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Assessment of soil erosion in olive orchards (*Olea europaea* L.) under cover crops management systems in the tropical region of Brazil

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ABSTRACT: In the tropics, water erosion is one of the most important factors leading to the degradation and deterioration of agricultural land. Olive orchards have a low canopy coverage, especially during the first years after planting, due to the low density of olive trees. Given the fast expansion of olive orchards in Brazil, this study aimed to evaluate the effect of cover vegetation on soil and water losses under natural rainfall. In addition, it was assessed the crop performance and the vegetation cover index in different management systems in olive orchards. The study was carried out in soil erosion plots, where water and sediment were sampled and measured over two crops season, under the following treatments: in the first season, bare soil with olive cultivation (OBS); olive trees intercropped with spontaneous vegetation (OSV); olive trees intercropped with jack beans (OJB); olive trees intercropped with millet (OM) and, as a control, only bare soil (BS). In the second season, the OM treatment was replaced by olive trees intercropped with sunn hemp (OSH). On bare soils, soil loss was the highest reaching 303.9 Mg ha^{-1} yr^{-1} and where the surface runoff amounted to 484.8 mm yr^{-1}. However, in the absence of competition for resources with other crops, olive trees performed best under this system. The olive orchards planted in shallow and sloping soils without cover crops showed unsustainable soil loss, crusting, and sealing in the superficial soil layer, which can progress quickly for soil degradation in the future. The efficiency in the reduction of loss in relation to bare soil was 4.11 and 12.93 % for the soil loss and 12.15 and 25.17 % for water loss, respectively, for olive with spontaneous vegetation and olive with jack beans. Cover crops combined with olive trees, and reconciled with the crop performance aspects of cultivation in tropical regions, is of great relevance for improving sustainability, especially regarding the reduction of soil and water losses due to water erosion.

Keywords: soil conservation, soil loss, land degradation, runoff, olive cultivation.

INTRODUCTION

Soil is a finite natural resource, where more than one generation is necessary for natural recovery of soil, depending on the relationship between the rate of soil genesis and soil erosion (Lal, 2009). The current increase in land degradation (García-Ruiz et al., 2017; Taguas et al., 2017) has been a global concern, considering the decline in soil functions (McBratney et al., 2014) and the decrease in the growth of world agricultural production (FAO/ITPS, 2015). Keesstra et al. (2018) emphasized that the soil has a key component in Land Degradation Neutrality (LDN) to achieve its ecosystem services. The LDN is part of the Sustainable Development Goals adopted by the United Nations for sustainable exploitation of the planet's resources to enhance food security, in a holistic approach aimed at reducing soil degradation and rehabilitation of degraded areas (Keesstra et al., 2016).

Soil resources are threatened by various degradation factors, such as water and wind erosion, compaction, leaching, and pollution. Worldwide, water erosion is one of the major causes of land degradation. Water erosion affects soil quality and induces soil deterioration due to the loss of its superface layer, which is usually the most fertile layer where organic matter and nutrients necessary for plant development are concentrated (Cerdà et al., 2018; Rodrigo-Comino et al., 2018; Keesstra et al., 2019).

Olives are predominantly cultivated in the Mediterranean region that accounts for 97 % of the total area of the world olive trees (FAO, 2019). Reducing soil erosion in olive orchards is also a major challenge in the Mediterranean region (Keesstra et al., 2019). Given the low density of olive trees and the intensive weeding, particularly during the first years after planting, soils are prone to water erosion (Repullo-Ruibérriz et al., 2018). Moreover, as olive trees can grow in poor environmental conditions, it is commonly grown in poor soils with pronounced slopes (Espejo-Pérez et al., 2013). Studies conducted by García-Orenes et al. (2012) consider that the main cause of erosion in olive orchards, besides natural factors, is the inadequate management systems. Espejo-Pérez et al. (2013) reported that the practice of removing spontaneous vegetation between the olive trees, which aims to reduce the competition for light, water, and nutrients between the weeds and the olive trees, renders the soil susceptible to erosion. However, Taguas and Gómez (2015) emphasized that the efficient use of the soil conservation strategies like the use of cover crops adapted for each region is the unique intervention that can reduce the unsustainable soil losses in olive orchards.

In tropical regions, the problem is increased by the high rainfall erosivity (Aquino et al., 2012). Southern Minas Gerais in Brazil, is a tropical region where agricultural lands have been impacted by water erosion due not only to high rainfall erosivity, but also due to the high altitudes and steep slopes that make up the regional landscape (Oliveira et al., 2012; Anache et al., 2017; Pinto et al., 2018). In this region, Silva et al. (2005) reported soil erosion values of 205.65 Mg ha^{-1} yr^{-1} in Cambisols (Eutrudepts) kept uncovered.

Considering the vast expansion of olive orchards in the Southern Minas Gerais in Brazil, there is a high need for assessing the potential and constraints of including cover crops on water erosion in olive orchards. In this context, the following hypotheses were formulated: in olive orchard, the water erosion can be significantly reduced by cover crops; the high soil erosion rates in the region can be caused by low soil infiltration, low vegetation cover index, and high erosivity; there is a relationship between soil and water erosion and crop performance of olive orchard.

This study aimed to evaluate the relationship between soil and water losses by water erosion and the crop performance in an olive orchard managed with or without cover crops in southern Minas Gerais, Brazil.

MATERIALS AND METHODS

Study area

The experiment was conducted at the experimental farm of the Federal University of Lavras (UFLA), Lavras, Minas Gerais, Brazil (21° 13’ 20” S and 44° 58’ 17” W) (Figure 1), during two hydrological years, between November 2015 and October 2017.

The experimental site is at an altitude of 918 m a.s.l., with a subtropical humid climate classified as Cwa according to the Köppen Climate Classification System. The mean annual rainfall is 1,530 mm and the mean annual temperature is 19.4 °C. The winter months are dry and cool, while the summer months are rainy and with daily average temperatures exceeding 22 °C (Dantas et al., 2007).

The soil in the study area was classified as *Cambissolo Háplico Tb Distrófico* according to the Brazilian Soil Classification System (Santos et al., 2018), which corresponds to Dystrustepts in Soil Taxonomy (Soil Survey Staff, 2014), and to Dystric Cambisols in WRB (IUSS Working Group WRB, 2015). The soil properties of the 0.00-0.05 and 0.05-0.10 m layers are presented in table 1.

Design of the experimental area

During the first year (2015/2016), each treatment consisted of the following management practices: olive trees (*Olea europaea* L.) on bare soil (OBS); olive trees intercropped with spontaneous vegetation (OSV); olive trees intercropped with jack beans (*Canavalia ensiformis* L.) (OJB); olive trees intercropped with millet (*Pennisetum glaucum* L.) (OM)

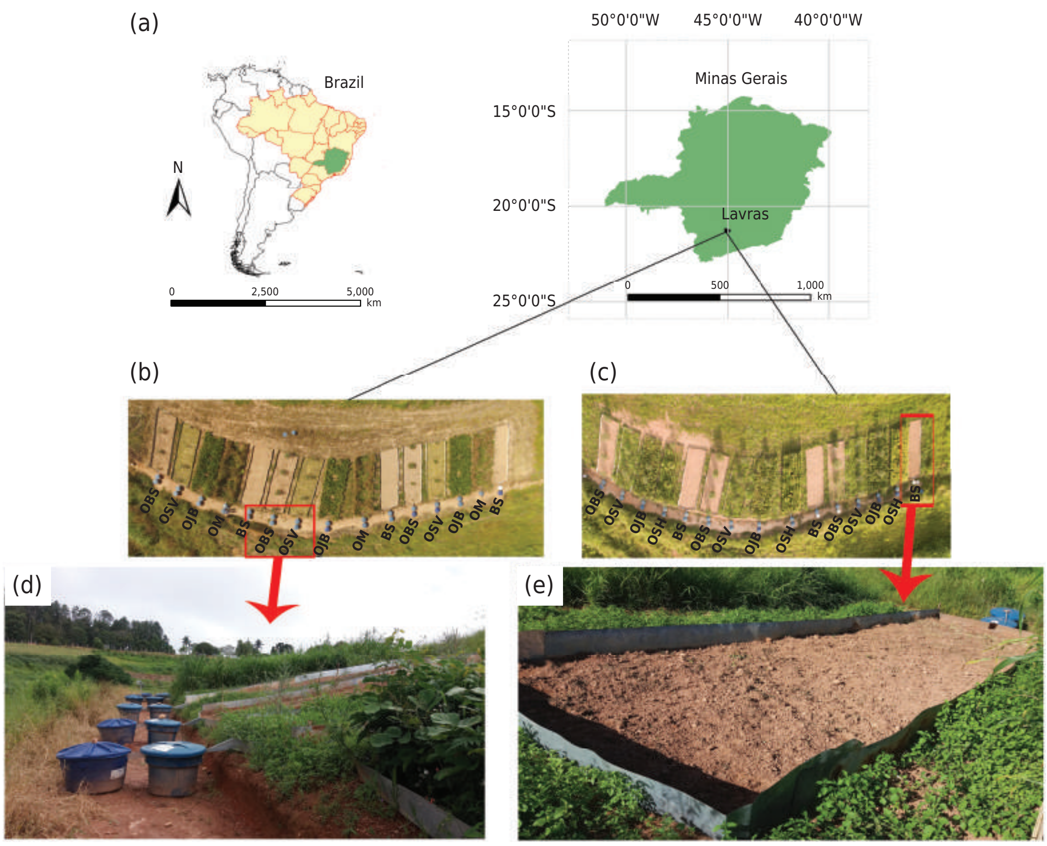

Figure 1. Location of the study area (Lavras) on the Southern of Minas Gerais, Brazil (a). Plots used in the study of erosion in hydrological years (b) 2015/2016 (March 23, 2016) and (c) 2016/2017 (February 15, 2017), under the following treatments: olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS). Side view of erosion plot (d). Bare soil plot (e).

Table 1. Soil physical and chemical properties of the *Cambissolo Háplico Tb Distrófico* in the experimental area

Properties	Layers	
	0.00-0.05 m	0.05-0.10 m
pH(H_2O)	5.58±0.39	5.24±0.38
K (mg dm^{-3})	153.39±67.2	80.47±44.58
P (mg dm^{-3})	4.83±7.19	2.43±2.56
Ca^{2+} ($cmol_c$ dm^{-3})	2.26±1.29	1.96±0.85
Mg^{2+} ($cmol_c$ dm^{-3})	0.56±0.2	0.47±0.16
Al^{3+} ($cmol_c$ dm^{-3})	0.12±0.06	0.17±0.12
H+Al ($cmol_c$ dm^{-3})	1.83±0.32	2.54±1.01
SB ($cmol_c$ dm^{-3})	3.22±1.48	2.63±1.04
t ($cmol_c$ dm^{-3})	3.34±1.44	2.8±0.96
T ($cmol_c$ dm^{-3})	5.05±1.43	5.17±1.46
V (%)	61.99±9.08	50.79±11.51
m (%)	4.37±3.33	7.44±6.84
SOM (g kg^{-1})	19.42±6.02	16.02±4.48
Clay (g kg^{-1})	369.13±2.99	384.77±2.8
AMG (g kg^{-1})	72.73±2.39	76.68±2.14
AG (g kg^{-1})	122.47±2.22	115.82±1.75
AM (g kg^{-1})	116.71±2.73	108.86±1.5
AF (g kg^{-1})	110.05±1.4	91.55±1.16
AMF (g kg^{-1})	33.17±0.13	33.38±0.13
Silt (g kg^{-1})	175.74±3.73	188.94±3.54

SB: sum of bases; t: effective cation exchange capacity; T: cation exchange capacity at pH 7; V: base saturation percentage; m: aluminum saturation percentage; SOM: soil organic matter; AMG: very coarse sand; AG: coarse sand; AM: intermediate sand; AF: fine sand; AMF: very fine sand. Soil pH(H_2O) at a ratio of 1:2.5 v/v; P and K extracted with Mehlich-1; Mg^{2+} and Al^{3+} determined according to McLean et al. (1958); soil organic matter (SOM) determined according to Walkley and Black (1934). The soil texture was determined by the pipette method. SB = sum of bases ($Ca^{2+}+Mg^{2+}+K^+$); t = SB+Al^{3+}; T = cation exchange capacity (SB+H^++Al^{3+}); V = base saturation (100 × SB/T); m = aluminum saturation (Al^{3+} × 100/t).

and, as a control, bare soil without any olive trees (BS). The spontaneous vegetation was composed of grasses with *Brachiaria decumbens* Stapf, as the dominant/most common species, followed by *Digitaria sanguinalis* L., *Melinis minutiflora* P. Beauv., and *Eleusine indica* L. Some broadleaf species included *Ipomoea acuminata* Roem., *Bidens pilosa* L., *Oxalis corniculata* L., *Emilia fosbergii* Nicolson., *Conyza bonariensis* L., *Euphorbia heterophylla* L., and *Amaranthus viridis* L.

In the second year (2016/2017), the OM treatment was replaced by olive trees intercropped with sunn hemp (*Crotalaria juncea* L.) (OSH), maintaining all other treatments from the first period. During both years, all treatments were done in three replicates (Figure 1).

The olive trees treatments were planted in March 2015 following the direction of the slope. A total of 4 olive plants per plot were used with a spacing of 4 m in the line and 5 m between lines. The chosen cultivar was Arberquina (*Olea europaea* L.), the most cultivated in Brazil (Borges et al., 2017).

The cover crops (jack beans, millet, and sunn hemp) were manually seeded at the beginning of November, which is the beginning of the rainy season of each hydrological year. In the treatment with jack beans as a cover crop, soil furrows were spaced at every 0.5 m in a density of 8 seeds m^{-1}. Regarding millet and sunn hemp, the spacing used was 0.25 m with densities of 90 seeds m^{-1} and 40 seeds m^{-1}, respectively. Table 2 presents more details about crop management during experimentation (Neto Vieira et al., 2008).

Table 2. Description of the management conducted in olive cultivation intercropped with cover plants during the experiment period from March 2015 to October 2017

Action	Details
Cover plant sowing (2015/2016)	- Millet and bean (11/2015)
Cover plant sowing (2016/2017)	- Sunn hemp and bean (11/2016)
Bare soil maintenance (with or without olive trees)	- Herbicide application and monthly weeding (between November and April)
Maintenance of the spontaneous vegetation plot maintenance	- 2015/2016 weeding: 3 times (11/15, 01/16, 04/16) - 2016/2017 weeding: 4 times (11/16, 12/16, 02/17, 05/16)
Cover plants and natural vegetation fertilization	- 2015/2016 application of 500 kg ha^{-1} NPK 8:28:16 - 2016/2017 application of 250 kg ha^{-1} NPK 8:28:16
Olive tree fertilization	- Plant fertilization: • Single superphosphate (500 g $plant^{-1}$) • Manure (20 L $plant^{-1}$) • Potassium chloride (200 g $plant^{-1}$) • Limestone (100 g $plant^{-1}$) - Annual fertilization 2015/2016: • Ammonium sulfate (50 g $plant^{-1}$) in November, December, and January - Annual fertilization 2016/2017: • October: 100 g $plant^{-1}$ ammonium sulfate, 50 g $plant^{-1}$ potassium chloride and 20 g $plant^{-1}$ boric acid • December: 100 g $plant^{-1}$ Ammonium sulfate and 50 g $plant^{-1}$ de potassium chloride • January: 100 g $plant^{-1}$ ammonium sulfate
Pruning	- July 2017

Erosivity determination

Erosivity was determined by calculating the index EI_{30} (MJ mm ha^{-1} h^{-1} yr^{-1}) developed by Aquino et al. (2012) for the southern region of Minas Gerais, Brazil (Equation 1):

$$EI_{30} = 85.672x \left(\frac{p^2}{P}\right)^{0.6557} \quad \text{Eq. 1}$$

in which *p* is the mean monthly rainfall (mm) and *P* the mean annual rainfall (mm) over 30 years.

In analogy, we determined the actual monthly erosivity index as EI_a (MJ mm ha^{-1} h^{-1} $month^{-1}$) by equation 2:

$$EI_a = 85.672x \left(\frac{p_a^2}{P_a}\right)^{0.6557} \quad \text{Eq. 2}$$

In which p_a is the actual monthly rainfall, P_a is the actual annual rainfall, and the EI_{30} (MJ mm ha^{-1} h^{-1} $month^{-1}$) was calculated by equation 3:

$$EI_{30} \approx \frac{1}{n+1} \sum_{i=1}^{n=30} EI_{a,i} \quad \text{Eq. 3}$$

We also calculated an actual annual erosivity (EI_{a12}) as the total of the 12 months EI_a per hydrologic years. Erosive rainfall events were considered when the rainfall was over 10 mm with 0.2 mm tolerance (Lima et al., 2018).

Soil chemical and physical properties

Soil pH(H_2O) was determined at a ratio of soil:solution equal to 1:2.5, exchangeable Ca^{2+}, Mg^{2+}, and Al^{3+} were determined according to the methodology described by McLean et al. (1958). The available P and K extracted with Mehlich-1. Soil organic matter (SOM) was determined according to Walkley and Black (1934). The soil texture was determined by the pipette method according to Day (1965). The variation of the soil organic matter (%) for both seasons was calculated by equation 4:

$$\text{Variation SOM}_{(\text{Treatment i})} = \frac{\text{SOM}_{(\text{season2})} - \text{SOM}_{(\text{season1})}}{\text{SOM}_{(\text{season1})}} \times 100 \qquad \text{Eq. 4}$$

In which $SOM_{season2}$ is the soil organic matter content in the second season, and $\text{SOM}_{\text{season1}}$ is the soil organic matter content in the first season.

Soil water infiltration was determined using the Mini Disk Infiltrometer, following the methodology proposed by Robichaud et al. (2008). Measurements were obtained from four points in each plot, with the suction rate of two cm. The infiltration was measured for ten times in the field, each 30 seconds. The infiltration calculation was determined by using Spreadsheet Macro available in the Decagon website Decagon (2016).

Evaluation of soil and water losses

Soil loss was measured following the methodology proposed by Wischmeier and Smith (1978), with plots size iqual to 12.0 m long by 4.0 m wide (Figure 1). The mean slope of the plots was 0.23 m m^{-1}.

Runoff and sediment collection was performed according to Cogo et al. (2003) at each erosive event, using two tanks with 250 L installed at the bottom of each plot (Figure 1). The first tank was connected to the second by a Geib divisor type, with nine entrance windows. When the first tank was completely filled, 1/9 of the runoff volume was conducted to the second tank.

The evaluation of the effect of each treatment over the Loss Reduction Efficiency (LRE) was calculated using the equation 5 proposed by Amaral et al. (2008):

$$\text{LRE} = \frac{\text{Loss of the cultivated treatment}}{\text{Loss of the bare soil treatment}} \times 100 \qquad \text{Eq. 5}$$

The Surface Runoff Coefficient (SRC) was also determined in relation to the total rainfall during the studied period for the different management systems by using the equation 6 (Şen and Altunkaynak, 2005).

$$\text{SRC} = \frac{\text{Loss of the cultivated treatment}}{\text{Total precipitation}} \times 100 \qquad \text{Eq. 6}$$

Vegetation cover index and crop performance

The vegetation cover index in each plot for cover crop and olive tree was determined by using images from an RGB digital camera with a 1/2.3 “CMOS” sensor and resolution of 12 megapixels, carried in Unmanned Aerial Vehicle (UAV), model professional DJI Phantom 3. The photographic parameters were: f/2.8aperture, shutter speed of 1/290 s, ISO 100, white balance of 4500 K, and focal length of 3.6 mm (DJI, 2018). The flights were automatically managed by an iPad (model A1489- ME279KH / A), every 15 days, with 20 minutes duration, at a height of twenty meters, by georeferencing using 36 control points to geotag.

A total of 200 photos were recorded per flight, in JPEG format, with a 60 % overlap. PhotoScan Pro 1.2.6 was used for image processing, alignment, georeferencing, and orthophoto generation (Agisoft, 2016). The images for calculating the vegetation cover index (VCI) were classified by equation 7, according to the methodology proposed by Beniaich et al. (2019).

$$VCI = \frac{\text{Number of pixels classified as vegetation}}{\text{Total number of pixels (per plot)}} \times 100 \qquad \text{Eq. 7}$$

Crop performances of the olive trees were monitored by measuring diameter at breast height, plant heights, and crown radius in May 2016 and May 2017.

Experimental and statistical design

The experimental design was a partial completely randonized block (Figure 1) due to a technical limitation of randonizing the bare soil treatment for each season in a perennial crop, so we replicate such treatment in the same order, aiming to reduce the effect of the previous crop. Differences between the treatment in terms of soil loss and water runoff were tested with analysis of variance and the means were compared by the Tukey test at 5 % probability.

RESULTS

Rainfall erosivity

From November to March, there was a high occurrence of rainfall, with 92.4 and 70.8 % of annual erosivity (Table 3), for the periods of 2015/2016 and 2016/2017, respectively. December and January, represented 55.0 and 30.0 % of the total annual erosivity for the periods of 2015/2016 and 2016/2017, respectively, which is close to the half of the total erosivity for the period of 2015/2017.

Soil water infiltration

There was no statistical difference for soil water infiltration between the treatments in both periods (Table 4). The water infiltration values presented a high variability

Table 3. Precipitation and actual monthly erosivity (EI_{a12}) and actual annual erosivity (EI_{ay}) for the two hydrologic years

Month	Precipitation		NEE		Erosivity	
	2015/2016	2016/2017	2015/2016	2016/2017	2015/2016	2016/2017
	mm				MJ mm ha^{-1} h^{-1} period^{-1}	
October	23	125	1	6	46	498
November	274	190	11	5	1,217	862
December	233	145	10	6	985	604
January	401	158	12	8	2,005	675
February	115	64	6	4	390	207
March	123	159	5	4	425	679
April	22	108	1	2	45	412
May	4	58	0	1	5	180
June	84	29	3	1	259	73
July	0	0	0	0	0	0
August	23	1	2	0	46	1
September	9	33	1	0	13	85
Total	1,310	1,070	52	37	5,437	4,277

NEE: number of erosive rainfall events.

for the treatments, the variation coefficient ranged from 19.70 to 86.28 %. The highest soil water infiltration was always registered in treatment with cultivated or spontaneous cover crops. In the first period, the treatments OJB and OM presented the highest values of infiltration. In the second period, the highest value occurred for the treatment of OSV.

Vegetation cover index

In the first period (2015/2016), the OJB treatment presented the highest mean vegetation cover index, with a value of 81 %, followed by OM, with a value of 70 % (Table 5). Regarding the second period (2016/2017), the OJB treatment presented the highest mean vegetation cover index, with a value of 60 %, followed by OSH, with a value of 46 %.

Olive cultivation on bare soil in the first two years presented a very low coverage, with mean values of 2 and 6 % in the first and second years, respectively (Table 5). The direct exposure of the soil surface inevitably means a high risk of erosion in the early years of cultivation.

The treatment with spontaneous vegetation presented mean vegetation cover index values of 58 % in the first period and 42 % in the second period. Similar findings were observed in the treatment using jack beans (OJB), with the vegetation cover index in the first period presenting higher mean values than the second does.

Table 4. Soil water infiltration for each period and in different soil cover management systems in olive cultivation

Parameters	Soil water infiltration				
	mm h^{-1}				
	2015/2016				
	OBS	OSV	OJB	OM	BS
Means	6.06±1.30 a	10.3±2.04 a	14.11±5.11 a	14.02 ±5.73 a	6.98 ± 2.39 a
CV (%)	21.24	19.70	36.23	40.87	34.32
	2016/2017				
	OBS	OSV	OJB	OSH	BS
Means	7.40±3.29 a	16.63±11.07 a	9.55±3.93 a	13.95±12.04 a	7.31±4.44 a
CV (%)	44.57	66.59	41.19	86.28	60.74

Means followed by the same letter in the columns do not differ by Tukey test (p≤0.05). Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and bare soil (BS).

Table 5. Vegetation cover index for each period and in different soil cover management systems in olive cultivation

Parameters	OBS	OSV	OJB	OM
	Vegetation cover index (%)			
	%			
	2015/2016			
Means	2 ± 1	58 ± 29	81 ± 21	70 ± 21
CV (%)	43.48	49.91	25.89	30.09
	2016/2017			
	OBS	OSV	OJB	OSH
Means	6 ± 4	42 ± 29	60 ± 32	46 ± 38
CV (%)	65.57	69.21	54.05	83.33

Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and bare soil (BS).

Figure 2 illustrates the temporal variation in the vegetation cover index in each treatment. By the visual observation, the OBS treatment showed a constant linear behavior along the time due to the slow growth of the olive plants when compared to the other treatments. The vegetation cover index of the OSV treatment presented a “saw teeth” behavior, also observed in a study conducted by Sastre et al. (2017).

Variation of soil organic matter

In the layer of 0.00-0.05 m, the variation of Soil Organic Matter (SOM) showed a statistically significant difference between the treatments (Table 6). The SOM variation presented a high variability with standard deviation ranging from 15.07 to 69.68 %. The SOM variation in the BS treatment was -23.77±69.68 (mean ± standard deviation). The highest SOM variation was observed in the treatment with spontaneous vegetation followed by the treatment constituted by Jack Beans. On the other hand, in the soil layer of 0.05-0.10 m, no differences were observed in SOM variation between the treatments (Table 6).

Soil loss assessment

Table 7 summarizes the mean values of soil loss for both periods studied. The first period showed high soil loss, which can be explained by the number of erosive events, 52 compared to 37 events of the second period, and by the number of events from November to January, 33 compared to 19 in the second period. Moreover, the values of erosivity should also be considered (Table 3).

The BS treatment presented higher values for both studied periods, with losses of 311.55 and 296.28 Mg ha^{-1} yr^{-1} in the first and second periods, respectively (Table 7). These values corroborates with the study performed by Silva et al. (2005) in which they found high variability of soil loss during the five years evaluating water erosion in a Cambisol

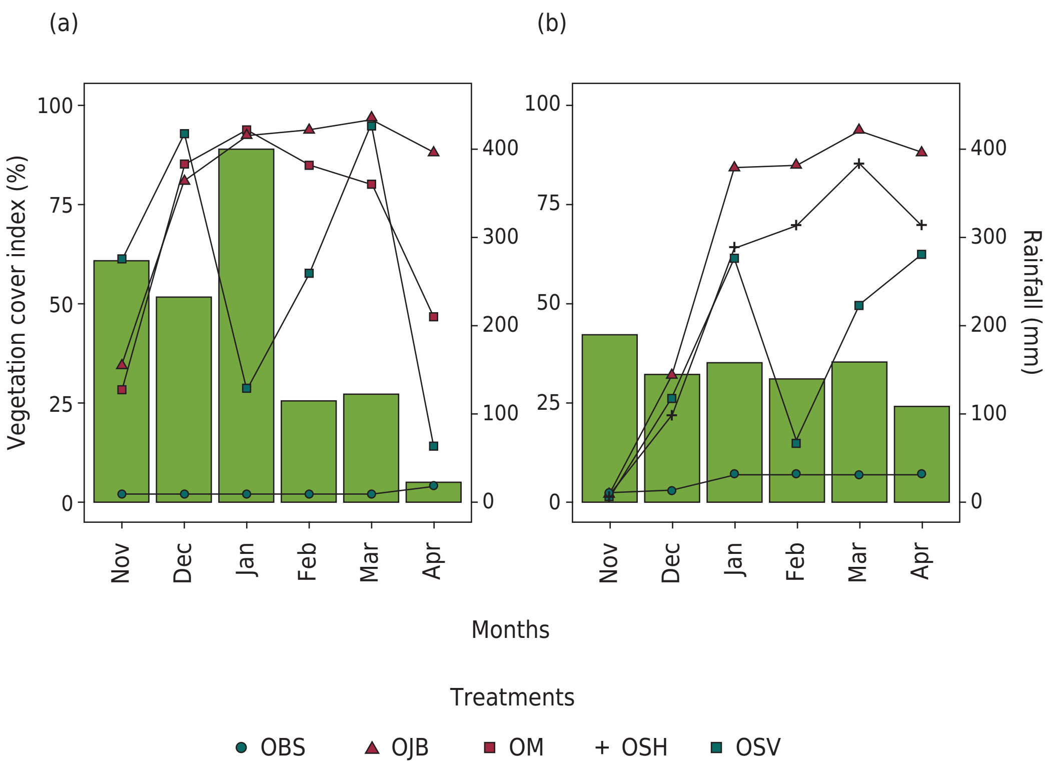

Figure 2. Vegetation cover index for the periods: 2015/2016 (a) and 2016/2017 (b) of different soil covers under young olive trees. Olive cultivation on bare soil (OBS); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and olive cultivation intercropped with spontaneous vegetation (OSV).

Table 6. Soil organic matter variation between both periods of experimentation

Treatments	Variation of soil organic matter(1)	
	%	
	0.00-0.05 m	0.05-0.10 m
BS	-23.77±69.68 b	16.33±33.32 a
OBS	12.22±15.07 ab	25.11±41.16 a
OSV	35.67±23.20 a	18.67±35.39 a
OJB	34.67±34.08 a	36.22±15.74 a
OM/OSH	8.00±25.05 ab	21.55±22.33 a

Means followed by the same letter on the lines do not differ by Tukey test (p≤0.05). Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and bare soil (BS). Soil organic matter (SOM) determined according to Walkley and Black (1934).

Table 7. Mean annual values of soil loss and efficiency in the reduction of loss in relation to bare soil in different vegetation cover management systems in olive cultivation

Treatment	Soil loss	LRE
	Mg ha^{-1} period^{-1}	%
	2015/2016	
BS	311.55±138.09 a	-
OBS	308.00±95.72 a	98.86
OSV	25.05±23.24 b	8.04
OJB	80.10±26.52 b	25.71
OM	64.12±31.79 b	20.84
	2016/2017	
BS	296.28±87.08 a	-
OBS	292.96±167.92 a	98.88
OSV	0.56±0.43 b	0.19
OJB	0.44±0.37 b	0.15
OSH	9.98±14.39 b	3.37

Means followed by the same letter do not differ by Tukey test (p≤0.05). Efficiency in the reduction of loss in relation to bare soil (LRE); olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and bare soil (BS).

with bare soil plots treatments, with a mean annual soil loss of 205.65 Mg ha^{-1} yr^{-1}, with values ranging from 98.47 to 374.10 Mg ha^{-1} yr^{-1}.

The OSV treatment presented a low soil loss in the first period. However, all treatments with intercropping cover crops (OSH, OJB, and OSV) presented no significant differences between them (Table 7).

The pattern of soil loss follows the erosivity evaluated in the same period (Figure 3), with higher soil loss values from November to April, most notably in December and January. We note that the OJB treatment presented a high soil loss in November (2015/2016), with a value equal to 49.80 Mg ha^{-1} yr^{-1}, which can be explained by the high rainfall erosivity (Table 3) at the cycle crop beginning, when there is a low soil cover index and along with there is a greater soil instability resultant from sowing operations.

Water loss assessment

The water loss had no significant difference between treatments BS and OBS for both studied periods (Table 8). Studies developed by Silva et al. (2005) with data from a 5-year study of soil and water losses in a bare plot (Cambisol), showed great variability

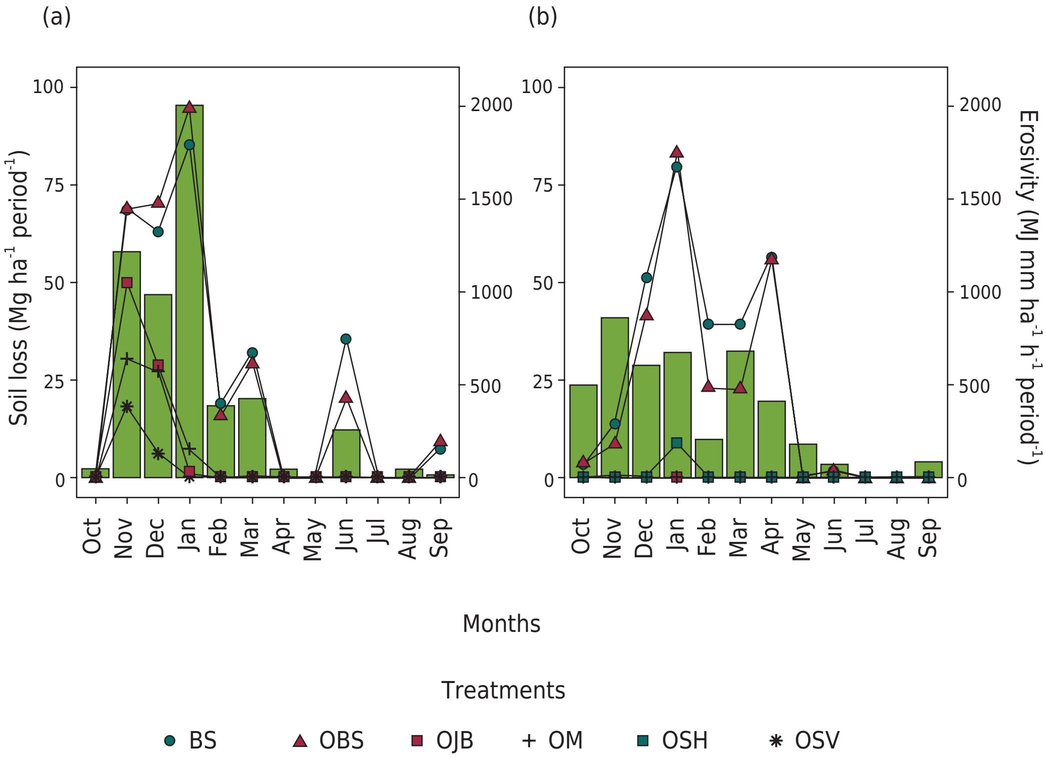

Figure 3. Soil loss in different vegetation cover management systems in olive cultivation during the studied periods of (a) 2015/2016 and (b) 2016/2017. Bare soil (BS); olive cultivation on bare soil (OBS); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and olive cultivation intercropped with spontaneous vegetation (OSV).

Table 8. Mean annual values of water loss, efficiency in reducing soil loss in relation to bare soil and surface runoff in relation to the total precipitation in different olive cultivation management systems

Treatment	Water loss	LRE	SRC
	mm yr^{-1}	%	
	2015/2016		
BS	594.83±285.03 a	-	45.42
OBS	590.40±340.15 a	99.25	45.08
OSV	103.11±52.14 b	17.33	7.87
OJB	269.53±117.60 b	45.31	20.58
OM	161.98±98.53 b	27.23	12.37
	2016/2017		
BS	374.77±187.68 a	-	35.03
OBS	342.35±137.57 a	57.50	32.00
OSV	41.49±8.77 b	6.97	3.88
OJB	29.97±4.57 b	5.04	2.80
OSH	33.13±5.10 b	5.57	3.10

Means followed by the same letter do not differ by Tukey test (p≤0.05). Loss reduction efficiency (LRE); surface runoff coefficient (SRC); olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and bare soil (BS).

of water loss, with a mean annual of 369 mm yr^{-1}, corroborating with the results found in the present study. We also verified a significant difference between the treatments with and without cover crops, for both studied periods.

Figure 4 shows the distribution of water losses during the studied periods, highlighting the variability caused by the irregular distribution of rain during the both periods evaluated (Silva et al., 2005).

Crop performance of olive cultivation

The results showed a negative effect of cover crops on the crop performance of olive plants and this effect was more pronounced in OM treatment (Table 9). Thus, the evaluation of plant hight showed a significant difference when comparing OM to the other treatments,

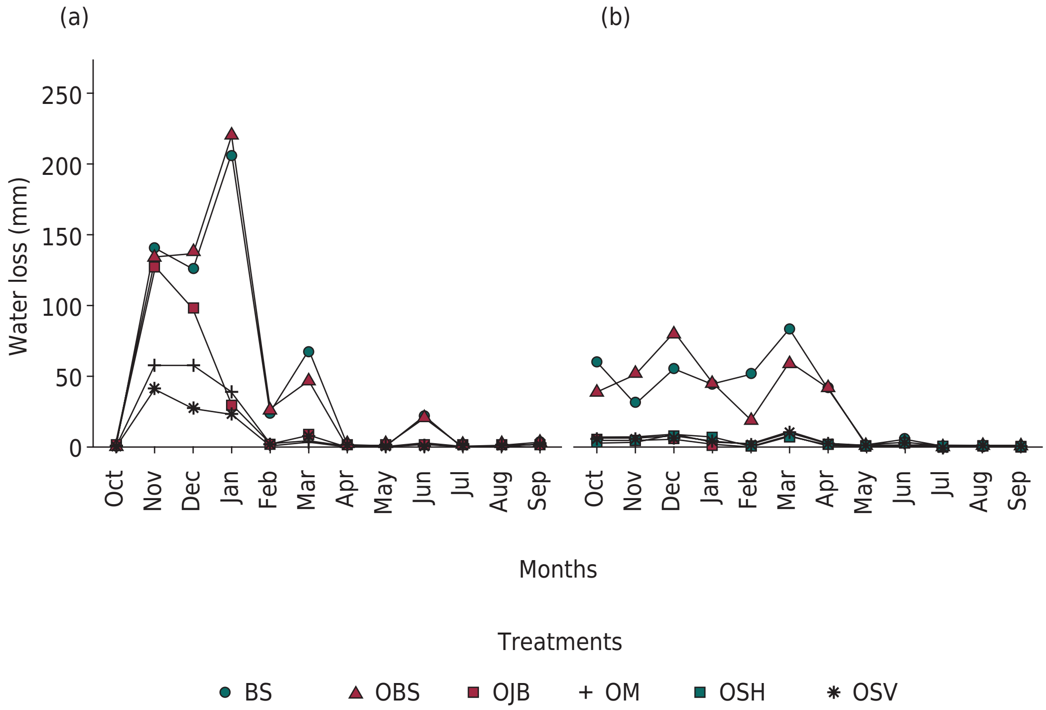

Figure 4. Average and monthly water loss in different olive cultivation management systems during the studied periods of (a) 2015/2016 and (b) 2016/2017. Bare soil (BS); olive cultivation on bare soil (OBS); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH); and olive cultivation intercropped with spontaneous vegetation (OSV).

Table 9. Values of mean, standard deviation, and coefficient of variation (CV) of the olive plantation performance for each period and in different soil cover management systems in olive cultivation

Treatment	Plant height	Crown radius	Trunk diameter
		cm	
		2015/2016	
OBS	173.00±23.51 a	62.91±15.71 a	2.99±0.70 a
OSV	137.75±40.85 ab	50.25±12.77 ab	2.38±0.69 ab
OJB	125.91±40.74 b	39.66±10.58 b	2.02±0.54 b
OM	70.08±25.35 c	22.50±8.44 c	1.17±0.50 c
		2016/2017	
OBS	257.66±43.55 a	94.83±23.74 a	4.54±1.00 a
OSV	217.58±51.47 ab	70.81±13.60 b	3.63±1.12 ab
OJB	240.33±79.78 a	70.06±17.73 b	3.73±0.98 ab
OSH	169.58±64.87 b	54.39±21.05 b	2.83±1.25 b

Means followed by the same letter on the lines do not differ by Tukey test ($p \leq 0.05$). Olive cultivation on bare soil (OBS); Olive cultivation intercropped with spontaneous vegetation (OSV); Olive cultivation intercropped with jack beans (OJB); Olive cultivation intercropped with millet (OM); Olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS).

and when comparing OSH to the OBS and OJB treatments. The highest values were obtained in the treatments OBS and OSV, in the period of 2015/2016, and OBS, OJB, and OSV in the period of 2016/2017.

Regarding olive tree heights (Table 9), the lower performance was obtained for olive cultivation intercropped with millet (OM), presenting a mean height of 70.08 cm compared to 173.00 cm in the OBS treatment. The OBS treatment presented the highest values for the median crown radius (Table 9), with an average value of 62.92 cm in the first period and 94.83 cm in the second. Concerning the trunk diameter (Table 9), in 2015/2016, there was a significant difference between the OM treatment and the other treatments. In 2016/2017, the highest trunk diameter values were obtained for the OBS, OVE and, OJB treatments.

DISCUSSION

Erosivity

The rainfall erosivity is the driving force of erosion and has a direct impact by the falling raindrop on the detachment of soil particles, the breakdown of aggregates, and the transport of eroded particles (Panagos et al., 2015). Mello et al. (2007) classified the erosivity in the studied region as a high erosivity. Results of annual erosivity showed the value of 5,437 mm ha^{-1} yr^{-1} in the first season and 4,277 MJ mm ha^{-1} yr^{-1} in the second season (Table 3). In the southern region of the state of Minas Gerais, Aquino et al. (2012) observed that the annual erosivity ranged from 5,145 to 7,776 MJ mm ha^{-1} h^{-1} yr^{-1} in a historical series of 40 years of meteorological data. The erosivity in the region was influenced by the orographic effect and local weather characteristics (Mello et al., 2007). From November to March, there was a high occurrence of rainfall, with 92.4 and 70.8 % of annual erosivity (Table 3), for the periods of 2015/2016 and 2016/2017, respectively. The high rainfall erosivity between November and March draws attention to the high risk of water erosion for the studied region.

The rainfall distribution has an important effect over soil saturation and runoff coefficient, what means that a large number of erosive events in a short time can lead to soil saturation and increase the water loss through runoff (Guimarães et al., 2017).

Soil infiltration

In many regions, it was demonstrated that cover crop in olive orchards increase soil porosity, water infiltration, and reduce runoff (Zuazo et al., 2009; Vicente-Vicente et al., 2017). However, the use of inadequate management practices reduced the soil protection by vegetation and caused the crusting and surface sealing, which are a result of the direct impact of raindrops on the soil.

The soil of the area had a low infiltration rate, and the lowest value was found in the bare soil treatment (Table 4). The crusting can explain this low infiltration in Cambisols due to the high silt/clay ratio (Pinto et al., 2018) and the soil compaction caused by the exposition of the soil to raindrops, as it was observed in the treatments BS and OBS. The OSV treatment is constituted mainly by *Brachiaria decumbens*, this grass that can provide greater soil structure, increase the soil aggregation and permeability (Bono et al., 2012).

The variation in the infiltration between BS and OBS can be explained by the fact that olive plantation was very young to have an effect in soil properties. In addition, the BS treatment is managed through plowing and harrowing in full area, allowing a larger area of water infiltration, whereas in OBS treatment, these practices are performed only between the rows. However, there is a tendency for this behavior to reverse over the time.

The variation in soil infiltration between the treatments with cover crops can be explained by the system root morphology of each cover crops, besides of the spatial variability that characterized the soil infiltration in Cambisols (Cardoso et al., 2013). According to Krstić et al. (2018), the choice of which cover crop depends on the farmer's objective. The legume cover crops (jack beans and sunn hemp) are chosen for the fast-growing and the ability to carry out the biological nitrogen fixation. On the other side, the cereals cover crops that are chosen because of increasing the content of soil organic matter and stabilizing the soil aggregates by their dense root system (Cardoso et al., 2013; Wittwer et al., 2017).

Vegetation cover index

Regarding the relation between water erosion and cover vegetation, it is crucial to have a good soil cover in periods with greater erosivity. Nevertheless, in periods with low rainfall, the vegetation cover greatly contributes to temperature regulation and water availability in the soil, which favors plant growth and development (Souza et al., 2010). Espejo-Pérez et al. (2013) demonstrated that the use of cover crops associated with olive trees is more appropriate when cover rates remain between 30 and 87 %.

The vegetation cover index had a difference in both periods. It can be explained by the higher precipitation in the period of 2015/2016 (Table 5), which favored crop development. In the treatment OSV, the low values of the vegetation cover index corresponded to the dates of vegetation weeding, as detailed in table 2. The curves of the cover crops (jack bean, millet, and sunn hemp) intercropped with olive cultivation presented a bell-type curve, also observed by Cardoso et al. (2012). In April, vegetation cover index decreases due to low rainfall and senescence of the cover crop leaves, because of the end of the crop cycle.

The spontaneous vegetation presented high growth variability in relation to time and space, which caused differences between the values of the cover indices between both studied periods. The same behavior was observed by Taguas et al. (2017) when they were studying the spatial and temporal variability of the cover plants (grasses) and their effects over erosion in olive cultivation.

Comparing the OSV treatment with the treatments with cover crops, we verify that OSV showed a high initial growth rate during some critical periods, from December to January, providing a cover vegetation index greater than 50 %. The good development of the spontaneous vegetation was favored by the climatic conditions and the seed bank present in the experimental area, along with the history of the study area and the adopted management (Nichols et al., 2015).

Comparing the cover plants with each other, we verify that jack beans stood out with the highest vegetation cover indexes, 81 and 60 %, in the first and second periods, respectively. Cardoso et al. (2012) also identified a higher vegetation cover index for jack beans when compared to sunn hemp and millet. The tropical climate revealed the importance of maintaining a continuous vegetation cover, especially during the summer season, when the rainfall erosivity is high, presenting a great risk of water erosion.

Variation of soil organic matter

The variation of SOM showed a negative value in bare soil in the topsoil (Table 6), this can be explained by the high impact of the erosion in the exposed soil, the soil particles transport and the acceleration of the organic matter decomposition (Almagro and Martínez-Mena, 2014). The behaviors of the variation of SOM in different treatments are consistent with the mean soil losses in the two periods (Tables 6 and 7). Gómez et al. (2009) demonstrated that the SOM in olive orchards has a positive correlation with infiltration and soil aggregation, which proves the important role of cover crops in improving soil conditions in olive orchards (Gómez et al., 2009; Soriano et al., 2014).

However, the OM treatment showed a low SOM variation; contrary to that, it was expected by cereal crop crops.

Soil loss assessment

There was no significant difference between BS and OBS, confirming the predisposition of olive cultivation to water erosion (Table 7). The high values of soil loss in the BS and OBS can be explained by the high Cambisols erodibility. According to Silva et al. (2005), these soils are considered shallow and reach saturation levels more quickly, thus, reducing the infiltration rate and increasing the surface runoff, especially in the absence of ground vegetal cover (Figure 2). Moreover, the crusting caused by the raindrop impact contributes to the formation of an impermeable layer, which contributes to the increase of water erosion. Nevertheless, the high values of loss that correspond to the first experimental period are due to the impact of installing the standard plots and planting the olive trees, providing great soil management.

The differences between different treatments and periods can be explained by the similar value of the vegetation cover index (Table 5) and by the soil protection by organic matter, resultant from periodic cutting operations (Sastre et al., 2017). According to Zuazo and Pleguezuelo (2008), the cover crops control the soil erosion in two ways. Firstly, in the short term, the cover crops intercept the rainfall and protect the soil against the impact of rainfall drops. Secondly, in the long term, the vegetation influences the fluxes of water and sediments by improving the soil aggregation, increasing water infiltration, and soil organic matter.

The high soil losses observed in the period of 2015/2016 in the plots with cover crops (millet and jack beans) were due to soil preparation and planting practices, which are explained by the lower soil loss in the plots with spontaneous vegetation (OSV). In this treatment, manual weeding was performed, with a preparation of the planting furrows in the direction of the slope. During the furrows planting, preferential paths may be formed, where water can concentrate its flow and increase its disintegrating and transporting power. Studies in olive orchards in the Mediterranean region indicated that cover crops which are sown or spontaneous can reduce soil erosion in the olive orchard by more than 92 % compared to management based in tillage (Repullo-Ruibérriz et al., 2018). However, the capacity of cover crops to reduce erosion depends on the characteristics of the plant species (De Baets et al., 2009).

Water loss assessment

The results of water loss illustrate the importance of cover crops in cultivated areas due to the increase in water infiltration rate, as observed by Almeida et al. (2018). High water loss in cultivated soils is critical for crops of agricultural species, notably in shallow and declining soils, and it can be aggravated during periods of higher water deficit, considering that, along with water, nutrients and organic matter, important components used by plants for growth and development, can be lost.

The first period presented the highest values for water loss in relation to the same treatments in the second period (Table 8), demonstrating the effect of management and the greater soil change in the first period in relation to the second, and the distinct precipitation between the studied periods (Table 3). In addition, cover crops presented a different performance in reducing water loss. Both treatments, BS and OBS, have uncovered soil, high silt content and high slope, these conditions promote soil sealing. The sealing makes the soil surface less permeable and increases the runoff (Assouline and Ben-Hur, 2006; Carvalho et al., 2015).

The OSV treatment proved to be the most efficient in reducing water loss, with an LRE of 8.04 % and an SRC of 7.87 % in 2015/2016. In 2016/2017, treatments OSV, OJB, and OSH presented similar values for the evaluation parameters of water loss. In a study conducted by Gómez et al. (2004) comparing the SRC in different management systems in olive cultivation in the region of Córdoba in Spain, an SRC value of 2.55 % was obtained for olive system associated with spontaneous vegetation, with low losses of soil and water.

Crop performance of olive cultivation

The vegetation cover index presented an inverse relation of the crop performance. The plants with the highest performance occurred in the plots with low vegetation cover rates and with higher soil and water losses (Tables 5 and 9).

By comparing the treatments with each other, we observed that the olive cultivation on bare soil (OBS) presented the highest soil and water losses and low vegetation cover index. The other treatments presented similar behavior. Olive cultivation intercropped with jack beans (OJB) and with millet (OCM) showed greater variability due to the high soil and water losses in the first period (Tables 7 and 8).

The results observed in the field illustrate the interference of the associated treatment over plant development, given that millet plants presented fast growth in January and February, shading the olive plants and interfering in their development. Despite this, the crowning in the millet was carried out in January but was not sufficient to attenuate the effect of the cover crop shade.

In this study, the olive plants of the experiment are still very young, so much more subject to cover crops competition. It is therefore still impossible to separate the effects of the cover crops protection to erosion from their competition with olive plants. Moreover, according to the results of soil loss in olive with bare soil treatment, the average loss is 300.48 Mg yr^{-1} ha^{-1} (2.32 cm yr^{-1}). In the future, with ten years of exploitation with the same management in the bare soil, it may cause a cumulative loss of 23.2 cm of soil. Considering that the depth of this soil is 0.60 m, as it was observed in the field, the soil will disappear in a few decades.

These results might support farmer's decisions to remove vegetation cover using chemical or manual methods, which is a common practice in olive orchards in Brazil and Mediterranean countries, as reported by several authors (Gómez et al., 2014; Ibáñez et al., 2014; Taguas et al., 2015). It is common for farmers to consider difficulties in managing olive cultivation with intercropped cover plants due to the additional management operations and, consequently, additional costs (Posthumus et al., 2015).

Conversely, Sastre et al. (2016) found no effect of cover crops over fruit yield or olive oil quality, highlighting the importance of cover crops in olive orchard. Also, cover crops reduce water erosion, improve water recharge and water retention (Bombino et al., 2019), increase soil organic matter and carbon accumulation (Cerdà et al., 2018; Guimarães et al., 2018; Novara et al., 2019), and there is a large reserve of nutrients coming from cover crops biomass decomposition (Gómez-Muñoz et al., 2014). Thus, an adequate olive orchard management should conciliate crop performance and environmental aspects of the crop, especially in Cambisols. It is necessary to have more studies that evaluate the erosion behavior in olive orchards in tropical conditions with different management practices and cover crops.

CONCLUSION

The olive orchards planted in shallow and sloping soils without cover crops showed unsustainable soil loss, crusting, and sealing the superficial soil layer, which can progress quickly for soil degradation.

The mitigation of soil erosion in olive cultivation is associated with the adoption of cover crops allowing the improvement of soil conditions by soil organic matter accumulation, increasing soil infiltration, and reducing runoff.

Spontaneous vegetation in between planting rows increases the performance of olive trees, improves soil conditions, and reduces environmental impact. However, the use of cover crops in the first year after planting the olive orchards needs some special care to conciliate olive plantation growth with soil protection.

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