 124*, 36–46. http://DOI: 10.1016/j.still.2012.04.003.

Sastre, B., Barbero-Sierra, C., Bienes, R., Marques, M. J., & García-Díaz, A. (2017). Soil loss in an olive grove in Central Spain under cover crops and tillage treatments, and farmer perceptions. *Journal of Soils and Sediments, 17*(3), 873–888. https://doi.org/10.1007/s11368-016-1589-9

Sastre, B., Marques, M. J., García-Díaz, A., & Bienes, R. (2018). Three years of management with cover crops protecting sloping olive groves soils, carbon and water effects on gypsiferous soil. *Catena, 171*, 115–124. https://doi.org/10.1016/j.catena.2018.07.003

Schulte, E. E., & Hopkins, B. G. (1996). Estimation of organic matter by weight loss-on-ignition. In F. R. Magdoff, et al. (Eds.), *Soil organic matter: Analysis and interpretation* (pp. 21–31). SSSA Spec. Pub. No. 46. SSSA, Madison.

Taguas, E. V., Arroyo, C., Lora, A., Guzmán, G., Vanderlinden, K., & Gómez, J. A. (2015). Exploring the linkage between spontaneous grass cover biodiversity and soil degradation in two olive orchard microcatchments with contrasting environmental and management conditions. *Soils, 1*, 651–664. http://doi: 10.5194/soil-

1-651-2015.
Thompson, S. E., Harman, C. J., Heine, P., & Katul, G. G. (2010). Vegetation infiltration relationships across climatic and soil type gradients. *Journal of Geophysical Research, 115*. https://doi.org/10.1029/2009jg001134. g02023.
Vogel, K. P., & Masters, R. A. (2001). Frequency grid–a simple tool for measuring grassland establishment. *Rangeland Ecology & Management/Journal of Range Management Archives, 54*(6), 653–655. http://doi: 10.2307/4003666.
Waldrop, M. P., & Firestone, M. K. (2006). Seasonal dynamics of microbial community composition and function in oak canopy and open grassland soils. *Microbial Ecology, 52*(3), 470–479. http://doi: 10.1007/s00248-006-9100-6.
Wang, D., Wang, G., & Anagnostou, E. N. (2007). Evaluation of canopy interception schemes in land surface models. *Journal of Hydrology, 347*(3–4), 308–318. https://doi.org/10.1016/j.jhydrol.2007.09.041
Wischmeier, W. H., & Smith, D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning* (Vol. 537, p. 58). Washington DC: USDA-ARS *Agriculture Handbook* N°.
Xiloyannis, C., Martinez Raya, A., Kosmas, C., & Favia, M. (2008). Semi-intensive olive orchards on sloping land: Requiring good land husbandry for future development. *Journal of Environmental Management, 89*(2), 110–119. https://doi.org/10.1016/j.jenvman.2007.04.023
Zema, D. A., Lucas-Borja, M. E., Carrà, B. G., Denisi, P., Rodrigues, V. A., Ranzini, M., Soriano, F. C., De Cicco, V., & Zimbone, S. M. (2018). Simulating the hydrological response of a small tropical forest watershed (Mata Atlantica, Brazil) by the AnnAGNPS model. *The Science of the Total Environment, 636*, 737–750. https://10.1016/j.scitotenv.2018.04.339.
Zhang, G. S., Chan, K. Y., Oates, A., Heenan, D. P., & Huang, G. B. (2007). Relationship between soil structure and runoff/soil loss after 24 years of conservation tillage. *Soil and Tillage Research, 92*(1–2), 122–128. https://doi.org/10.1016/j.still.2006.01.006
Zhu, Y., Bennett, J. M., & Marchuk, A. (2019). Reduction of hydraulic conductivity and loss of organic carbon in non-dispersive soils of different clay mineralogy is related to magnesium induced disaggregation. *Geoderma, 349*, 1–10.