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Relationship Among Crop Systems, Soil Cover, and Water Erosion on a Typic Hapludox

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ABSTRACT: Several soil conservation practices are used to reduce water erosion and ensure sustainable agriculture. An effective crop management practice is intercropping, in which two or more crops with different architectures and vegetative cycles are grown simultaneously in the same area. We hypothesized that intercropping of corn and jack-bean increases soil cover and reduce soil erosion by water in comparison to monocropping. The objective of this study was to evaluate the effects of different crop systems on soil cover and on soil erosion by water. Soil and water losses from a Typic Hapludox were measured under the following systems: corn cultivation (CO), jack-bean cultivation (JB), intercropping of corn and jack-bean (IC), and bare soil (BS), as a reference for maximum erosion rates. For each crop system, erosion plots with dimensions of 12 × 4 m were set up in the field on a 0.12 m m^{-1} slope gradient. The experiment was carried out under natural rainfall, over three crop seasons (November to March) from 2011 to 2014. The soil cover index of the systems was monitored during crop growth, and rainfall erosivity for the crop seasons was calculated according to the EI_{30} index to interpret soil and water losses. A set of linear mixed models was fitted to relate soil losses to rainfall erosivity, crop systems, and soil cover. The average rainfall erosivity in the study area was 6,132 MJ mm ha^{-1} h^{-1} per crop season. The results indicate that water losses are directly related to erosivity and are less influenced by soil cover and cultivation systems than the soil losses. A linear maximum value of the soil cover index was achieved 70 days after sowing. Intercropping exhibited greater soil cover than single crops. Total soil losses from the three seasons display the trend: BS > CO > JB > IC. The best fitted model of the linear mixed models indicates that soil loss responses are strongly correlated with rainfall erosivity and soil cover, which nullified the influence of the crop systems in the model.

Keywords: intercropping, soil conservation, *Zea mays*, *Canavalia ensiformis*, linear mixed models.

INTRODUCTION

Soil erosion is a natural process that can be accelerated by anthropic activities; this process has a direct impact on the environment and food production (Lal, 2001). Erosion processes include the detachment, transport, and deposition of soil particles. Rainfall is the main agent that initiates detachment, and rates increase when the soil surface lacks vegetative cover (Lal, 2001; Pimentel, 2006; Zuazo and Pleguezuelo, 2008).

Several edaphic, mechanical, and vegetative conservation practices and management systems have been developed and implemented in order to reduce soil erosion and ensure sustainable agriculture (Powlson et al., 2011; Maetens et al., 2012). Maintenance of cover plants is particularly vital among the different factors involved (Lal, 2001; Ruiz-Colmenero et al., 2013). Vegetation will intercept rainfall, protecting the soil surface from direct impact of rain drops, and decrease runoff, promoting water infiltration and improving the stability and cohesion of soil aggregates (Zuazo and Pleguezuelo, 2008).

Alternative solutions have been proposed to minimize erosion rates in the cultivation of a single crop, such as corn (*Zea mays* L.). One effective conservation practice is intercropping, which involves cover plants and crop systems, by including two or more crops with different architectures and vegetative cycles growing simultaneously. Intercropping is a very common practice in tropical areas, and some of the benefits from this practice include improvement in soil and water quality, increased nutrient fixation and cycling efficiency, and better protection against the impact of raindrops and consequent soil erosion by water (Troeh et al., 1980; Connolly et al., 2001; Snapp et al., 2005; Gómez et al., 2009; Maetens et al., 2012; Chieza et al., 2013; Rieger et al., 2016).

Combining corn with cover crops has been an intercropping combination effective in improving soil physical properties, controlling water erosion, and reducing organic carbon, nutrient, soil, and water losses (Debarba and Amado, 1997; Spagnollo et al., 2001; Albuquerque et al., 2005; Gilles et al., 2009; Silveira and Stone, 2010; Chen and Weil, 2011; Gabriel and Quemada, 2011; Freitas et al., 2012; Pereira et al., 2016). The benefits of using cover plants were also demonstrated by Gómez et al. (2011), who concluded that they significantly reduced water erosion in comparison to traditional tillage practices in Southern France, Spain, and Portugal. Cover plants with corn intercropping was recommended by Ngome et al. (2011), who stated that *Mucuna* and *Arachis* increased corn yields in Kenya.

Research investigations on soil and water losses by erosion often use standard sized plots, as proposed by Wischmeier and Smith (1978). These plots have been employed to measure erosion from different tillage systems through the world. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) (Equation 1) integrates the following parameters:

$$A = R \times K \times LS \times C \times P \qquad \text{Eq. 1}$$

in which A refers to soil losses (Mg ha^{-1} $year^{-1}$), R is rainfall erosivity (MJ mm ha^{-1} h^{-1}), K is soil erodibility (Mg h MJ^{-1} mm^{-1}), LS is the slope length factor (dimensionless), C is the soil cover factor (dimensionless), and P is the conservation practice factor (dimensionless) (Wischmeier and Smith, 1978).

The Universal Soil Loss Equation parameters for different conditions of soil tillage and types have been the object of review in the literature, such as Cogo et al. (2003), Mello et al. (2003), Castro et al. (2011), Cardoso et al. (2012), Schick et al. (2014a,b), and Silva et al. (2016). The USLE equation has become an important planning tool in the United States, but it needs to be calibrated for local conditions, for example in Brazil and in South America.

In this sense, high erosion rates are observed in the region of Lavras, MG, Brazil; according to Gomide et al. (2011), large areas are susceptible to advanced soil degradation by water erosion, specifically gully areas. Thus, in order to develop sustainable soil use and management, it is important to conduct research that considers different plants and management systems for the purpose of measuring soil and water losses.

The hypothesis is that intercropping of corn and jack bean increases soil cover and reduce soil erosion by water in comparison to single crop cultivation. The objective was to analyze the effect of different crop systems on soil cover and on water erosion.

MATERIALS AND METHODS

The experiment was performed at the Federal University of Lavras (UFLA), in Lavras, Minas Gerais, Brazil (21° 13’ 20’’ S and 44° 58’ 17’’ W), at 925 m altitude. Four crop seasons (November to March) were analyzed in the period from 2011 to 2014. The climate, according to the Köppen classification system, is Cwa, with a dry winter and temperate summer (Alvares et al., 2013), average annual rainfall of approximately 1,530 mm, and mean annual temperature of 19.4 °C (Dantas et al., 2007).

The soil was classified as a Typic Hapludox (Soil Survey Staff, 2014), which corresponds to a *Latossolo Vermelho-Amarelo distrófico* (Santos et al., 2013), on a 0.12 m m^{-1} slope gradient. The main soil properties (Claessen, 1997) are shown in table 1.

Rainfall erosivity (EI_{30}) was calculated from continuous monitoring of rainfall events during the rainy season, from November to March, at the weather station of Lavras, approximately 1 km from the research site. Rain events over 10 mm rains were recorded with tolerance of 0.2 mm. Total kinetic energy was determined for each rain event according to the equation 2, proposed by Wischmeier and Smith (1958), adapted for international units by Foster et al. (1981) as follows:

$$E = 0.119 + 0.0873 \log I \qquad \text{Eq. 2}$$

in which E is the kinetic energy (MJ ha^{-1} mm^{-1}) and I is the rain intensity (mm h^{-1}).

Table 1. General characterization of the soil from experimental area at a 0.00-0.20 m depth

Property	Values
pH(H_2O)	5.5
P (mg dm^{-3})	2.6
K (mg dm^{-3})	97
Ca^{2+} ($cmol_c$ dm^{-3})	2.0
Mg^{2+} ($cmol_c$ dm^{-3})	0.4
Al^{3+} ($cmol_c$ dm^{-3})	0.2
t ($cmol_c$ dm^{-3})	2.8
T ($cmol_c$ dm^{-3})	5.5
SOM (g kg^{-1})	20.0
Sand (g kg^{-1})	460
Silt (g kg^{-1})	80
Clay (g kg^{-1})	460

t: effective cation exchange capacity (SB+Al^{3+}); T: cation exchange capacity at pH 7.0. P and K: extracted by Mehlich-1. Ca^{2+}, Mg^{2+} and Al^{3+}: extracted by 1.0 mol L^{-1} KCl. SOM (soil organic matter): oxidation with $K_2Cr_2O_7$. Sand, silt and clay determined by Pipette method. pH in water at a ratio of 2:5:1 v/v.

This study considered individual rains, defined as those separated by at least 6 h with rainfall of less than 1 mm in the 6 h interval. Events with less than 10 mm of rain, with intensity less than 24 mm h^{-1} in 15 min, or kinetic energy less than 3.6 MJ, were considered non-erosive (De Maria, 1994). The kinetic energy value multiplied by rainfall resulted in the kinetic energy expressed as MJ ha^{-1}. Values obtained were accumulated to obtain the total kinetic energy for a given rain event.

The EI_{30} index was obtained by multiplying the total kinetic energy by the maximum intensity in a 30 min period (I_{30}), accordingly to the method proposed by Wischmeier and Smith (1958). By summing the values for each rain event during the month, the total erosivity for each month was obtained.

Four experimental plots (4 x 12 m, on a 0.12 m m^{-1} slope) were set up to evaluate soil and water losses in the first and second crop season. Data from soil erosion plots have great coefficient of variation, due to natural factors and/or imprecise measurements (Nearing et al., 1999), however, the replication required in such field experiment is likely to be far greater than scientists can monitor in practical terms (Wendt et al., 1986; Deasy et al., 2014). Although the present study does not have the number of field replications required, data obtained is vital since it contributes to a large database from the authors of the present study.

All plots were delimited by galvanized zinc sheet metal inserted 0.20 m into the soil and leaving 0.20 m above the soil surface. At the bottom of each plot, a runoff collection system was set up to receive eroded soil and water in two 250 L tanks connected to each other by a GEIB divisor with nine entry slots (Geib, 1933). Once the first reservoir was filled, one ninth of the runoff was carried to the second reservoir, as described by Aquino et al. (2012).

Soil and water losses were quantified after each erosive rain according to the method described by Cogo et al. (2003). After each erosive event, solid suspension samples were shaken, being collected three aliquots of the coarser sediment and the runoff water with fine sediments in proportion to their amounts in the tanks. These aliquots were taken to the laboratory for decanting. The settled material was oven dried at 105 °C for 24 h, and dry weight was determined to quantify soil erosion.

In order to evaluate the adequacy of cultivation systems, soil loss tolerance limit values were estimated. The soil profile methodology used considered rooting depth, soil permeability, organic matter content, and the textural ratio between the B and A horizons (Bertol and Almeida, 2000).

The treatments involved four systems (involving three plant systems): corn (*Zea mays* L.) hybrid cultivar AS1598PRO (CO); jack bean [*Canavalia ensiformis* (L.) DC] (JB); intercropping corn and jack bean (IC); and bare soil (BS) as a control plot. Hybrid corn was chosen since it is frequently used in the region for grain production. A cover plant (jack bean) was used due its N_2 fixing capacity, high vegetable matter production, ability to improve soil physical properties, and substantial soil cover (Castro et al., 2011; Maetens et al., 2012; Chieza et al., 2013).

The seeds were sown manually in November of each crop season with 0.70 m between rows when testing a single crop, and 0.35 m between rows in intercropping with alternating crops. Plants were spaced at 0.20 m. Rows were established perpendicular to the slope. Plots were weeded manually before planting, and all residues from previous crops were removed. The bare soil control plot was kept free of vegetation through periodic hoeing. The plots were not plowed or tilled. Fertilizers were applied at a rate of 300 kg ha^{-1} of NPK 10:20:30, as well as topdressed fertilization of 100 kg ha^{-1} NPK 20:05:20 according to soil analyses (Ribeiro et al., 1999). At 130 days after seedling, all plants were mowed and crop residues were left on the soil surface.

The history of use of the area is shown in table 2, which includes different cover plants.

The Soil Cover Index (SCI) was established according to the methodology developed by Stocking (1994), which makes use of an apparatus with 19 circular orifices of 9 mm diameter each, spaced at 0.10 m apart along a two-meter rod placed 1.20 m above the soil surface. Random readings through the crop rows were taken, with three replications for each plot. A zero value was attributed to bare soil, 0.5 for any crop coverage detected inside the circle, and 1.0 when the circle was fully covered by crop leaves. The soil cover index was calculated according to equation 3:

$$SCI\ (\%) = \frac{number\ of\ plant\ cover\ readings}{total\ number\ of\ readings} \times 100 \qquad \text{Eq. 3}$$

Soil cover index measurements started at 10 days after sowing and were made continuously with 15-day intervals between readings, resulting in a soil cover percentage index (De Maria and Lombardi Neto, 1997). The SCI values were fitted by quadratic polynomial equations for each crop system.

Statistical modelling was used to compare the interaction of the factors studied (different systems, rainfall erosivity, and soil cover index) and to better understand the factors influencing soil losses. The Linear Mixed Model (LMM), which appears in Haskard et al. (2010), Suuster et al. (2012), and Doetterl et al. (2013), has been successfully used in different soil science studies and was adopted here. Models were generated using a methodology similar to that described in Gelman and Hill (2007) and Zuur et al. (2007). The LMM, with "season" as a random term to account for clustering, was analyzed using the *lmer* function in the *lme4* package (Bates et al., 2014) of R version 3.1.2 (R Core Team, 2014). Thus, the influence of groups of variables on the likelihood of each model was compared. Variables that best improved model likelihood were selected, according to the lowest Akaike's Information Criterion value.

RESULTS AND DISCUSSION

Rainfall erosivity

Monthly rainfall during the study period ranged from 52 to 507 mm, with the highest amount in January 2013 and the lowest in February 2013. Total values were 1,317; 1,063; and 621 mm for the 2011/12, 2012/13, and 2013/14 crop seasons, respectively. The total erosivity of each period per event resulted in the sums shown in table 3, ranging from 220 to 3,280 MJ mm ha^{-1} h^{-1} $month^{-1}$ during the first crop season, from 359 to 3,245 MJ mm ha^{-1} h^{-1} $month^{-1}$ during the second crop season, and from 124 to 1,672 MJ mm ha^{-1} h^{-1} $month^{-1}$ during the third crop season. This corresponds to energy of 8,384, 5,962, and 4,050 MJ mm ha^{-1} h^{-1} per crop season during the 2011/12, 2012/13, and 2013/14 crop seasons, respectively (Table 3).

Table 2. Historical use of the area

Period	History	Reference
Before 2007	Area was cultivated with *Brachiaria decumbens*.	Freitas et al. (2012)
2007 to 2008	Soil cover crop research: sun hemp (*Crotalaria juncea* L.), jack bean (*Canavalia ensiformis* DC.), and millet (*Pennisetum sp* Rich.).	Cardoso et al. (2012)
2008 to 2009	Soil cover crop research: pigeon pea legumes [*Cajanus cajan* (L.) Huth], sun hemp (*Crotalaria juncea* L.), jack bean (*Canavalia ensiformis* DC.), and millet (*Pennisetum sp* Rich.).	Castro et al. (2011)
2010 to 2011	Soil cover crop research: pigeon pea legumes [*Cajanus cajan* (L.) Huth], jack bean (*Canavalia ensiformis* DC.), and millet (Pennisetum sp Rich.), cultivated under different planting systems.	Dias et al. (2013)

Table 3. Total monthly precipitation, non-erosive and erosive rains, and rain erosivity values during three crop seasons from November to March of 2011 to 2012, 2012 to 2013, and 2013 to 2014 in Lavras, MG, Brazil

Month/year	Rainfall			Erosivity(1)
	Total	Non-erosive	Erosive	
	mm			MJ mm ha^{-1} h^{-1} $month^{-1}$
		2011-2012		
Nov-11	173	14	159	1,168
Dec-11	498	11	501	3,280
Jan-12	431	9	408	3,147
Feb-12	80	5	75	220
Mar-12	134	24	110	571
Total	1,317	64	1,253	8,385
		2012-2013		
Nov-12	153	17	136	1,034
Dec-12	156	6	150	693
Jan-13	507	15	492	3,245
Feb-13	75	9	66	359
Mar-13	172	16	156	631
Total	1,063	64	999	5,962
		2013-2014		
Nov-13	177	68	109	927
Dec-13	209	24	185	1,672
Jan-14	52	12	39	131
Feb-14	64	4	60	124
Mar-14	120	29	91	1,196
Total	621	137	484	4,050

(1) EI_{30} index was obtained by multiplying the total kinetic energy by the maximum intensity in a 30 min period (I_{30}), accordingly to the method proposed by Wischmeier and Smith (1958).

Erosivity values observed in the first crop season were slightly higher than the 5,145 to 7,776 MJ mm ha^{-1} h^{-1} yr^{-1} for the southern region of Minas Gerais that was reported by Aquino et al. (2012) in a 15- to 40-year historical series analysis. The present study exhibited higher values in the first crop season, and lower values in the second and third crop season than the values presented by Val et al. (1986), who were the first to present erosivity values for the Lavras region (6,837 MJ mm ha^{-1} h^{-1} yr^{-1}), using a 22-year database.

Soil and water losses

Soil losses from water erosion for all crop systems are listed in table 4. Soil loss values showed a variation of 1.12 to 14.10 Mg ha^{-1} per crop season. The lowest monthly soil losses (null soil loss) were measured in January and February 2014 in the corn, jack bean, and intercrop plots, whereas the highest monthly soil losses (10.88 Mg ha^{-1} $month^{-1}$) were measured in December 2013 in the bare soil plot. In the average of the three crop cycles, the highest soil loss values were found for bare soil, followed by corn, jack bean, and corn intercropped with jack bean (9.93, 3.30, 2.86, and 2.31 Mg ha^{-1} per crop season). In field observations, bare soil plots had surface crusting, which seals the soil surface and thus increases runoff and soil erosion. In contrast, soil crusting did not occur in the crop plots.

During the first crop season, from November 2011 to March 2012, the months of December and January had the highest soil loss values, due to high rainfall erosivity in that period (Table 3). In November, some high soil loss values were measured in all treatments. Such results were probably related to a lack of soil cover, as this month corresponds to the initial phase of crop growth, from seeding to post-planting. Tillage prior to seeding can contribute to higher soil losses due to readily available sediments. In the short term, it is clear that the presence of crop plants decreased soil loss, as bare soil plots produced two to four times more soil loss than the crop systems. The soil cover by aboveground plant parts decrease erosion effects mainly by intercepting rainfall and protecting the soil surface against direct impact of raindrops. In contrast, the lack of soil cover (bare soil) drastically increases the detachment and transport of soil particles.

For the second and third crop seasons (November 2012 to March 2013, and November 2013 to March 2014) the response of treatments to natural rainfall was similar to that of the first season. In the second season, the effect of high rainfall erosivity in January was clear, leading to higher values of soil losses. After crop establishment and development (February and March), soil losses tended to decline as a result of canopy growth (Table 4).

In the third crop season, December and March had high soil losses as a natural consequence of the elevated rain erosivity in those months. In March, all crops were already established, leading to dissipation of the kinetic energy of raindrops, in which case only the bare soil plot had high erosion rates.

The soil losses presented here are similar to others found in the Brazilian scientific literature. Soil losses for jack bean in the present study are higher than values presented by Cardoso et al. (2012), who reported soil loss values of 1.59 Mg ha^{-1} for a monocropped jack bean plot with a 0.5 m row spacing in the same study area. Dias et al. (2013) found soil loss values of 0.72 Mg ha^{-1} and 2.81 Mg ha^{-1} for jack bean under different crop systems in a Hapludox (*Latossolo Vermelho-Amarelo distrófico*), which were similar to the soil loss rates found in this study. Debarba and Amado (1997) found a 99 % decrease in soil and water loss comparing corn intercropped with jack bean to bare soil in a Hapludult (*Argissolo Vermelho-Amarelo distrófico*), revealing a major contribution in growing such cover plants. Regarding the bare soil control plot, similar results were also found by Dias et al. (2013), who found a 7.67 Mg ha^{-1} soil loss in a Hapludox *(Latossolo Vermelho-Amarelo distrófico).*

Table 4. Soil losses by water erosion in three crop systems, for each month and for the total period, from November to March of 2011 to 2012, 2012 to 2013, and from 2013 to 2014, in Lavras, MG, Brazil

Crop systems	Soil losses[1]					
	November	December	January	February	March	Total
	Mg ha^{-1} per period					
	2011-2012					
BS	0.57	1.60	4.06	1.09	0.94	8.27
CO	0.79	1.22	1.29	0.25	0.19	3.74
JB	0.69	0.54	1.29	0.10	0.03	2.65
IC	0.40	0.69	1.24	0.06	0.06	2.44
	2012-2013					
BS	0.49	0.78	4.84	0.33	0.97	7.42
CO	0.15	0.28	2.90	0.09	0.09	3.51
JB	0.38	0.38	1.58	0.04	0.17	2.54
IC	0.62	0.23	0.85	0.04	0.28	2.03
	2013-2014					
BS	0.41	10.88	0.05	0.11	2.65	14.10
CO	0.09	2.56	0.00	0.00	0.00	2.65
JB	0.04	3.28	0.00	0.00	0.08	3.40
IC	0.06	2.38	0.00	0.00	0.00	2.45

[1] Soil losses were quantified after each erosive rain according to the method described by Cogo et al. (2003). BS: bare soil; CO: corn only; JB: jack bean only; IC: corn intercropped with jack bean.

In order to evaluate the adequacy of crop systems, the soil loss tolerance limit value was estimated, which was 10.90 Mg ha^{-1} yr^{-1}, according to the method suggested by Bertol and Almeida (2000). The tolerance values found corroborate values presented in the literature, from 9 to 11 Mg ha^{-1} yr^{-1} for Hapludox (Oliveira et al., 2011; Cândido et al., 2014). As the present study was conducted in the rainy season (crop season from November to March each year), which corresponds to approximately 75 % of total annual rainfall (Mello et al., 2007), it is possible that soil loss values of bare soil plots (7.42, 8.27, and 14.10 Mg ha^{-1} per period) exceed such soil loss tolerance limits when the whole year is considered. In contrast, it is safe to assume that the crop systems researched here are adequate, since soil loss values are lower than tolerance limits (ranging from 22 to 34 %).

Water losses (surface runoff) for all crop systems are presented in table 5. Surface runoff was similar to soil losses for each crop season. Water loss values ranged from 42 to 213 mm ha^{-1} per period, with the highest monthly water loss (133 mm ha^{-1} $month^{-1}$) measured in January 2013 for the bare soil plot and the lowest (null soil loss) in January 2014 for corn, jack bean, and intercropping plots, and in February 2014 for corn, jack bean, and intercropping plots. These results follow a trend similar to soil loss measurements (Table 4). In bare soil plots, soil crusting may have contributed to higher water losses.

In the first crop season (November 2011 to March 2012), December and January resulted in the highest water loss values, due to high rainfall erosivity registered for those months (Table 3). In fact, the maximum surface runoff percentage in the first season was for the bare soil plot in January 2012, in which water loss collected from the plot corresponded to 22 % of rainfall for the total month (Tables 3 and 5).

Table 5. Water losses by water runoff in different crop systems and natural rainfall in three crop systems, for each month and for the total period, from November to March of 2011 to 2012, 2012 to 2013, and 2013 to 2014, in Lavras, MG, Brazil

Crop systems/ natural rainfall	Water losses by water runoff[(1)]					
	November	December	January	February	March	Total
	mm ha^{-1} $period^{-1}$					
			2011-2012			
BS	18.58	58.46	92.71	3.64	1.90	175.30
CO	16.62	42.54	49.53	6.03	2.96	117.68
JB	1.59	29.60	38.52	13.97	5.08	88.76
IC	2.94	45.20	43.58	7.54	5.48	104.74
Rainfall	173	498	431	80	134	1,317
			2012-2013			
BS	15.66	21.27	132.80	8.20	34.66	212.59
CO	11.08	15.62	86.23	5.86	4.19	122.98
JB	6.37	8.74	80.79	1.83	2.12	99.85
IC	13.12	15.24	61.19	3.35	4.37	97.28
Rainfall	153	156	507	75	172	1,063
			2013-2014			
BS	12.94	84.21	1.04	2.90	40.72	141.82
CO	1.83	63.94	0.00	0.00	0.11	65.88
JB	1.50	64.51	0.00	0.00	1.55	67.56
IC	1.10	40.51	0.00	0.00	0.11	41.72
Rainfall	177	209	52	64	120	621

(1) Water losses were quantified after each erosive rain according to the method described by Cogo et al. (2003). BS: bare soil; CO: corn only; JB: jack bean only; IC: corn intercropped with jack bean.

During the second crop season, high water loss values in November and December were probably due to a lack of soil cover, as this month corresponds to the initial phase of crop cultivation. The highest water loss values were for the bare soil plot in January 2013, mainly due to high rainfall erosivity in that month. Water loss corresponded to 26 % of total rainfall measured in January 2013.

In the third season, December 2013 had the highest percentage of water loss in the period. Surface runoff was equivalent to almost 40 % of total rainfall for bare soil plots. Only the bare soil plot had water loss measured in January and February 2014. In those months, lower rainfall, associated with already established crops that resulted in elevated soil cover, was not enough to cause surface runoff.

Unlike soil losses, water losses were directly related to erosivity and less influenced by soil cover and management. In December and January, even though crops were already established, greater rainfall led to high water losses in the crop plots, most likely a consequence of antecedent soil moisture (Bracken et al., 2008; Medeiros et al., 2014; Santos et al., 2017). Hence, support practices, such as terracing, should be encouraged to reduce surface runoff.

High vegetation density also has a direct effect on water and sediment fluxes by increasing soil-aggregate stability and improving water infiltration, especially in the long term (Zuazo and Pleguezuelo, 2008). In the present study, the intercropping system decreased water loss by 40 to 71 % compared to bare soil, or by 11 to 37 % compared to corn monocropping.

Soil cover index

The Soil Cover Index (SCI) for the different systems for all the crop seasons is illustrated in figure 1. The values plotted were fitted by a quadratic polynomial model that related SCI values to days after seeding (DAS). All model treatments had a coefficient of determination higher than 0.90, indicating adequate data fit.

From 35 to 60 days after sowing (crop establishment), SCI values gradually increased, until establishing almost similar values (ranging from 60 to 80 %) and, consequently, higher soil cover protection against the direct impact of natural rainfall. Such high SCI values directly decreased soil and water losses (Tables 4 and 5). Therefore, support practices, such as terracing, are essential for protecting soil against erosion processes, especially during initial plant growth when soil cover density is very low.

Intercropping tends to provide better soil cover than single crops, with a maximum SCI (94 %) obtained in the second cycle. On average, the SCI was 39 % higher in intercropping than in corn monocropping (Table 6). As stated by Troeh et al. (1980), soil conservation is an important bonus from multiple cropping, especially after initial plant growth.

Comparing the soil and water losses in tables 4 and 5 to the average SCI (Table 6), it is clear that the greater the average SCI, the lower the erosion losses. This relationship is mainly due to protection of the soil surface from the impact of raindrops, which decreases soil and water losses.

The results obtained here are comparable to those reported by Souza et al. (2010) from investigation of different varieties of corn. They found maximum SCI values of 80 %, whereas 68 % was the maximum obtained in this study (Figure 1). The SCI values corroborate with Castro et al. (2011), who studied several cover crops, including jack bean. Freitas et al. (2012) and Dias et al. (2013) found that cultivation of jack bean reduced soil, water, nutrient, and soil organic matter losses, and strongly recommending it as a soil cover crop for the Lavras region.

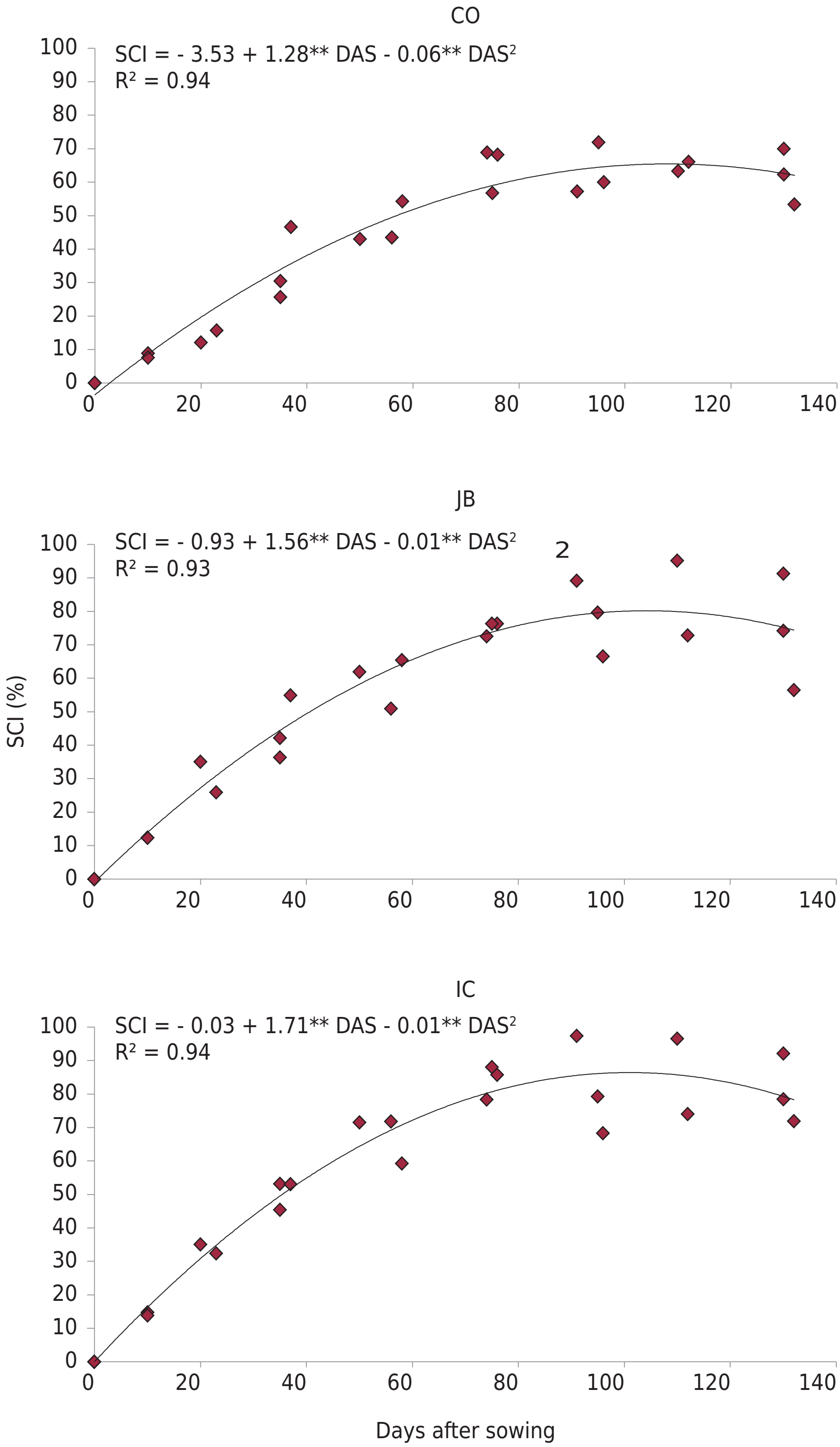

Figure 1. Soil cover index (SCI) of different crop systems in three crop seasons in a Typic Hapludox. CO: corn only; JB: jack bean only; IC: corn intercropped with jack bean.

Linear mixed model analysis

In order to evaluate the interaction between crop systems and water erosion, a set of linear mixed models (LMM) associating rain erosivity (R), soil cover index (SCI), and cultivation systems (CS) are presented in table 7. Model 5 exhibited the lowest Akaike's Information Criterion (AIC) value (188), and therefore it can be considered the best fitted model. This model correlated the interaction of R and SCI to better estimate soil loss, highlighting the importance of greater soil cover protection, as promoted by intercropping systems, in reducing high rainfall erosivity effects on soil erosion.

Plant physiologies and soil water infiltration capacities differed among the treatments evaluated (Debarba and Amado, 1997), but soil cover proved to have a more preponderant role regarding soil loss response. Values from Model 5 were plotted in figure 2.

The fitted LMM shows a strong correlation between soil losses and the interaction of R and SCI. Hence, these parameters might be useful in predicting erosion rates under uniform topographic conditions. However, this effect decreases considerably when one of the parameters, R or SCI, is analyzed separately, resulting in less influence on soil

Table 6. Average soil cover index for the three crop seasons from November to March of 2011 to 2012, 2012 to 2013, and 2013 to 2014 in Lavras, MG, Brazil

Crop Season	Average soil cover index (%)		
	CO	JB	IC
		%	
2011/12	36	43	50
2012/13	37	56	61
2013/14	43	48	50

CO: corn only; JB: jack bean only; IC: corn intercropped with jack bean.

Table 7. Linear mixed models, associating different parameters to predict soil loss from a Typic Hapludox in Lavras, MG, Brazil

Model		DF	AIC
M1	R*LU + R*SCI + LU*SCI	14	274.81
M2	R*LU + R*SCI	12	250.58
M3	LU + R*SCI	9	201.72
M4	R + LU + SCI	8	222.31
M5	R*SCI	6	187.81
M6	R + SCI	5	209.51

R: rainfall erosivity; LU: land use; SCI: soil cover; DF: degrees of freedom; AIC: Akaike's Information Criterion.

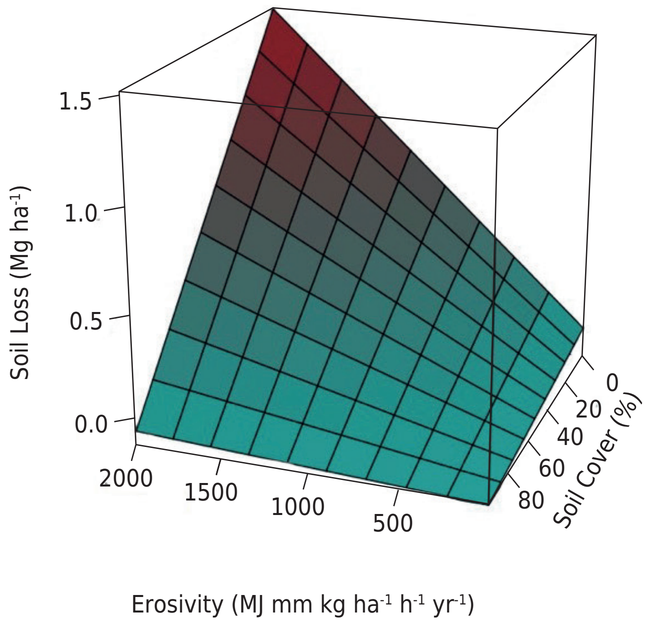

Figure 2. Interaction between erosivity and the soil cover index variable using linear mixed models to predict soil loss in a Typic Hapludox in Lavras, MG, Brazil (p<0.001).

losses. For example, higher erosivity values associated with a high SCI value (around 80 %) would generate lower soil loss values than a situation in which SCI is around 10 %. Sastre et al. (2017) presented a statistical linear modelling analysis relating soil losses to soil cover and rainfall kinetic energy; in this analysis, when more soil is covered, less soil is lost.

CONCLUSIONS

Intercropping reduces erosion rates in relation to monocropping, although all studied crop systems exhibit lower soil losses than the calculated tolerance limits. Water losses were directly related to erosivity, and plant cover and cultivation systems affected water loss less than soil loss.

Intercropping corn and jack bean provides better soil cover than monocropping. According to the selected linear mixed model, the soil loss was better predicted by the rainfall erosivity and soil cover, indicating the lower effect of the land use over soil erosion.

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