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Water Erosion in a Long-Term Soil Management Experiment with a Humic Cambisol

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ABSTRACT: Water erosion, the main factor in soil degradation, is strongly influenced by soil cover and management. The objective of this study was to determine soil and water losses under natural rainfall conditions from 1993 to 2012 in the southern Santa Catarina Plateau, Brazil, in 3.5 × 22.1 m plots with crops in rotation to study the following management treatments: conventional tillage (CT), minimum tillage (MT), and no-tillage (NT), and a treatment with bare soil (BS). The soil cover remaining after tillage was negatively affected by the increase in soil tillage intensity. Soil losses were strongly affected by the management system, while water losses were less affected. Soil losses were 85.29, 6.41, 2.00, and 0.82 Mg ha^{-1} yr^{-1} in the BS, CT, MT, and NT treatments, respectively, while water losses were 38, 24, 15, and 9 % of the rainfall, respectively, in the annual mean. Soil losses in spring/summer were similar to those of autumn/winter in the CT, MT, and NT treatments, while water losses were influenced by the time of year in all soil management systems. The accumulated soil losses in the MT and NT treatments tended to stabilize over the period evaluated, whereas they increased an average of 88.12 Mg ha^{-1} yr^{-1} in the BS and 7.23 Mg ha^{-1} yr^{-1} in the CT treatments. The accumulated water losses had a linear response, with positive angular coefficients for all treatments. The relationship between annual soil and water loss data was significant in the BS treatment; in the CT, MT, and NT treatments, this relation was not significant.

Keywords: soil and water losses, no-tillage, minimum tillage, conventional tillage.

INTRODUCTION

Erosion is the main cause of soil degradation (Kumar and Mishra, 2015) and, therefore, causes damage to the agricultural sector and the environment, with economic and social consequences (Telles et al., 2011; Rieger et al., 2016; Bertol et al., 2017a).

Factors affecting water erosion are: rainfall through potential erosivity, soil subject to erodibility, relief affected by the degree of slope and slope length, soil cover by plants and crop residues, and soil management by mechanical tillage. These factors can be affected by conservation practices such as contour farming, crop rotation, strip cropping, and terracing (Wischmeier and Smith, 1978). Among the factors, soil cover and how it is managed is the most important because it has a greater influence on erosion than the other factors (Hudson, 1995).

Soil management, mainly mechanical tillage, influences surface cover and roughness, and represents the main factor that affects water erosion (Leite et al., 2004; Souza et al., 2017). In planning conservation of agricultural property, it is essential to know the soil cover and management factor, especially the relationship between the capacity of this factor to cause erosion and the capacity to control it (Bertol et al., 2014).

Agricultural production systems capable of promoting soil and water conservation are fundamental to improve the efficiency of agricultural and livestock production and lead to more sustainable use of natural resources (Kumar and Mishra, 2015; Rieger et al., 2016). Thus, experimental studies on soil erosion are important for the viability of conservation planning in a reliable manner (Bertol et al., 2017b; Zhang et al., 2017).

Studies related to water erosion in field experiments in Brazil were analyzed by Anache et al. (2017) that identified 52 study sites; approximately 50 % of the published studies had a duration less than or equal to two years, and only three included series with a period greater than or equal to 20 years. The authors also claim that the observed values are influenced by the length of data collection, and they emphasize the importance of data obtained in long-term experiments in order to develop models and support decision making.

The two hypotheses tested in this study were that soil erosion from rainfall is influenced by the soil cultivation and management system, conducted over a long period, and soil susceptibility to water erosion varies throughout the evaluation period. Thus, the aim of this study was to obtain data on soil and water losses over 48 continuous crop cycles for a representative soil from the state of Santa Catarina, Brazil, under different commonly used land use and management systems in a long-term field experiment under natural rainfall conditions, as well as draw conclusions regarding water erosion over the period evaluated.

MATERIALS AND METHODS

This study was developed in the south of the Santa Catarina Plateau (27° 49’ S and 50° 10’ W), with an altitude of 923 m at the experiment site. The climate is of type Cfb according to the Köppen classification system, with average annual temperature of 15.7 °C and average annual rainfall of 1,556 mm (Wrege et al., 2011). The soil of the experiment site is a *Cambissolo Húmico Alumínico léptico* (Santos et al., 2013), a clayey Humic Cambisol according to the Soil Survey Staff (2014), with average slope of 0.102 m m^{-1}.

From 1993 to 2012, soil and water losses by water erosion were continuously evaluated in a field experiment under natural rainfall conditions under different soil management situations. The experiment was conducted in experimental units, or plots, of 3.5 × 22.1 m (77.35 m^2). Each plot was delimited by galvanized metal sheets at the sides and top end and by a runoff collector at the lower end connected to a pipe that carried the runoff to a collection point 6 m below the plot.

Four soil management treatments were evaluated, with two replicates (plots) per treatment: soil with two annual crops under conventional tillage (CT), minimum tillage (MT), and no-tillage (NT), and bare soil (BS), where the surface was kept permanently free of vegetation and without a crust (standard plot of the Universal Soil Loss Equation - USLE).

Mechanical soil tillage operations were carried out with the following equipment: a reversible plow with three discs, passing in the direction parallel to the slope and set to an operating depth of 0.20 m; a chisel plow with thirteen rods, spaced at 0.25 m from each other, with an operating depth of 0.15 m from the soil surface; and a 32-disc tandem harrow, adjusted to operation at a depth of 0.12 m.

Row crops in the CT, MT, and NT treatments were corn (*Zea mays* L.), dry edible bean (*Phaseolus vulgaris* L.), and soybean [*Glycine max* (L.) Merrill] seeded with the aid of a manual seeder. Black oat (*Avena strigosa* L.), vetch (*Vicia sativa* L.), forage turnip (*Raphanus sativus* L.), and wheat (*Triticum aestivum* L.) were broadcast by hand. The crops and their growing periods are listed in table 1. Complementary crop management practices are described in Schick (2014).

Table 1. Duration of each cultivation period and respective plant species grown in the period during the water erosion experiment in a Humic Cambisol under natural rainfall conditions

Cultivation	Period	Crops
1st	12/01/1993 to 08/06/1993	Soybean
2nd	28/06/1993 to 17/11/1993	Wheat
3rd	23/12/1993 to 12/07/1994	Beans
4th	23/07/1994 to 18/11/1994	Vetch
5th	30/12/1994 to 30/07/1995	Corn
6th	01/08/1995 to 30/11/1995	Vetch
7th	01/12/1995 to 30/04/1996	Soybean
8th	01/05/1996 to 15/11/1996	Wheat
9th	15/11/1996 to 30/04/1997	Beans
10th	01/05/1997 to 15/11/1997	Forage turnip
11th	16/11/1997 to 30/04/1998	Corn
12th	01/05/1998 to 15/10/1998	Black oat
13th	20/10/1998 to 30/04/1999	Soybean
14th	01/05/1999 to 30/10/1999	Wheat
15th	01/11/1999 to 30/04/2000	Beans
16th	01/05/2000 to 30/10/2000	Vetch
17th	01/11/2000 to 30/05/2001	Corn
18th	01/06/2001 to 30/10/2001	Black oat
19th	01/11/2001 to 22/06/2002	Soybean
20th	01/07/2002 to 15/11/2002	Forage turnip
21st	16/11/2002 to 15/05/2003	Beans
22nd	16/05/2003 to 30/10/2003	Vetch
23rd	01/11/2003 to 15/05/2004	Corn
24th	23/07/2004 to 08/12/2004	Black oat
25th	15/11/2004 to 15/05/2005	Soybean
26th	15/05/2005 to 15/11/2005	Wheat
27th	01/12/2005 to 31/05/2006	Beans
28th	01/06/2006 to 31/10/2006	Vetch
29th	03/11/2006 to 30/04/2007	Corn
30th	01/05/2007 to 03/11/2007	Black oat
31st	28/11/2007 to 10/05/2008	Soybean
32nd	11/05/2008 to 21/11/2008	Forage turnip
33rd	22/11/2008 to 30/03/2009	Beans
34th	01/04/2009 to 30/10/2009	Vetch
35th	01/11/2009 to 14/04/2010	Corn
36th	15/04/2010 to 05/11/2010	Black oat
37th	06/11/2010 to 31/05/2011	Soybean
38th	01/06/2011 to 08/11/2011	Forage turnip
39th	09/11/2011 to 10/03/2012	Beans
40th	11/03/2012 to 15/11/2012	Vetch

The dry matter of residues produced was obtained immediately after harvest from three samples in each plot. The area sampled was a rectangle with internal dimensions of 0.40 × 0.60 m. The samples were placed in paper bags and dried in a forced air ventilation laboratory oven for 72 h at 60 °C, and then weighed. Determination of soil cover by crop residues was performed immediately after soil tillage for each crop (after sowing in the NT treatment). The tape measure method, described by Hartwing and Laflen (1978), was used for this purpose, with two replications per plot.

Sediments were withdrawn from inside the tanks (quantity permitting) and weighed at the time of collection. Soil losses were evaluated according to the method described in Cogo (1978). Soil loss data were adjusted to the standard slope of the USLE, i.e., 0.09 m m^{-1}, by means of the slope degree factor, as proposed by Wischmeier and Smith (1978).

The criterion adopted for definition of erosive rains was that of Wischmeier and Smith (1958), modified by Cabeda (1976). A rain gauge set up at 600 m from the experimental area registered the distribution of rainfall volume over time, allowing association of erosivity with soil loss and association of rainfall volume with water loss due to erosion. In the daily rainfall charts, erosive rains were manually separated into segments of uniform intensity, and recorded on spreadsheets. Subsequently, the *Chuveros* program (Cassol et al., 2008) was used to calculate rainfall erosivity (EI_{30} index), according to Wischmeier and Smith (1978).

During the experimental period, soil losses from 991 erosive rains were quantified, resulting in 795 individual soil loss events. Thus, 163 soil loss events resulted from two or more cumulative erosive rains, due to operational difficulties of immediate, individualized collection. Subsequently, these data were grouped according to the crop and season of the year. Thus, annual results refer to the losses in each crop year, including the spring/summer and fall/winter crops.

The results were subjected to analysis of variance by adopting a mixed hierarchical linear model in three levels. Soil tillage treatments were considered in the first level, the seasons of the year in the second, and the years in the third level. Treatments and seasons were considered as fixed-effect factors and years as a random effect factor. The values of the means were compared by the Student-Newman-Keuls (SNK) (Steel et al., 1997; Little et al., 2006) test, when necessary. The linear model, $y = a + bx$, and the logarithmic model, $y = a + b \ln (x)$, were fitted to the values of accumulated soil and water loss data. The annual soil and water loss values were related by means of the linear model, $y = a + bx$. Before these analyses, normality tests of Shapiro-Francia and homogeneity of variance tests of Fligner-Killeen were carried out. All analyses were performed using the SAS® (SAS, 2003) and R (R Core Team, 2013) software, and for the tests of averages, the minimum significance level of 5 % was considered.

RESULTS AND DISCUSSION

The dry matter produced per crop (Table 2) was high in the CT, MT, and NT treatments, explained partly by the crop rotation adopted (Table 1) and partly by the regularity of rainfall without periods of marked water deficit (Schick et al., 2014) and by the appropriate physical and chemical properties of the soil (Andrade et al., 2010; Andrade et al., 2012).

The soil surface covered (Table 2) was significantly different between treatments with crops, due to the degree of soil mobilization, as verified by Levien and Cogo (2001), Cogo et al. (2003), and Amaral et al. (2008). Thus, the soil cover and the high dry matter production values (Table 2) influenced the performance of treatments in relation to soil and water losses.

Soil and water loss values were dispersed between the crops in each management system, as can be seen from the value of the coefficients of variation (Table 3). This was expected to some extent due to variations that occurred in the rainfall and the

Table 2. Dry matter of the shoots of the cultivated plant species and soil cover from crop residues under different cropping and management systems in a Humic Cambisol under natural rainfall conditions (mean value of 40 crops)

	Bare soil	Conventional tillage	Minimum tillage	No-tillage
Dry matter (kg ha^{-1})	0 b	4,885 a	5,723 a	5,724 a
CV (%)	-	53	49	48
Soil cover (%)	0 d	12 c	60 b	95 a
CV (%)	-	103	34	6

CV: coefficient of variation. Mean values followed by different letters are significantly different by the SNK test (p<0.05).

Table 3. Values of rainfall, erosivity, soil loss, and water loss by cultivation under different cropping and soil management systems in a Humic Cambisol under natural rainfall conditions

Cultivation	Rainfall	EI_{30}	Soil loss[(1)]				Water loss[(1)]			
			BS	CT	MT	NT	BS	CT	MT	NT
	mm	MJ mm ha^{-1} h^{-1}	Mg ha^{-1}				mm			
1	415	2,221	2.77	0.11	0.05	0.02	13	3	2	1
2	602	2,754	29.39	1.31	1.11	0.72	116	79	67	62
3	946	4,175	35.75	5.48	2.49	0.54	248	129	80	36
4	438	1,171	4.21	0.21	0.27	0.15	52	18	16	8
5	529	1,841	4.47	0.68	0.99	0.30	21	5	6	3
6	340	898	2.06	0.35	0.28	0.08	60	16	10	3
7	769	4,705	73.21	2.75	1.98	0.52	170	53	37	8
8	701	1,346	6.62	2.49	1.54	0.30	97	48	32	10
9	668	3,907	72.94	1.58	0.52	0.23	230	144	110	44
10	1,059	3,185	24.06	7.07	4.02	2.76	397	235	108	65
11	950	4,743	99.24	8.35	4.18	1.48	368	300	128	65
12	835	2,094	22.17	2.14	2.10	1.05	372	221	140	72
13	610	2,240	59.45	1.53	0.43	0.09	172	50	25	5
14	625	1,348	12.16	4.55	2.34	0.67	201	109	72	11
15	550	2,323	17.07	0.25	0.17	0.04	61	16	16	4
16	845	3,272	91.90	8.98	1.69	0.38	370	292	154	57
17	866	3,514	62.69	1.91	0.67	0.21	299	195	81	28
18	628	1,575	16.64	2.43	0.73	0.56	296	262	169	142
19	578	2,531	33.28	0.44	0.21	0.11	179	86	68	22
20	704	2,204	64.97	1.08	0.78	0.35	261	138	98	62
21	677	4,164	132.07	33.80	2.42	0.70	337	200	157	58
22	301	872	1.25	0.30	0.22	0.05	58	18	14	2
23	585	2,371	41.29	0.61	0.53	0.12	171	38	39	9
24	622	2,075	25.15	1.19	0.56	0.23	279	169	108	71
25	461	1,687	10.18	0.27	0.15	0.05	130	55	17	4
26	985	2,470	31.64	4.11	1.54	0.80	635	455	285	161
27	406	1,789	34.53	1.70	0.10	0.06	81	14	4	4
28	333	621	5.30	0.47	0.20	0.10	90	67	39	29
29	659	2,716	57.93	0.68	0.12	0.08	208	88	26	26
30	851	1,603	47.15	1.86	0.58	0.36	501	279	199	111
31	605	3,037	76.27	6.88	0.31	0.13	284	162	72	33
32	773	1,565	17.85	1.83	0.98	0.37	409	342	219	121
33	380	1,486	41.71	0.59	0.12	0.08	183	97	26	15
34	1,041	2,815	76.00	3.31	1.34	0.73	529	463	327	228
35	742	3,146	43.25	0.83	0.38	0.16	377	237	120	60
36	799	2,417	25.66	1.62	0.73	0.44	467	418	305	258
37	932	4,964	118.44	6.60	0.79	0.35	523	357	197	127
38	1,098	2,431	75.49	6.39	1.29	0.75	617	488	409	371
39	484	2,172	104.00	1.24	0.79	0.22	190	96	48	47
40	591	1,217	5.55	0.21	0.21	0.10	196	100	93	42
Total	26,985	97,662	1,705.8	128.2	39.93	16.45	10,246	6,543	4,123	2,485
Mean	675	2,442	42.64 a	3.20 b	1.00 c	0.41 c	256 a	164 b	103 c	62 d
CV (%)	31	45	82	173	101	121	65	85	95	126

(1) Mean value of two replications. BS: Bare soil; CT: conventional tillage; MT: minimum tillage; NT: no-tillage; CV: coefficient of variation. Mean values followed by different letters are significantly different by the SNK test (p<0.05).

interval between the rains, in soil water content prior to rainfall, and in crop type and cycle, among others, as already indicated by Cogo et al. (2003), Silva et al. (2009), and García-Ruiz et al. (2015). That is why Wischmeier and Smith (1978) and Nearing et al. (1999) have recommended a long period for field experiments of this nature, to obtain representative and reliable data values.

The highest soil loss, at 42.64 Mg ha^{-1}, and water loss, at 256 mm, in the average of the crops, occurred in the BS treatment (Table 3). This was expected, since the soil management practice was performed to potentiate the effect of water erosion, as recommended for the USLE (Wischmeier and Smith, 1978) standard plot. The direct impact of raindrops on the soil probably caused the soil particles to break up, clogging the pores, sealing the surface, and lowering the infiltration. This increased the volume and speed of runoff and soil erosion, according to Duley (1939), reflected in the data in table 3.

The CT treatment promoted a 92 % reduction in soil loss and 36 % reduction in water loss in relation to BS in the average of the crops. Reductions of 85 % in soil loss and 29 % in water loss from CT in a corn crop in relation to BS are common (Bertol and Miquelluti, 1993). This is explained by the protection given to the soil by the crops in the CT treatment. This protection, together with the remaining residues (Table 2), which, even incorporated into the soil, protected it from erosive agents, reduced soil disintegration and transport. In addition, the roots probably stimulated microbial action and increased water infiltration and soil resistance to the runoff action (Volk, 2006). However, annual water losses in the CT were 164 mm (Table 3), which represented 24 % of the rainfall in the average of the crops.

The MT treatment showed soil loss of 1 Mg ha^{-1} and water loss of 103 mm in the average of the crops, values between CT and NT, as also verified by Mello et al. (2003) and Amaral et al. (2008). The MT showed reductions of 98 % compared to BS and 69 % compared to CT in soil losses, and 60 % compared to BS and 37 % compared to CT in water losses. This can be explained by the reduced soil mobilization in MT, which, in addition to maintaining considerable soil cover (Table 2), decreased the erosivity action and possibly increased surface roughness, which favored infiltration, as verified by Gilles et al. (2009).

The NT treatment had the lowest values of soil and water losses in all crops (Table 3), which was also verified by several authors (Schick et al., 2000; Cogo et al., 2003; Leite et al., 2004; Amaral et al., 2008). Soil and water losses were 0.41 Mg ha^{-1} and 62 mm, respectively, in the average of the crops. The average loss of water in the NT treatment represented only 9 % of the average rainfall of the crops and represented 24, 38, and 60 % of the average losses verified in the BS, CT, and MT treatments, respectively. The mean soil loss in the NT treatment represented approximately 1 % of that observed in the BS treatment and 13 % of that observed in the CT treatment. Although the average soil losses in the MT treatment were 2.4 times higher than in the NT, statistically, no differences were observed between these treatments, and both were characterized as most efficient in control of soil losses. This result, in the case of NT, can be attributed to minimum mobilization of the soil, given the lack of tillage. This maintained a great deal of soil cover (Table 2), which protected the surface against kinetic energy from raindrops and surface runoff, imposed a physical barrier that slowed the flow and drag of particles, and improved the physical properties of the soil surface and subsurface. These characteristics favored infiltration of water into the soil and decreased particle drag and soil and water losses (Table 3).

The average annual soil loss of 85.29 Mg ha^{-1} in the BS treatment was obtained under annual mean erosivity of 4,883 MJ mm ha^{-1} h^{-1} (Table 4). Under the same soil use and management conditions, Silva et al. (2009) obtained annual losses of 175.4 Mg ha^{-1} in Lavras (MG) for a *Cambissolo Háplico* (Cambisol) subjected to an annual mean erosivity of 4,865 MJ mm ha^{-1} h^{-1}. Rieger et al. (2016) in Sinop (MT) obtained annual losses of 87.63 Mg ha^{-1} for a *Latossolo Vermelho-Amarelo* (Ferralsol), with annual mean erosivity of 16,092 MJ mm ha^{-1} h^{-1}. These data demonstrate the importance of conducting studies on the behavior of water erosion in different soils and sites.

Table 4. Annual values of rainfall, erosivity, soil loss, and water loss under different soil management systems in a Humic Cambisol under natural rainfall conditions (mean value of 20 years)

Data	Rainfall	EI_{30}	Soil loss[(1)]				Water loss[(1)]			
			BS	CT	MT	NT	BS	CT	MT	NT
	mm	MJ mm ha^{-1} h^{-1}	Mg ha^{-1}				mm			
Mean	1,349	4,883	85.29 a	6.41 b	2.00 c	0.82 c	512 a	327 b	206 c	124 d
CV (%)	23	27	50	115	72	86	52	68	69	95

BS: Bare soil; CT: conventional tillage; MT: minimum tillage; NT: no-tillage; CV: coefficient of variation. Mean values followed by different letters are significantly different by the SNK test ($p<0.05$).

In relation to the soil in this study, Bertol and Almeida (2000) established the soil loss tolerance limit of 9.6 Mg ha^{-1} yr^{-1}. The annual losses values observed for the soil without cultivation (Table 4) extrapolated this limit nine times. The loss of 6.41 Mg ha^{-1} yr^{-1} in the CT treatment (Table 4) was lower than the limit established by Bertol and Almeida (2000). This confirms the assertion of Foster (1982) that the incorporation of large amounts of crop residues into the soil (Table 2) can reduce soil losses in more intensive soil tillage practices. In the case of the present experiment, the high organic matter content of the soil stands out; high organic matter content promotes improvement of soil physical properties (Braida and Reichert, 2014) and a decrease in water erosion (Bertol et al., 2014).

The mean annual soil losses of the CT, MT, and NT treatments at 6.41, 2, and 0.82 Mg ha^{-1}, respectively, were lower than the limit established by Bertol and Almeida (2000) for the soil in question. However, according to Cogo et al. (2003), in agricultural areas, declivity and slope length greater than in the study plots (9 % and 22.1 m, respectively) is usually found, which leads to losses above the established limit. It should also be noted that the soil loss tolerance suggested by Bertol and Almeida (2000) only serves the criterion of maintenance of the productive capacity of the soil by preserving its depth; however, it does not meet the criterion of environmental contamination caused by erosion displacing soil outside its place of origin.

When the intensity of soil tillage is decreased and soil cover is increased, water losses decrease, just as observed with soil losses (Table 4); this has been verified by several authors (Levien et al., 1990; Mello et al., 2003; Panachuki et al., 2011). This response is explained by the maintenance of water infiltration capacity, promoted by lower soil disintegration upon reducing the intensity of tillage, as well as by plant cover protecting the soil from the impact of raindrops and surface runoff.

Water losses, in general, followed the same tendency as soil losses (Table 4); however, the reductions were smaller than reductions in soil losses, which was also verified by Cogo et al. (2003), Amaral et al. (2008), and Ramos et al. (2014). The smaller influence of soil management on reduction in water losses compared to reduction in soil losses can be explained by the fact that the soil has a limit of water absorption and storage, according to the soil capacity. Once the limit is exceeded, the excess rainwater flows over the terrain, with the different management systems having practically the same effectiveness in controlling water losses by erosion (Kohnke, 1968).

In the BS treatment, soil losses during the spring/summer crops were greater than those observed in the fall/winter (Table 5). This is explained in part by the erosivity, concentrated in the spring/summer, that acted directly on the soil due to its mechanical mobilization and absence of soil cover (Table 5). This shows the adequacy of the EI_{30} index as an estimator of rain erosivity under standard USLE conditions (Schick et al., 2014). However, in the CT, MT, and NT treatments, there was no statistical difference between soil losses in the seasons, which can be explained by lower or no soil mobilization and the presence of surface cover by residues and by crops, which dissipated the energy of the rain (Table 5).

Although rainfall was similar between seasonal periods and erosivity was greater in the spring/summer, in all treatments there were larger water losses in autumn/winter (Table 5), as verified by Schick et al. (2000) and Amaral et al. (2008). Such results show a smaller influence of erosivity in water losses, especially in conservationist tillage practices (Table 5). Possibly, the differences in water losses between the periods considered were because of the water content in the soil prior to the rains, which was higher during the fall/winter, and probably increased the water in the soil and decreased the infiltration in that period. In autumn/winter, the rains are longer and lesser intense, and the days are shorter and milder, which reduces evaporation (Beutler et al., 2003).

A linear model was fitted to the annual soil losses accumulated throughout the time, with positive angular coefficients in the BS and CT treatments (Figure 1a), and these losses increased at an average of 88.12 and 7.23 Mg ha^{-1} yr^{-1}, respectively. For the MT and NT treatments, the logarithmic model better fitted the data (Figure 1b), indicating that these accumulated losses tended to stabilize over time in these treatments. Water erosion evaluated over 17 years in an *Argissolo Vermelho* (Acrisol) with sandy texture decreased three years after the adoption of the no-tillage system (Lanzanova et al., 2013). The linear model was fitted to the accumulated losses of water according to time (Figures 1c and 1d) for all treatments, with the angular coefficients being 534, 338, 209, and 119 mm yr^{-1} for BS, CT, MT, and NT, respectively. Models similar to those obtained for soil and water losses in this study were fitted by Hernani et al. (1997), who worked with a *Latossolo Roxo* (Ferralsol) in Dourados (MS) over seven years.

Table 5. Seasonal values of rainfall, erosivity, shoot dry matter, soil cover from crop residues, and soil and water losses under different cropping and soil management systems in a Humic Cambisol under natural rainfall conditions

	Spring/summer crops	Fall/winter crops
Rainfall (mm)	641 ± 40 a[(1)]	709 ± 54 a
Erosivity (MJ mm ha^{-1} h^{-1})	2,987 ± 249 a	1,897 ± 176 b
	Dry matter (Mg ha^{-1})	
Bare soil	0.00 ± 0.00 a	0.00 ± 0.00 a
Conventional tillage	4.68 ± 0.85 a	5.01 ± 0.70 a
Minimum tillage	5.52 ± 1.02 a	5.84 ± 0.68 a
No-tillage	5.35 ± 0.99 a	6.01 ± 0.64 a
	Soil cover (%)	
Bare soil	0 ± 0 a	0 ± 0 a
Conventional tillage	16 ± 2 a	6 ± 2 b
Minimum tillage	65 ± 2 a	52 ± 3 b
No-tillage	97 ± 3 a	92 ± 3 a
	Soil loss (Mg ha^{-1})	
Bare soil	56.03 ± 8.27 a	29.26 ± 6.14 b
Conventional tillage	3.81 ± 1.67 a	2.59 ± 0.55 a
Minimum tillage	0.87 ± 0.24 a	1.13 ± 0.21 a
No-tillage	0.28 ± 0.08 a	0.55 ± 0.13 a
	Water loss (mm)	
Bare soil	212 ± 29 b	300 ± 42 a
Conventional tillage	116 ± 22 b	211 ± 36 a
Minimum tillage	63 ± 12 b	143 ± 26 a
No-tillage	30 ± 7 b	94 ± 22 a

[(1)] Mean value ± standard error. Mean values followed by different letters, in the same row, are significantly different by the SNK test ($p<0.05$).

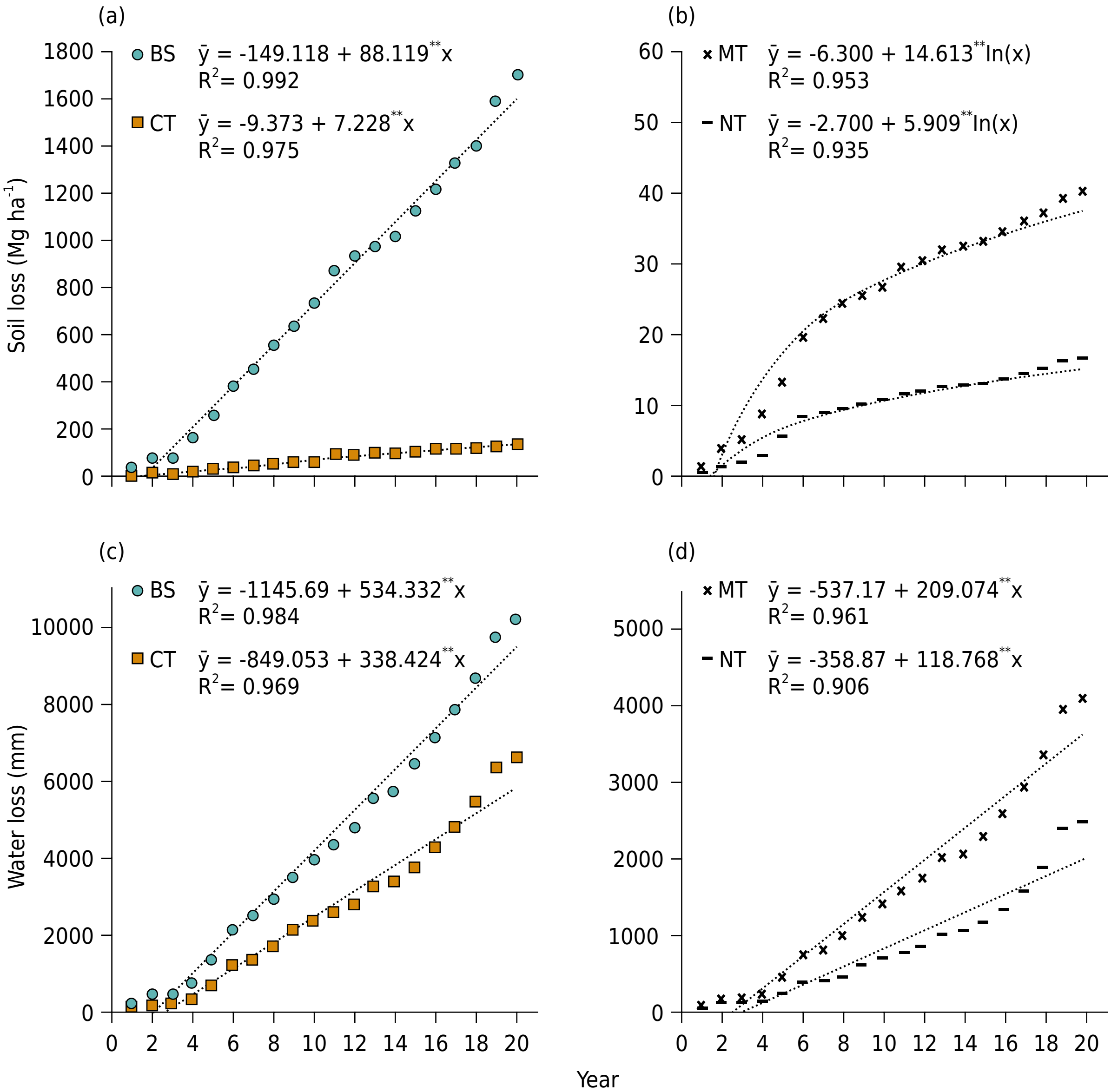

Figure 1. Cumulative values of (a) soil loss in bare soil (BS) and under conventional tillage (CT); (b) soil loss in minimum tillage (MT) and no-tillage (NT); (c) water loss in bare soil (BS) and under conventional tillage (CT); (d) water loss under minimum tillage (MT) and no-tillage (NT), in a Humic Cambisol under natural rainfall conditions. **: significant at 1 % by Student's t-test.

The soil losses obtained in this same experiment in six years of cultivation were 70.07, 4.66, 3.14, and 1.49 Mg ha^{-1} yr^{-1} and the water losses were 455, 301, 181, and 148 mm yr^{-1} for the BS, CT, MT, and NT treatments, respectively (Schick et al., 2000). For the 20-year series, the values were 85.29, 6.41, 2.00, and 0.82 Mg ha^{-1} yr^{-1} and 512, 327, 206, and 124 mm yr^{-1}, for these same treatments (Table 4). This shows relative proportionality between the two sets of data obtained in the two seasons. However, the variation between the same treatments shows the importance of evaluating long historical series so that the data are reliable, with less variation due to climate.

A linear model fit the annual losses of soil and water in all treatments (Figure 2). In the BS, the relation was significant (Figure 2a), whereas, in the CT, MT, and NT, the models did not fit the data (Figures 2b, 2c, and 2d). These results corroborate the claims of several authors (Wischmeier and Smith, 1978; Foster, 1982; Cogo et al., 1984; Leite et al., 2004; Amaral et al., 2008) that the increased soil cover by crop residues favors dissipation of the kinetic energy of raindrops, decreasing initial soil disintegration, while they serve as a physical barrier and dissipate the energy of runoff, reducing soil transport.

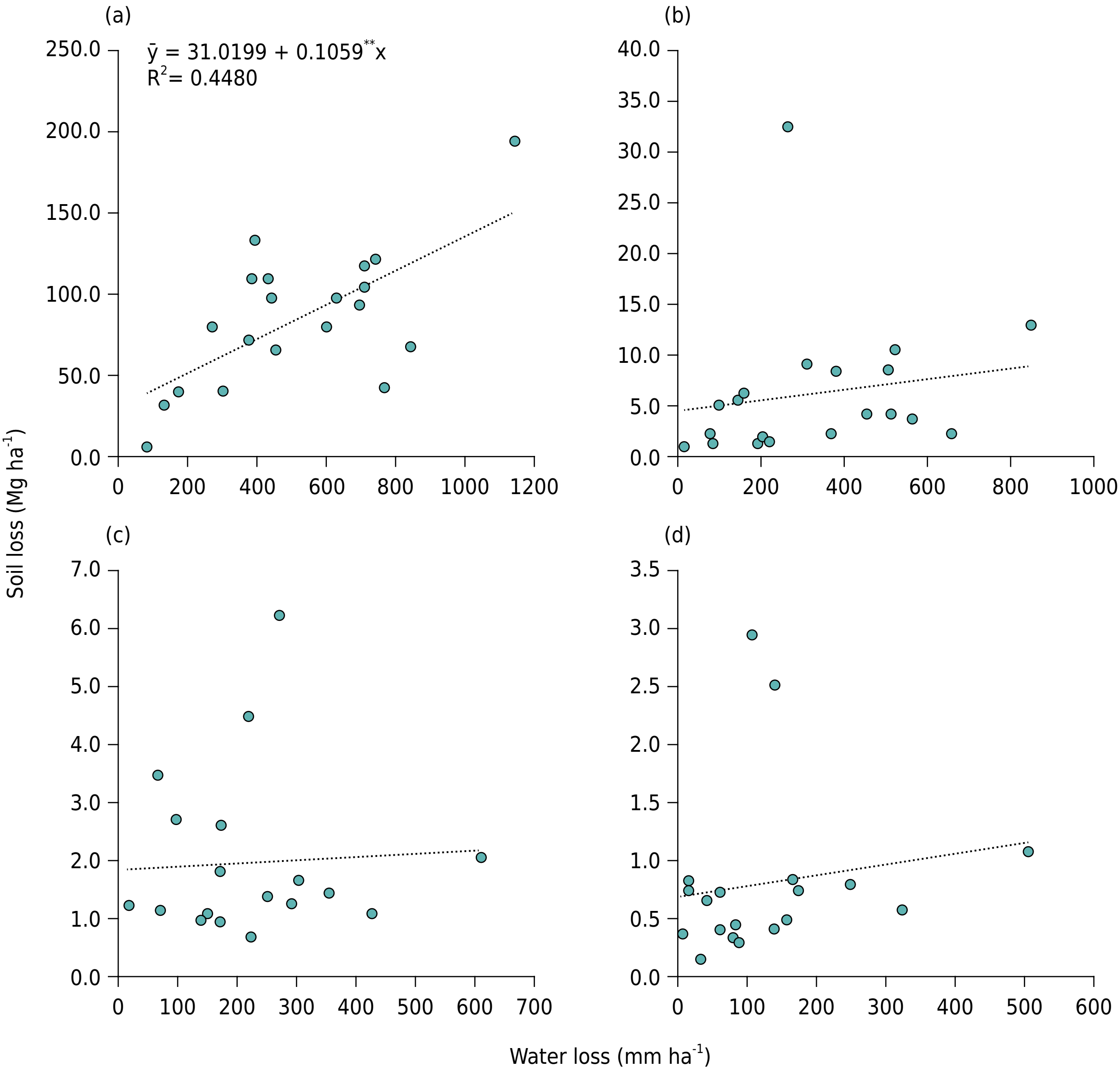

Figure 2. Relationship between the annual values of soil and water loss under different cropping and management systems: (a) bare soil; (b) conventional tillage; (c) minimum tillage; and (d) no-tillage, in a Humic Cambisol under natural rainfall conditions. **: significant at 1 % by Student's t-test.

CONCLUSIONS

Mechanical mobilization, soil cultivation, and surface coverage by crop residues affect soil and water losses by water erosion. No-tillage is the most effective treatment to control soil loss, followed by minimum tillage, conventional tillage, and bare soil.

Water losses follow the same tendency of soil losses in comparing treatments, although water losses are less influenced by mechanical mobilization, soil cultivation, and surface coverage than soil losses.

The uncultivated soil has greater soil loss in spring/summer, depending on the erosivity, while in conventional tillage, minimum tillage, and no-tillage, soil losses are similar in spring/summer and autumn/winter. All soil cultivation and management systems have greater water losses in autumn/winter.

Accumulated soil losses tend to stabilize in minimum tillage and no-tillage over time, while in conventional tillage and bare soil they increase linearly. Accumulated water losses increase linearly over time in all treatments.

Soil losses are not explained by water losses in the case of cultivated soil and in the presence of crops residues, regardless of the type of soil management, while in the absence of crop, the relationship between soil and water losses is significant.

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