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Effects of Soil Management Practices on Water Erosion under Natural Rainfall Conditions on a Humic Dystrudept

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ABSTRACT: Water erosion is the main cause of soil degradation and is influenced by rainfall, soil, topography, land use, soil cover and management, and conservation practices. The objective of this study was to quantify water erosion in a Humic Dystrudept in two experiments. In experiment I, treatments consisted of different rates of fertilizer applied to the soil surface under no-tillage conditions. In experiment II, treatments consisted of a no-tillage in natural rangeland, burned natural rangeland and natural rangeland. Forage turnip, black beans, common vetch, and corn were used in rotation in the treatments with crops in the no-tillage during study period. The treatments with crops and the burned rangeland and natural rangeland were compared to a bare soil control, without cultivation and without fertilization. Increasing fertilization rates increased organic carbon content, soil resistance to disintegration, and the macropore volume of the soil, due to the increase in the dry mass of the crops, resulting in an important reduction in water erosion. The exponential model of the $\hat{y} = ae^{-bx}$ type satisfactorily described the reduction in water and soil losses in accordance with the increase in fertilization rate and also described the decrease in soil losses in accordance with the increase in dry mass of the crops. Water erosion occurred in the following increasing intensity: in natural rangeland, in cultivated natural rangeland, and in burned natural rangeland. Water erosion had less effect on water losses than on soil losses, regardless of the soil management practices.

Keywords: water and soil losses, natural rangeland, burned natural rangeland, no-tillage.

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INTRODUCTION

Water erosion is one of the main consequences of inadequate soil management (Bagatini et al., 2011), and it can reduce soil productive capacity and make an agricultural property no longer economically viable (Mota et al., 2008). Reducing or eliminating soil cover, either mechanically or by burning, results in the increase in soil degradation and fragility due to erosion (Bertol et al., 2011; Cebecauer and Hofierka, 2008). Replacing native vegetation with agricultural crops usually triggers and worsens water erosion (Zachar, 1982). However, different soil management practice, for example, different amounts of fertilizer, alters soil ability to produce plant biomass and, thus, alters soil resistance to erosion.

Soil management consists of the set of operations to make soil fit to fulfill a given function, as, for example, production of an agricultural crop.Conventional management (plowing + disking) begins with a mechanical tillage operation, and no-tillage management (without previous tillage) begins with the sowing operation, followed by fertilization, crop treatment, treatment of crop residues, and conservationist practices, among others. Soil tillage reduces plant cover and disaggregates surface soil in conventional tillage, decreases water infiltration, and increases water erosion (Castro et al., 2006). No-tillage allows soil cover to remain more compact, promotes better water infiltration and lessens erosion in comparison to conventional management (Cassol et al., 2002; Amaral et al., 2008).

In no-tillage, crop residues on the soil surface improve soil structure and control water erosion. The residue dissipates the kinetic energy of the rain and, in part, of the runoff and, therefore, maintains high water infiltration in the soil (Bagatini et al., 2011; Schick et al., 2016). The increase in soil resistance to disaggregation results from the increase in the stability of aggregates because of increased organic matter and consolidation of the soil (Cassol et al., 2002). Runoff has reduced capacity to transport materials, because an increase in tortuosity caused by the residues lowers runoff flow speed (Braida, 1994; Cassol et al., 2002). In this case, the residues retain the suspended disaggregated particles and they are deposited (Cogo et al., 1984; 2003).

Fertilizer application is one soil management operation. Higher fertilizer application rates increase biomass production in both shoots and roots of the plants, which increases protection of the soil at the surface and its resistance in the subsurface (Bezerra et al., 2006; Costa et al., 2008). The combined effect of biomass on the surface and on the roots reduces water erosion in relation to the condition in which fertilizers are not applied, or where the fertilizer application rate is lower (Bagatini et al., 2011). Soil properties are also improved by application of fertilizers because of an increase in root and shoot biomass of corn, which reduces soil and water losses from water erosion in relation to the absence of fertilization (Gilles et al., 2009).

Burningof natural rangelandvegetation reduces or eliminates the soil surface cover (Bertol et al., 2011) that could dissipate the impact energy of raindrops and the surface runoff. Burning also decreases the surface porosity and water infiltration in the soil (Baretta et al., 2005) and increases soil susceptibility to water erosion (Cassol et al., 2004; Bertol et al., 2011). In addition, burning mineralizes the nutrients and organic matter contained in the vegetation (Baretta et al., 2005), which allows runoff to transport more of these nutrients compared to the absence of burning (Bertol et al., 2011).

The hypothesis of this study is that increasing the fertilization rate under no-tillage conditions decreases water erosion, and that water erosion is lower in a totally natural rangeland than in a natural rangelandwith crops underno-tillage, and, in the latter, water erosion is lower than in a burned natural rangeland.

The objective of this study was to determine the effect of fertilizer application rates in a no-tillage cultivation system on soil water erosion and to determine the effect of several forms of natural rangeland management on soil water erosion.

MATERIALS AND METHODS

The study was conducted from April 2014 to May 2016 in two experiments, both with four crop cycles in the period studied, in an area in the Southern Plateau of Santa Catarina, Brazil (27° 49’ S and 50° 20’ W), at 923 masl. The experiment I was established in 2003 and experiment II in 2012. The climate is type Cfb according to Köppen system (Wrege et al., 2011), with average annual rainfall of 1,533 mm (Schick et al., 2014). The area has a mean slope of 0.102 m m^{-1} and the soil is a clayey Humic Dystrudept (*Cambissolo Húmico Alumínico*), described by Guadagnin (2003). Under natural conditions, the soil had the following properties in the 0.0-0.2 m soil depth: 110, 70, 420, and 400 g kg^{-1} of fine sand, coarse sand, silt, and clay, respectively; and 40 g kg^{-1} of organic C.

At the beginning of experiment I, the following soil management were carried out before the treatments were implemented: one plowing in November 2002, followed by three diskings and one plowing in February 2003. In March, two more diskings were performed, followed by chisel plowing, a plowing, and one pass witha leveling harrow in May. Under those conditions the treatments were set up.

In the five treatments that included crops, starting in 2003, limestone was applied (expressed in Mg ha^{-1}) for correction of soil pH, and P was applied in the form of triple superphosphate (TSP) (expressed in kg ha^{-1}) in the following amounts and modes of application: T1 - 12 of limestone and 12.9 of P, incorporated into the soil at the time of setting up the experiment (total application); T2 - 2.4 limestone and 2.58 P per year for five years (⅕ of the total amount per year) from the time of setting up the experiment, applied to the soil surface; T3 - 4 limestone and 4.3 P per year for three years (⅓ of the total amount per year) from the time of setting up the experiment, applied to the soil surface; T4 - 6 limestone and 6.45 P per year for two years (½ of the total amount per year) from the time of setting up the experiment, applied to the soil surface; T5 - 6 limestone and 6.45 P only in the first year at the time of setting up the experiment, applied to the soil surface; and T6 - the soil remained without limestone and P and without crops.

In the T1, T2, T3, and T4 treatments, soybean (*Glycine max*), corn (*Zea mays*), and black beans (*Phaseolus vulgaris*) were cultivated in spring-summer with fertilizer, since 2003. Phosphorus was applied in the form of TSP and K in the form of potassium chloride (KCl) for resupply of nutrients at the following rates of the elements, in kg ha^{-1} per crop: 55.6, 34.6, 27.0, and 19.4 of P and 94.2, 54.2, 47.2, and 40 of K, in T1, T2, T3, and T4, respectively, applied to the soil surface. In the T5 treatment, cultivation and fertilization occurred until 2009; the soil remained without fertilization and without cultivation from 2010 to 2013; and then fertilization and cultivation continued from 2014 to 2016. Black oat (*Avena strigosa*), common vetch (*Vicia sativa*) and forage turnips (*Raphanus sativus*) were cultivated without fertilizer in autumn-spring, since 2003.

At the beginning of experiment II, in 2012, a natural rangeland area without grazing and without any other type of management was used. The treatments consisted of the different forms of soil management. In T7, the natural rangeland was kept untouched (NR). In T8, the shoot plant matter of the rangeland was cut and burned once a year, always in the month of August (BR). In T9, the rangeland plant matter was cut in March 2012 and removed from the plot area. This was followed by application of 6.5 Mg ha^{-1} of dolomitic limestone, 333 kg ha^{-1} of TSP (150 kg ha^{-1} of P_2O_5), and 80 kg ha^{-1} of common vetch seed + 100 kg ha^{-1} of black oats. After that, the rangeland plant matter was returned to the soil surface to cover the inputs and then crops were planted. A no-tillage system was used for soil management and nutrients were resupplied through fertilization in types and quantities as in T1 of experiment I in the spring-summer (NT).

In the treatments T1, T2, T3, T4, T5, and T9, soil cultivation involved the following rotation: oats, soybean, vetch, corn, turnips, and beans. Soybean, corn, and bean crops received fertilization with P and K, whereas oat, vetch, and forage turnip were sown without fertilization; nevertheless, they received topdressing fertilization with urea as a source of N, according to the recommendations in CQFS-RS/SC (2004).

Soybean, corn, and bean crops were sown manually at a spacing of 0.45, 0.7, and 0.45 m between rows, respectively, and a spacing of 0.2 m in the row for the three crops. Cover crops were broadcast and manually sown on the soil surface.

In the T1, T2, T3, T4, T5 and T9 treatments, the first crop, forage turnip, was grown in the period from 04/29/2014 to 08/30/2014, at which time it was cut. The plant matterwas left on the soil as cover for the next crop. Then black bean was cultivated from 11/10/2014 to 03/06/2015 and, after harvest, the residue of the crop shoots remained on the soil. Vetch cultivation followed from 03/11/2015 to 10/15/2015, and it was manually mown at the end of the cycle. Corn was sown on the vetch residue and the cycle was from 10/16/2015 to 05/05/2016. In the T8 treatment, the mowing of plant matter and later burning occurred from 08/18/2014 to 08/23/2014 in the first year and from 08/12/15 to 08/20/2015 in the second year. In the T7, no management operation was conducted.

The experimental unit (plot) measured 22.1 × 3.5 m, delimited by galvanized sheets driven 0.1 m into the ground. At the lower end of the plot, a runoff collection system was composed of a gutter to receive the eroded material, which was piped to a first sedimentation tank 6 m below the plot. This first tank was connected to a second storage tank by means of a “Geib” divisor with nine slots.

Before the beginning and at the end of the study, undisturbed samples were collected from the soil at depths of 0.0-0.025, 0.025-0.05, 0.05-0.1, and 0.1-0.2 m using volumetric rings (Blake and Hartge, 1986) with 0.025 or 0.05 m height and 0.05 m diameter and, in the same layers, disturbed samples. Soil bulk density (BD) and macropore volume (Ma) were determined in the undisturbed samples, while the stability of aggregates in water and the levels of extractable P and of organic C were determined in the disturbed samples.

The collection of runoff samples and processing them for determination of sediments and water lost by erosion after the occurrence of each erosive rainfall followed the method proposed by Cogo (1978). The sediment samples contained in the runoff of the individual rains were collected in two replicates, oven dried at 40 °C and stored in a dry place for later chemical analysis.

The soil bulk density (BD) was determined by the relationship between mass and volume, with soil on a dry basis at 105 °C, and the volume of macropores was obtained by the difference between the total volume of pores and that of micropores, in accordance with Claessen (1997). In order to determine the stability of aggregates in water, the structural aggregates of the soil samples were shaken vertically in water, according to Yoder (1936), and the results were expressed as mean weighted diameter, according to Kemper and Chepil (1965).

The extractable P content in the soil and in the erosion sediments was obtained by the double acid extraction method (Mehlich-1) with an acid solution of 0.05 mol L^{-1} HCl and 0.0125 mol L^{-1} H_2SO_4, and was determined by reading absorbance in a UV-VIS spectrophotometer. In the runoff water, the determination of soluble P followed the method described in Tedesco et al. (1995). The organic C content, after wet combustion of the soil sample, was determined by colorimetry. For determination of the total losses of P and organic C in the sediments and in the erosion water, the content of each element found in the sediments and in the water was multiplied by the total amount of sediment and water lost by erosion.

At the end of each crop, a sample of the crop residues was collected in an area of 0.24 m^2 to determine the weight of residue, expressed in dry basis at 50 °C. The soil was covered with crop residues immediately after sowing each crop using the marked rope method described by Hartwig and Laflen (1978).

The rain volumes were recorded from reading a rain gauge. Rainfall recorded in daily pluviograph values was used to calculate erosivity (EI_{30}), following the recommendation of Wischmeier and Smith (1958) modified by Cabeda (1976).

The plots of experiment I were in a completely randomized design, without replication, due to the lack of available area; therefore, only the mean and the coefficient of variation of the data are presented. In experiment II, the treatments had two replicates in a randomized design and, therefore, analysis of variance for the data was performed and when the means differed from each other, they were subjected to the Duncan test ($p \leq 0.05$).

RESULTS AND DISCUSSION

The soil cover by crop residues (SC) was low only in the T5 treatment of experiment I (less than 50 %), whereas in the other treatments, it was higher than 85 %, regardless of the crop (Table 1). The SC decreased by 54 % because of a 64 % reduction in dry

Table 1. Soil cover (SC) and dry mass (DM) of the crops, resulting from the crops in the treatments of experiments I and II

Experiment I			**Experiment II**		
Treatment(1)	**SC**	**DM**	**Treatment(2)**	**SC**	**DM**
	$m^2 m^{-2}$	kg ha^{-1}		$m^2 m^{-2}$	kg ha^{-1}
			Forage turnip		
T1	99	5,820	NR	93 b	5,495
T2	96	5,550	BR	96 ab	-
T3	92	4,830	NT	100 a	-
T4	89	4,200			
T5	48	2,550			
Mean	85	4,590	Mean	96	-
CV (%)	22	25	CV (%)	1.5	-
			Black bean		
T1	99	5,790	NR	94 b	5,480
T2	97	5,520	BR	87 c	-
T3	95	4,900	NT	100 a	-
T4	87	3,740			
T5	46	2,860			
Mean	85	4,562	Mean	94	-
CV (%)	23	24	CV (%)	1	-
			Common vetch		
T1	99	5,600	NR	96 b	4,985
T2	98	5,330	BR	97 b	-
T3	97	4,150	NT	100 a	-
T4	85	3,640			
T5	42	2,410			
Mean	84	4,226	Mean	98	-
CV (%)	26	28	CV (%)	0.6	-
			Corn		
T1	100	17,813	NR	97 b	13,199
T2	98	11,413	BR	98 ab	-
T3	94	7,676	NT	100 a	-
T4	83	6,551			
T5	44	4,650			
Mean	84	9,621	Mean	98	-
CV (%)	25	54	CV (%)	0.9	-

(1) T1, T2, T3, and T4: annual cultivation and fertilization with P (TSP) and K (KCl), at the following rates of the elements (kg ha^{-1}) per crop: 55.6, 34.6, 27.0,and 19.4 of P and 94.2, 54.2, 47.2, and 40 of K in T1, T2, T3, and T4, T5: cultivation and fertilization until 2009, without cultivation and fertilization from 2010 to 2013, and once more with cultivation and fertilization from 2014 to 2016. (2) NR: no-tillage in natural rangeland; BR: burned natural rangeland; NT: natural rangeland. (-): no data. Mean values in experiment II followed by the same lowercase letter in the column do not differ by the Duncan test ($p \leq 0.05$).

matter (DM) in the crop shoots in relation to T1, for example, in the average ofcrops in experiment I, which can be explained by the decrease in the fertilizer application rates. Moreover, it is likely that the root DM decreased in the same proportion since it is linearly related to the shoot DM (Wolschick et al., 2016).

Dry matter production was similar in the NT and T2 treatments, whereas in T1, DM production was numerically higher than in the other treatments of experiment I (Table 1). These results of T1 may be due to the higher fertilization rate and the incorporation of pH correctives in the soil depth (up to 0.02 m) at the time the experiment was set up. DM production was 56, 51, 57, and 74 % lower in T5 than in T1 in the turnip, bean, vetch, and corn crops, respectively. In the T5 treatment, the soil was maintained without coverage and without fertilization from 2010 to 2013, which was reflected in a decline in soil fertility and, consequently, in a decline in the DM of the subsequent crops. The value of DM of turnip in T1 of experiment I was similar to the value observed by Wolschick et al. (2016) in the same soil, whereas for vetch, the value was lower. The DM was similar in the turnip, bean, and vetch crops and in the treatments, while the DM of corn was 3.1 times the average of other crops in the T1. In experiment II, the DM production of turnip, bean, and vetch crops were similar. These values were similar to those observed in treatments T1 and T2 of experiment I.

The mean weighted diameter of aggregates (MWD) in most treatments with fertilization in experiment I and in the treatments of experiment II (Table 2) had higher values than those obtained by Carpenedo and Mielniczuk (1990). High MWD values are common in clayey soils with high organic matter content and low physical degradation, such as the soil used in the present study. In the treatments with fertilization in experiment I, the MWD values

Table 2. Mean weighted diameter of aggregates (MWD) and organic carbon concentration (CO) in the soil at the beginning and at the end of the study, determined in the treatments (Treat) of experiments I and II in the 0.0-0.025 m layer and in the mean of the 0.0-0.025, 0.025-0.05, 0.05-0.10, and 0.10-0.20 m layers

Treatment	Experiment I				Treatment	Experiment II					
	MWD		CO			MWD			CO		
	0.0-0.025 m					0.0-0.025 m					
	Begining	End	Begining	End		Begining	End	CV	Begining	End	CV
	mm		$g\ kg^{-1}$			mm		%	$g\ kg^{-1}$		%
T1	5.6	5.7	31.8	34.5	NR	5.9 aA	5.6 aB	0.93	31.5 aA	32.6 abA	6.2
T2	5.5	5.6	30.6	33.4	BR	5.7 aA	5.6 aA	0.79	32.7 aA	30.2 bB	0.7
T3	5.4	5.4	29.7	32.0	NT	5.8 aA	5.6 aA	0.56	33.1 aA	33.9 aA	1.4
T4	5.3	5.4	24.9	26.8							
T5	2.9	4.3	19.4	22.2							
T6	2.3	2.2	13.3	11.7	-	-	-	-	-	-	-
Mean	4.5	4.8	25.0	26.8	Mean	5.8	5.6	-	32.4	32.2	-
CV (%)	30	26	27	30	CV (%)	1.1	1.2	-	4.2	3.4	-
Mean of the soil layers											
T1	5.6	5.7	24.6	26.2	NR	4.5 bA	4.5 aB	0.35	24.0 bA	25.4 aA	2.1
T2	5.5	5.6	23.6	25.0	BR	4.5 bA	4.5 aA	0.78	23.8 bA	23.8 aA	0.7
T3	5.4	5.5	23.1	24.0	NT	4.7 aA	4.5 aB	0.45	25.2 aA	25.0 aA	0.9
T4	5.4	5.5	18.9	20.0							
T5	2.2	4.7	16.0	17.1							
T6	1.8	1.8	12.6	10.0	-	-	-	-	-	-	-
Mean	4.3	4.8	19.8	20.7	Mean	4.7	4.5	-	24.3	24.7	-
CV (%)	38	29	22	22	CV (%)	0.6	0.5	-	1.5	4.2	-

(1) T1, T2, T3, and T4: annual cultivation and fertilization with P (TSP) and K (KCl), at the following rates of the elements (kg ha^{-1}) per crop: 55.6, 34.6, 27.0, and 19.4 of P and 94.2, 54.2, 47.2, and 40 of K in T1, T2, T3, and T4, T5: cultivation and fertilization until 2009, without cultivation and fertilization from 2010 to 2013, and once more with cultivation and fertilization from 2014 to 2016. (2) NR: no-tillage in natural rangeland; BR: burned natural rangeland; NT: natural rangeland. (-): no data. Mean values in experiment II followed by the same lowercase letter in the column and uppercase letter in the line do not differ by the Duncan test ($p \leq 0.05$).

increased along with higher fertilization rates. Higher fertilization rates led to an increase in plant biomass, which resulted in an increase inorganic C, with a positive effect on soil aggregation, especially in the surface layer. Thus, the model $y=y_0+ax^b$ satisfactorily fit the data and soil organic C explained the MWD at a level of 89 % (Figure 1). Organic C has a positive effect on the formation and stabilization of aggregates and on BD and porosity (Carpenedo and Mielniczuk, 1990; Barilli, 2005; Costa, 2009; Ensinas et al., 2014).

The effect of fertilization on MWD and soil organic C is confirmed by comparing treatments T1 and T5. For example, in the 0.0-0.025 m soil depth, the MWD was 57 % higher and the organic C 59 % higher in T1 than T5, in the average of times of collection, while at the depth of 0.0-0.2 m this difference was 64 and 53 %, respectively (Table 2). This difference in MWD and organic C between 2012 and 2014 can be considered a significant improvement in these attributes because the experiment had already been conducted under the same management practices since 2003, and this demonstrates the positive effect of fertilization on the structural quality of the soil. Comparison of evaluation times shows the trend of improvement in MWD and organic C over time because in the 0.0-0.025 m soil depth, both of these indicators were 7 % greater at the end of four crop cycles than at the beginning of the study, and in the depth of 0.0-0.2 m, MWD was 11 % higher and organic C 28 % higher, in the average of the treatments. Therefore, in the long term, these soil management systems promote an increase in the soil organic C supply, and may increase the levels of organic matter (Carpenedo and Mielniczuk, 1990; Ensinas et al., 2014).

In experiment I, in the 0.0-0.025 m soil depth, the MWD in the T1 treatment was 2.5 times greater than in the T6, and the organic C was 2.7 times greater (average of evaluation times), while in the 0.0-0.2 m soil depth this difference was 3.2 and 2.2 times, respectively (Table 2). In this case, it means that the cultivated soil with higher rates of fertilizer application increased plant biomass and organic C, and had better soil aggregation in comparison to soil without cultivation and without fertilization. Paul et al. (2013) observed that accumulation of organic C in the soil increases biomass production and plant cover, in the case of NT. In the T5 treatment, small numerical differences in the MWD and in the organic C at collection times can be explained by the small amount of crop residues produced as a result of low fertilization.

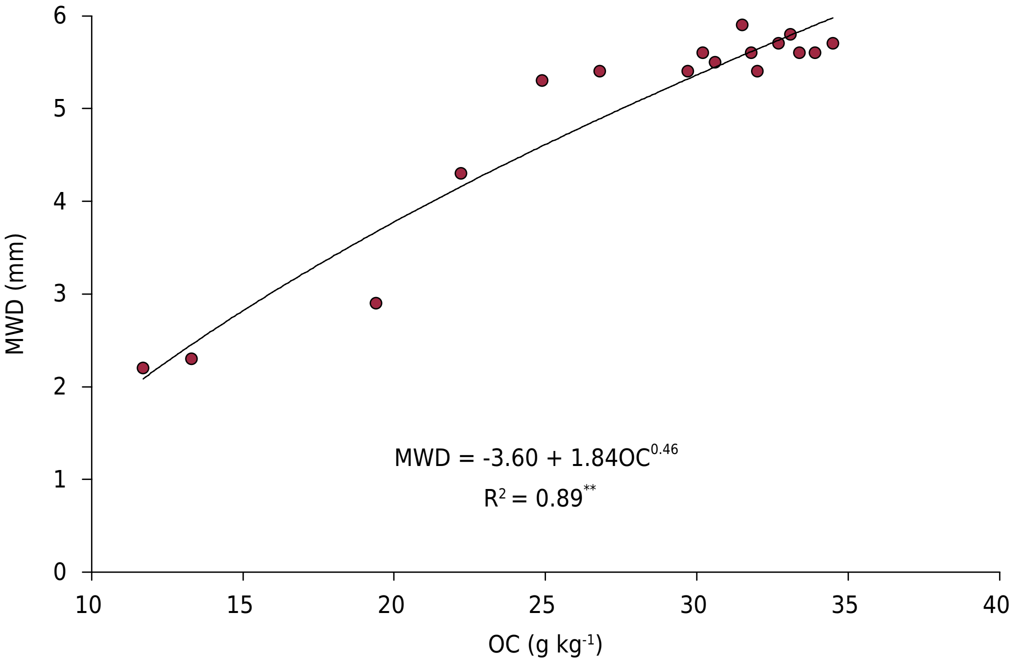

Figure 1. Relationship between the mean weighted diameter (MWD) of aggregates and soil organic C (OC) in the 0.0-0.025 m soil depth, at the beginning and at the end of experiment I and II. **: $p \leq 0.01$).

In experiment II, crop seasons had different values of MWD, and the NT in the 0.0-0.025 m depth and the NR in the average of the soil layers had lower values at the end of the study (Table 2). NR treatment presented higher MWD than the other treatments, at the beginning of the study, on the average of the depths. The organic C was higher in the NR than in the other treatments at the beginning of the study in the 0.0-0.025 m soil depth, and at the end of the study in the average of the soil layers. The small difference between periods, of these soil properties, is due to the fact that the experiment started recently (2012), therefore, without the necessary time for the forms of management to influence them. In long-term evaluations, differences in contents of organic C were observed in different forms of land use (Ensinas et al., 2014); under native vegetation, the organic C supply was higher than in an area under cultivation managed by NT.

Values of BD were different only in the evaluation periods of experiment II and, in general, showed little numerical variationin the treatments of experiment I, with some exceptions (Table 3). The variation in BD values, between evaluation periods, was in the order of 23 % in the 0.0-0.025 m soil depth and 24 % in the average of the layers in experiment I, whereas in experiment II, these variations were 54 and 48 %, respectively, in the average of the seasons. In the average of the layers, the BD values were within the range identified for this type of soil (average texture), between 1.30 and 1.40 kg m^{-3}. This physical property is not as sensitive to soil management practicesas others, such as the macropore volume (Ma) in a Humic Dystrudept (Luciano et al., 2010).

Virtually all the Ma values in the 0.0-0.025 m soil depth (Table 3) were above the critical limit of 10 % established by Thomasson (1978), which was based on the level that makes for critical resistance to root growth for most crops and adequate infiltration and drainage of water in the soil. In contrast, in the average of the soil layers in the treatments with

Table 3. Soil bulk density (BD) and macroporosity (Ma), at the beginning and end of the study, determined in the treatments (Treat) of experiments I and II, in the 0.0-0.025 m layer and in the mean of the 0.0-0.025, 0.025-0.05, 0.05-0.10, and 0.10-0.20 m layers

Treatment(1)	Experiment I				Treatment(2)	Experiment II					
	BD		Ma			BD			Ma		
	0.0-0.025 m					0.0-0.025 m					
	Begining	End	Begining	End		Begining	End	CV	Begining	End	CV
	g dm^{-3}		%			g dm^{-3}		%			
T1	1.23	1.13	13.4	16.7	NR	1.52 aA	1.03 aB	4.5	15.5 aA	18.5 abA	4.2
T2	1.26	1.24	10.2	16.3	BR	1.52 aA	1.20 aB	3.1	13.6 bB	16.8 bA	4.1
T3	1.30	1.26	12.7	15.5	NT	1.59 aA	1.04 aA	14.8	17.1 aB	20.6 aA	3.6
T4	1.31	1.27	12.8	14.2							
T5	1.38	1.31	6.2	11.9							
T6	1.40	1.35	12.6	10.2	-	-	-	-	-	-	-
Mean	1.31	1.26	11.32	14.13	Mean	1.54	1.09	-	15.4	18.6	-
CV (%)	5	6	24.	18	CV (%)	2.5	15.2	-	3.7	4.1	-
	Mean of the soil layers										
T1	1.26	1.20	9.45	17.68	NR	1.23 bA	0.95 aB	1.4	11.4 bB	15.4 aA	3.5
T2	1.29	1.25	8.25	15.98	BR	1.27 abA	0.92 aB	2.3	10.1 bA	12.5 bA	7.5
T3	1.38	1.33	9.60	15.00	NT	1.36 aA	0.98 aA	8.1	14.3 aA	16.6 aA	4.2
T4	1.41	1.37	9.23	14.00							
T5	1.43	1.39	7.30	13.55							
T6	1.49	1.47	10.55	9.08	-	-	-	-	-	-	-
Mean	1.38	1.33	9.06	14.21	Mean	1.28	0.93	-	11.9	14.8	-
CV (%)	7	7	13	21	CV (%)	2.5	7.8	-	4.02	6.0	-

(1) T1, T2, T3, and T4: annual cultivation and fertilization with P (TSP) and K (KCl), at the following rates of the elements (kg ha^{-1}) per crop: 55.6, 34.6, 27.0, and 19.4 of P and 94.2, 54.2, 47.2, and 40 of K in T1, T2, T3, and T4, T5: cultivation and fertilization until 2009, without cultivation and fertilization from 2010 to 2013, and once more with cultivation and fertilization from 2014 to 2016. (2) NR: no-tillage in natural rangeland; BR: burned natural rangeland; NT: natural rangeland. (-): no data.Mean values in experiment II followed by the same lowercase letter in the column and uppercase letter in the line do not differ by the Duncan test (p≤0.05).

cultivation in experiment I, the values were below this limit at the beginning, meaning problems for root growth and water infiltration and drainage. At the end of the study, however, the soil had Ma below the critical limit only in T6, and the average was 14.2 %. The Ma increased 21 % from the beginning to the end of the study in the average of the soil layers and in the treatments of the two experiments (Table 3). This increase in Ma was significant and represented an important improvement in this soil property, which was reflected in the BD.

Erosivity (EI_{30}) was 3,922 MJ mm ha^{-1} h^{-1} and rainfall was 1,300 mm, 9.6 and 19.6 % higher in the autumn/winter crops than in the spring/summer crops, respectively (Table 4). At the research site, a 23-year data series indicates that rainfall accumulation and EI_{30} are lower in the autumn-winter (Schick et al., 2014), thus contradicting the values found in this study. This result may be related to the time period in which this study was conducted, much shorter than that of the authors cited. The EI_{30} value is influenced by the rain intensity that varies over time, by its maximum intensity in 30 min, and by the total rainfall amount (Wischmeier and Smith, 1978), which explains the variation in EI_{30} between crops.

Soil losses (SL) increased from the T1 to the T6 treatment in the four crops of experiment I (Table 4) because of the decrease in crop residues (CR) and SC between T1 and T5 and the absence of these variables in T6 (Table 1). The reduction in the fertilizer application rate resulted in a decrease in CR and SC, in less dissipation of rainfall and runoff energy, and in the maximization of water erosion (Bertol et al., 2014). The amount of CR and the surface cover, which depend on soil management practices, influence the dynamics of surface runoff, and are fundamental in control of SL (Panachuki et al., 2011). The satisfactory fit of the exponential model $\hat{y}=ae^{-bx}$ ($R^2=0.97$) to the data means that SL are well explained (97 %) by the variation in the fertilizer application rate, regardless of the type of crop (Figure 2).

In the T1 treatment, SL were 20 % lower than those occurring in T5 (Table 4), in the average of the crops, due to the full fertilization applied to the soil in T1, which resulted in higher

Table 4. Erosivity (EI_{30}) and accumulation (Ac) of the rain, soil losses, and water losses during the crop seasons (Crop) of the treatments of experiments I and II

Crop	EI_{30}	Ac	Experiment I(1)						Experiment II(2)			
			T1	T2	T3	T4	T5	T6	NR	BR	NT	CV
	MJ mm ha^{-1} h^{-1}	mm										%
						Soil losses (Mg ha^{-1})						
Turnip	2,714	918	0.44	0.51	1.15	10.12	38.74	95.81	1.73 a	1.55 a	0.29 b	25.2
Bean	1,715	507	0.17	0.26	0.35	0.59	22.67	49.39	0.68 b	2.02 a	0.28 b	22.4
Vetch	1,387	499	0.41	0.51	0.63	0.78	10.98	80.26	0.26 b	0.49 a	0.13 c	8.4
Corn	2,026	677	0.11	0.21	0.34	0.62	19.31	50.94	0.21 ab	0.34 a	0.11 b	20.9
Mean	1,961	650	0.28	0.37	0.61	3.02	22.92	69.15	0.72	1.10	0.20	-
CV (%)	29	30	59	43	61	156	51	33	98	74	47	-
						Water losses (% of the rain)						
Turnip	2,714	918	11	18	32	48	60	71	14 a	15 a	12 a	8.9
Bean	1,715	507	3	3	4	9	37	62	10 b	22 a	8 b	13.7
Vetch	1,387	499	19	27	42	48	55	74	19 a	21 a	16 b	3.0
Corn	2,026	677	3	5	9	13	19	46	8 a	6 a	5 a	38.7
Mean	1,961	650	9	13	22	30	43	63	12.7	16	10.2	-
CV (%)	29	30	85	86	84	73	44	20	38	46	47	-

(1) T1, T2, T3, and T4: annual cultivation and fertilization with P (TSP) and K (KCl), at the following rates of the elements (kg ha^{-1}) per crop: 55.6, 34.6, 27.0, and 19.4 of P and 94.2, 54.2, 47.2, and 40 of K in T1, T2, T3, and T4, T5: cultivation and fertilization until 2009, without cultivation and fertilization from 2010 to 2013, and once more with cultivation and fertilization from 2014 to 2016. (2) NR: no-tillage in natural rangeland; BR: burned natural rangeland; NT: natural rangeland. (-): no data. Mean values in experiment II followed by the same lowercase letter in the line do not differ by the Duncan test ($p \leq 0.05$).

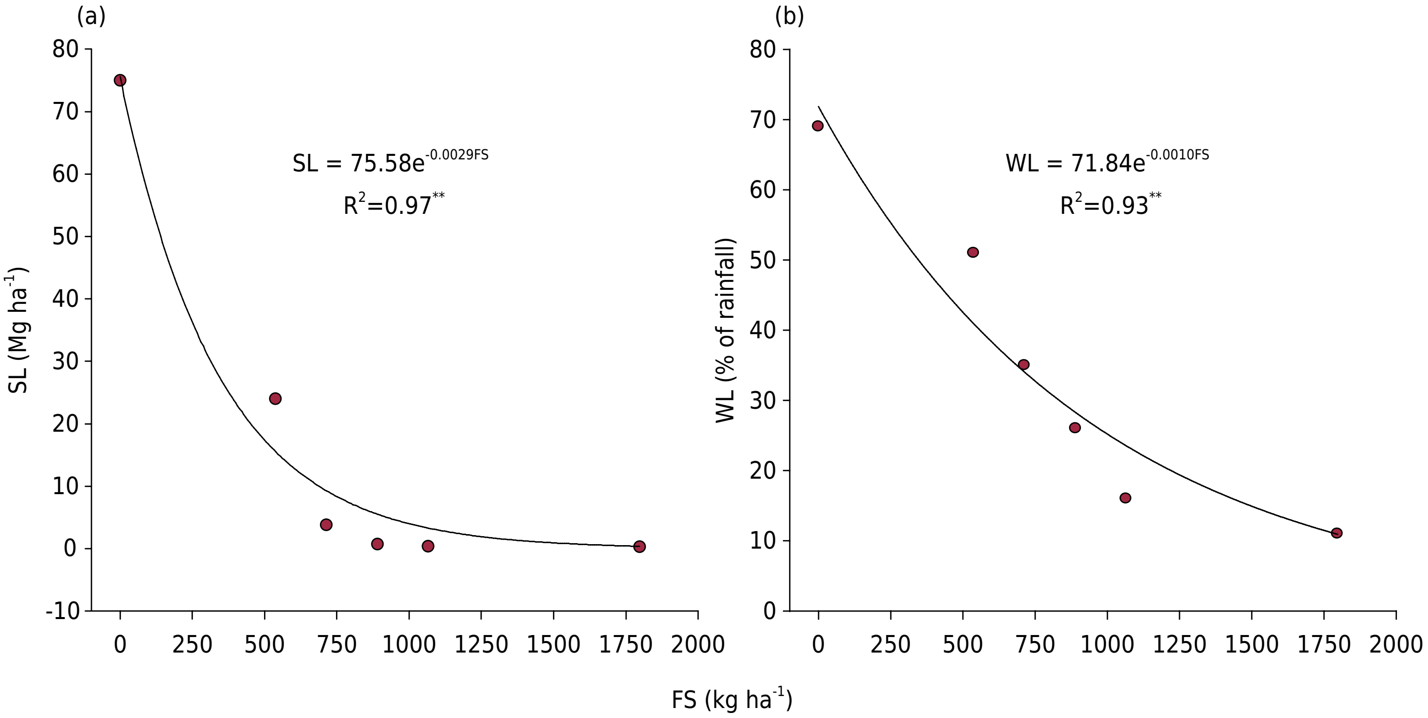

Figure 2. Relationship of (a) soil losses (SL) and (b) water losses (WL) to the fertilizers applied (FS) in the soil (triple superphosphate - TSP and potassium chloride - KCl) during the experimental period from 2003 to 2015 in the treatments studied in experiment I. **: p≤0.01.

CR and SC production (Table 1). Thus, with the exception of T5, the SC was sufficient to adequately control water erosion on a plot scale in an NT system, where the slope length was only 22.1 m and the slope was 10 %. In T5, however, the amount of CR did not adequately cover the soil to control erosion, due to insufficient soil fertilization. Soil coverage dissipates the kinetic energy of raindrops and, in part, of surface runoff, reducing water erosion (Wischmeier and Smith, 1978). In T5, annual soil losses were 2.5 times greater than the maximum level of tolerance for the soil, and in T6 these losses were 7.7 times greater than the level of tolerance of 9 Mg ha^{-1} yr^{-1} estimated by Bertol and Almeida (2000). A rate of 4 Mg ha^{-1} of CR on the soil surface in the NT controls 100 % of soil losses under simulated rainfall conditions with a micro simulator that produces only erosion between furrows (Panachuki et al., 2011). Most of the treatments in this study produced more than 4 Mg ha^{-1} of CR (Table 1) and, therefore, it would be possible to totally control erosion between furrows under conditions similar to the study mentioned.

In experiment II, the highest SL occurred in the BR, followed by the NT, with losses in the NR equivalent to 18 % of those that occurred in the BR, in the average of the crops (Table 4). This demonstrates the effect that burning of rangeland vegetation has on soil water erosion (Baretta et al., 2005; Bertol et al., 2011). In general SL were lower than those of the level of tolerance of 9 Mg ha^{-1} yr^{-1} determined by Bertol and Almeida (2000), except in T5 and T6 treatments and turnip crop in T4 treatment.

The SL in experiment I varied as a consequence of the combined effect of EI_{30} and the crops (Table 4). This variation tended to increase as the fertilizer application rate decreased, due to the increase in the DM and SC. This same trend occurred in experiment II, in which the influence of EI_{30} was higher in the NT and lower in the NR. The increase in soil management efficiency, mainly due to the increase in SC, decreases the relative influence of EI_{30} and increases the influence of the amount of rainfall on SL (Bagatini et al., 2011).

The treatments with crops in experiment I exhibited less variation in water loss (WL) than in SL (Table 4). The fertilization rate affected CR and SC, which influenced WL, as occurred with SL, such that the exponential model $\hat{y} = ae^{-bx}$ satisfactorily fit the data, and variation in the fertilization rate explained 93 % ($R^2 = 0.93$) of WL (Figure 2).The WL

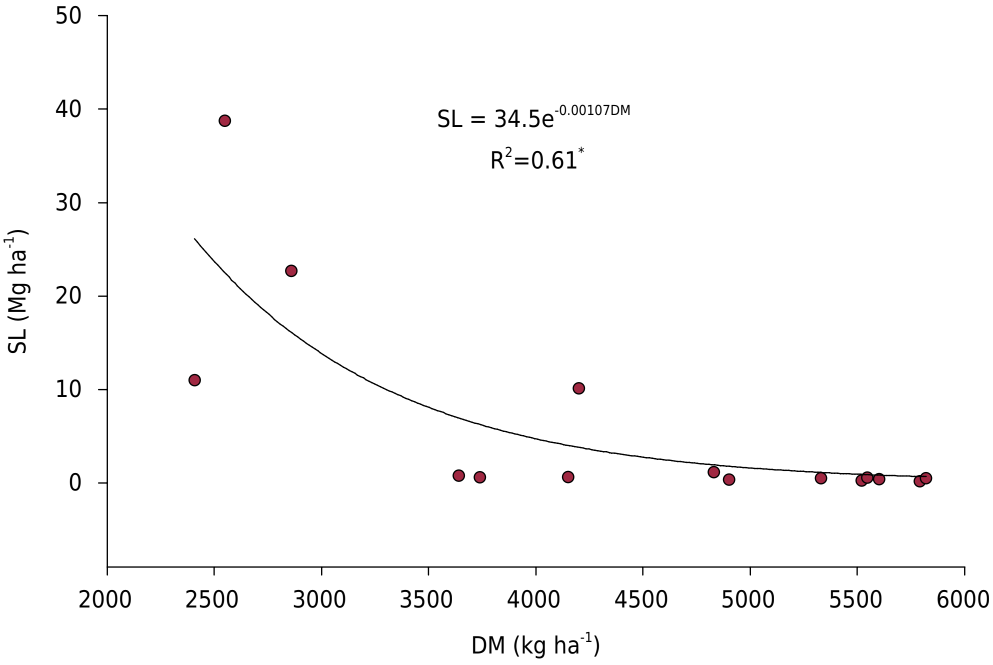

Figure 3. Relationship between soil losses (SL) and dry massof aerial part of the crops (DM) in treatments with forage turnip, black bean, and common vetch, in experiment I. *: $p \leq 0.05$.

among the crops varied with the seasonal climate so that in the spring-summer they corresponded to 45 % of the average loss that occurred in the four crops, whereas in the autumn-winter, WL were 1.5 times higher. This difference in seasonal effect in WL between climatic seasons may largely be due to the variation in water content in the soil preceding the rains (not determined) and by the characteristics of the plants grown in each seasonal cycle, as verified by Schick et al. (2016) and, to a lesser degree, by the variation in rainfall accumulation. In autumn-winter, the rains are generally longer and of lower average intensity, and since the days are short and the temperature is low, at this time of year the evaporation is lower (Beutler et al., 2003).

In experiment II, the difference in WL between treatments was smaller than in experiment I, with 11 % of the rainfall lost in the NR and 17 % in the BR (Table 4). Burning the natural rangeland removes most of the residue of the shoots and thereby decreases surface retention and water infiltration in the soil (Hester et al., 1997), due to the decrease in CR. Moreover, the hydrophobic effect caused by the burning of CR is potentiated, which results in a decrease in water infiltration in the soil (Ferreira et al., 2008) and an increase in surface runoff (Bertol et al., 2011). The seasonal variation of WL was lower in experiment II than in experiment I, but explained in the same way as in this experiment, especially in the case of the NT treatment.

The SL were explained by the shoot CR in the treatments with soil cultivation in experiment I (Figure 3). The exponential model $\hat{y}=ae^{-bx}$ satisfactorily fit the data (R^2=0.61), so that the CR explained 61 % of SL. Thus, in the NT, increasing the application rate of fertilizers applied to the soil surface increases CR and SC by crop residues; it also increases root mass (Bezerra et al., 2006; Costa et al., 2008), which increases the resistance of the soil against the erosive energy of the rain and runoff and reduces water erosion (Foster, 1982).

CONCLUSIONS

The increase in the fertilizer rate applied to the soil surface under no-tillage conditions has a significant positive effect on organic carbon content, on soil resistance to disaggregation, and on the soil macropore volume.

Soil losses due to water erosion decrease with an increase in the fertilizer rate applied to the soil and with an increase in the plant biomass of the crop shoots.

The exponential model of the type $\hat{y}=ae^{-bx}$ satisfactorily describes the decrease in soil losses and water losses with the increase in the fertilizer application rate, and it also fits the data regarding the decrease in the soil losses with the increase in the shoot dry matter of the crops.

In the natural rangeland under full conditions, water erosion is lower than in the natural rangeland cultivated under no-tillage, and in the latter, it is less than in the burned natural rangeland.

Water erosion has less effect on water losses than soil losses, regardless of soil management.

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