UNIVERSIDADE FEDERAL DE LAVRAS

ADNANE BENIAICH

WATER EROSION IN OLIVE ORCHARDS UNDER DIFFERENT COVER CROPS:

FIELD EXPERIMENTS FROM TROPICAL BRAZIL

LAVRAS-MG

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Thesis presented to the Federal University of Lavras, as part of the requirements of the Post-Graduate Program in Soil Science, area of concentration in Environmental Resources and Land Use, to obtain the title of Doctor.

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Supervisor

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ABSTRACT

The present research was carried out to investigate the relationship between the soil and water losses due to water erosion, the phytotechnical aspects in olive tree management systems, in consortium or not with cover crops in the southern region of the state of Minas Gerais; and also study different cover crops plants monitoring methods using multispectral and conventional images from digital cameras boarded in unmanned aerial vehicle (UAV). Soil and water loss were evaluated using the standard erosion plots, and vegetation cover monitoring was evaluated using the vegetation indexes calculated from the bands of images generated by the UAVs. The results obtained show that the vegetation indices generated from the images obtained by UAV showed to be more practical and efficient, allowing the monitoring with more frequency and area coverage during the crop cycle. In addition, the total vegetation cover index presented better performance in soil loss prediction and in the determination of Factor C in the Universal Soil Loss Equation (USLE). The management plants consortium with olive cultivation reconciles the phytotechnical and environmental aspects of the crop in the tropical region aiming to the reduction of soil and water losses due to water erosion, especially in shallow soils with low hydraulic conductivity and slopes.

Keywords: Soil conservation. Sustainability. Soil degradation.

RESUMO

O presente trabalho foi realizada com o objetivo de estudar as relações entre as perdas de solos e água por erosão hídrica, os aspectos fitotécnicos, em sistemas de manejo do cultivo da oliveira em consórcio ou não com plantas de cobertura na região Sul do estado de Minas Gerais, e também estudar diferentes metodologias de monitoramento das plantas de cobertura usando imagens de câmeras digitais multiespectral e convencional embarcadas em veículo aéreo não tripulado (VANT). A avaliação das perdas de solo e agua foi feita usando as parcelas padrão da erosão, e o monitoramento da cobertura vegetal foi feito usando os índices de vegetação calculados a partir das bandas de imagens geradas pelos VANT. Os resultados obtidos mostram que os índices de vegetação gerados à partir de imagens obtidas por VANT mostraram ser mais práticos e eficientes, permitindo o monitoramento com maior frequência e abrangência de área durante o ciclo das culturas. Além de isso o índice de cobertura vegetal total apresentou melhor resultados na predição de perda de solo e na determinação de Fator C da Equação Universal de Perda do Solo (USLE). O manejo de plantas de coberturas consorciadas com o cultivo da oliveira concilia entre os aspectos fitotécnicos e ambientais do cultivo na região tropical visando à redução das perdas de solo e água por erosão hídrica notadamente em solos rasos, de baixa condutividade hidráulica e declivosos.

Palavras chaves: Conservação do solo. Sustentabilidade. Degradação do solo.

SUMMARY

FIRST PART – GENERAL INTRODUCTION

1. INTRODUCTION

Brazil is currently the second largest importer of olive oil worldwide, classed just after the United States of America. In 2017, Brazil imported 59.5 thousand tons of olive oil. The olive oil Brazilian importation reaches the threshold of 73.0 thousand tons in 2013, and it marked an historical record, according to data from the International Olive Council (IOC, 2017). This growth in the olive oil market shows a great agricultural potential for the development of this culture. As a result, there was a great expansion of the olive cultivation in the south of the state of Minas Gerais (Brazil), particularly in the region of the Mantiqueira Range (SILVA et al., 2012).

However, there is a great challenge regarding the control of water erosion during the crop cycle, with the aim to achieve a sustainable production with a low cost. In Mediterranean countries, water erosion is also a major problem in olive groves, because the most olive orchards are planted on steep slopes (GARCÍA-RUIZ, 2010; GÓMEZ et al., 2004; SASTRE et al., 2017). Dotterweich (2013) reported that the earliest description of erosion phenomena was in olive plantations in ancient Greece.

Water erosion is a natural process that begins with the detachment of soil particles by raindrop impact and/or overland flow. It occurs with a fast rate when it has compared to other processes of soil formation (KOURGIALAS et al., 2016). In addition, in agricultural soils with different agricultural production systems, various studies have showed that the erosion rate is higher than in soils with native vegetation (ANACHE et al., 2017; DOTTERWEICH, 2013; MERTEN; MINELLA, 2013).

The continuous monitoring of the processes involving surface water flow, sediment, and solute flows is fundamental for understanding the environmental dynamics of water erosion. However, obtaining this information is laborious, costly, consuming, and the results are achieved in a long-term (GOVERS et al., 2017).

The introduction of olive plantation into new regions may have negative impacts in the environment (ZAMBON et al., 2018) . In addition, anthropic action changes the natural balance between the soil and the vegetation cover, causing an erosion increase, sediment production and water losses (GOVERS et al., 2017; OLIVEIRA et al., 2015) even in the areas where the soils are considered to be resistant to water erosion (AYER et al., 2015).

In Mediterranean region, where the erosion is one of the major causes of soil degradation (PANAGOS et al., 2015), olive orchards are set on steep slopes with shallow soils, where other crops would have low yields (IBÁÑEZ et al., 2014).

Studies conducted on olive plantations show that the inadequate management is among the origins of erosion (FLESKENS; STROOSNIJDER, 2007; KAIRIS et al., 2013; LÓPEZ-VICENTE; ÁLVAREZ, 2018). According to Gómez et al. (2014) the soil losses ranges from 61 to 184 Mg ha-1 year-1 in the southern Spain, and these values tend to increase due to the introduction of new management techniques, such as mechanization and weed control (TAGUAS et al., 2015; VANWALLEGHEM et al., 2011). In tropical regions the erosive process may be more aggressive due to high rainfall erosivity (AQUINO et al., 2012), that makes soils more susceptible to erosion (CARVALHO et al., 2005).That can be particularly problematic for shallow and highly erodible soils, such as Cambisols.

The knowledge of the factors that control erosion processes become an important tool for making decisions about the appropriate use and soil management. Thus, it is necessary to know the dynamics of the erosive processes and to quantify their environmental impacts (ANACHE et al., 2017; DOTTERWEICH, 2013).

The objectives of this study were to: 1) study the relationships between soil and water losses, and phytotechnical aspects of olive plantations in different management in the South of the State of Minas Gerais (Brazil); 2) evaluate different methodologies for monitoring cover plants using images from multispectral and conventional digital cameras boarded on unmanned aerial vehicles (UAVs).

2. THEORETICAL REFERENCE

2.1 Water erosion

Water erosion is one of the major factors of soil degradation and reduction of agricultural land worldwide (LAL, 2001), threatening the sustainability and productivity of agroecosystems and human health (BREVIK et al., 2015; GOVERS et al., 2017; NOVARA et al., 2017).

Water erosion is a serious problem in Brazil, which has been reported by different authors (AMARAL et al., 2008; ANACHE et al., 2017; GUIMARAES et al., 2017; WILLAARTS et al., 2016).

Particularly, in the south of the State of Minas Gerais, where there is a dominance of soil very susceptible to soil erosion (MENEZES et al. 2014 ; PINTO et al., 2018). All of these studies warn about the erosion problem, its consequences on other environmental sectors, showing the importance of adopting conservation practices.

Erosion processes are physically initiated by the disintegration of soil particles, under the effect of kinetic energy of raindrops, causing surface runoff, transport and movement of particles, and finally the deposition of particles when kinetic energy decreased (BERTONI; LOMBARDI NETO, 2014; KINNELL, 2016).

In erosive process, the superficial layer is partially or completely eroded, depending on the erosion intensity, causing reduction of the arable layer, and therefore a reduction of soil fertility and biodiversity (GARCÍA-DÍAZ et al., 2017), as well as the impacts on biochemical carbon cycles (QUINTON et al., 2010).

Sediments and nutrients are carried and deposited in the lower areas of the landscape, also the reducing in the infiltration rate and the increasing of water runoff, causing the deterioration of water quality (BERTONI; LOMBARDI NETO, 2014).

Several erosion studies were developed in the south of the State of Minas Gerais, some of its are summarized in the table 1, which stand out the high susceptibility of Cambisols to erosion, when it is comparing to the other soil classes. Cambisols are soils generally characterized as shallow; occur in high slopes, low fertility, and with restrictions to water infiltration (PEREIRA et al., 2010).

The erosive processes are dynamics and complexes, and their understanding requires monitoring of soil and water losses over long term to overcome the spatial and temporal variability of the data (MICKELSON et al., 1983). Assessment of erosion is indispensable to adopt the suitable management in agricultural systems, since the soil is an irrecoverable resource and its degradation will undermine the productivity of the system (ANACHE et al., 2017).

The experimental study of erosive processes has a great importance to improve the management of the agricultural production, in order to look for a sustainable agriculture (ANACHE et al., 2017; DOTTERWEICH, 2013).

In Brazil, Anache et al.(2017) noted that the number of erosion monitoring plots has been decreasing in the last 15 years. The same author warned that out of a total of 401 erosion studies, about 50% of the experimental studies have 2 years or less of monitoring data.

In Brazil, exponential expansion of agriculture becomes the primary environmental aspect of sustainable management (OLIVEIRA et al., 2015). In this sense, there were several studies in agricultural systems aiming at to evaluate of soil and water losses combining different management systems. Including, the evaluation of cover crops performance in different soil classes (CARDOSO et al., 2013; FREITAS et al., 2012; LIMA et al., 2018). Such studies showed that the best vegetation cover index was provided by the jack bean, promoting the best soil protection compared to others (Millet; sunn hemp; corn) (CARDOSO et al., 2012; LIMA et al., 2014). In the permanent plantation, (CARVALHO et al., 2007) observed good results of cover crops in different coffee management systems.

Table 1- Water erosion assessment studies conducted in standard plots in the southern state of Minas Gerais (Brazil).

Study period	Soil class	Slope m m^{-1}	Erosivity MJ mm ha^{-1} h^{-1}	Cover crops	Soil loss Mg Ha^{-1} period^{-1}	Reference
November 2011-March 2012	Red-Yellow Argisol	0.12	8,768.04	BS	4.20	(LIMA et al., 2014)
				M	1.86	
				JB	1.38	
				JB-M	1.14	
December 2007-March 2008	Red-Yellow Argisol	0.12	3,388.00	SH	2.15	(CARDOSO et al., 2012)
				JB	0.24	
				M	0.45	
April 2003-March 2004	Red Latosol	0.12	8,102.00	BS	67.24	(CARVALHO et al., 2007)
				OCM	0.21	
				OCR	0.19	
				CCH	0.20	
				CCT	0.11	
1998 -2002	Cambisol	0.15	4,865.00	BS	205.65	(SILVA et al., 2005)
	Latosol	0.12		BS	14.90	
2013-2015	Argisol	0.27	6,469.00	BS	0.64	(BISPO et al., 2017)
		0.27		M	0.53	
		0.32		DP	0.06	
		0.32		WMP	0.06	
		0.31		RF	0.03	

BS: bare soil; JB: jack bean; M: millet, JB-M: jack bean interleaved with millet; DP: Degraded pasture; WMP: Well-managed Pasture; RF: Reforestation; CJ: sunn hemp; OCM: organic coffee with manual weeding; OCR: organic coffee with rotted weeding; CCH: coffee under conventional tillage using herbicide; CCT: coffee under conventional tillage with rotted weeding.

2.2 The olive tree culture in Brazil

In recent years, the olive cultivation has reached new regions, where are principally situated in the tropics, in countries such as Australia, Peru, Colombia, some regions of Africa and Brazil (ZAMBON et al., 2018). In Brazil, according to Silva et al. (2012) olive plantation areas is located in the Brazilian states of Rio Grande and Minas Gerais. The latter last has been considerable increase in olive planted areas, with a promised production, allowing the increasing the planted areas and improving the production techniques.

The Mantiqueira Range Region presents the region with the dominance of the olive plantations in Minas Gerais, with the cultivar Arbequina (SILVA et al., 2012). The olive tree is cultivated in shallow soils with low fertility in the sloping landscape. Different factors may interfere in the production of the olive tree, such as the climatic conditions, because this crop needs a cumulative of cold hours equivalent to one month with a low temperature at 10 ° C (CARDOSO et al. , 2006).

2.3 The Mantiqueira Range Region

The Mantiqueira Range region is a region that has a great hydrological importance in Brazil, where it localized large spring flow that forms the great rivers of important state in Brazil (São Paulo; Rio de Janeiro; and Minas Gerais). As reported by Menezes et al. (2014), the dominant pedologic class in the Mantiqueira Range region is Cambisol. These soils are shallow soils, with low infiltration and very susceptible to water erosion. According to Pinto et al. (2018), the Cambisols in this region present a high silt/clay ratio, and can develop crusting when the vegetation cover is absent or removed.

2.4 Erosion in the olive orchard

In the early years of post-planting, the olive cultivation present a high risk of erosion caused by the low vegetation cover, as well as the high spacing between olive plants, to allow a good development of the plants. In addition, it is commonly cropped in poor soils with high slopes (ESPEJO-PÉREZ et al., 2013; IBÁÑEZ et al., 2014).

The Mediterranean region that presents the region originated from olive cultivation, but also the region with the highest numbers of olive tree cultivation (SASTRE et al., 2017). In this region, some authors consider that erosion control is the key for sustainable management (AL-WADAEY; ZIADAT, 2014; GÓMEZ et al., 2014).

In other words, the crop management and the vegetation cover index are the most important factors causing erosion beyond rainfall erosivity and topography of the planting area (GARCÍA-RUIZ, 2010).

Several studies have examined the severity of the erosion problem and the impact of the type of management on the erosive process acceleration, generating a high rate of soil loss (GÓMEZ et al., 2004, 2006; GÓMEZ et al., 2001; PARRAS-ALCÁNTARA et al., 2016; SASTRE et al., 2017).

Studies conducted by García-Orenes et al. (2012) consider that the main cause of erosion in olive plantations, besides natural factors, is the inadequate management. Espejo-Pérez et al. (2013) reported that the wrong practices, aiming to remove the spontaneous vegetation associated with olive plantations, in order to reduce competition between olive and spontaneous vegetation by light, water and nutrients, on the other hand, these practices make the soil more exposed to erosion.

2.5 Management types in the olive orchard

According to García-Ruiz (2010), there are three categories of management systems used in olive orchard : conventional tillage with control of spontaneous vegetation with plowing for 3 or 4 times per year; the control of spontaneous vegetation with herbicide; and the use of the cover crops between the tree lines.

The cover crops play an important role in the reducing water erosion in olive orchards, and research investigations in olive orchards erosion show that the cover crops use is efficient in reducing erosion. Studies in Spain olive plantations show the importance of cover crops to compensate the low cover rate of olive tree (GÓMEZ et al., 2011; GOMEZ et al., 2009; SASTRE et al., 2017).

The efficiency of erosion reduction by the cover crops depends mainly on the morphological characteristics of the plant (leaf size; shape; and angle of disposal relative to the stem), speed of growth and soil aggregation capacity (CASTRO et al., 2011). According to Stocking (1994), there are many conservation practices, but the most efficient and adapted practice with different management is the use the cover crops.

3. FINAL CONSIDERATIONS

The assessment of erosion processes has a great importance to improve the management of agricultural crops, and to achieve sustainable agriculture.

Olive cultivation presents low coverage, especially in the first years after planting, making the soil exposed to water erosion, requiring the adoption of management and conservation practices.

The knowledge of the effect of cover crops on olive plantations on water erosion in the southern region of Minas Gerais is an immediate necessity, considering that this fruit is in the stage of expansion in this region.

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SECOND PART – ARTICLES

Article elaborated according to standards of the scientific journal: **Semina: Ciências Agrárias**

ARTICLE 1: Determination of vegetation cover index under different soil management systems of cover plants by using an unmanned aerial vehicle with an onboard digital photographic camera

Determinação do índice de cobertura vegetal em sistemas de manejo do solo com plantas de cobertura, utilizando veículo aéreo não tripulado com câmera fotográfica digital embarcada

Abstract

The permanent monitoring of vegetation cover is important to guarantee a sustainable management of agricultural activities, with a relevant role in the reduction of water erosion. This monitoring can be carried out through different indicators such as vegetation cover indices. In this study, the vegetation cover index was obtained using uncalibrated RGB images generated from a digital photographic camera on an unmanned aerial vehicle (UAV). In addition, a comparative study with 11 vegetation indices was carried out. The vegetation indices CIVE and EXG presented a better performance and the index WI presented the worst performance in the vegetation classification during the cycles of jack bean and millet, according to the overall accuracy and Kappa coefficient. Vegetation indices were effective tools in obtaining soil cover index when compared to the standard Stocking method, except for the index WI. Architecture and cycle of millet and jack bean influenced the behavior of the studied vegetation indices. Vegetation indices generated from RGB images obtained by UAV were more practical and efficient, allowing a more frequent monitoring and in a wider area during the crop cycle.

Keywords: Vegetation cover index. RGB image. Vegetation index. Unmanned Aerial Vehicle.

Resumo

O monitoramento permanente da cobertura vegetal é importante para garantir o manejo sustentável das atividades agrícolas, com relevante papel na redução da erosão hídrica. Este monitoramento pode ser realizado por meio de diferentes indicadores, como os índices de cobertura vegetal. Nesse artigo o índice de cobertura de vegetação foi obtido usando imagens RGB não-calibradas, geradas a partir de câmera fotográfica digital embarcada em um veículo aéreo não tripulado (VANT). Além disso, foi feito um estudo comparativo de 11 índices de vegetação. Os índices de vegetação CIVE e EXG apresentaram melhor desempenho e o índice WI apresentou o pior desempenho na classificação da vegetação durante o ciclo das culturas de feijão-de-porco e milheto, conforme a acurácia global e o coeficiente Kappa. Os índices de vegetação se apresentaram como uma ferramenta eficaz na obtenção dos índices de cobertura de solo, quando comparados ao método padrão de Stocking, exceto para o índice WI. A arquitetura e o ciclo das culturas milheto e o feijão-de-porco influenciaram no comportamento dos índices de vegetação estudados. Os índices de vegetação gerados à partir de imagens RGB obtidas por VANT mostraram ser mais práticos e eficientes, permitindo o monitoramento com maior frequência e abrangência de área durante o ciclo das culturas.

Palavras-chave: Índice de cobertura vegetal. Imagem RGB. Índice de vegetação. Veículo Aéreo Não Tripulado.

Introduction

The permanent monitoring of vegetation cover is important to guarantee a sustainable management of agricultural activities, with a relevant role in the reduction of water erosion (CARDOSO et al., 2012; FAUSTOLO et al., 2017; GUIMARAES et al., 2017; SPERANDIO et al., 2012). This monitoring can be carried out by different indicators (CARDOSO et al., 2012; LIMA et al., 2014; MARRERO et al., 2009; PASSOS et al., 2015) such as vegetation cover indices, which represent the percentage of area covered by vegetation in relation to the total surface area of study (ZHONGMING et al., 2010).

In this context, different methods can be used to determine vegetation cover index such as the Stocking method (STOCKING, 1994) or unmanned aerial vehicles (UAV) onboard camera (CARUSO et al., 2017). By the Stocking method, measurements are performed in situ, providing relevant information, but with high delays in data acquisition and a low spatial cover of the area. On the other hand, unmanned aerial vehicles (UAVs) and onboard digital cameras have low operating costs, allowing a fast data acquisition with a significant spatial cover, whose images and by-products are obtained in a simple way (BENDIG et al., 2015). Another advantage is a higher temporal resolution, which provides important subsidies for decision-making (YU et al., 2013).

When comparing images obtained by multi or hyperspectral cameras with those by RGB (Red Green Blue) on UAV, the latter carries limited spectral information. In contrast, its more affordable price, high spatial resolution (centimeters), as well as the possibility of obtaining different vegetation indices in the visible spectrum have increased its use, and studies are needed to better define methodologies and indices for different vegetation cover situations (DANDOIS et al., 2015).

Vegetation indices are formed from combinations of spectral values aiming at obtaining a single value, which allows easily interpreting the quantity or quality of the vegetation within a pixel (CAMPBELL; WYNNE, 2013). Furthermore, these indices have been used to estimate the vegetation cover in pixel-based images, which include vegetated or non-vegetated areas. According to Torres-Sánchez et al. (2014), once the images have a high resolution, in which each pixel covers only the vegetation or bare soil, the proportion of pixels with this information combined is reduced.

Regarding the vegetation cover index, Cardoso et al. (2012) assessed jack bean and millet as cover crops and observed different soil losses due to water erosion as a function of different soil protection. Thus, changes in vegetation cover directly affect the surface runoff rate (SANTOS et al., 2000). Considering the importance of these cover plants and the lack of information regarding their vegetation cover dynamics, this study aimed to calculate and assess different vegetation indices of the visible spectrum and determine the vegetation cover index from aerial images obtained by UAVs in management systems of cover plants.

Material and methods

Study area

The experiment was conducted in the Federal University of Lavras (UFLA) in Lavras, Minas Gerais, Brazil, located between the coordinates 21°13′20″ S and 44°58′17″ W and with an average altitude of 925 m. The study area consisted of plots 4.0 m wide and 12.0 m long (Figure 1). Treatments consisted of a bare soil (non-vegetation class) and the crops jack bean (*Canavalia ensiformis* L.) and millet (*Pennisetum glaucum* L.) (vegetation class), with three replications each. Cover plants were manually sown at the beginning of November 2015.

Figure 1. Orthophoto of the experimental plots with the treatments jack bean, millet, and bare soil.

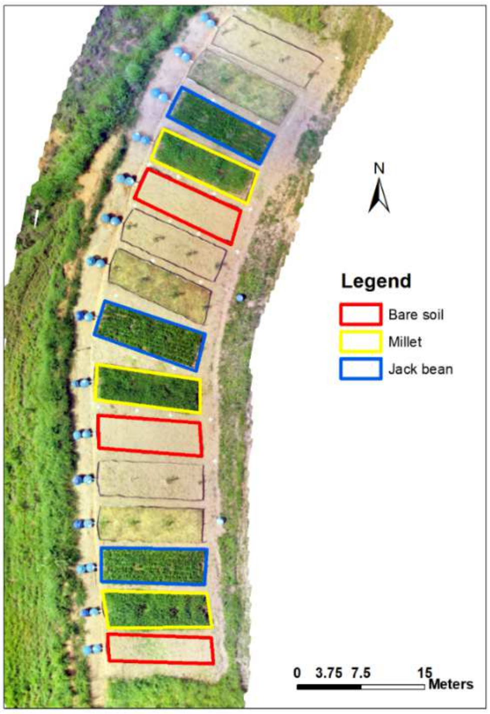


Image acquisition by UAV

Image acquisition was performed by using the unmanned aerial vehicle (UAV) DJI Phantom 3 professional, serial number: p76ddc18b271, register certificate non-recreational at the National Civil Aviation Agency of Brazil (ANAC), number PP-011111110, according to the methodology proposed by Bendig et al. (2015) with a camera resolution of 12 megapixel. The photographic parameters were an aperture of f/2.8, shutter speed of 1/290 s, ISO of 100, white balance of 4500 K, and focal length of 3.6 mm. Flights were carried out during the crop cycle at 5, 15, 30, 75, 105, and 135 days after sowing (DAS) (Figure 1).

Six flights with a height of 15 m were carried out. For image georeferencing, 18 control points were used. Between 150 and 200 photos were recorded per flight with 80% overlap. In the next step, the program PhotoScan Pro1.2.6 (AGISOFT, 2017) was used for image processing.

Vegetation indices

Nine indices and two combinations were used in this study. RGB bands were normalized to calculate the chromatic levels (ARROYO et al., 2016; WOEBBECKE et al., 1995) (Equation 1).

$$r = \frac{R}{R+G+B},\ g = \frac{G}{R+G+B},\ \text{and}\ b = \frac{R}{R+G+B} \tag{1}$$

Where r, g, and b are the normalized values of the bands R (red), G (green), and B (blue), respectively.

In order to find the best optical contrast between plants and soil and discriminate them automatically, the indices Excess Green (ExG) (Equation 2) and Woebbecke Index (WI) (Equation 3) were used according to Woebbecke et al. (1995).

$$ExG = 2g - r - b \tag{2}$$

$$WI = \frac{g-b}{r-g} \tag{3}$$

The index Excess Green Minus Excess Red (EXGR), proposed by Meyer and Neto (2008) (Equation 4), was used to distinguish plant canopy from different soil or residue backgrounds.

$$EXGR = ExG - 1.4r - g \tag{4}$$

The index Color Index of Vegetation (CIVE) (KATAOKA et al., 2003) was based on the principal component analysis of the information contained in the RGB bands (Equation 5).

$$\mathrm{CIVE} = 0.441r - 0.881g + 0.385b + 18.78745 \tag{5}$$

For estimating the vegetation fraction, the Normalized Green-Red Difference Index (NGRDI) was used (GILABERT et al., 2002) (Equation 6).

$$\mathrm{NGRDI} = \frac{G - R}{G + R} \tag{6}$$

Based on the physical study of the image, Marchant and Onyango (2000) developed the Vegetativen index (VEG) (Equation 7).

$$\mathrm{VEG} = \frac{g}{r^{a} b^{(1-a)}} \tag{7}$$

where a is a constant with a reference value of 0.667.

Using different results obtained in studies on the aforementioned indices, Guijarro et al. (2011) proposed the indices COMB1 and COMB2 (Equations 8 and 9).

$$\mathrm{COMB1} = 0.25\mathrm{ExG} + 0.3\mathrm{EXGR} + 0.33\mathrm{CIVE} + 0.12\mathrm{VEG} \tag{8}$$

$$\mathrm{COMB2} = 0.36\mathrm{ExG} + 0.47\mathrm{CIVE} + 0.17\mathrm{VEG} \tag{9}$$

In addition, the indices Ratio Green/Red (GR) (Equation 10) and SAVI green (SAVI) modified by Li et al. (2010) (Equation 11) were tested.

$$\mathrm{GR} = \frac{G}{R} \tag{10}$$

$$\mathrm{SAVI} = \frac{1.5 * (G - R)}{(G + R + 0.5)} \tag{11}$$

In this study, the index hue (HUE) was also used, constituting one of the components of HSV (Hue, Saturation, Value) color space. HSV model defines a color space in three components: hue (HUE), which determines the type of color and varies from 0 to 360°; saturation (S), which shows the color vibration and varies from 0 to 1; and value (V), which is the color brightness and ranges from 0 to 1. HUE was determined using the methodology proposed by Purcell et al. (2011) (Equation 12).

$$\text{If } \max(R,G,B) = R,\ HUE = 60*\{(G - B)/[(\max(R,G,B) - \min(R,G,B)]\}$$
$$\text{If } \max(R,G,B) = G, HUE = 60*\{2+\{(B - R)/\left[\max(R,G,B) - \min(R,G,B)\right]\}\} \quad (12)$$
$$\text{If } \max(R,G,B) = B,\ HUE = 60*\{4+\{(R - G)/\left[\max(R,G,B) - \min(R,G,B)\right]\}\}$$

Assessment of vegetation indices to generate vegetation classes

Initially, from the mosaic of six orthophotos, 100 random points were extracted with values of vegetation indices for each of the nine plots. These values were submitted to the logistic regression in order to generate probability intervals from 0 to 1, as Equation 13 (HILBE, 2009):

$$P = \frac{1}{(1+e^{-z})},\ z = b_0 + b_1 x \quad (13)$$

where P is the probability of an event, which, in this case, is vegetation or non-vegetation, z is the linear function of the exploratory variable x, b_0 is the intercept, and b_1 is the angular coefficient. Thus, from the values of z for each vegetation index, the value P = 0.5 served as a limit to distinguish vegetation classes (vegetation or non-vegetation) (JAFARI GOLDARAG et al., 2016). Since the data has a binary, the logistic regression is adequately applied to the data.

For validating the vegetation classes, 50 random points were extracted from the orthophotos containing vegetation classes for each plot. Classification accuracy was obtained by calculating the Kappa coefficient (LANDIS; KOCH, 1977) and overall accuracy (FOODY, 2010).

Cover index calculation

Two methods were used to calculate the vegetation cover index. The first method used the methodology proposed by Stocking (1994) during crop cycle (jack bean and millet) in relation to the days after sowing (DAS).

In addition, the vegetation cover index was determined for each vegetation index (generated by logistic regression) (CI VI) (Equation 14).

$$CI\ VI = \frac{\text{Pixels classified as vegetation}}{\text{Total pixels of the plot}} \quad (14)$$

The comparison between the cover indices was performed by means of linear regression (coefficient of determination, R^2) and Pearson correlation, in addition to the calculation of the residual sum of squares (RSS) for each plot (FERREIRA, 2005).

Results and discussion

Assessment of vegetation indices in the visible

Figure 2 shows that the maps generated from the combinations of RGB bands allowed recording the variability of responses of vegetation indices in relation to vegetation in each plot. Table 1 shows the descriptive statistics of vegetation indices for different classes (vegetation or non-vegetation).

The indices WI and HUE presented a higher variation and high values of the standard deviation when compared to the others. Moreover, it is possible to observe the contrast between indices when analyzed for vegetation and non-vegetation, considering their average values and respective standard deviation. Thus, most of the indices presented a difference between the average values in each class (Table 1). This reinforces the potential of the indices in discriminating different types of vegetation cover. The indices GR, HUE, and WI, on the other hand, did not present an adequate distinction between classes.

Torres-Sánchez et al. (2014) assessed the accuracy of vegetation indices and obtained average values of vegetation index limits around −0.01, 18.73, 6.12, 9.05, 0.16, 5.21, 1.17, and −0.79 for NGRDI, CIVE, COM1, COM2, EXG, WI, VEG, and EXGR, respectively. The index WI found in our study stood out with a great difference between the results of the aforementioned study, unlike the other indices, which present little difference. Saberioon et al. (2014) found average values of 0.002, 0.471, and 0.210 for NGRDI, EXG, and EXGR, respectively, in rice. These values are in line with those obtained in our study. On the other hand, Hunt (2005) found an average NGRDI value of 0.05 in corn and 0.13 in soybean. Motohka et al. (2010) analyzed time variation of the index NGRDI for 4 years and found values ranging from 0.371 to −0.112. In our study, the index NGRDI presented an amplitude between 0.25 and −0.46.

Figure 2. Maps of the visible vegetation indices CIVE (a), COMB1 (b), COMB2 (c), ExG (d), EXGR (e), GR (f), HUE (g), NGRDI (h), SAVI (i), VEG (j), and WI (k) calculated on February 2, 2016 from the RGB composition.

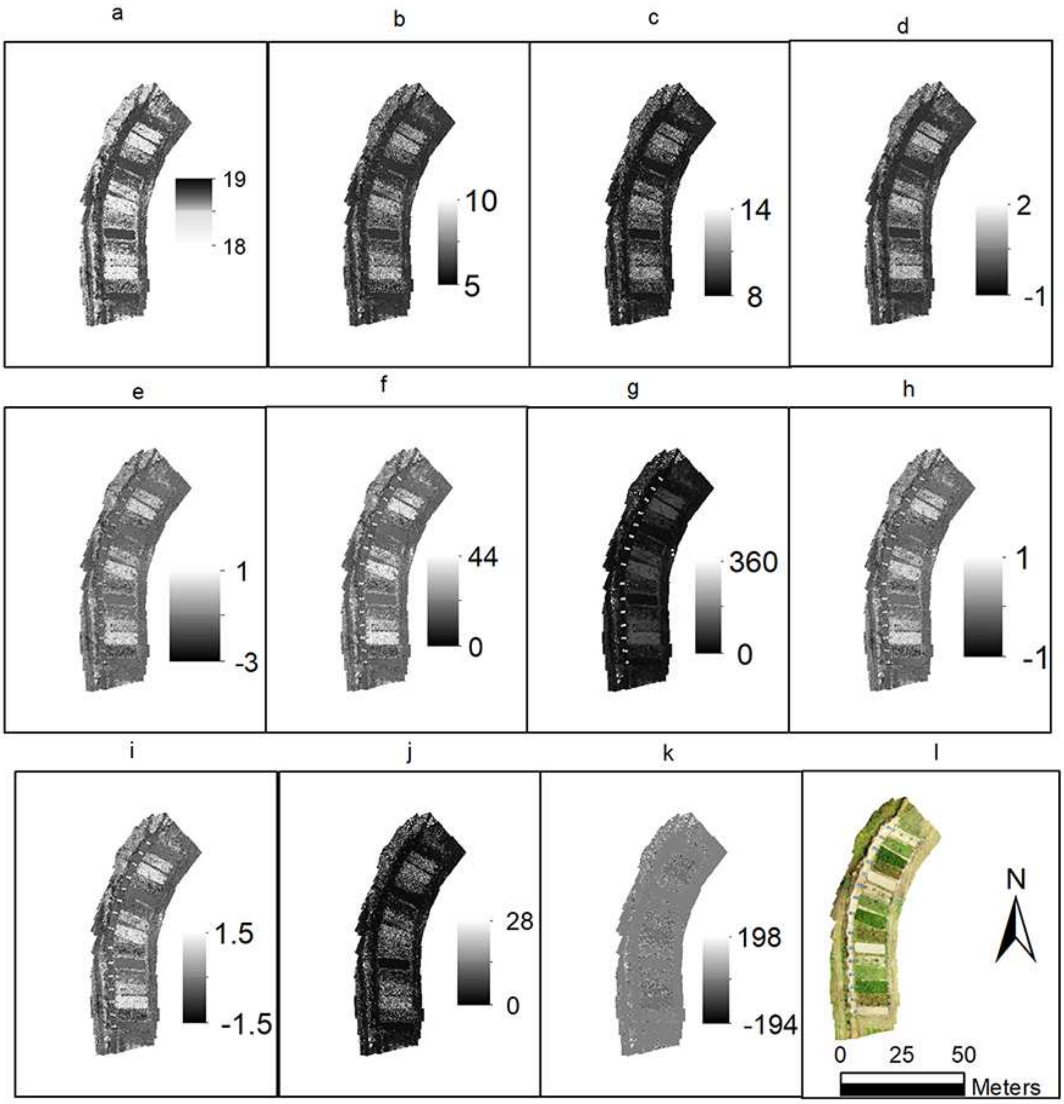


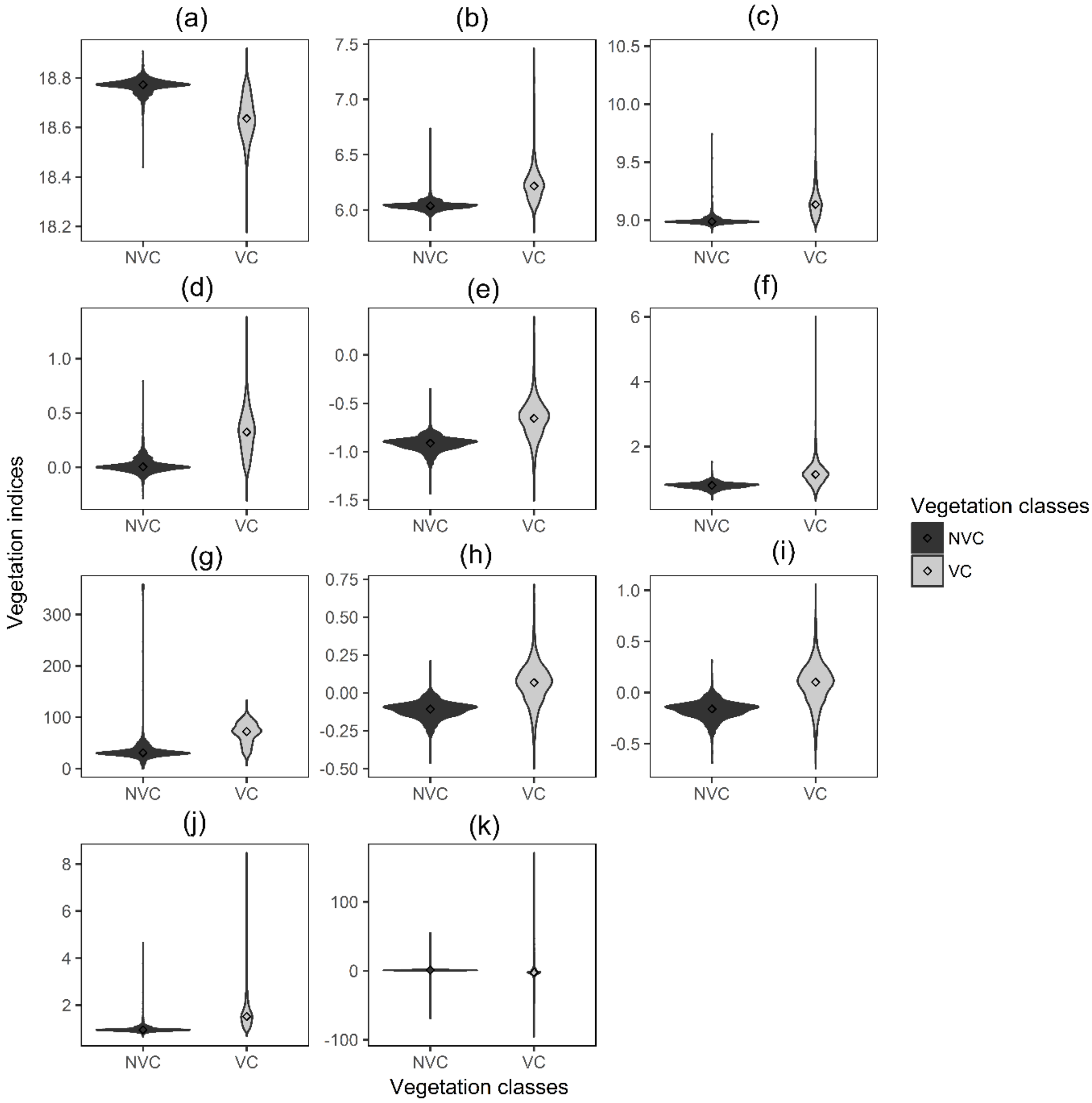
Table 1. Descriptive statistical analysis of vegetation indices visible in both vegetation and non-vegetation classes.

Parameter[1]	Mean		SD		Maximum		Minimum	
	VC	NVC	VC	NVC	VC	NVC	VC	NVC
CIVE	18.63	18.77	0.09	0.03	18.92	18.91	18.18	18.44
COMB1	6.23	6.04	0.15	0.04	7.46	6.74	5.80	5.82
COMB2	9.16	8.99	0.15	0.03	10.48	9.74	8.90	8.89
EXG	0.33	0.01	0.21	0.06	1.38	0.79	−0.31	−0.29
EXGR	−0.66	−0.92	0.20	0.08	0.39	−0.35	−1.51	−1.43
GR	1.18	0.80	0.36	0.09	6.00	1.54	0.33	0.37
HUE	61.63	34.29	30.64	37.89	133.33	358.33	0.17	0.00
NGRDI	0.06	−0.12	0.13	0.06	0.71	0.21	−0.50	−0.46
SAVI	0.09	−0.17	0.20	0.09	1.06	0.32	−0.74	−0.69
VEG	1.67	0.98	0.68	0.14	8.47	4.66	0.69	0.65
WI	−1.80	1.43	12.46	4.27	171.00	55.00	−96.00	−69.00

[1] SD: standard deviation; [2] VC: vegetation class, NVC: non-vegetation class.

Figure 3 shows the Violin Plot of each class (vegetation or non-vegetation) in relation to vegetation indices, allowing a better presentation of the variability of point distribution of indices in each class. The indices WI, VEG, and GR presented a similarity in the distribution of both vegetation and non-vegetation classes, with statistically equal median values in each of them, demonstrating their low performance. The other indices presented the same tendency of point distribution, with a great amplitude in the vegetation class and a low variability in the non-vegetation class, showing a concentration of points in the median. As a consequence, these indices may present good classifiers.

Figure 3. Violin plot of the vegetation indices CIVE (a), COMB1 (b), COMB2 (c), ExG (d), EXGR (e), GR (f), HUE (g), NGRDI (h), SAVI (i), VEG (j), and WI (k) in relation to vegetation (VC) and non-vegetation (NVC) classes.



The curve shape of the logistic regression model (S or Z curves) is shown in Figure 4. The type of relationship between the binomial variable and the vegetation index response related to b_1 value is shown in Table 2. When the b_1 value is positive ($b_1>0$), as in the indices COMB1, COMB2, and EXG, the relationship is direct between both variables, but it is likely to be classified as vegetation when the index value is raised. When the opposite occurs, i.e. the b_1 value is negative ($b_1<0$), as in the indices CIVE and WI, their relation with vegetation class is inverted (Figure 4).

Figure 4. Logistic regression models of the vegetation indices CIVE (a), COMB1 (b), COMB2 (c), ExG (d), EXGR (e), GR (f), HUE (g), NGRDI (h), SAVI (i), VEG (j), and WI (k) in the visible.

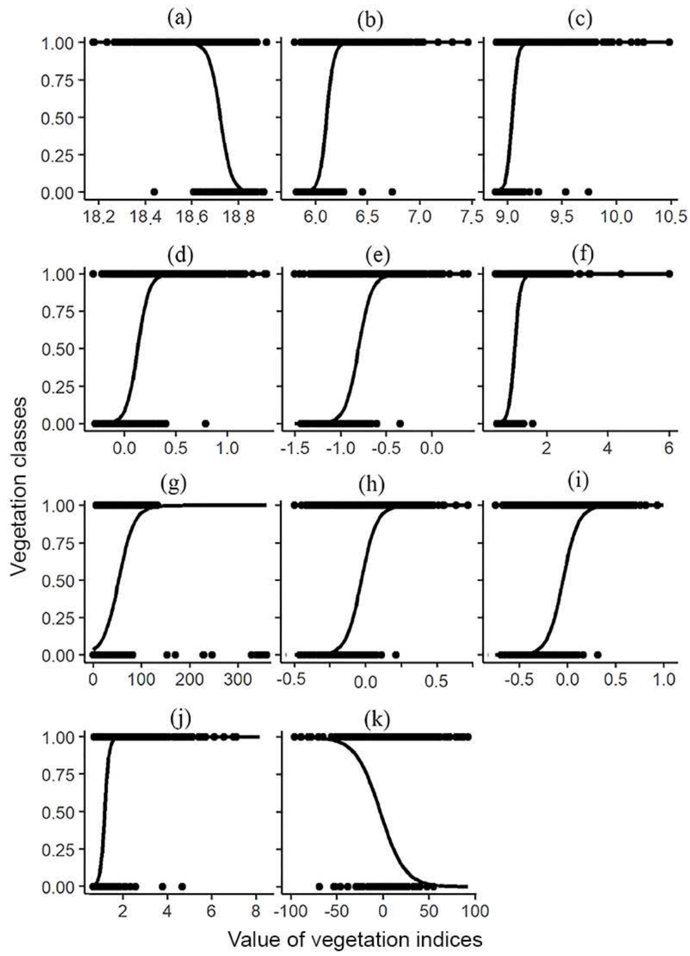


Table 2. Parameters of the logistic regression models for each vegetation index in the visible.

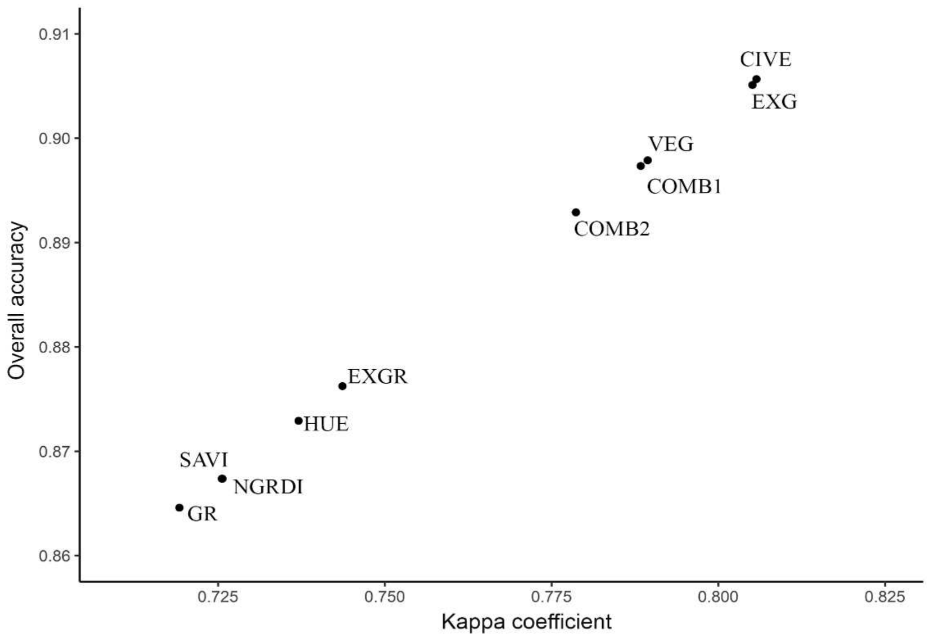
Parameter[1]	b_0	b_1	Limit values	p value
NGRDI	0.612	18.856	−0.032	<0.001
EXG	−2.304	18.357	0.126	<0.001
CIVE	788.240	−42.110	18.719	<0.001
EXGR	11.220	13.910	−0.807	<0.001
WI	−0.237	−0.069	−3.439	<0.001
VEG	−12.10	10.35	1.169	<0.001
COMB1	−177.68	29.11	6.104	<0.001
COMB2	−365.30	40.40	9.042	<0.001
HUE	−3.299	0.063	52.561	<0.001
GR	−10.18	10.79	0.943	<0.001
SAVI	0.612	12.599	−0.049	<0.001

[1] b_0 and b_1 are parameters of the equation $z = b_0 + b_1 x$

Classification assessment of vegetation indices in the visible spectrum

Regarding the accuracy of the classification performed through vegetation indices (Figure 5), the indices CIVE and EXG stood out with the highest values of Kappa coefficient (0.806 and 0.805, respectively). Subsequently, the indices VEG, COMB2, and COMB1 were grouped with values of 0.789, 0.788, and 0.779, respectively. In a third group were the indices HUE, NGRDI, SAVI, and GR, with values of 0.737, 0.726, 0.726, and 0.719, respectively. The index WI presented the lowest value (0.325). The results of the overall accuracy confirmed the same order of the values obtained by Kappa coefficient, with the highest value for CIVE (0.906) and the lowest value for WI (0.694). In Figure 5, the results of the index WI were not presented due to their low magnitude.

Figure 5. Relationship between Kappa indices and overall accuracy of the calculated vegetation indices.



According to Landis and Koch (1977) classification, Kappa coefficient values between 0.81 and 1.0 showed an almost perfect agreement. However, values between 0.61 and 0.80 presented a substantial agreement, which means the presence of a good relationship between the classification methods. The indices that presented this level of agreement were CIVE, EXG, VEG, COMB2, COMB1, EXGR, HUE, SAVI, NGRDI, and GR. Values of Kappa coefficient between 0.41–0.60 and 0.21–0.40 represent a moderate and reasonable agreement, respectively. The index WI, in addition to presenting a reasonable level of agreement, showed a low position in the coefficient scale. Therefore, WI is not recommended for classifying the vegetation for conditions similar to those of this experiment.

The overall accuracy and Kappa coefficient obtained by the indices CIVE and EXG showed a good performance to classify the vegetation. This may be explained by their ability to mitigate the effects of lighting and variability in soil reflectance. Although vegetation depends on G-band reflectance (HUNT, 2005), models that combine the three RGB bands are more accurate due to the variability of soil reflectance. These results are in accordance with those obtained by Kazmi et al. (2015).

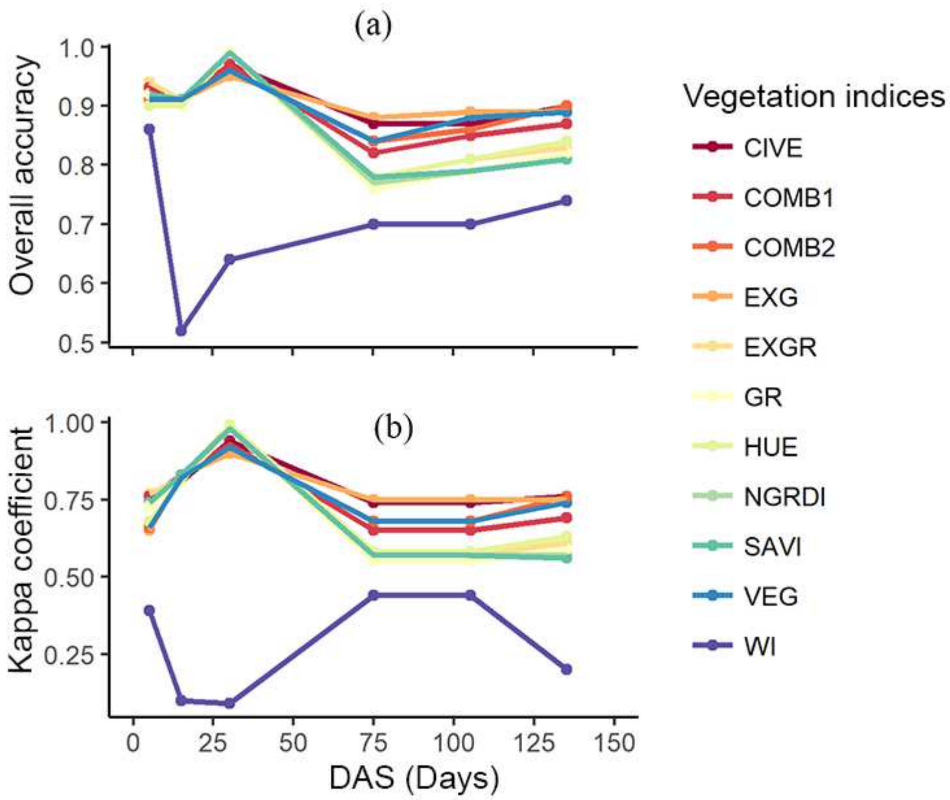
All indices calculated from the normalized bands presented an overall accuracy above 0.85 and Kappa coefficient above 0.70, except for the index WI. Woebbecke et al. (1995) obtained a better performance of the index EXG in classifying mono- and dicotyledonous by using different backgrounds in relation to the indices WI and HUE.

According to Hague et al. (2006), the use of the index VEG, generated from images of cameras boarded in a tractor for weed classification, allowed a good correlation between the automatic method and manual classification. However, these authors observed that the use of the index VEG overestimated crop and weed density due to the camera angle in relation to the vertical projection.

Regarding the effect of development stages of jack bean and millet cycles, the indices presented a similar behavior over DAS, except for WI (Figure 6). The curves of vegetative dynamics, represented by vegetation indices, can be grouped into the intervals 0–30 and 30–135 DAS. In the first interval, an increase in the values of overall accuracy and kappa coefficient were observed as DAS increased, which is due to an increase in leaf area and vegetation cover index. In the second interval, there is a decrease in vegetation index accuracy, which, according to Zheng et al. (2017), is related to a decrease of plant size, leaf area, cover index, and leaf dryness. However, the index WI showed a great variation over crop cycle, always presenting a less accuracy when compared to the others.

According to Motohka et al. (2010), Hunt et al. (2005), and Tucker (1979), the applicability of vegetation indices to different crops may be limited to a certain stage of plant development. Zheng et al. (2017) showed that the vegetation indices EXG, CIVE, and EXGR allowed a vegetation segmentation in corn, in which the highest accuracy values were obtained at the first crop development stages.

Figure 6. Overall accuracy (a) and Kappa coefficient (b) of vegetation indices in relation to the days after sowing (DAS) of cover plants.



Vegetation cover indices obtained by vegetation indices and Stocking method

The linear regression between Stocking vegetation indices and those calculated from vegetation indices presented different behaviors in relation to cover plants. For jack bean, correlations presented a high predictive power, with regressions with high coefficients of determination and statistical significance, except for the index WI (Table 3). The indices that presented a good performance are those that also presented a higher value of Kappa and overall accuracy. The index EXG presented an R^2 of 0.85 and a correlation coefficient of 0.92, followed by the index CIVE, which showed an R^2 of 0.80 and a correlation coefficient of 0.92.

Table 3. Description of the analyzed models related to cover indices calculated among vegetation indices (x) and the Stocking method (y) for the cover plants jack bean and millet.

Model	Cover plant	Vegetation index	Linear regression	R^2	p-value	RSS[1]
1		CIVE	y = 0.75x + 0.10	0.84	<0.001	0.1306
2		COMB1	y = 0.79 x + 0.09	0.81	<0.001	0.0119
3		COMB2	y = 0.80 x + 0.94	0.82	<0.001	0.0007
4		EXG	y = 0.75 x + 0.11	0.85	<0.001	0.0114
5		EXGR	y = 0.78 x + 0.86	0.83	<0.001	0.0043
6	Jack bean	NGRDI	y = 0.79 x + 0.08	0.82	<0.001	0.0004
7		VEG	y = 0.78 x +0.11	0.82	<0.001	0.0102
8		WI	y = 0.92 x + 0.47	0.52	<0.001	1.8873
9		HUE	y = 0.85 x + 0.02	0.84	<0.001	2.1118
10		GR	y = 0.79 x + 0.08	0.82	<0.001	0.0109
11		SAVI	y = 0.80 x + 0.08	0.82	<0.001	0.0001
12		CIVE	y = 0.55 x + 0.29	0.46	0.002	0.3132
13		COMB1	y = 0.54 x + 0.32	0.40	0.004	0.0277
14		COMB2	y = 0.58 x + 0.27	0.47	0.002	0.0542
15		EXG	y = 0.56 x + 0.28	0.47	0.001	0.0061
16		EXGR	y = 0.40 x + 0.41	0.26	0.030	0.2298
17	Millet	NGRDI	y = 0.36 x + 0.42	0.23	0.045	0.0036
18		VEG	y = 0.57 x + 0.29	0.46	0.001	0.3211
19		WI	y = 3.21 x + 0.31	0.34	0.010	1.1613
20		HUE	y = 0.42 x + 0.37	0.37	0.007	1.068
21		GR	y = 0.38 x + 0.40	0.32	0.014	0.0056
22		SAVI	y = 0.39 x + 0.40	0.33	0.012	0.0006

[1] Residual sum of squares between the cover index determined by the Stocking method and that calculated from vegetation indices.

The coefficients of determination were low for millet, with regressions without a statistical significance. The indices CIVE, COMB2, and EXG presented the highest values of R^2 and correlation coefficient, with values of 0.68 and 0.47, respectively. These results are due to the short millet cycle and/or to a higher jack bean leaf area, allowing a more contrasting vegetation cover. In addition, the indices EXG, CIVE, VEG, and COMB2 presented a Pearson correlation coefficient higher than 0.90 for jack bean and 0.68 for millet.

Regarding the adjustment of vegetation cover index dynamics obtained by both methods, high values of RSS were observed for HUE and WI for jack bean and millet (Table 3). The higher the RSS value is, the greater the discrepancy between the assessed methods. Subsequently, the indices CIVE, COMB1, EXG, GR, and VEG presented intermediate RSS values for jack bean, ranging from 0.01 to 0.13. The lowest values were obtained by EXGR, COMB2, NGRDI, and SAVI. Regarding the millet, the indices VEG, CIVE, EXGR, COMB2, and COMB1 presented values between 0.0277 and 0.3211, being the lowest value observed by EXG, GR, NGRDI, and SAVI. Thus, SAVI stood out as the index that most approached the standard Stocking method in both studied crops.

The relationship between vegetation cover indices (Stocking and CI VI) over DAS is shown in Figure 7 for jack bean and in Figure 8 for millet. The index WI presented an over or overestimation of Stocking vegetation index regarding CI VI for both covers. For the others, in general, the temporal dynamics of cover indices presented a similar tendency between both methods by both cover plants, with greater discrepancies (overestimation) occurring for millet as DAS increased. Moreover, an overestimation of the vegetation cover index calculated from the vegetation index was observed in both crops, except for the index WI (Figure 7).

The difference between vegetation cover index estimation methods tends to decrease as the crop cycle advanced, which can be explained by plant size, change in cover index, and plant senescence at the end of the cycle. According to Kazmi et al. (2015), the highest accuracy of vegetation classification occurs at the early crop stages, allowing a better estimation of the cover index.

The differences observed between both methods of calculating vegetation cover index can be explained by the difference in the nature to which the data are collected since the Stocking method considers three diagonal lines in each plot to calculate the average index value. In contrast, vegetation cover indices calculated from vegetation index represent, in pixel-based maps (information exhaustively discussed), the plots in their totality.

Figure 7. Comparison between vegetation cover indices calculated by the Stocking method (Stocking CI) and from the vegetation indices (CI VI) CIVE (a), COMB1 (b), COMB2 (c), ExG (d), EXGR (e), GR (f), HUE (g), NGRDI (h), SAVI (i), VEG (j), and WI (k) for jack bean as a function of days after sowing (DAS).

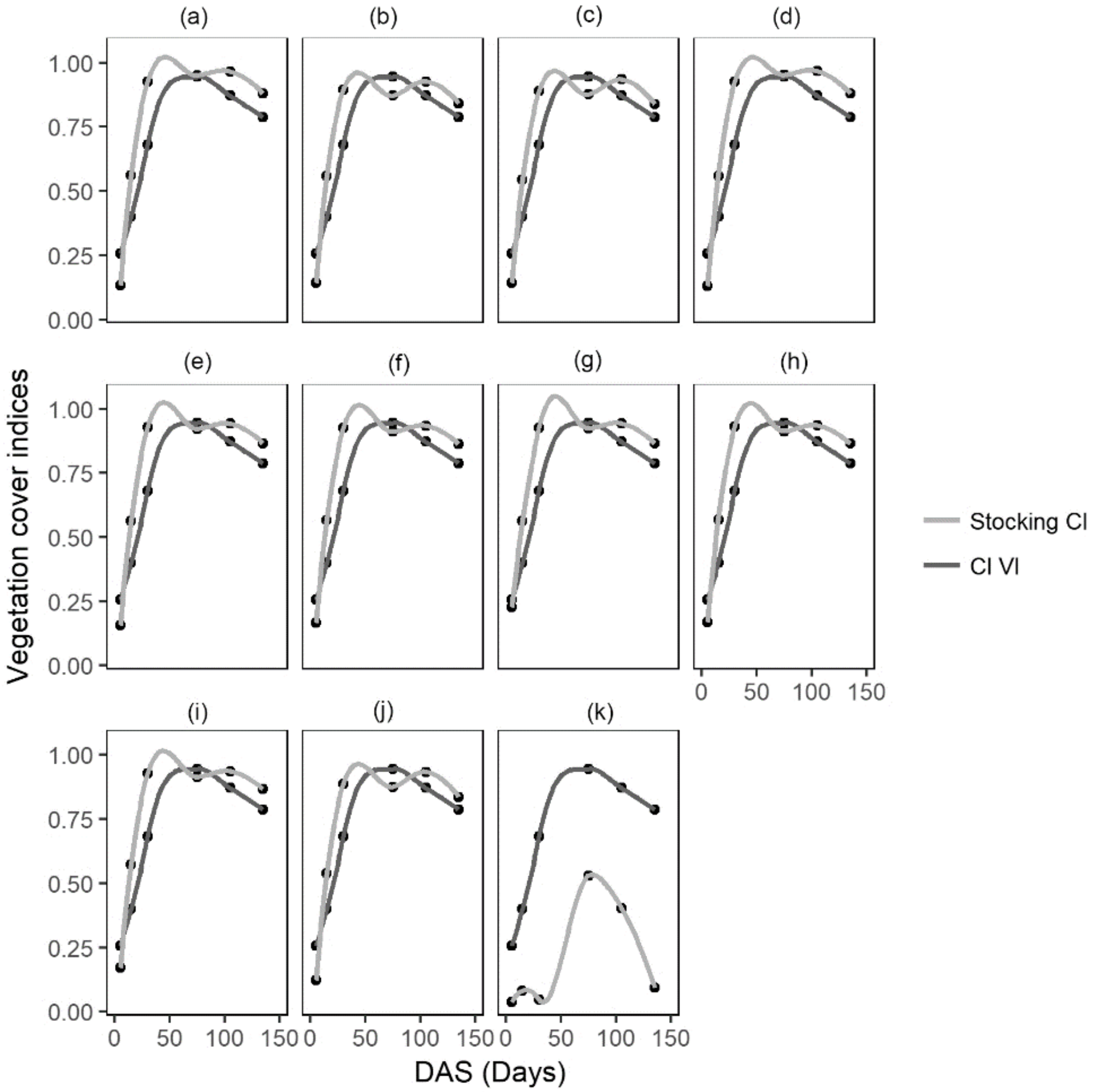
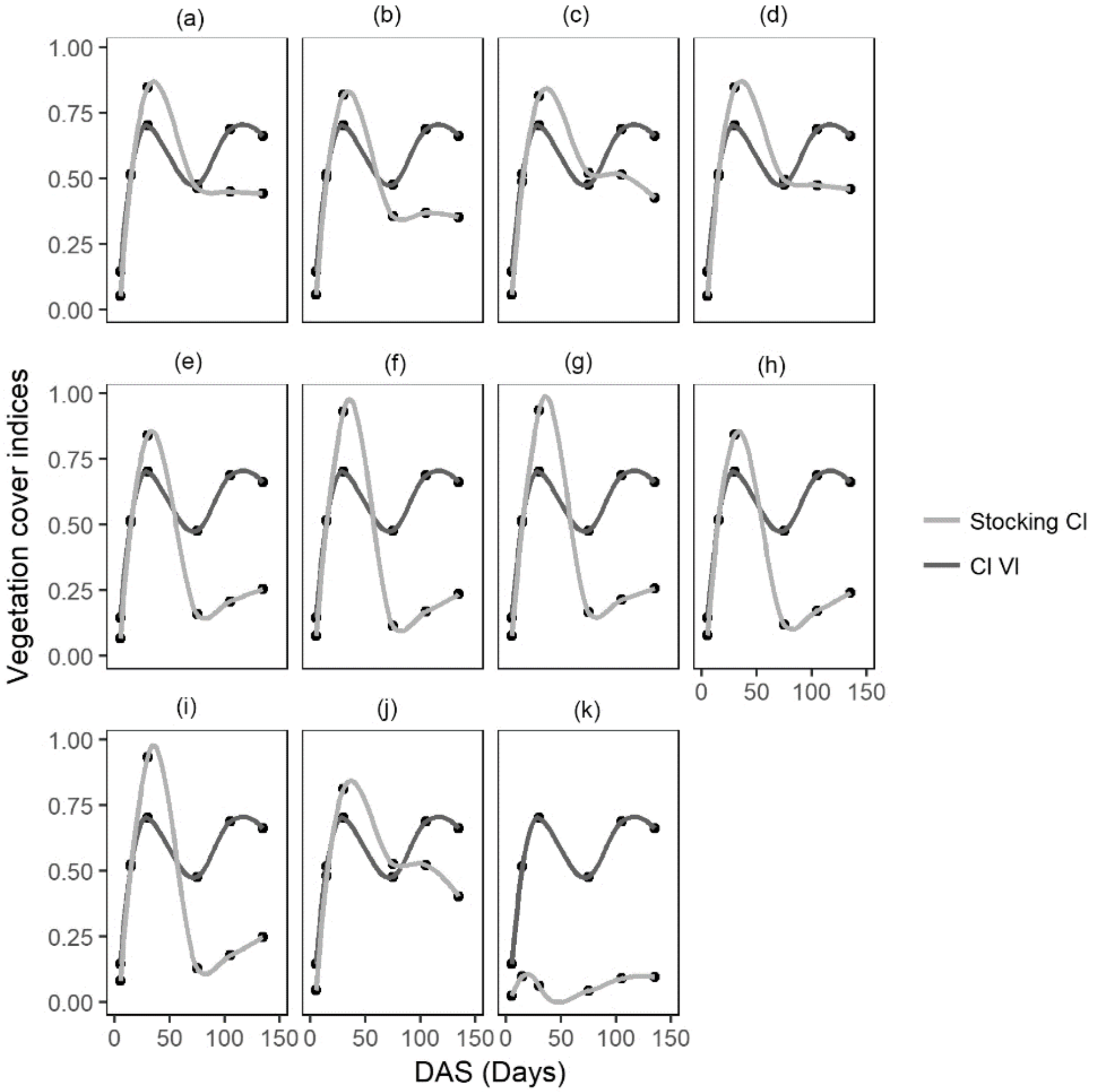


Figure 8. Comparison between vegetation cover indices calculated by the Stocking method (Stocking CI) and from the vegetation indices (CI VI) CIVE (a), COMB1 (b), COMB2 (c), ExG (d), EXGR (e), GR (f), HUE (g), NGRDI (h), SAVI (i), VEG (j), and WI (k) for millet as a function of days after sowing (DAS).



Conclusions

The vegetation indices CIVE and EXG presented a better performance and the index WI presented the worst performance regarding the vegetation classification during jack bean and millet cycles, according to the overall accuracy and Kappa coefficient. Vegetation indices were an effective tool in obtaining soil cover indices when compared to the standard Stocking method, except for the index WI.

Architecture and cycle of millet and jack bean influenced the behavior of the studied vegetation indices.

We recommend the use of UAVs with onboard digital cameras in the visible (RGB) to obtain vegetation cover indices due to the following factors: a) vegetation indices could be obtained quickly, with a higher spatial cover; b) vegetation indices showed good correlations with vegetation cover indices, especially for jack bean; c) the high dynamism of UAVs allow a higher temporal resolution; and d) relatively lower costs of onboard digital cameras in the visible (RBG).

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ARTICLE 2: Assessment of soil erosion in olive orchard (*Olea europaea* L.) under cover crops management systems in the tropical region of Brazil

Avaliação da erosão do solo no pomar de oliveira (*Olea europaea* L.) sob sistemas de manejo de plantas de cobertura na região tropical do Brasil

ABSTRACT

Soil is a natural resource threatened by several degradation factors. Under tropical conditions, water erosion is the most important factor in the degradation and deterioration of agricultural soil sustainability. Olive cultivation has low coverage, especially in the first years after its implantation, due to the low density of olive trees. The high spacing required between canopies exposes the soil to water erosion. In this context, the present study aimed at evaluating soil and water losses due to water erosion under natural rainfall in different management systems using several cover crops. In addition, it aims to evaluate the vegetation cover index and the phytotechnical attributes for olive tree cultivation. The results showed that the greatest soil and water losses occurred in the bare soil system. However, this system presented the highest phytotechnical performance. The vegetal cover management system with jack beans and with spontaneous vegetation presented a greater performance in reducing soil and water losses by erosion. Spontaneous vegetation presented greater efficiency in this reduction and in the phytotechnical aspects of the olive tree cultivation. Cover crop management combined with olive tree cultivation, and reconciled with the phytotechnical 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 and water conservation. Soil loss. Land degradation. Inceptisol. Runoff.

RESUMO

O recurso natural solo está ameaçado por diversos fatores de degradação. Nas condições tropicais, a erosão hídrica constitui o fator mais importante de degradação e da deterioração da sustentabilidade dos solos agrícolas. O cultivo de oliveira apresenta baixo índice de cobertura, especialmente nos primeiros anos após sua implantação, devido à baixa densidade de oliveiras frente ao elevado espaçamento requerido entre copas para aumentar a produtividade de oliveira e, nesse caso, o solo permanece exposto à erosão hídrica. Neste contexto, o presente estudo teve por objetivo avaliar as perdas de solo e água por erosão hídrica, sob chuva natural, nos diferentes sistemas de manejo das plantas de cobertura consorciadas ao cultivo de oliveira no sul de Minas Gerais, além da avaliação do índice de cobertura vegetal e atributos fitotécnicos, para o cultivo da oliveira. As maiores perdas de solo e água foram encontradas no sistema de manejo da oliveira sem cobertura vegetal, entretanto, mostrando o maior desempenho fitotécnico. O manejo da cobertura vegetal com o feijão de porco e a vegetação espontânea apresentaram maior desempenho na redução das perdas de solo e água por erosão no cultivo da oliveira. O manejo da cobertura vegetal com vegetação espontânea apresentou maior eficiência na redução das perdas de solo e de água e nos aspectos fitotécnicos no cultivo da oliveira. O manejo de plantas de coberturas consorciadas com o cultivo da oliveira conciliando com os aspectos fitotécnicos do cultivo na região tropical visando à redução das perdas de solo e água por erosão hídrica é de grande relevância para a sustentabilidade desta fruteira, notadamente em se tratando de solos rasos, de baixa condutividade hidráulica e declivosos.

Palavras-chaves: Conservação do solo e da água. Perda de solo. Degradação do solo, Cambissolo. Escoamento superficial.

INTRODUCTION

Soil is a natural non-renewable resource that can be finite in the time under the effect of several degradation factors, thus 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 condition of land degradation is a global concern, considering the food security and the decrease in the growth of world agricultural production in recent years (FAO, 2015; Colen et al., 2016), the increase of land degradation (García-Ruiz et al., 2017; Taguas et al., 2017) and the decline of soil functions (McBratney et al, 2014).

Land degradation has arisen concerns regarding the role of the soil in the future of human activity prosperity (Amundson et al., 2015, Taguas et al., 2017), with expanding world demand for food products and a decrease of agricultural land with potential for use (Anache et al., 2017; FAO, 2015). Soil resources are threatened by various degradation factors, such as erosion, compaction, leaching, among others. Under tropical conditions, water erosion is one of the major causes of decreasing in the sustainability of agricultural soils (FAO, 2015; Anache et al., 2017).

The soil erosion is a dynamic process physically initiated by the movement of soil particles under the effect of the kinetic energy of the raindrops (Lal, 2001). However, this process can be accelerated by anthropic disturbances through inadequate management or by removing the vegetation cover (Carvalho et al., 2005; Avanzi et al., 2013; Lima et al., 2014).

Water erosion can affect soil quality and induce soil deterioration due to the loss of its superficial layer, which is usually the most fertile layer, concentrating organic matter and nutrients, necessary for species development (Moreno et al, 2016; Guimaraes et al., 2017). Many studies report that the layer removed by erosion can be 1.5 to 5 times richer in organic matter and nutrients than the continuing layers (Cardoso et al., 2012; Faustolo et al., 2017; García-Ruizet al., 2017).

Olive cultivation presents low cover index, especially in the first years after its implantation, due to the low density of olive trees and the high spacing between canopies required for the rational production (Repullo-Ruibérriz et al., 2018). Thus, the soil can be more exposed to water erosion. Moreover, due a high ability of olive cultivation to grow in stress condition, it is a common crop in poor soils with marked declivity (Espejo-Pérez et al., 2013).

Mediterranean region is considered the most expressive areas of olive cultivation in the world, representing 97% of the total area of olive trees on the global surface (Fernández-Romero et al., 2016; Repullo-Ruibérriz et al., 2018). In this region the water erosion decreasing is one of the greatest challenges (Marques et al, 2010; Gómez et al., 2014; Quijano et al 2017). In this scenario, several studies consider the severity of the erosion problem and the impact of the type of management over the acceleration of the erosive process, generating a high rate of soil loss (Gomez et al., 2009; Gómez et al., 2011; Ibáñez et al., 2014; Parras-Alcántara et al., 2016; Sastre et al., 2017).

Studies conducted by García-Orenes et al. (2012) considered that the main cause of erosion in olive plantations, apart from natural factors, is inadequate management. Furthermore, Gómez et al. (2014) highlighted the important role of the well-management of cover crops for soil protection. In tropical regions, the erosive process might be aggravated by high rainfall erosivity (Aquino et al., 2012), leading soils, especially Cambisols, to serious losses (Silva et al., 2005). Studies conducted by Silva et al. (2005) and Silva et al. (2009) in Cambisol in the southern region of the State of Minas Gerais, Brazil, found that, when kept uncovered, soil loss corresponded to 175.0 Mg ha^{-1} $year^{-1}$. According to Schick et al. (2000), concerning Humic Cambisol, in Lages, Santa Catarina state, Brazil, when kept uncovered, soil loss was equivalent to 111.8 Mg ha^{-1} $year^{-1}$, which was related to the higher values of organic matter.

In southern Minas Gerais (Brazil), water erosion is one of the most concerning problems of agricultural activities (Pinto et al., 2018), given the incidence of high rainfall, high altitudes and relief with high slope values. Several studies had indicated the severity of the problem of water erosion in this region (Oliveira et al., 2012; Bispo et al., 2017; Batista et al., 2017).

The knowledge of the effect of cover crops on water erosion in olive plantations from southern Minas Gerais is an immediate necessity, considering the expansion stage of this cultivation in this region. Thus, this work aimed to study the relationship between soil and water losses due to water erosion and phytotechnical aspects in the olive tree management systems, individually or in a consortium with cover crops in southern Minas Gerais (Brazil).

MATERIAL AND METHODS

Study area

The experiment was conducted at the Federal University of Lavras (UFLA), Lavras, Minas Gerais, Brazil (21º13'20" S and 44º58'17" W), during two hydrological years, between November 2015 and October 2017 (Figure 1).

The area presented an average altitude of 918 m. The climate classified as Cwa according to the Köppen Climate Classification System, with average annual rainfall of 1,530.0 mm and average temperature of 19.4 ºC. The region climate is humid subtropical climate, with dry winter and rainy summer, with warmer month temperature higher than 22 ° C (22.8 ° C in February) (Dantas et al., 2007).

The study area soil is classified as typical Tb Eutrophic Haplic Cambisol (Curi et al., 2017), which corresponds to Inceptisol in US Soil Taxonomy (Table 1).

Management systems adopted in olive cultivation

At the first period (2015/2016), the treatments consisted of four olive trees (*Olea europaea* L.) management practices and three replicates, in the following combination: olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (*Canavalia ensiformis* L.) (OJB); Olive cultivation intercropped with millet (*Pennisetum glaucum* L.) (OM) and bare soil (BS), the latter used as control. In the second period (2016/2017) the OM treatment was replaced by olive cultivation intercropped with sunn hemp (*Crotalaria júncea*) (OSH), maintaining the other treatments from the first period (BS; OBS; OJB; and OSV).

The treatment with spontaneous vegetation (OSV) presented dominant composition of narrow leaf species: *Brachiaria decumbens*, the most dominant species, followed by *Digitaria sanguinalis*, *Melinis minutiflora* and *Eleusine indica*. A less dominant broadleaf species included *Ipomoea acuminate, Bidens pilosa, Oxalis corniculata, Emilia fosbergii Nicolson, Conyza bonariensis, Euphorbia Heterophylla* and *Amaranthus viridis*.

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

Gerais. The cover plants were manually seeded at the beginning of November, which is the beginning of the rainy season of each hydrological year.

Considering jack beans as cover crop, soil grooves were spaced at every 0.5 m in a density of 8 seeds m^{-1}. Regarding millet and sunn hemp, the spacing used was of 0.25 m with densities of 90 seeds m^{-1} and 40 seeds m^{-1}, respectively. Table 2 presents more details about soil characterization.

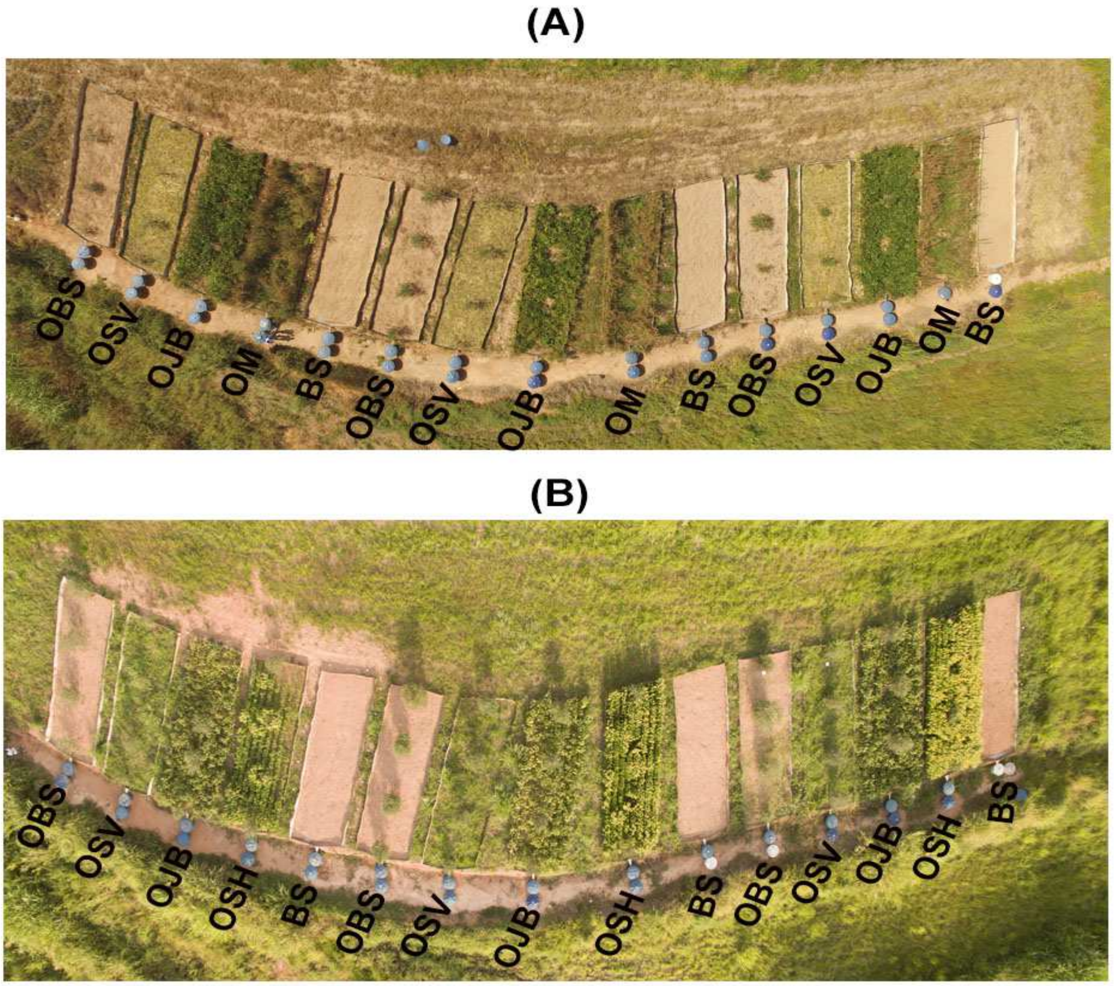

Figure 1. Plots used in the study of erosion in hydrological years (A) 2015/2016 (March 23, 2016) and (B) 2016/2017 (February15, 2017), under the following treatments: olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS).

Table 1. Soil Physical and chemical properties of the Haplic Cambisol of the experimental area.

Properties	Depths (m)	
	0-0.05	0.05-0.10
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 ($cmol_c$ dm^{-3})	2.26±1.29	1.96±0.85
Mg ($cmol_c$ dm^{-3})	0.56±0.2	0.47±0.16
Al ($cmol_c$ 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})	177.86±3.73	190.44±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.

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 EI30 index using the Fourier index (equation 1) proposed by Renard & Freimund (1994) and equation 2 developed by Aquino et al. (2012) considering southern of the State of Minas Gerais.

$$R_c = \frac{p^2}{P} \quad (1)$$

in which Rc is the coefficient of rainfall (mm), p is the monthly precipitation (mm) and P is the annual precipitation (mm).

$$EI_{30} = 85.672 * R_c^{0.6557} \quad (2)$$

Soil chemical and physical properties

Soil chemical properties were determined : such as soil pH in water, exchangeable Ca^{2+}; Mg^{2+}; Al^{3+}; available P and K extracted with Mehlich-1, were determined according to the methodology described by Mclean et al. (1958) . Soil organic matter (SOM) was determined according to Walkley and Black (1934). Soil texture was determined by the pipette method according to Day (1965).

Soil water infiltration was determined using the Mini Disk Infiltrometer, following the methodology proposed by Decagon (2016) for determining the hydraulic conductivity of unsaturated soil (Kns). Measurements were obtained from 4 points in each plot, with the suction rate of 2 cm. The infiltration was measured for 10 times in the field, each 30 seconds. The infiltration calculation was determined by using of Spreadsheet Macro available in the Decagon website (Decagon, 2016).

Soil and water losses

Soil loss assessment was conducted according to the methodology proposed by Wischmeier and Smith (1978), with changes in the size of the plots: 12.0 m in length and 4.0 m in width (Figure 1). Many studies have evaluated changes in the standard dimensions of the plots, showing better results in plots between 10.0 and 20.0 m in length (Carvalho et al., 2005; Rocha Junior et al., 2017; Anache et al., 2017). The plots were limited with galvanized plates with a height of 40.0 cm, buried at a depth of 20.0 cm installed in the direction of the area’s slope. The mean slope of the plots was of 0.23 m m^{-1}.

Runoff and sediment collection were performed according to Cogo et al. (2003) at each erosive event, using collection tanks installed at the bottom of each plot (Figure 1). The tanks were comprised of two boxes with 250 L capacity connected through a Geib type splitter with 9 windows. These windows allow that only 1/9 of the runoff was conducted into the second tank, after filling the first.

After homogenizing the material retained in the tanks, three pots of 250 mL were collected, weighed, placed in contact with three drops of hydrochloric acid and left for 24 hours at rest for sedimentation of the material. After this period, the water was drained and the pots were oven dried at 60°C and weighed. To evaluate the effect of each treatment over the reduction of soil and water losses, the loss reduction efficiency (LRE) was calculated using the following equation, proposed by Amaral et al. (2008):

$$\text{LRE} = \frac{\text{Loss of the cultivated treatment}}{\text{Loss of the bare soil treatment}} \qquad (3)$$

Surface runoff coefficient (SRC) was also determined in relation to the total rainfall during the study period for the different management systems (Equation 4).

$$\text{SRC} = \frac{\text{Loss of the cultivated treatment}}{\text{Total precipitation}} \qquad (4)$$

Cover vegetation index and phytotechnical parameters

The cover vegetation index was determined 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, serial number p76ddc18b271, registered with at the National Civil Aviation Agency (ANAC) PP-011111110. The photographic parameters were aperture f / 2.8, shutter time = 1/290 s, ISO = 100, white balance = 4500 K and focal length = 3.6 mm (DJI, 2018). The flights were automatically managed by an iPad (model A1489- ME279KH / A), every 15 days, with duration of approximately 20 minutes, flight height of 20 m, by georeferencing, using 36 control points.

A total of 200 photos were recorded per flight, in JPEG format, with 60% overlap. PhotoScan Pro 1.2.6 (Agisoft LLC, 2016) was used for image processing, alignment, georeferencing and orthophoto and orthomotic generation. The images for calculating the vegetation cover index (VCI) were classified by equation 5, according to the methodology proposed by Torres-Sánchez et al. (2014).

$$VCI = \frac{\text{Pixels classified as vegetation}}{\text{Total of pixels of the plot}} \quad (5)$$

The phytotechnical attributes were measured using 48 plants in the field, using conventional methods: pachymeter and ruler, used for measuring trunk diameter, plant height, and crown radius. The measurements were obtained in May 2016 and 2017.

Experimental and statistical design

The experimental design was Complete Randomized Block, using a standard plot for monitoring water erosion (Figure 1). The data were submitted to analysis of variance and the means were compared by the Tukey test at 5% probability.

Principal component analysis (PCA) was used to understand the relationship between soil and water losses, precipitation, rain erosivity, soil water infiltration, phytotechnical attributes and cover index.

RESULTS AND DISCUSSION

Rainfall Erosivity

The precipitation, number of erosive events and rainfall erosivity evaluated during the study period are displayed in Table 3. From November to March, there was a high occurrence of rainfall, with 92.36% and 70.78% of annual erosivity, for the periods of 2015/2016 and 2016/2017, respectively. In December and January, erosivity presented values of 54.98% and 29.91%, respectively, which is close to half the total annual erosivity for the period of 2015/2016. The period of 2015/2016 was marked by rainfall in the months of March and April (25.51% of annual erosivity).

These results are similar to those obtained by Silva et al. (2009), who observed that erosivity between November and March represented nearly 90.3% of the annual erosivity and that December and January presented 51.3% of annual erosivity for the studied area. These results were also confirmed by Lima et al. (2014), who studied the effect of cover plants intercropped with maize cultivation, using a standard plot.

The high rainfall erosivity between the months of November and March awake attention to the high risk of water erosion for the studied region, which can have drastic implications for maintaining soil quality under the cultivation of olive trees in shallow soils and without any vegetation cover between lines. Such scenario may lead to the loss of water, nutrients, and organic matter due to water erosion, which is aggravated in shallow soils (Silva et al., 2005; Silva et al., 2009) and in periods of water deficit that occur in the region.

Table 3. Precipitation and erosivity values for the studied periods.

Months	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	22.7	125.2	1	6	46.48	498.08
November	273.8	190.2	11	5	1,217.25	861.90
December	232.9	145	10	6	984.55	603.83
January	400.6	157.9	12	8	2,005.05	675.24
February	114.9	64.1	6	4	389.79	207.02
March	122.8	158.6	5	4	425.31	679.17
April	22.2	108.3	1	2	45.14	411.82
May	4.3	57.6	0	1	5.24	179.94
June	84.2	29	3	1	259.29	73.16
July	0	0	0	0	0.00	0.00
August	22.6	1.4	2	0	46.21	1.37
September	8.6	32.6	1	0	13.01	85.30
Total	1,309.60	1,069.90	52.00	37.00	5,437.33	4,276.82

NEE: number of erosive rainfall events.

Soil water infiltration

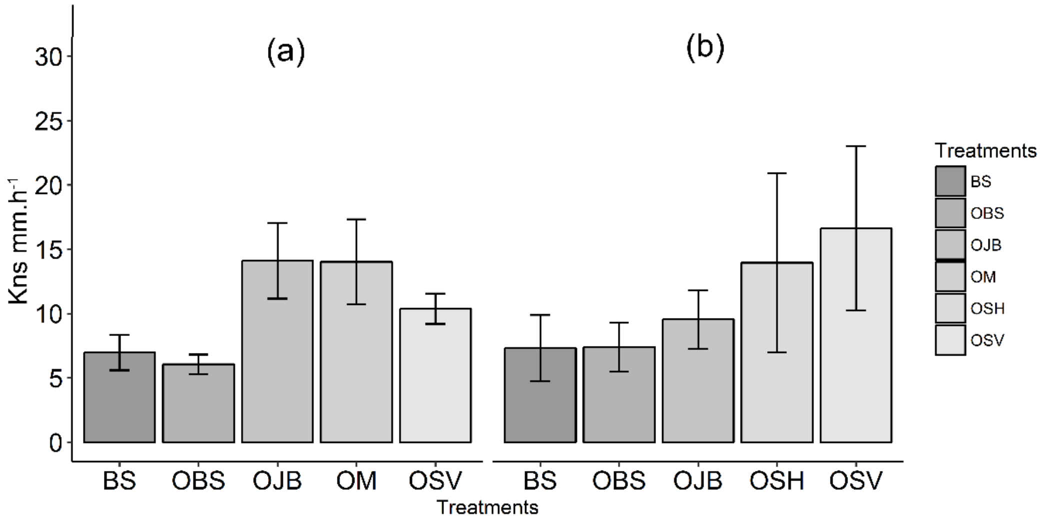

Figure 2. Unsaturated hydraulic conductivity (Kns) in olive tree plots in different management systems in the periods of (a) 2015/2016 and (b) 2016/2017. Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); Olive cultivation intercropped with jack beans (OJB); Olive cultivation intercropped with millet (OM); Olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS).

The results presented in Figure 2 showed the high variability between the unsaturated hydraulic conductivity values of the soil for the studied treatments. In the first period, the treatment of olive cultivation intercropped with jack beans (OJB) presented the highest value (14.11 mm h^{-1}), followed by olive cultivation intercropped with millet (OM) (14.02 mm h^{-1}); olive cultivation intercropped with spontaneous vegetation (OSV) (10.38 mm h^{-1}); bare soil (BS) (6.98 mm h^{-1}) and olive cultivation on bare soil (OBS) (6.06 mm h^{-1}). In the second period, the highest value occurred for the treatment of olive cultivation intercropped with spontaneous vegetation (OSV) (16.63 mm h^{-1}). The low infiltration in bare soil can be explained by the crusting in Cambisol due to high silt/clay ratio (Pinto et al., 2016), as it was observed in the treatments (BS and OBS). Thus, the ground cover plants improved soil physical attributes, increasing infiltration. The study conducted by Dohnal et al. (2010) showed great variability of the unsaturated hydraulic conductivity of the Cambisols, which usually present low values (Silva et al., 2005; Silva et al., 2009).

Vegetation cover index

In the first period (2015/2016), the OJB treatment presented the highest vegetation cover index mean, with a value of 0.811, followed by OM, with a value of 0.698 (Table 4). Regarding the second period (2016/2017), the OJB treatment presented the highest vegetation cover index, with a value of 0.592, followed by OSH, with a value of 0.456.

Table 4. Values of mean, standard deviation, and coefficient of variation (CV) of the vegetation cover index for each period and in different soil cover management systems in olive cultivation.

Parameters	Vegetation cover index			
	2015/2016			
	OBS	OSV	OJB	OM
Means	0.023 ±0.01	0.581 ±0.29	0.811 ±00.21	0.698 ±0.21
CV (%)	43.48	49.91	25.89	30.09
	2016/2017			
	OBS	OSV	OJB	OSH
Means	0.061 ±0.04	0.419 ±0.29	0.592 ±0.32	0.456 ±0.38
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).

Olive cultivation in the first two years presented low coverage, with values of 0.023 and 0.061 in the first and second years, respectively (Table 4). This is an indication of the high risk of erosion in the early years of cultivation, which alerts to the need for other conservation practices, such as the adoption of ground cover plants, as used in this study.

The treatment with spontaneous vegetation presented a vegetation cover index of 0.581 in the first period and 0.419 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 values than the second. This difference can be explained by the higher precipitation in the period of 2015/2016 (Table 3), which favored the crop development.

Figure 3 shows the evolutionary dynamics of the vegetation cover index in each treatment in relation to the experimental period. By the visual observation, the OBS treatment showed constant linear behavior in relation to 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), who evaluated soil loss in different management practices and their relationship with the vegetation cover index.

In the treatment with olive cultivation intercropped with spontaneous vegetation (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 other authors (Cardoso et al., 2012; Lima et al., 2014). 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.

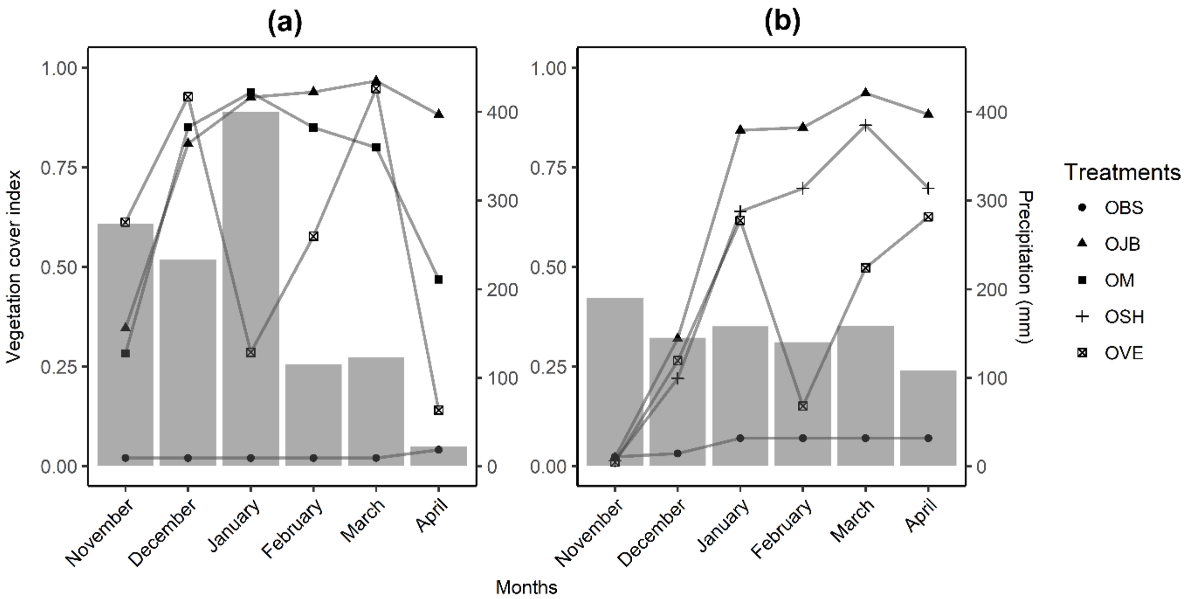

Figure 3. Vegetation cover index for the periods: 2015/2016 (a) and 2016/2017 (b) in different soil cover management systems for olive cultivation. Olive cultivation on bare soil (OBS); Olive cultivation intercropped with spontaneous vegetation (OSV); Olive cultivation intercropped with jack beans (OJB); Olive cultivation intercropped with millet (OM); and Olive cultivation intercropped with sunn hemp (OSH).

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 studying the spatial and temporal variability of the cover plants (grasses) and their effect over erosion in olive cultivation.

According to Lopes et al. (1987), plants that present a vegetation cover index mean superior to 0.3 in the different crop phases may be considered as effective in reducing soil erosion, and can, therefore, be considered conservation systems. However, regarding soil and water losses, 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) showed that the use of cover crops associated with olive trees is more appropriate when cover rates remain between 0.30 and 0.87.

Considering the behavior of each treatment in relation to the period of greatest precipitation, from November to April (Figure 3), we observe that the olive cultivation intercropped with jack beans (OJB) presented a cover index superior to 0.30, even in the month of planting, demonstrating the rapid development of the crop. Regarding sunn hemp, in addition to demanding more time for growth, its morphology does not provide a high cover index (CARDOSO et al., 2012).

Comparing the OSV treatment with the treatments with cover crops, we verify that OSV showed high initial growth rate during the critical period, from December to January, providing a cover index superior to 0.50. The good development of the spontaneous vegetation was favored by 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, of 0.811 and 0.592, in the first and second periods, respectively. Cardoso et al. (2012) also identified higher vegetation cover index for jack beans when compared to sunn hemp and millet. Similar results were found by Lima et al. (2014) when studying corn intercropped with jack beans as a ground cover crop. The tropical climate revealed the importance of maintaining a continuous vegetation cover, especially during the summer season, where rainfall erosivity was high, presenting a great risk of water erosion.

Soil Loss assessment

Table 5 shows the values of soil loss for both periods studied. The first period showed high soil loss, which can be explained by both the number of erosive events, 52 compared to 37 events of the second period, and the number of events from November to January (33) compared to 19 in the second period. Moreover, the values of erosivity should be considered (Table 3).

Treatments BS and OBS presented no significant differences, confirming the predisposition of olive cultivation to water erosion, especially for soils that are susceptible to water erosion (Table 5). The BS control treatment presented higher values for both studied periods, with losses of 311.55 Mg ha^{-1} $year^{-1}$ and 296.28 Mg ha^{-1} $year^{-1}$ in the first and second periods, respectively (Table 5).

The high values of soil loss in the BS and O BS can be explained by the high susceptibility to water erosion in Cambisols. According to Silva et al. (2009), 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. The study developed by Schick et al. (2000) in Cambisols, with a slope of 0.10 m m^{-1}, showed that the mean annual loss was of 66.47 Mg ha^{-1} $year^{-1}$, ranging between 6.17 and 146.97 Mg ha^{-1} $year^{-1}$ in bare soil plots.

The study conducted by Silva et al. (2005) with bare soil in Cambisol, plots showed a great variability in soil loss during 5 years, with a mean annual soil loss of 205.65 Mg ha^{-1} $year^{-1}$, with values ranging from 98.47 to 374.10 Mg ha^{-1} $year^{-1}$. 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.

Table 5. Mean annual values of soil loss and efficacy 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±95.72a	98.86
OSV	25.05±23.24 b	8.04
OJB	80.10±26.52 b	25.71
OM	64.12±31.79b	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±0.37b	0.15
OSH	9.98±14.39b	3.37

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). Means followed by the same lowercase letter in the lines do not statistically differ by the Tukey Test at 5%.

Treatments BS and OBS presented significant differences in relation to the other treatments. 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 5). This can be explained by the similar value of the vegetation cover index (Table 4) (Lopes et al, 1987; Sastre et al., 2017) and by soil protection by organic matter, resultant from periodic cutting operations (LOPES et al., 1987).

The pattern of soil loss followed the order: BS> OBS> OJB> OM> OSV in 2015/2016 and BS> OBS> OSH> OSV> OJB in 2016/2017 (Table 5).

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 demonstrated by the lower soil loss in the plots with olive tree intercropped with spontaneous vegetation. In this treatment, manual weeding was performed, with a preparation of the planting grooves in the direction of the slope. During the groove planting, preferential paths may be formed, where water can concentrate its flow and increase its disintegrating and transporting power.

Figure 4 shows the detail of soil loss during the studied periods. The pattern of soil loss follows the erosivity evaluated in the same period (Table 3), with higher soil loss values from November to April, most notably in December and January. We note that the OJB treatment presented high soil loss in November (2015/2016), with a value of 49.80 Mg ha^{-1} year^{-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 greater soil instability resultant from sowing operations.

The vegetation coverage in olive trees were more efficient in reducing erosion in the second period when compared to the first (Table 5). The highest losses of efficiency reduction, compared to the bare soil plot, were observed for the OSV treatment in the first period, and for OSH, OSV, and OJB in the second period (Table 5).

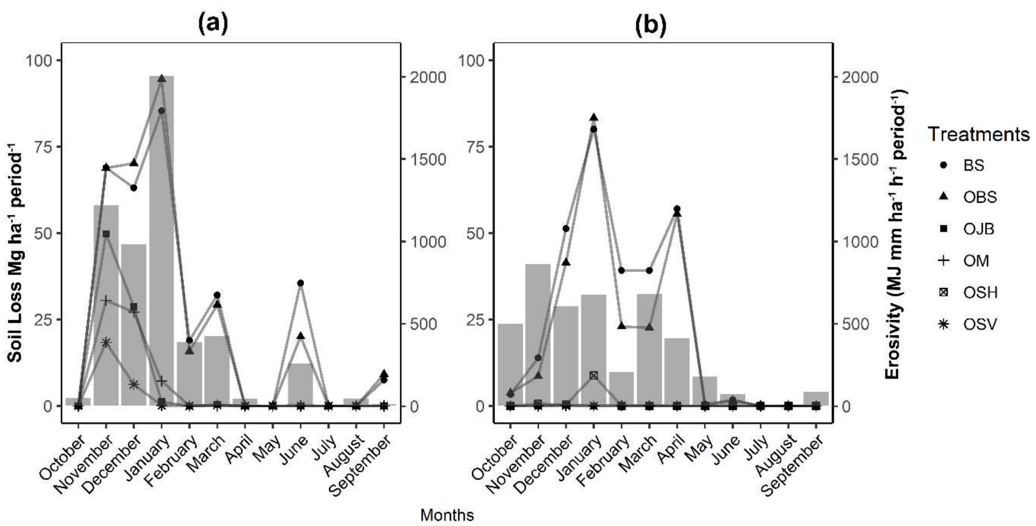

Figure 4. Soil loss in different vegetation cover management systems in olive cultivation during the studied periods of (a) 2015/2016 and (b) 2016/2017. Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans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

Water loss assessment

Table 6 shows the mean annual values of water loss, efficacy in the reduction of water loss in relation to the bare soil (ERP-WATER), and surface runoff in relation to the total rainfall in different olive tree cover management systems (SRC). When comparing water loss, no significant difference was observed between treatments BS and OBS for both studied periods (Table 4). 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 of water loss, with a mean annual water loss of 369 mm year^{-1}, corroborating with the results found in the present study.

We also verified a significant difference between the treatments, where the soil was totally exposed (BS and OBS) and the other treatments with ground cover crops (OJB, OCM, and OSH) and spontaneous vegetation (OSV), for both studied periods. The results show the importance of cover crops over water loss in cultivated areas, due to the increase in water infiltration rate, as observed by Almeida, et al. (2018). High water loss in cultivated soils are critical for crops of agricultural species, notably in shallow and declining soils, and 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 of the second period (Table 6), 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.

The OSV treatment proved to be the most efficient in reducing water loss, with an ERP 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.

Figure 5 shows the distribution of water losses during the studied periods, highlighting the variability caused by the irregular distribution of rain during both periods evaluated (Silva et al., 2005). The rainfall distribution has an important effect over soil saturation and runoff coefficient, meaning a large number of erosive events in a short time can lead to soil saturation and increase water loss through runoff.

Table 6. Mean annual values of water loss, efficacy in reducing loss in relation to bare soil and surface runoff in relation to total precipitation in different olive cultivation management systems.

Treatment	Water loss	LRE	SRC
	-------- mm year^{-1} -------	----- % ------	----- % -----
		2015/2016	
BS	594.83±285.03 a	-	45.42
OBS	590.40±340.15 a	99.25	45.08
OSV	103.11±52.14b	17.33	7.87
OJB	269.53±117.60 b	45.31	20.58
OM	161.98±98.53b	27.23	12.37
		2016/2017	
BS	374.77±187.68 a	-	35.03
OBS	342.35±137.57a	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 lowercase letter in the lines do not statistically differ by the Tukey Test at 5%. 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).

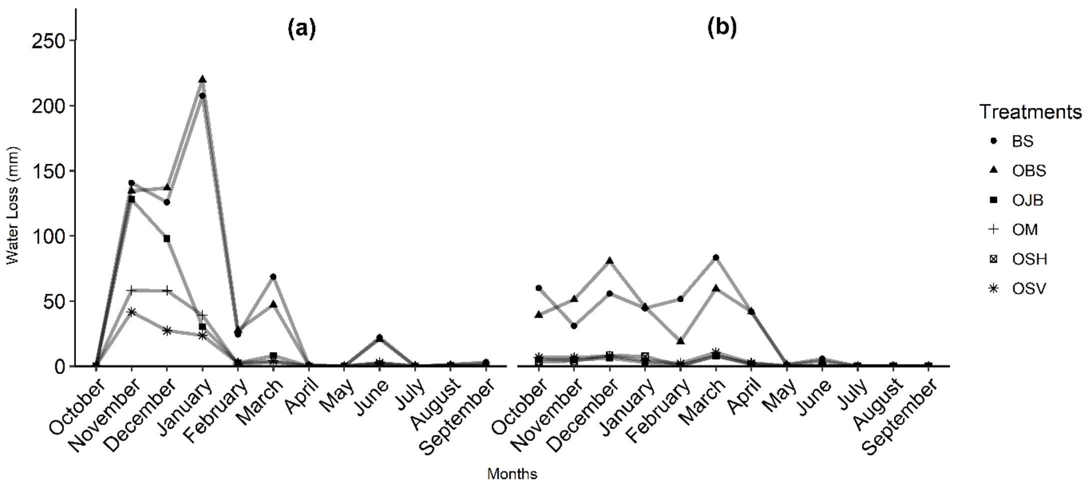

Figure 5. Average and monthly water loss in different olive cultivation management systems during the studied periods of (a) 2015/2016 and (b) 2016/2017. Olive cultivation on bare soil (OBS); Olive cultivation intercropped with spontaneous vegetation (OSV); Olive cultivation intercropped with jack beans (OJB); Olive cultivation intercropped with millet (OM); Olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS).

Phytotechnical parameters of olive cultivation

The phytotechnical parameters of olive tree cultivation are presented in Figure 6. We verified that the associated treatments impacted the development of olive plants. Thus, the evaluation of height showed a significant difference between OM and OSH with the other treatments. The highest values were obtained in treatments OBS and OSV in the period of 2015/2016, and OBS, OJB, and OSV in the period of 2016/2017.

The OBS treatment presented the highest values for the median crown radius (Figure 6b), with an average value of 62.92 cm in the first period and 94.83 cm in the second. Regarding the trunk diameter (Figure 6c), in 2015/2016, there was a significant difference between the OM treatment and the other treatments. In the 2016/2017, the highest trunk diameter values were obtained for the OBS, OSV and OJB treatments.

Regarding olive tree heights (Figure 6a), the greatest performance was obtained for olive cultivation intercropped with millet (OM), presenting mean height of 70.08 cm compared to 173.00 cm in the OBS treatment. We clearly verified interference of the associated treatment over plant development, given that millet plants presented fast growth in the months of January and February, shading the olive plants and interfering in their development.

The results of the phytotechnical parameters of the olive trees show that the best plant development occurred in bare soil (OBS) plots, where there was less competition for light, water and nutrients between the olive trees and the intercropping ground cover plants.

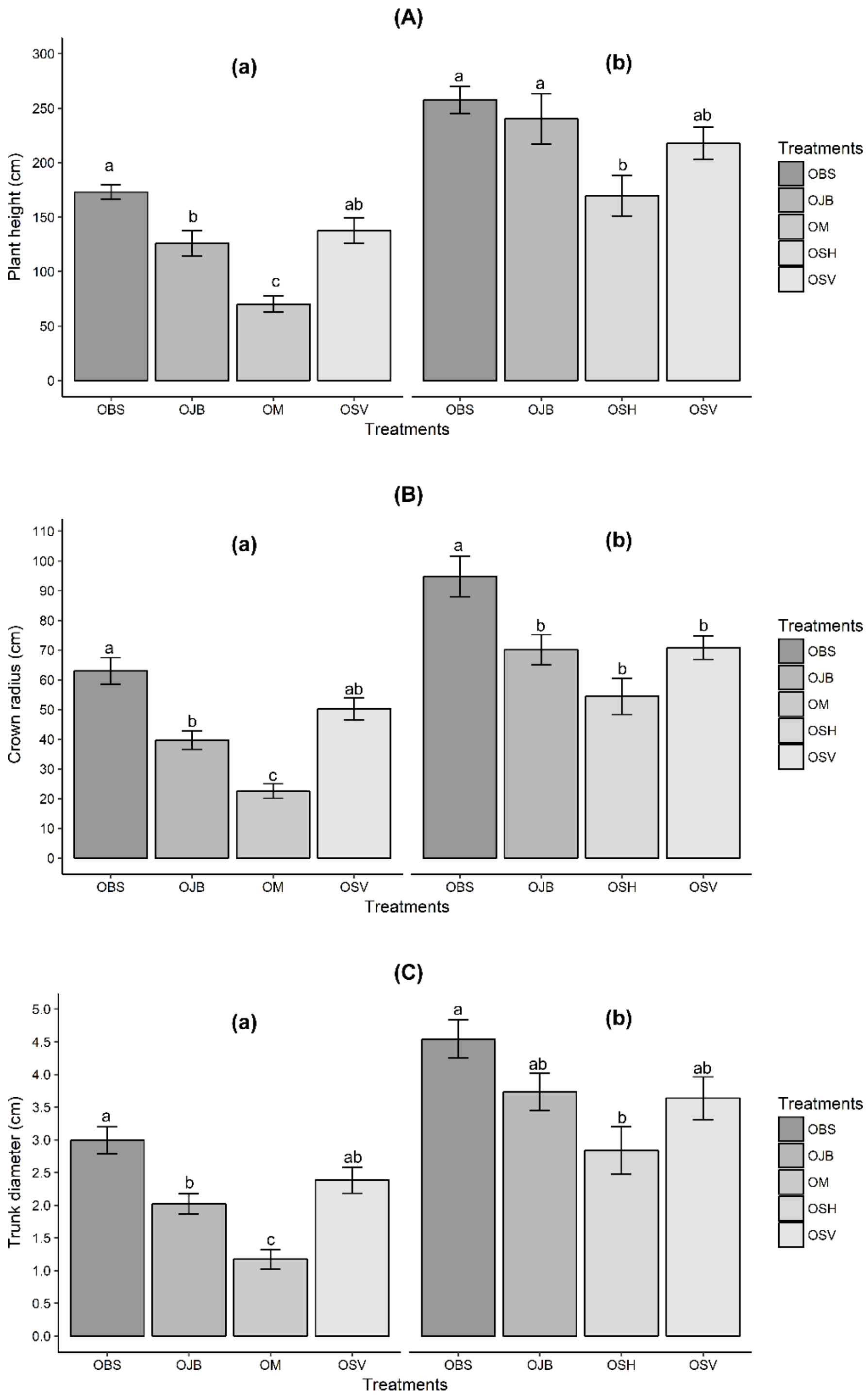

Figure 6. Phytotechnical parameters in the periods of 2015/2016 (a) and 2016/2017 (b) in different plant cover management systems: (a) plant height, (b) crown radius, (c) trunk diameter. Olive cultivation on bare soil (OBS); olive cultivation intercropped with spontaneous vegetation (OSV); olive cultivation intercropped with jack beans (OJB); olive cultivation intercropped with millet (OM); olive cultivation intercropped with sunn hemp (OSH) and bare soil (BS). Means followed by the same lowercase letter in the lines do not statistically differ by the Tukey Test at 5%.

Multivariate analysis between soil, plant, precipitation and water attributes

Figure 7 shows the results of the principal component analysis (PCA) for the different studied variables the periods of 2015/2016 (Figure 7.A) and 2016/2017 (Figure 7.B). The angles formed for each vector with the axis and the lengths of the vectors expressed the correlation level of each variable with the corresponding component.

In the first period (Figure 7.A), The first two dimensions of PCA express 90.7 % of the total dataset inertia ; that means that 93.09% of the variables cloud total variability is explained by the plane. Besides, in the second period (Figure 7.B), the first two components accounted for 83.95% of the variability.

From the PCA results, we observed that the variables had the same behavior during the two periods. The principal component analysis 1 (PC 1) presented a positive correlation with the five soil and water losses parameters soil loss: water loss, soil reduction efficiency, water reduction efficiency, runoff coefficient, and phytotechnical parameters. Negative correlations were obtained for vegetation cover index, hydraulic conductivity of unsaturated soil. The principal component analysis 2 (PC 2) showed a medium correlation with phytotechnical variables, and low correlation with soil and water loss variables.

The vegetation cover index and the unsaturated hydraulic conductivity of soil showed a negative correlation with the soil and water losses parameters, confirming the role of cover crops in reducing erosion. The interception of raindrops can cause reduction of their kinetic energy, which reduces the erosive power of rainfall by decreasing the volume of water that directly reaches the soil, also reducing surface runoff. Moreover, water infiltration increases (Cardoso et al., 2012; Rodrigo-Comino et al., 2018).

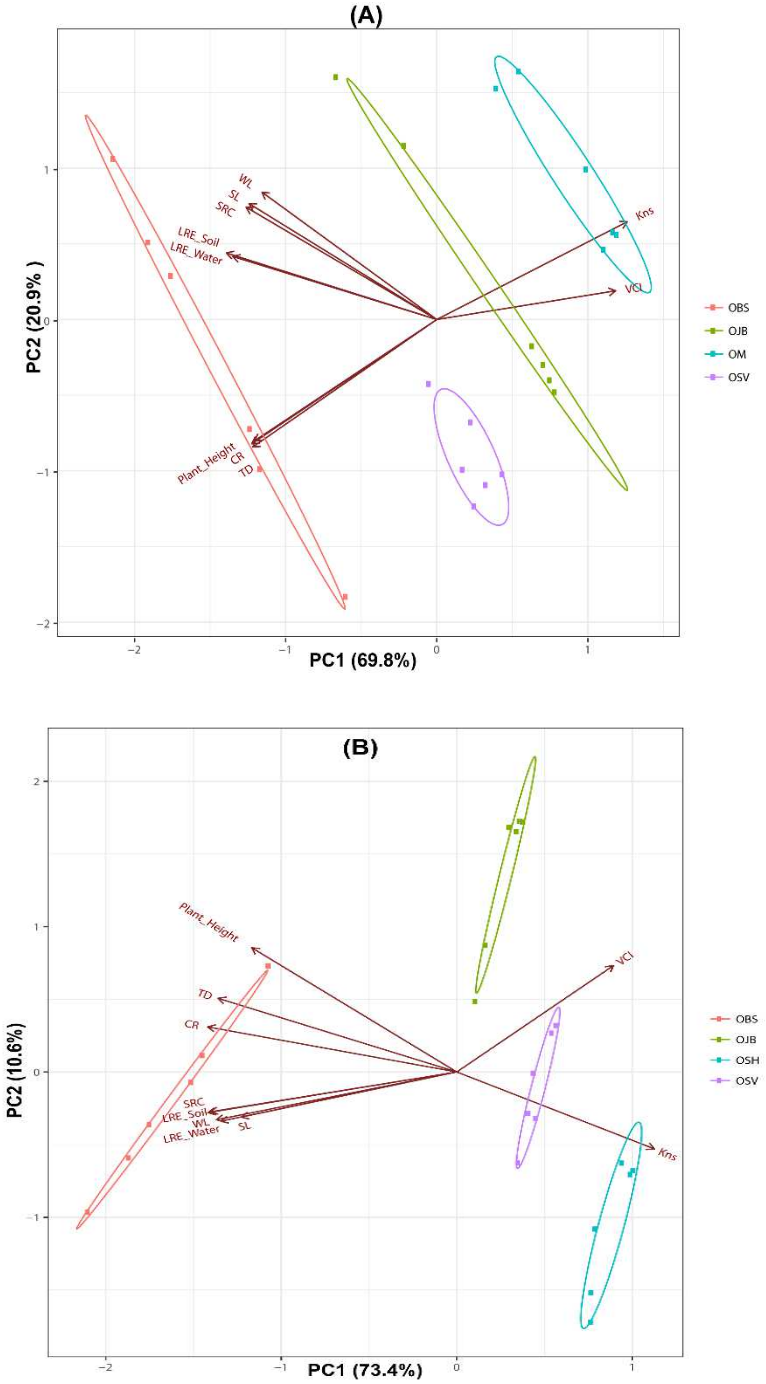

Figure 7. Principal component analysis of the main components the periods of 2015/2016 (A) and 2016/2017 (B), for the variables : soil loss (SL), water loss (WL), surface runoff coefficient (SRC), water loss reduction efficiency (LRE_Water), soil loss reduction efficiency (LRE_Soil), erosivity, precipitation, vegetation cover index (VCI), hydraulic conductivity of unsaturated soil (Kns), plant height (plant_height), crown radius (CR) and trunk diameter (TD), Principal component analysis 1 (PC1) and principal component analysis 2 (PC2). 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).

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 (OM) showed greater variability due to the high soil and water losses in the first period (Tables 5 and 6).

The vegetation cover index presented an inverse relation of the phytotechnical parameters. The plants with the highest performance occurred in the plots with low vegetation cover rates and with higher soil and water losses.

These results might support farmers' decisions to remove vegetation cover using chemical or manual methods, which is common practice in olive orchards in southern Minas Gerais and in Mediterranean countries, as reported by several authors (Gómez et al., 2006; 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). As a measure of erosion control, without competition from the plants intercropped with olive trees, it would be prudent to design high vulnerability terraces for the erosive process. However, the efficacy of this practice was not tested in this study.

The results of this study differ from those obtained by Sastre et al. (2016), who studied the effect of cover plants over the production of olive trees and its relation with the quality of olive oil. The authors concluded that there is no effect of cover crops over fruit yield or olive oil quality. Nevertheless, cover crops environmentally benefit from the reduction of water erosion, better water recharge and increasing carbon stock.

Many authors reported the negative effect of common practices, such as eliminating spontaneous vegetation in dry seasons, to reduce competition and the evapotranspiration caused by spontaneous vegetation, in olive tree management systems (Taguas et al. al., 2017). However, the absence of conservation practices favors the processes of water erosion and soil exposure, contributing to the reduction of water infiltration rates. Adequate management should reconcile both phytotechnical and environmental aspects of the crop, reducing soil and water losses through water erosion, providing soil quality and contributing to its sustainable use, especially for Cambisols.

CONCLUSION

The greatest soil and water losses occurred in the system with the highest phytotechnical performance: the system without vegetation cover.

Spontaneous vegetation is the most efficient treatment in reducing soil and water losses and phytotechnical aspects of olive tree cultivation.

Cover crops have a great relevance for the olive production sustainability in the tropical region, where shallow soils, with slopes and low hydraulic conductivity are predominant.

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ARTICLE 3: Determination of the Cover-Management factor in cover crops management systems of olive orchard

Determinação do fator Cobertura-Manejo em sistemas de manejo de culturas de cobertura na cultura de oliveira

ABSTRACT

In Brazil, olive orchard is in great expansion in shallow and sloping soils, with low vegetation cover and high exposure to water erosion, requiring a particular care in the management of cover crops to reduce water erosion losses, especially in the tropical region. In this context, the objective of this study was to verify the bestcover crops management in the olive orchard in the post-planting period, using vegetation indices generated from images obtained by passive sensors onboard in an unmanned aerial vehicle (UAV) in order to evaluate soil erosion losses under natural rainfall in different olive tree management systems, thus evaluating the relationship between the cover indices and the Cover Management factor (C-factor) for soil erosion. The study was carried out in an experimental area of the Federal University of Lavras, in a standard erosion plot with different vegetation cover management systems associated to the olive cultivation. The images were classified by the Random Forest algorithm and the soil losses were quantified by sediment collection in standard erosion plots after each erosive event. The results showed that the use of Random Forest in the classification of the image obtained by UAV and RED-NIR camera presented good results of the global accuracy and Kappa coefficient, allowing the calculation of different indices. The total vegetation cover index presented better performance in the prediction of soil loss and in the C factor determination.

Keywords: Water erosion. UAV. C-Factor. NDVI. Random Forest.

RESUMO

No Brasil o cultivo de oliveira está em grande expansão em solos rasos e declivosos, com baixo índice de cobertura vegetal e alta exposição à erosão hídrica, exigindo um cuidado particular no manejo das plantas de cobertura para reduzir os prejuízos da erosão hídrica sobretudo na região tropical. Neste contexto, o objetivo do estudo foi verificar o melhor manejo das plantas de cobertura na cultura de oliveira no período pós plantio, usando índices de vegetação gerados a partir de imagens obtidas por sensores passivos embarcados em veículo aéreo não tripulado (VANT), além de avaliar as perdas de solos por erosão hídrica, sob chuva natural, em diferentes sistemas de manejo do cultivo de oliveira, avaliando assim a relação entre os índices de cobertura gerados e o Fator Cobertura do solo (C). O estudo foi realizado em área experimental da Universidade Federal de Lavras, em parcela padrão de erosão com diferentes sistemas de manejo da cobertura vegetal associada ao cultivo de Oliveiras. As imagens obtidas foram classificadas pelo algoritmo de Random Forest e as perdas de solo quantificadas por coleta de sedimento em parcelas padrão de erosão após cada evento erosivo. Os resultados mostram que o uso de Random Forest na classificação da imagem obtida pelo VANT e câmera RED-NIR apresentou bons resultados da acurácia global e coeficiente Kappa, permitindo calcular os diferentes índices. O índice de cobertura vegetal total apresentou melhor desempenho na predição de perda de solo e na determinação do Fator C.

Palavras-chaves: Erosão hídrica. VANT. Fator C. NDVI. Random Forest.

INTRODUCTION

Vegetation plays an important role in protecting the soil against water erosion, since it constitutes a protective layer. Bertoni and Lombardi Neto (2014) considered that vegetation is the natural defense of the soil in the erosion processes, as it constitutes a barrier against the impact of raindrops, it disperses the kinetic energy of the rain and contributes, through roots and organic matter, for the improvement of soil infiltration rate and aggregation (Almeida et al., 2018).

The contribution of vegetation to soil protection is more important in crops with low coverage, for example, olive trees, which are common, cultured in shallow and declining soils. One of the most assessed parameters in the evaluation of vegetation for soil conservation is the vegetation cover index, which represents the ratio, in percentage, between the area covered by the vegetation and the total area (Zhongming et al., 2010), i.e., the contribution of vegetation to soil protection.

Standard methods for determining the vegetation cover index are performed in the field using different methodologies, like as described by Wischmeier and Smith (1978), which is based on the use of a chord with points and counting the number of vegetation points relative to the total number of points. Stocking methodology (Stocking, 1994) consists of the use of a ruler with holes, in which the vegetation cover is observed at each point. Besides that, there are other methodologies to determine cover vegetation index, such as the use of a sampling frame (Causton, 1988), or the determination by digital photography with different acquisition and processing methods, that can be manual (Macfarlane et al., 2014) or with the use of aerial images obtained from conventional vehicles (Karl et al., 2012), or from a digital camera, fixed on an unmanned aerial vehicle (UAV) (Torres-Sánchez et al., 2014; Caruso et al., 2017). The cover vegetation index was used in different studies to evaluate the efficiency of olive tree management (Kairis et al., 2013; Sastre et al., 2016; Rodrigo-Comino et al., 2018).

The relationship between soil cover and soil loss is established in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and is represented by the C-factor, which, according to Renard et al. (1991), is the most important for erosion, because it is the most controllable in relation to the others. In addition, it represents the combined effects of soil, plant and biomass cover on soil erosion (Prasannakumar et al., 2012), reflecting on erosion reduction as effect of conservation practices associated with different crop management systems (Panagos et al., 2015).

There are different methods for determining the C-factor. For example, the using of standard USLE plots for erosion quantification. Martins et al. (2010) and Silva et al. (2016) determined this factor in eucalyptus plantation. Other authors have also studied it in annual crops (Bertol et al, 2001; Bertol et al, , 2002; Lima et al., 2014). However, this method presents many difficulties, since it requires a wide series of temporal data to validate the results, and depends the different variables like as on the soil classes, vegetation species and the adopted management systems (Tiwari et al., 2000).

In this sense, the use of empirical models based on the characterization of the vegetation is a feasible alternative for the determination of the C-factor. Among the methods, we highlight the estimation of the C-factor from vegetation indices, such as the normalized difference vegetation index (NDVI) (Van Der Knijff and Montanarella, 2000), the leaf area index (Yang et al., 2003), the vegetation cover index (Elwell and Stocking, 1976) and the stratified cover index (Feng et al., 2018).

The values of C-factor range from close to zero (very high degree of soil protection) to one (soils with very high exposition to water erosion). For olive trees, studies developed in the Mediterranean region reported different C-factor values, such as 0.296, obtained by Borselli, et al. (2008), or values between 0.1 and 0.3, as found by Panagos et al. (2015) and between 0.10 and 0.25, as observed by Bakker et al. (2008). Nevertheless, there is a lack of data for the cultivation of the olive tree in tropical conditions.

Therefore, the objective of this study was to estimate the vegetation cover index using different vegetation indices derived from remotely sensed data obtained by an UAV, in different systems of vegetation cover management, aiming to assess the relationship between vegetation cover rates and calculated C factor.

MATERIAL AND METHODS

Study area

The experiment was conducted at the Federal University of Lavras (UFLA) in Lavras, Minas Gerais (21º13'20" S, 44º58'17"W) and average altitude of 925 m. The study area is composed of 15 plots that are 4.0 m wide and 12.0 m long (Figure 1).

The climate, according to the Koppen classification system, is Cwa, with average annual rainfall of 1,530.0 mm and average temperature of 19.4 ºC. The soil class of the area is typical Eutrophic Haplic Cambisol (Curi et al. 2017).

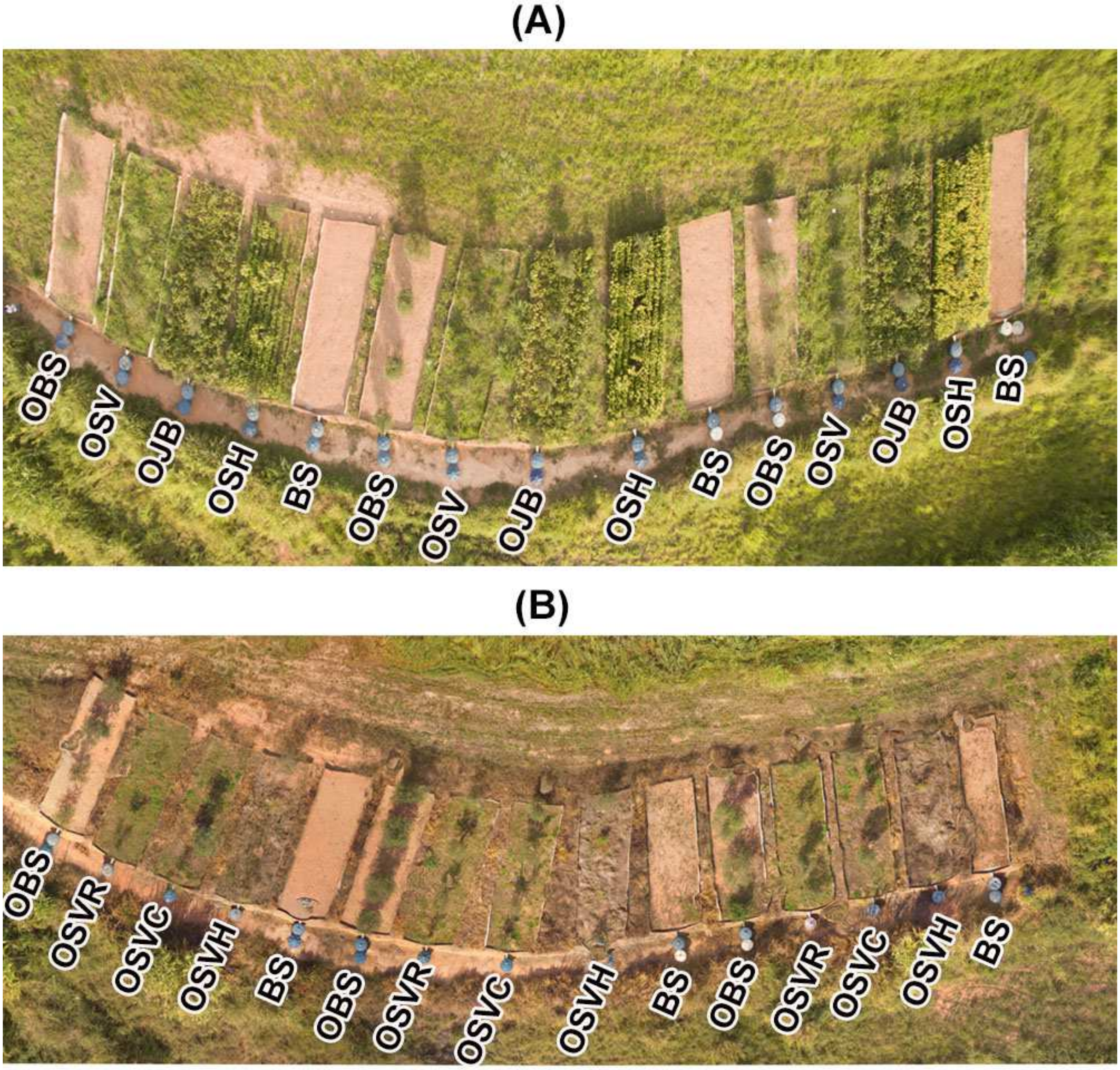

Figure 1. Arrangement of the 15 plots installed in the experiment area and used in the evaluation of soil and water losses in the agricultural periods (a) 2016/2017 (March 17th, 2017) and (b) 2017/2018 (April 18th, 2018) under different treatments. BS: bare soil, OBS: Olive trees cultivated in bare soil; OSV: olive trees cultivated with spontaneous vegetation; OJB: olive trees cultivated with jack beans; OSH: olive trees cultivated with sunn hemp; OSVR: olive trees cultivated with mowed spontaneous vegetation; OSVC: olive trees cultivated with mowed spontaneous vegetation and olive plants crow; OSVH: olive trees cultivated with spontaneous vegetation treated with herbicide.

Acquisition of images by the Unmanned Aerial Vehicle

The Unmanned Aerial Vehicle (UAV) used for image acquisition was the professional DJI Phantom 3 model, serial number p76ddc18b271 and ANA register CPP-011111110. It carried Mapir Survey 2 NDVI RED + NIR (DJI, 2018). The flights were programmed using the Pix4D software (Pix4D, 2018) to plan and delimit the study zone and also to control the distance of the UAV. For the estimation of the reflectance values images, data from the USGS Spectral Library were used in the Mapir Survey 2 (Kokaly et al., 2017).

Ten flights of approximately 20 minutes (Table 1), with 30-m altitude, were carried out using 36 georeferenced control points. A total of 200 photos were recorded per flight in JPEG format, with an overlap of 60%. PhotoScan Pro 1.2.6 (Agisoft LLC, 2016) was used for image processing, alignment, georeferencing and the generating of orthophotos. Vegetation indices were calculated to characterize the images and prepare their classifications using the Random Forest method (Yano et al., 2016).

The vegetation cover index (VCI) was calculated using equation 1:

$$\text{VCI} = \frac{\text{Pixels classificated as vegetation}}{\text{Total Pixels of splot}} \quad (1)$$

The soil cover index (SCI) was obtained by equation 2:

$$\text{SCI} = \frac{\text{Pixels classificated non} - \text{photosynthetic vegetation}}{\text{Total Pixels of splot}} \quad (2)$$

The total coverage index (TCI) was calculated by equation 3:

$$\text{TCI} = \text{VCI} + \text{SCI} \quad (3)$$

Table 1. Flight dates and plots treatments in the study area.

Date	Period	Treatment
March17, 2017	2016/2017	**BS**: bare soil
April 15, 2017		**OBS**: Olive trees cultivated in bare soil
May 25, 2017		**OSV**: Olive trees cultivated with spontaneous vegetation
June 23, 2017		**OJB**: Olive trees cultivated with jack beans
July 19, 2017		**OSH**: Olive trees cultivated with sunn hemp
December 18, 2017	2017/2018	**BS**: bare soil
January 22, 2018		**OBS**: Olive trees cultivated in bare soil
February 21, 2018		**OSVR**: Olive trees cultivated with mowed spontaneous vegetation
March 20, 2018		**OSVC**: Olive trees cultivated with mowed spontaneous vegetation and olive plants crow
May 20, 2018		**OSVH**: Olive trees cultivated with spontaneous vegetation treated with herbicide

Calculation of vegetation indices

In order to classify the images, two spectral bands: NIR (near infrared reflectance) and RED (visible red reflectance), were evaluated. From these bands and five vegetation indices were calculated:

Normalized Difference Vegetation Index (NDVI)

The NDVI is the most used index in vegetation studies due to its great capacity of discrimination between vegetation and non-vegetation (Feng et al., 2018). However, the performance of this index is reduced in areas with high biomass values (Rouse et al., 1973).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \tag{4}$$

where NIR is the near infrared band reflectance and RED is the visible infrared band reflectance.

Ratio Vegetation Index (RVI)

The RVI index presents in a simpler way the contrast between red and near infrared of green vegetation in good condition (Birth & McVey, 1968).

$$RVI = \frac{NIR}{RED} \quad (5)$$

where NIR is the near infrared band reflectance and RED is the visible infrared band reflectance.

Infrared Percentage Vegetation Index (IPVI)

The IPVI was developed in order to facilitate the calculation of NDVI. The creator of this index, Crippen (1990), justifies that it is not necessary to subtract the near infrared red in the numerator for the calculation of the NDVI.

$$IPVI = \frac{NIR}{(NIR + RED)} \quad (6)$$

where NIR is the near infrared band reflectance and RED is the visible infrared band reflectance.

Transformed Vegetation Index (TVI)

The TVI index is a modification of the NDVI index with addition of a constant (0.5) and to all values applied to the square root of the result.

$$TVI = \sqrt{NDVI + 0.5} \quad (7)$$

Optimized Soil Adjusted Vegetation Index (OSAVI)

The OSAVI index is a modified form of the NDVI index, with L correction factor equivalent to 0.16, which considers the setting value of the sun to weigh the variable effects of the ground (Huete, 1988; Baret and Guyot, 1991).

$$OSAVI = \frac{(1 + L) * (NIR - RED)}{(NIR + RED + L)} \quad (8)$$

where NIR is the near infrared band reflectance, L=0.16, and RED is the visible infrared band reflectance.

Random Forest and Classification

Random Forest (RF) is among a variety of classification and regression trees methods (CART) (Breiman,2001). CART methods are based on the ‘mining’ of relationships among target classes and the feature space spanned by the image data. RF method showed good performances for a wide range of image classification and mapping applications that involved vegetation studies (Breiman, 2001; Belgiu e Drăguţ, 2016; Yano et al., 2016; Castro et al., 2018)

Initially, from the mosaic of the 10 generated orthophotos, 100 random points were generated in each portion of the study area, resulting in a total of 1500 points, constituting a database of 1500 rows and 7 features space variables (RED; NIR; NDVI; OSAVI; RVI; TVI; IPVI) extracted with values of vegetation indices for each of the fifteen plots. This database was analyzed with the Random Forest algorithm.

Each point (database row) was classified according to its presence in each orthophoto in 4 classes: Vegetation (VEG); Bare soil (BS); Shadow and non-photosynthetic vegetation (NPV). From the generated points, the statistical analyzes of the indices values were performed in relation to the treatments and classes. The Random Forest algorithm was performed in the R (RC Team, 2017) software using the Random Forest package (Liaw and Wiener, 2018) with the following parameters: number of trees in the model (ntrees = 1000), number of variables in each node (nodesize = 10), and number of variables randomly sampled in each division (mtry = 2) (Pelletier et al., 2016).

Accuracy assessment of the classification models were performed through the evaluation of the following parameters: class errors, user accuracy, producer accuracy and overall accuracy. In addition, the Kappa coefficient was determined using the external validation, which corresponds to samples that were not used in the validation of the models (Congalton, 1991).

Assessment of soil loss

Soil loss evaluation was carried out following the methodology proposed by Wischmeier and Smith (1978), with a change in the dimension of the plots to 12 m length and 4 m width. The plots were limited with galvanized sheets measuring 40 cm in height and buried to a depth of 20 cm.

The plots were installed in the direction of the slope of the land. Runoff collection was made in the lower part of the plots, with galvanized gutters, the flood being collected in tanks. The collecting tanks had a capacity of 250 L, with a first settling tank (Tank A) and a second holding tank (Tank B) of the same capacity. The first tank was connected to the second tank by a Geib divider with 9 windows so that, after filling the settling tank (Tank A) only 1/9 of the runoff is conducted to the collecting tank (Tank B).

Soil loss quantification was performed by collecting samples at each erosive event. Then, three samples of runoff and sediment were collected in 250 mL pots after each tank collection event (COGO, 1978). The pots were weighed and set for decanting with the addition of three drops of hydrochloric acid to facilitate flocculation. After 24 hours, the pots were drained to leave only the pellet, in the next step the pots were placed in an oven and dried at 60 °C for later weighing.

Rainfall erosivity R factor

The erosivity of each period was estimated by the EI30 index, using a model proposed by Aquino et al. (2012) for the city of Lavras (equation 9).

$$EI_{30} = 85.672 * R_c^{0.6557} \quad (9)$$

The model considers the coefficient of rain proposed by Renard & Freimund (1994), according to equation 10.

$$R_c = \frac{p^2}{P} \quad (10)$$

where Rc is the rainfall coefficient (mm); p is the mean monthly precipitation (mm); and P is the annual mean precipitation (mm).

Cover- Management Factor (C-factor)

The calculation of the Cover-Management factor (C-factor) of the USLE was determined on the calculation of the soil loss ratio (SLR) for the eight months of the study period (n=8), which is the sum of the soil losses of a plot cultivated with a cover plant divided by the sum of the bare soil in the same time interval (Wischmeier and Smith, 1978), as shown in equation 11:

$$SLR = \frac{\sum_{i=1}^{8} SLcc}{\sum_{i=1}^{8} SL_{BS}} \qquad (11)$$

where i is the month of the study period, SLR is the soil loss ratio (Mg ha Mg^{-1} ha^{-1}), SLcc is the plot soil loss with cover plants, SLBS is the soil loss of the bare soil plot.

The C factor was calculated by equation 12 (Renard et al., 1991; Panagos et al., 2015).

$$C = \frac{(SLR1.EI1 + SLR2.EI2 + \ldots + SLRn.EIn)}{EIt} \qquad (12)$$

Where SLRi is the soil loss ratio in the considered month and EIi is the rainfall erosivity of that month and EIt is the total annual rainfall erosivity.

Statistical analysis

The experiment followed a Complete Randomized Block design in a standard plot of water erosion monitoring (Figure 1). The losses data and the vegetation indices were submitted to analysis of variance and the means were compared by the Tukey test at 5% probability.

The residuals of the soil loss prediction models and the C factor were tested using the Shapiro-Wilk test. The variables were submitted to log transformation when necessary, as used by Keesstra et al. (2018), using the statistical program R (RC Team, 2017).

RESULTS AND DISCUSSION

Assessment of plant cover

Figure 2 shows the maps generated from the vegetation indices dated March 17, 2018. It shows the ability to use UAV images for vegetation mapping through the vegetation indices chosen in this study.

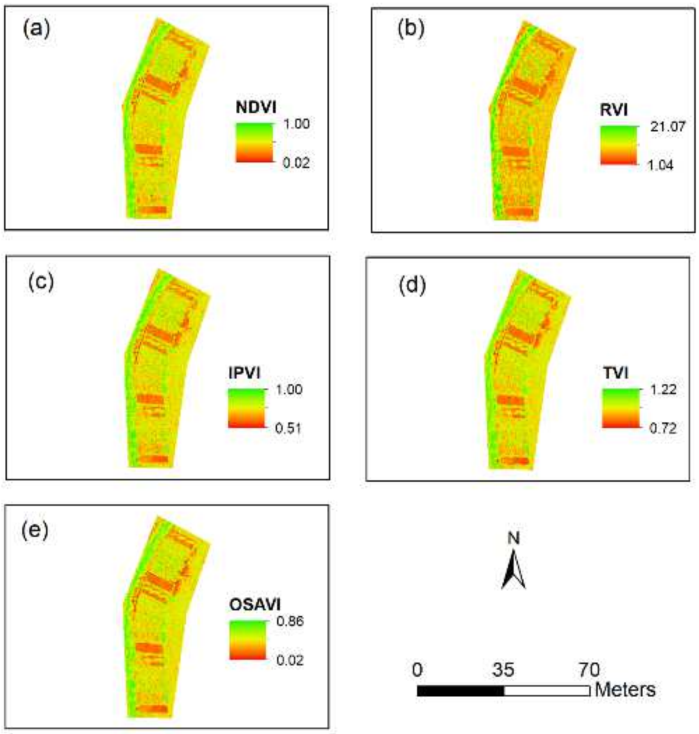

Figure 2. Vegetation indices maps of study area: NDVI (a); RVI (b); IPVI (c); TVI (d); OSAVI (e) Calculated on March 17, 2017.

Figure 3 shows the result of vegetation mapping using the Random Forest classifier based on the use of vegetation indices. The evaluation of this mapping was done using the results presented in Figures 4 and 5.

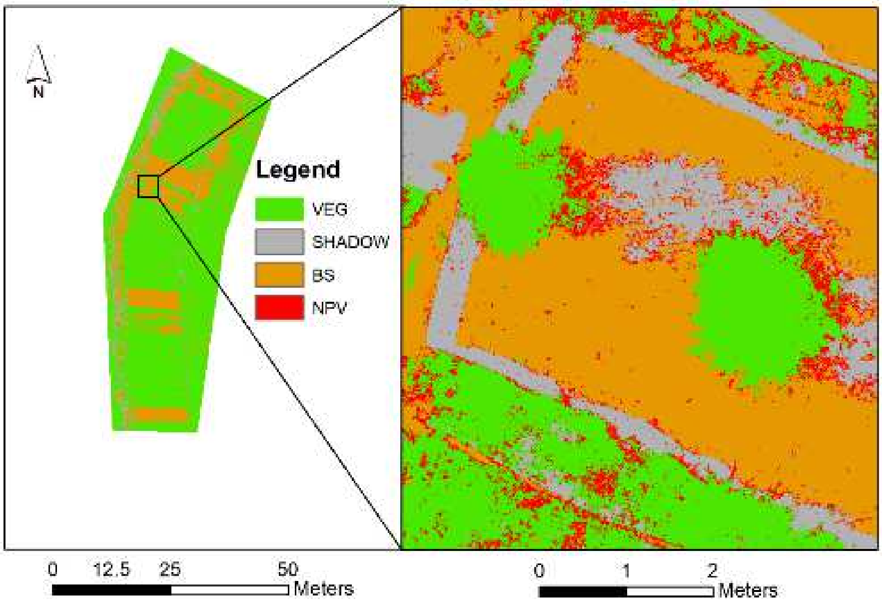

Figure 3. Vegetation classification maps of study area using Random Forest on March 17, 2017, with the following classes: Bare soil (BS), Shadow, vegetation (VEG) and non-photosynthetic vegetation (NPV).

Figure 4 shows the graph of the importance of the average accuracy of the covariates used in Random Forest, at different dates. Note that the NIR band and the OSAVI index were the most important variables in the constitution of the Random Forest classifier model. The NIR band presented the highest rank of importance among the variables, thus agreeing with the results found by Fletcher (2015), when using different bands in the constitution of Random Forest classifier for the detection of weeds in the soybean crop. According to Ahamed et al. (2011), the reflectance variation of the vegetation cover occurs at the wavelengths in the near infrared range during the growing season, and the most important reflectance change occurs during the biomass growth period. The importance of the NIR band rank can be explained by the capacity of the absorption or the reflectance of the NIR in each class classified by the model (Fletcher, 2015). On the other hand, Red band reflectance (RED) increases with leaf water stress associated with a reduction in chlorophyll concentration (Adam et al., 2010), which may explain the low importance of the variable RED for the classification of vegetation.

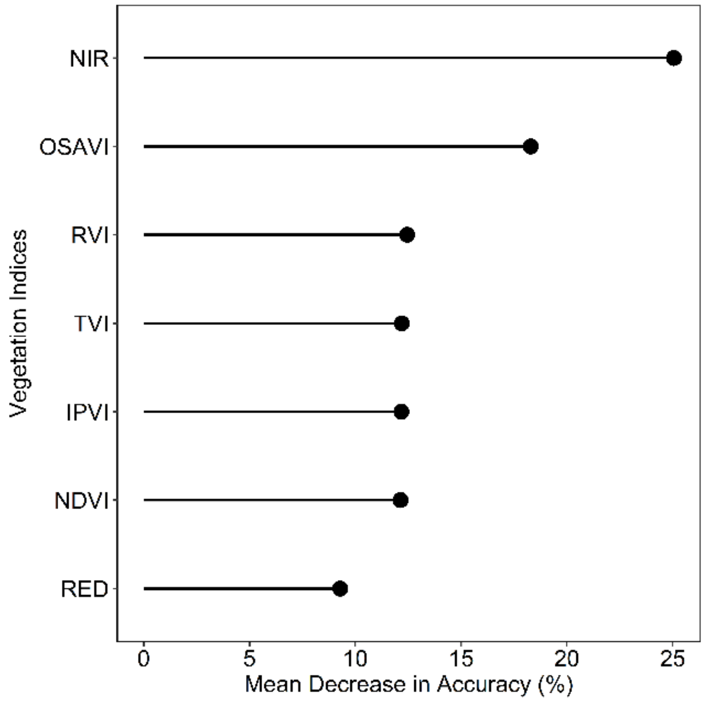

Figure 4. Importance of covariates in the classification of vegetation by the Random Forest classifier.

Figure 5 illustrates the variations of the Random Forest classifier parameters during the study period. Regarding the overall accuracy, the values range from 78% to 90%, with an average value of 86%. Except for February 21, 2018, all dates have an overall accuracy above 90%. The Kappa coefficient variation follows the same trend of overall accuracy, with values ranging from 0.69 to 0.85, with an average of 0.79. The low values of accuracy on February 21, 2018 can be explained by the low average vegetation cover rate for this day, which was equivalent to 0.38, while the average value of the other days was 0.50.

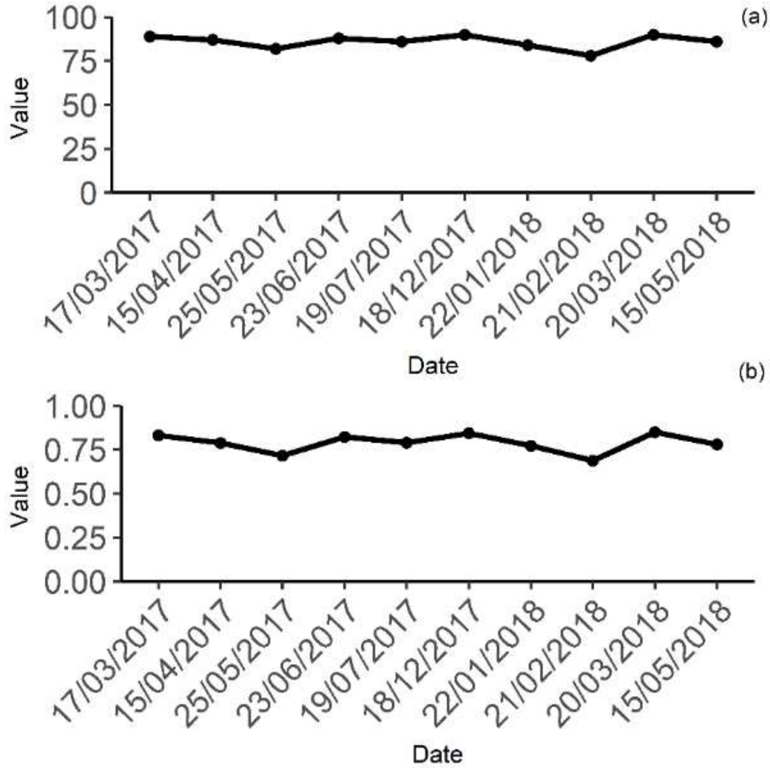

Figure 5. Overall accuracy (a) and Kappa coefficient (b) of the Random Forest classifier during the study period.

The other parameters of the Random Forest evaluation are presented in Table 3. The values of the user accuracy range from 53% to 100% and the highest accuracy was obtained in the vegetation class on March 20, 2018. The values of the producer accuracy varied from 35% to 99% with the highest value in the class of vegetation of 99%. Class errors presented a range of values from 0.01 to 0.66 with the highest error value in class NPV. The high error values in the Shadow classes and non-photosynthetic vegetation (NPV) are associated with the low overall accuracy and the Kappa coefficient, thus reflecting the variability of these two classes, which are transitional. The non-photosynthetic vegetation (NPV) is composed of dry matter, so that its reflectance varies in relation to humidity. However, one should also consider the problem of unbalanced training samples, caused by the low frequency of occurrence of some classes (Lin and Chen, 2013; Pelletier et al., 2016).

Figure 6 shows the comparison among treatments for both periods of study. There was no significant difference using the five vegetation indices used in the study. The TCI showed a significant difference between the olive tree treatments associated with cover crops or spontaneous vegetation and the olive tree with bare soil.

The mean value of NDVI was 0.38 in the first period and 0.36 in the second period for the treatment of olive with bare soil. The results are within the range of values found by García Torres et al.(2008), ranging from 0.12 to 1 for images obtained from UAV, while the study of Brilli et al.(2013), which considered multisensor satellite images, presented an average value of 0.80. According to Ouzemou et al. (2018), the NDVI values of olive cultivation range from 0.35 to 0.7. The same authors showed that the olive trees maintain values of NDVI with small variations due to the high sustainability of this crop in terms of the variation of the chlorophyll rate.

According to Barati et al. (2011), the NDVI index is the most appropriate for vegetation classification. However, the same authors report that NDVI does not show good accuracy in dry vegetation, as in the case of the herbicide treatment. These authors also affirmed that the NDVI; IPVI; RVI and OSAVI indices have the same behavior and the TVI index shows poor performance in vegetation classification, which was confirmed by the results of these indices in Figure 6.

Table 3. Parameters of the different results of classification models using Random Forest

Data	User Accuracy			
	BM	BS	Shadow	VEG
March 17, 2017	56	99	80	92
April 15, 2017	69	91	84	90
May 25, 2017	52	93	76	84
June 23, 2017	83	91	71	95
July 19, 2017	75	91	73	95
December 18, 2017	81	96	90	92
January 22, 2018	71	85	88	94
February 21, 2018	67	72	72	99
March 03, 2018	75	97	64	100
May 15, 2018	68	97	53	89
Average	69.7	91.2	75.1	93
	Producer accuracy			
March 17, 2017	44	92	88	95
April 15, 2017	59	84	89	97
May 25, 2017	40	95	74	89
June 23, 2017	84	95	71	89
July 19, 2017	82	86	61	95
December 18, 2017	86	84	88	96
January 22, 2018	75	82	91	90
February 21, 2018	76	59	80	96
March 03, 2018	82	96	56	99
May 15, 2018	74	95	35	90
Average	70.2	86.8	73.3	93.6
	Class errors			
March 17, 2017	0.6	0.09	0.17	0.07
April 15, 2017	0.54	0.14	0.13	0.05
May 25, 2017	0.66	0.04	0.19	0.12
June 23, 2017	0.13	0.07	0.16	0.08
July 19, 2017	0.21	0.13	0.43	0.07
December 18, 2017	0.18	0.12	0.11	0.05
January 22, 2018	0.26	0.19	0.05	0.08
February 21, 2018	0.27	0.4	0.24	0.04
March 03, 2018	0.19	0.06	0.39	0.01
May 15, 2018	0.24	0.04	0.83	0.11
Average	0.33	0.13	0.27	0.07

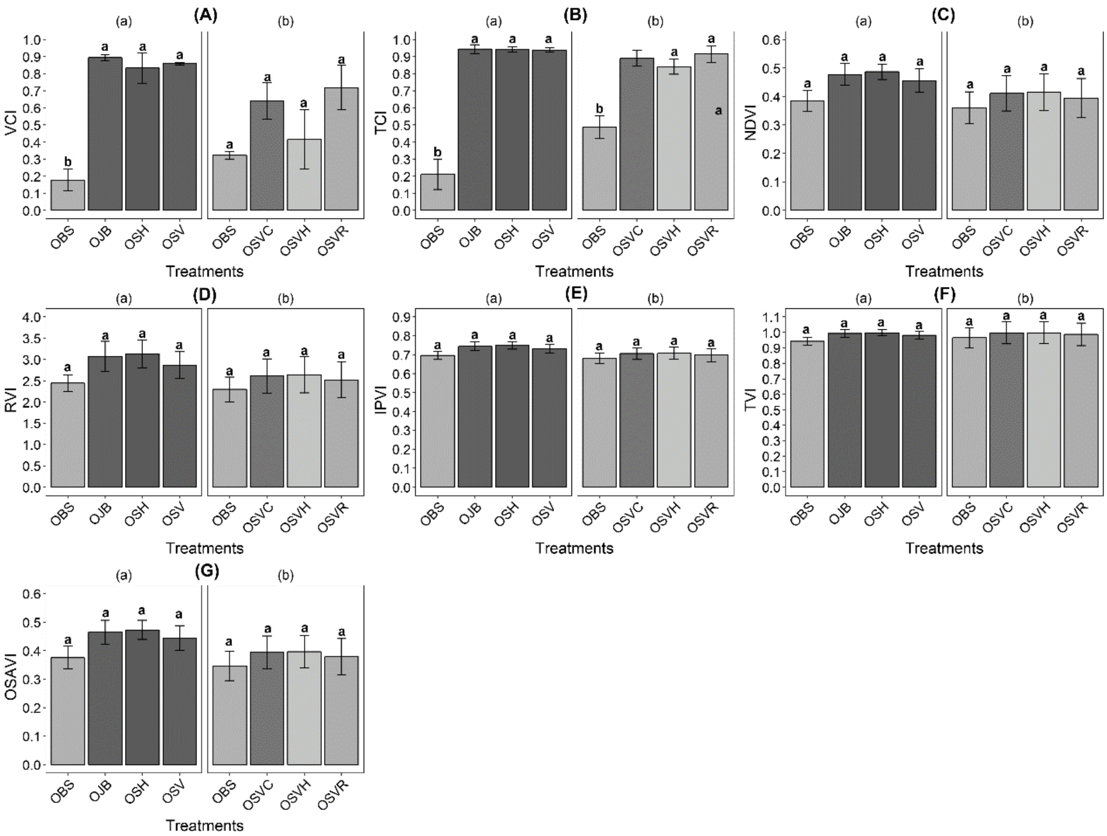

Figure 6. Comparison of averages of coverage rates: vegetation cover index (A),total cover index (B), and vegetation indices: NDVI (C); RVI (D); IPVI (E); TVI (F) and OSAVI (G) in different management systems olive trees in 2016/2017 (a) and 2017/2018 (b). Means followed by the same letters do not differ by the Tukey test at 5%. BS: bare soil, OBS: olive trees cultivated in bare soil; OSV: olive trees cultivated with spontaneous vegetation; OJB: olive trees cultivated with jack beans; OSH: olive trees cultivated with sunn hemp; OSVR: olive trees cultivated with mowed spontaneous vegetation; OSVC: olive trees cultivated with mowed spontaneous vegetation and olive plants crow; OSVH: olive trees cultivated with spontaneous vegetation treated with herbicide.

Erosivity assessment

Figure 7 shows the precipitation and erosivity values for the study period, from October to May, in the two hydrological periods, 2016/2017 and 2017/2018. The total erosivity was 4,750.59 Mg ha^{-1} $period^{-1}$ in 2016/2017, and 4,577.76 MJ mm ha^{-1} $h^{-1}perid^{-1}$ in 2017/2018. The period with the highest risk of erosion was from November to March, representing 75.71% in 2016/2017 and 86.38% in 2017/2018 of total erosivity, with a value higher than 500 MJ mm ha^{-1} h^{-1} $month^{-1}$, which is considered critical according to Cardoso et al. (2012). These data agree with those presented by Silva et al. (2009), which reported the high rainfall erosion in Lavras from November to March, totaling 82.75% of rainfall erosivity, according to the study, between 1998 and 2002.

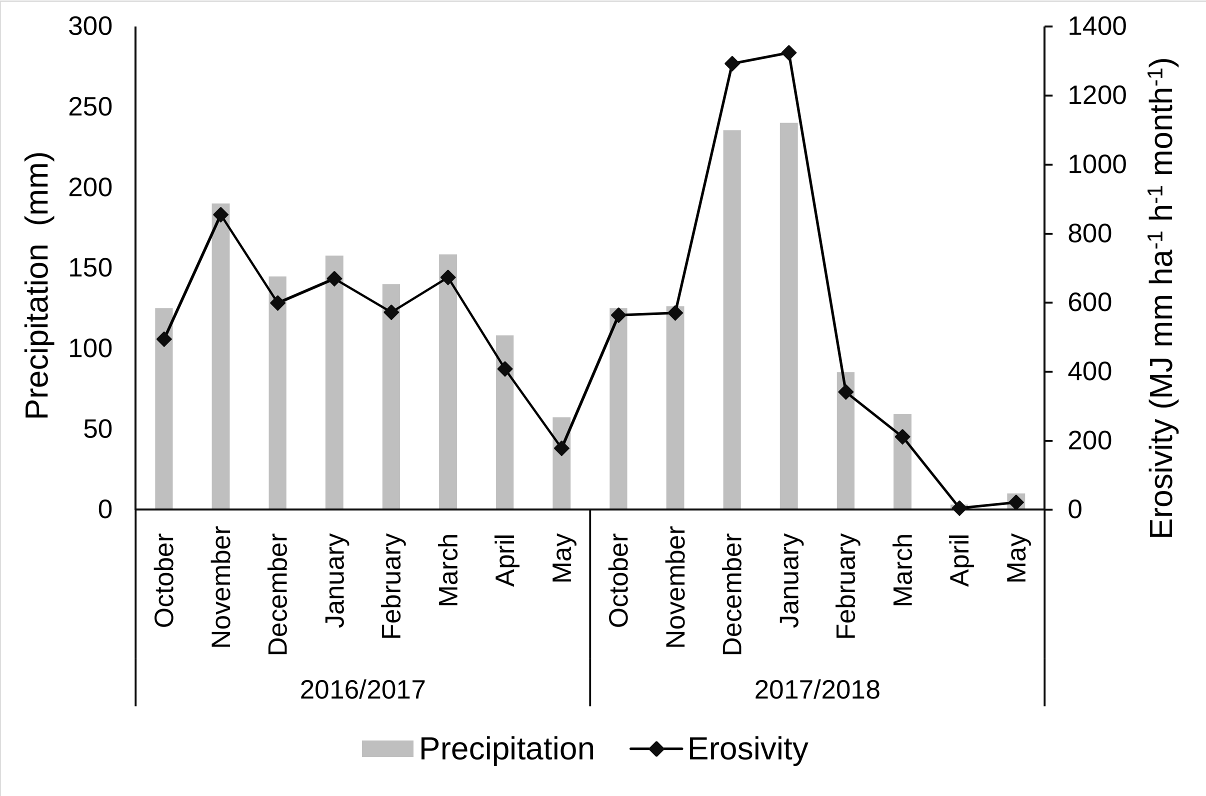

Figure 7. Precipitation and erosivity for the study period, Lavras (MG).

Soil loss assessment

Table 4 shows the monthly soil loss data and the totals for the period evaluated. The trend of soil loss in time follows the distribution of rain erosivity over the same period, with higher losses in the months of December to January. In 2017/2018, there was a high soil loss in the month of October caused by high erosivity and the low coverage rate in that month.

Table 4. Soil losses in the study period in different cover management systems of olive tree.

Treatments	Soil loss								
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
					2016/2017				
	--- Mg ha^{-1} period^{-1}-------------------------------								
OBS	3.76	8.64	41.44	83.3	22.97	75.73	55.5	0.00	291.38±166.53 **a**
OSV	0.01	0.05	0.09	0.08	0.14	0.18	0.01	0.00	0.56±0.44 **b**
OJB	0.04	0.04	0.25	0.02	0.01	0.07	0.01	0.00	0.45±0.37 **b**
OSH	0.01	0.6	0.36	8.82	0.02	0.15	0.02	0.00	9.98±14.39 **b**
BS	3.35	13.91	51.31	80.06	39.19	49.13	57	0.6	294.54±85.58 **a**
					2017/2018				
OBS	35.73	27	12.64	6.45	4.89	0.86	0.00	0.00	87.59±76.82 **a**
OSVR	0.08	0.01	0.01	0.03	0.02	0.00	0.00	0.00	0.16±0.07 **b**
OSVC	0.04	0.04	0.03	0.02	0.02	0.00	0.00	0.00	0.16±0.03 **b**
OSVH	0.23	0.01	0.03	0.02	0.01	0.00	0.00	0.00	0.31±0.35 **b**
BS	96.74	26.29	12.76	11.23	6.02	6.75	0.00	0.1	159.86±86.44**a**

Means followed by the same lowercase letter in the lines do not statistically differ by the Tukey Test at 5%. Months: Oct.: October; Nov.: November; Dec.: December; Jan.: January; Feb.: February; Mar.: March; Apr.: April. Treatments: BS: bare soil, OBS: Olive trees cultivated in bare soil; OSV: Olive trees cultivated with spontaneous vegetation; OJB: Olive trees cultivated with jack beans; OSH: Olive trees cultivated with sunn hemp; OSVR: Olive trees cultivated with mowed spontaneous vegetation; OSVC: Olive trees cultivated with mowed spontaneous vegetation and olive plants crow; OSVH: Olive trees cultivated with spontaneous vegetation treated with herbicide.

It is noteworthy that the treatments with spontaneous vegetation presented greater performance in the reduction of erosion. The treatments OSVR and OSVC presented equal accumulated losses with a different distribution. In the period from December to February 2017/2018 the losses, in Mg ha^{-1} period ^{1}, were in the following order: BS (30.00)> OBS (23.98)> OSVC (0.07)> OSVH (0.06)> OSVR (0.05), showing that the OSVR treatment had lower loss in the period with high erosivity. This shows the effect of the management on the losses, since the treatments with lower coverage index present greater soil loss in relation to the others (Figure 3).

The highest total losses were recorded in the treatment of bare soil (BS), with a value of 294.54 Mg ha^{-1} period^{-1} in 2016/2017 and 159.86 Mg ha^{-1} period^{-1} in 2017/2018. The olive tree treatments associated with the cover plants in the two monitoring periods did not present significant differences due to the great variability of the losses.

Soil preparation and practices for the insertion of cover crops during the year 2016/2017 contributed to the increase of soil losses when compared to management systems based on spontaneous crops of the year 2017/2018.

The treatments with spontaneous vegetation showed efficient erosion control. The most efficient treatment in the first period was the olive tree intercropped with jack beans and in the second period, the olive treatments intercropped with spontaneous vegetation and crowning (OSVR and OSVC).

The efficiency of the erosion control of the treatments can be explained by the vegetation cover index, since greater soil cover results in less erosion (Sastre et al., 2017). In the first period, the plant cover indices were 0.89, 0.85, 0.83, and 0.17 for the OJB, OSV, OSH, and OBS treatments, respectively. In the second period, the plant cover indices were 0.71, 0.64, 0.41, and 0.32 in OSVR, OSVC, OSVH, and OBS treatments, respectively (Figure 3).

The higher efficiency of jack beans in the reduction of erosion is due to the foliar architecture, high growth and the high coverage ratio, which was confirmed by several studies in the southern Minas Gerais region (Freitas et al., 2012; Lima et al., 2014).

Cover crops and spontaneous vegetation play an important role in the reduction of soil losses, and can act as a physical barrier intercepting raindrops, as well as soil fixation by the roots and the reduction of surface runoff due to the increase of infiltration and the kinetic energy of the flow (Cardoso et al., 2012, Lima et al., 2018).

It was observed a temporal variation of SRL in each treatment (Table 5), which may be related to the cover plant intercropped with the olive trees and the monthly variation of rain erosivity. The SRL was high in the olive trees cultivated in bare soil, with a maximum value in the period 2017/2018 of 1,125 and 1.02 in 2017/2018. The lowest SRL average of the study period was in the OVE treatment in the first period, and in the OSVH treatment in the second period. These results agree with Bertol et al. (2002), showing that grasses used as cover crops (treatments with spontaneous vegetation) are more efficient in erosion reductions than legumes (jack beans and sunn hemp). McGregor and Mutchler (1983) showed that spontaneous vegetation had an effect on SRL reduction in annual cultures.

Table 5. Soil loss ratio for olive orchard under different management systems in a Haplic Cambisol.

Treatments	Soil losses ratio								
	2016/2017								
	--------------------------------- Mg ha Mg^{-1} ha^{-1} period^{-1}---------------------------------								
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Average
OBS	1.1250	0.6214	0.8078	1.0406	0.5862	1.5412	0.9733	0.0511	0.8433
OSV	0.0035	0.0035	0.0018	0.0010	0.0037	0.0036	0.0001	0.0027	0.0025
OJB	0.0111	0.0031	0.0049	0.0003	0.0003	0.0014	0.0001	0.0002	0.0027
OSH	0.0037	0.0432	0.0070	0.1102	0.0004	0.0030	0.0003	0.0000	0.0210
	2017/2018								
OBS	0.3693	1.0271	0.9909	0.5745	0.8118	0.1280	0.0000	0.1612	0.50785
OSVR	0.0009	0.0004	0.0006	0.0025	0.0035	0.0005	0.0000	0.0229	0.00391
OSVC	0.0005	0.0016	0.0024	0.0018	0.0033	0.0007	0.0000	0.0032	0.00169
OSVH	0.0024	0.0005	0.0022	0.0021	0.0018	0.0004	0.0000	0.0000	0.00117

Months: Oct.: October; Nov.: November; Dec.: December; Jan.: January; Feb.: February; Mar.: March; Apr.: April. Treatments: BS: bare soil, OBS: Olive trees cultivated in bare soil; OSV: Olive trees cultivated with spontaneous vegetation; OJB: Olive trees cultivated with jack beans; OSH: Olive trees cultivated with sunn hemp; OSVR: Olive trees cultivated with mowed spontaneous vegetation; OSVC: Olive trees cultivated with mowed spontaneous vegetation and olive plants crow; OSVH: Olive trees cultivated with spontaneous vegetation treated with herbicide..

The values of the C-factor of the USLE equation are shown in Table 7. The highest values were in the olive crop cultivated on bare (OBS) for both periods, with the tendency of the treatments with greater cover to have low C-factor values. Arhonditsis et al. (2002) found that the C factor depends on the percentage of vegetation covering the crown of the olive cultivation with spontaneous vegetation. For Di Stefano et al. (2016), the seasonal variability of the olive tree C-factor is caused by the variability of erosivity, management system and the cultivar.

Table 7. Soil Cover Management factor (C factor) for olive cultivation in different management systems of cover crops in a Haplic Cambisol.

Treatments	Soil Cover Management factor (C factor)
	2016/2017
	Mg ha Mg^{-1} ha^{-1}
OBS	0.8110
OSV	0.0023
OJB	0.0025
OSH	0.0398
	2017/2018
OBS	0.6720
OSVR	0.0016
OSVC	0.0018
OSVH	0.0016

BS: Bare soil, OBS: olive trees cultivated in bare soil; OSV: olive trees cultivated with spontaneous vegetation; OJB: olive trees cultivated with jack beans; OSH: olive trees cultivated with sunn hemp; OSVR: olive trees cultivated with mowed spontaneous vegetation; OSVC: olive trees cultivated with mowed spontaneous vegetation and olive plants crow; OSVH: olive trees cultivated with spontaneous vegetation treated with herbicide.

The models of prediction of the C factor and soil loss are presented in Tables 8 and 9. According to different authors (Van Der Knijff and Montanarella, 2000; Feng et al., 2018), the exponential models are the most appropriate for the prediction the soil loss and C-Factor by the use of vegetation and cover indices. Thus, based on the values of R^2 and mean square error (RMSE), it was observed that the exponential models have the best fit, corroborating with the results obtained by Feng et al.(2018). The best models that presented higher R^2 and low mean square error (RMSE) are plotted in Figures 6 and 7.The total coverage index showed a better prediction of soil loss, followed by other indices (VCI, NDVI, RVI, IPVI, and OSAVI).

Table 9 shows the results of the C factor depreciation models. The R^2 of the models obtained using the vegetation cover index was 0.21 and 0.61 in the case of total coverage index. The difference can be explained by the important role of crop residues in the reduction of water erosion, resulting in the reduction of the kinetic energy of the raindrops and the increase of water infiltration in the soil (Lopes et al., 1987).

The relationship of vegetation indices (NDVI, RVI, IPVI, TVI, and OSAVI) and the C factor showed that the vegetation cover is insufficient to explain the C factor. Similar results were found by Feng et al. (2018), relating the C factor with vegetation indices generated from Landsat 8 OLI image, with low R^2 values.

In Figure 8, it is observed that with the increase of the total vegetation cover, there was an exponential decrease in soil losses. This same tendency of the curve of the index of vegetation cover with the losses of soil was found by Nunes et al (2011). According to Keesstra et al. (2016), practices in plantations where the soil is kept uncovered and thus exposed to erosive agents are considered unsustainable.

In the present study, the results obtained showed that the vegetation cover index presented a better relation between the soil losses and the C factor. On the other hand, the vegetation indices were inadequate to estimate soil loss on the plot scale. Feng et al. (2018) found similar results in relation to vegetation indices and particularly the NDVI index. The authors verified that the NDVI index showed great sensitivity regarding the vitality of the vegetation (chlorophyll activity) and the effects of the soil. In addition, the NDVI tends to overestimate the vegetation cover in the first physiological states (Asis and Omasa, 2007).

Table 8. Soil loss prediction models using the vegetation index

Models	R^2	RMSE	P value
SL=0.82*exp(-2.33*VCI)	0.21	11.4092	<0.01
SL=10.89*exp(-5.09*TCI)	0.68	9.9215	<0.001
SL=3.07*exp(-5.09*NDVI)	0.21	11.4396	<0.01
SL=2.72*exp(-0.96*RVI)	0.19	11.5024	<0.05
SL=1045.23*exp(-11.98*IPVI)	0.19	11.4995	<0.05
SL=104.17*exp(-6.63*TVI)	0.23	11.5252	<0.01
SL=2.94*exp(-6.56*OSAVI)	0.20	11.4984	<0.05

Root Mean Square Error; SL: Soil Loss; VCI: Vegetation cover index; TCI: Total cover index.

Table 9. C-factor prediction models using vegetation indices

Models	R^2	RMSE	P value
C=0.92*exp(-2.99*VCI)	0.42	0.2038	<0.01
C=7.02*exp(-4.81*TCI)	0.73	0.1554	<0.001
C=18.26*exp(-11.37*NDVI)	0.19	0.2711	<0.01
C=13.23*exp(-1.66*RVI)	0.17	0.2738	<0.01
C=81,633.90*exp(-18.52*IPVI)	0.15	0.2826	<0.01
C=53.70*(10^18)*exp(-	0.63	0.1668	<0.05
C=9.78*exp(-10.25*OSAVI)	0.16	0.2805	<0.01

Root Mean Square Error; C: C-factor; VCI: Vegetation cover index; TCI: Total cover index.

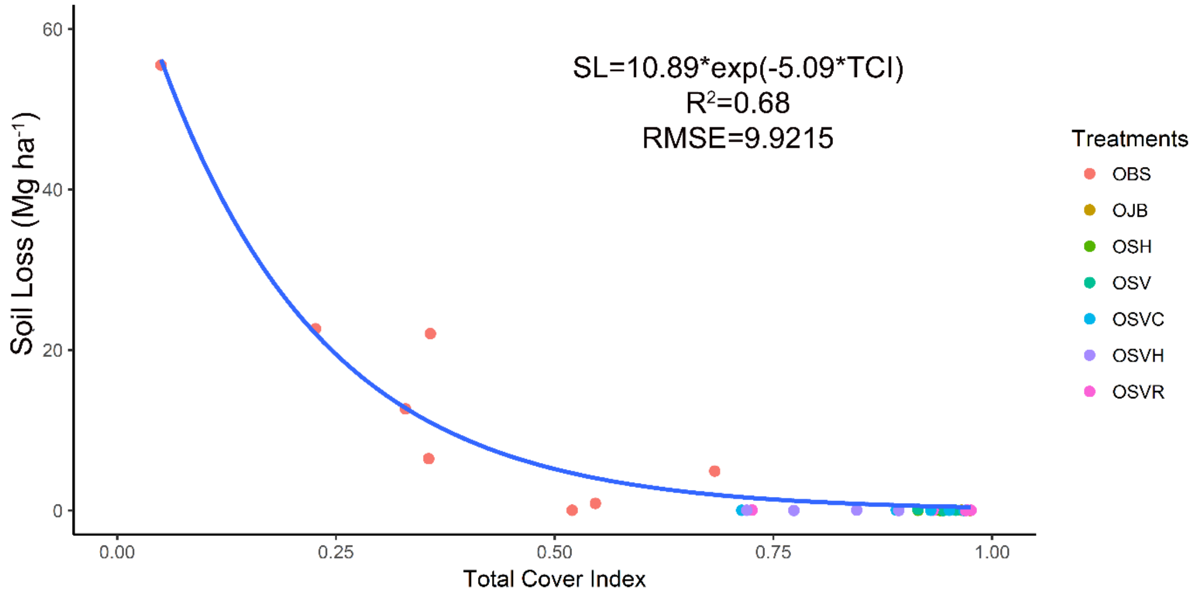

Figure 8. Relationship between soil loss (SL) and total cover index (TCI). SL: Soil Loss; TCI: Total cover index.

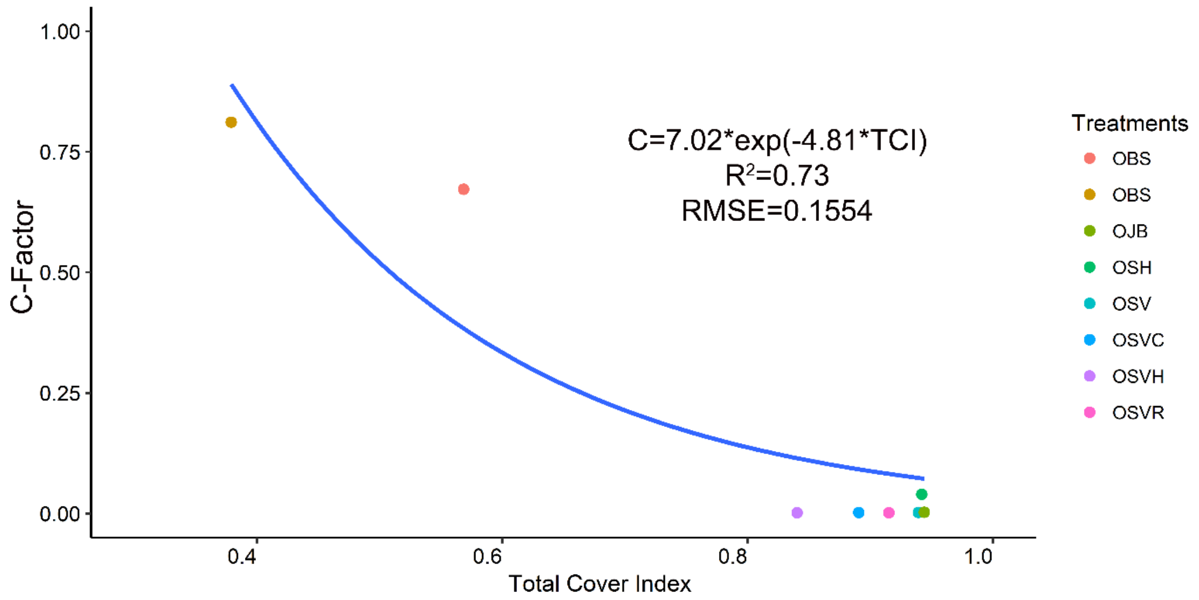

Figure 9. Relationship between the C factor (C) and total coverage index (TCI). C: C-Factor; TCI: Total cover index.

CONCLUSIONS

The use of Random Forest in the classification of the images generated by the RED-NIR camera fixed in an UAV showed results allowing the accurate classification of vegetation cover.

The total vegetation cover index presented better performance in the prediction of soil loss and in the determination of C-factor.

The vegetation indices of the present study presented poor relation with soil loss and the C-factor.

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