Acta Scientiarum
http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v46i1.63164

Soil loss and runoff in southern Brazil in conservation systems: a long-term experiment

Liana Dambros[1], Luciana da Silva Corrêa Lima[2], Claudia Alessandra Peixoto de Barros[3]* and Elemar Antonino Cassol[3]

[1]Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 7712, Agronomia, 91540-000, Porto Alegre, Rio Grande do Sul, Brazil. [2]Departamento de Solos, Universidade Federal de Pelotas, Pelotas, Rio Grande do Sul, Brazil. [3]Departamento de Solos, Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil. *Author for correspondence. E-mail: claudia.barros@ufrgs.br

ABSTRACT. Brazil has high soil loss rates due to its tropical and subtropical climate characteristics. In this sense, soil use and management practices may minimize such losses. In this study, experimental plots were monitored for eight years in southern Brazil during natural rainfall events. Treatments were as follows: I) bare soil under conventional tillage, II) barley-oat/ soybeans succession under conventional tillage, III) oat-lupine-vetch/ maize succession under conventional tillage, IV) barley-oat/ soybeans succession under no-tillage, and V) oat-lupine-vetch/ maize succession under no-tillage. Data on rainfall amount and erosivity indices (EI_{30}, EI_{20}, and EI_{10}) were subjected to regression analyses, evaluating the effects of climatic variables on soil and water losses. We could also analyze crop species, conventional and no-tillage systems, and winter and summer seasons. The highest soil and water losses occurred in treatments under conventional tillage. In addition, soybeans treatments increased soil and water losses. Maize under no-tillage was the most efficient practice, as it had soil losses (3.4 times) and water losses (1.5 times) lower than soybeans under conventional tillage. Rainfall amounts and EI_{30} were better correlated with soil and water losses in conventional tillage treatments. However, EI_{10} could better explain the soil losses from the conservationist treatment.

Keywords: experimental plots; erosivity index; soil management; runoff; soil erosion.

Received on April 5, 2022.
Accepted on December 12, 2022.

Introduction

Erosion is considered a major global threat to soil and water degradation (Borrelli et al., 2020), especially in tropical regions, as it causes soil particles to detach and be transported more easily (Miranda, Scarpinella, Silva, & Mauad, 2015). Research on water erosion has been often carried out in delimited plots, whose surface runoff and soil losses are monitored after each rainfall event (Strohmeier, Laaha, Holzmann, & Klik, 2016; Anache, Wendland, Oliveira, Flanagan, & Nearing, 2017; Yang et al., 2019). In Brazil, the first experimental studies at a plot scale were conducted in the 1940s. However, since the peak of studies on soil erosion in the 2000s, field experiments have decreased by roughly 86% (Anache et al., 2017), and about 50% of experimental studies have only two or fewer years of monitored data. Between 1990 and 2001, research in this field focused primarily on the USA and Europe, then expanding to China and Australia, and finally reaching South America and eastern and southern South Africa (Zhuang, Du, Zhang, Du, & Li, 2015).

Experimentation for several years is crucial due to climatic phenomena that have frequently occurred in southern Brazil over the last years (Grimm, Almeida, Benetti, & Leite, 2020; Nóia Júnior, Fraisse, Karrei, Cerbaro, & Perondi, 2020). In recent years (15 to 20 years), the frequency of extreme events has increased, with alternating periods of drought and flood. The phenomena known as El Nino and La Nina have intensified in recent years. Between 2009 and 2010, a large volume of rainfall was observed, generating heavy flooding and reductions in crop yields (Theisen, Vernetti Jr., & Silva, 2009). In the 2011-2012 crop season, according to data from Empresa de Assistência Técnica e Extensão Rural [EMATER] (2012), crop yields in Rio Grande do Sul (RS) were severely affected by the lack of water in the soil (Cunha et al., 2011). And more recently, in the 2021/2022 crop season, RS again experienced a severe drought, which was similar to that in the 2004-2005 crop season, which was considered the worst drought in RS according to meteorological records.

Furthermore, since the beginning of the insertion of long-term experiments in Brazil, researchers have shown that, in conventional tillage systems, soil loss is more significant than in minimum cultivation and no-tillage systems (Chowaniak et al., 2020; Silva, Cassol, Levien, Eltz, & Schmidt, 2020). More residue on the soil surface maintained by no-tillage practices in southern Brazil has had positive effects, controlling soil losses. In this way, compared to a conventional system, no-tillage began to show efficiency in terms of reduction in soil and water losses (Schick, Bertol, Batistela, & Júnior, 2000; Cogo, Levien, & Schwarz, 2003; Bertol et al., 2008), improving soil properties and increasing agricultural productivity through the use of cover crops and crop rotation practices (Debarba & Amado 1997; Barcelos, Cassol, & Denardim, 1999; Amado, Bayer, Eltz, & Brum, 2001). Nonetheless, soil loss-control efficiency has not been compared to runoff control efficiency (Merten, Araújo, Biscaia, Barbosa, & Conte, 2015; Chowaniak et al., 2020). Moreover, Deuschle, Minella, Hörbe, Londero and Schneider (2019) argued that the dynamics of soil and water losses in no-tillage depend on rainfall magnitude and intensity, as this system is more vulnerable to runoff during high-magnitude and high-intensity events.

Lastly, field studies on soil water erosion are scarce in Brazil due to the cost and time to collect representative data. Brazil ranked first in soybeans production in the world, with 154.6 million tons out of the 369.0 million tons produced worldwide (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2023) in the 2022/23 harvest. In addition, such data availability may provide subsidies to face the lack of conservation practices or inadequate soil management, which has been observed in this study region (Didoné, Minella, & Evrard, 2017; Didoné et al., 2014).

Based on that, an eight-year experiment (1978-1986) was performed under natural rainfall events in experimental plots under the following treatments: i) bare soil under conventional tillage, ii) barley-oat/ soybeans succession under conventional tillage, iii) oat-lupine-vetch/ maize succession under conventional tillage, iv) barley-oat/ soybeans succession under no-tillage, and v) oat-lupine-vetch/ maize succession under no-tillage.

Material and methods

Study site

The experiment was conducted for eight years (1977 to 1985), monitoring one of the research centers of the current Department of Agricultural Diagnosis and Research (DDPA), formerly known as the State Foundation for Agricultural Research (FEPAGRO/ Floresta), part of the Department of Agriculture, Livestock, and Irrigation (SEAPI). It is located in the district of Boca do Monte, in the municipality of Santa Maria (Figure 1). Santa Maria is in the physiographic region of the central depression, in Rio Grande do Sul State, southern Brazil (29°30'45" S, 54°48'15" W, and 95-135 m altitude; Figure 1).

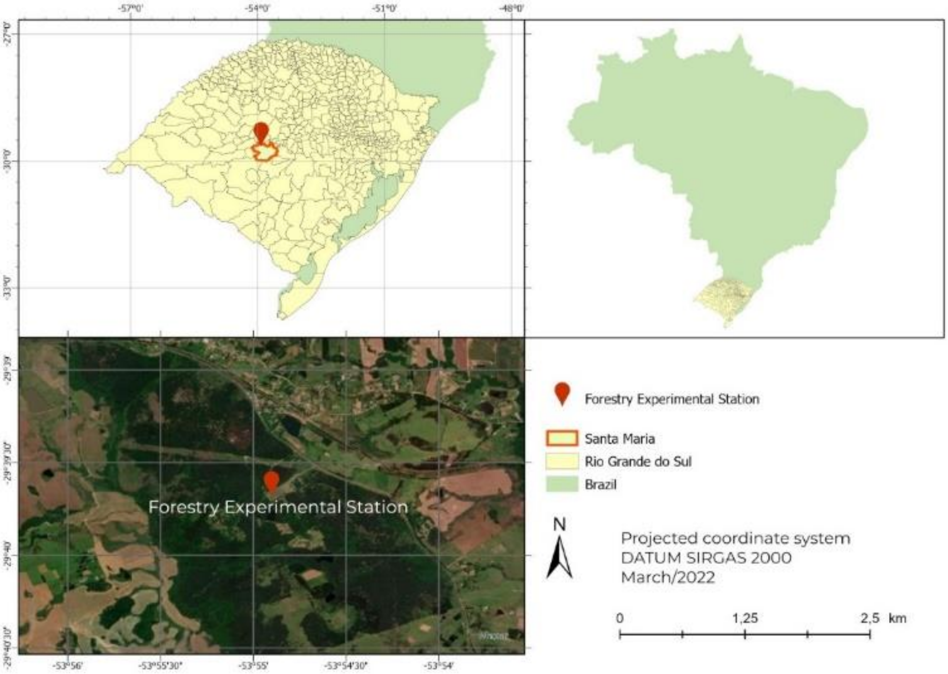

Figure 1. Location of the study area in the city of Santa Maria, Rio Grande do Sul State, Brazil.

According to Köppen's classification, the region has a Cfa humid subtropical climate without droughts. The average annual rainfall was 1578 mm, according to daily rainfall data provided by the National Institute of Meteorology (INMET), considering the period 1962-2012. The soil was classified as a Ultisol with low natural fertility, low organic matter content, and a sandy–clayey–loamy texture (IUSS Working Group WRB, 2015).

Experimental design and treatment characterization

The experiment was carried out with five treatments and two repetitions each, totaling ten experimental plots (22.0 × 3.5 m), on a 9% slope terrain. The plots were delimited by galvanized sheets to a depth of about 10 cm on the sides and upper end, with a drainage collection system at the lower end, which consisted of a gutter and two collection tanks. Coarser sediments were collected in the first tank (reservoir 1), while thinner ones were in the second tank (reservoir 2).

The treatments comprised: i) bare soil under conventional tillage. The soil was tilled twice a year, as plots were prepared with annual crops. Weeding was performed throughout the year using hoes or manually removing spontaneous vegetation to keep the soil bare. The standard plot, bare soil under conventional tillage, was referred to as SB; ii) oat-lupine-vetch/ maize succession under conventional tillage. In the first two years, oat-maize succession under conventional tillage with one plowing and two harrowings towards the slope. After five years, vetch (*Vicia sativa*) replaced white lupine as a winter crop. Crop substitutions during the experiment occurred due to phytosanitary issues. Oat-lupine-vetch/ maize succession under conventional tillage was referred to as Maize CT; iii) barley-oat/ soybeans succession under conventional tillage. The crops were harvested manually with a sickle, and straw was spread over the plot before tilling. After two years (1980–1981), oat (*Avena sativa*) was replaced with barley as a winter crop due to phytosanitary issues. Barley-oat/ soybeans succession under conventional tillage was referred to as Soybeans CT; iv) oat-lupine-vetch/ maize succession under no-tillage. This treatment followed the same cropping protocol as in treatment 2, and differed regarding minimum tillage at sowing, characterizing direct sowing. Oat-lupine-vetch/ maize succession under no-tillage was referred to as Maize NT; and v) barley-oat/ soybeans succession under no-tillage. It followed the same cropping protocol as in treatment 3 and differed regarding minimum tillage at sowing, also characterizing direct sowing. Barley-oat/ soybeans succession under no-tillage was referred to as Soybeans NT.

Crop treatments

The soil was fertilized in October 1977 as recommended by the Soil Analysis Laboratory of the Department of Agriculture (Eltz, Cassol, Guerra, & Abrão, 1984). It was tilled towards the slope and harrowed to incorporate lime and corrective fertilizers. Another tilling was carried out with two more harrowings towards the slope, followed by sowing maize and soybeans under a conventional tillage system.

In all treatments, weed was controlled using applications of paraquat and glyphosate herbicides before crop sowing or whenever needed, along with manual weeding. The plots and freshly cut oat were harvested manually. For oat, two cuts were made per cycle, with the green mass being cut and removed from plots to simulate grazing. Grains from the remaining crops were crushed, and straw returned to the soil after being manually chopped using a machete, being incorporated in conventional tillage treatments, and merely distributed superficially in the no-tillage treatments.

Data collection and processing

Rainfall monitoring

Rainfall data were obtained using a pluviograph that was located at plots to calculate the amount, intensity, and rainfall erosivity indices (EI_{30}, EI_{20}, and EI_{10}), according to criteria proposed by Wischmeier (1959) and later adapted for regions with tropical climate by Cabeda (1976).

Runoff and sediment monitoring

Surface drainage collection systems were installed at the lower ends of the plots and consisted of gutters connected by PVC pipes to tank 1 (300-500 L capacity). When the collected volume reached the tank capacity, the surplus finest material was transferred to tank 2 (400-600 L capacity). Tank 2 was connected to tank 1 by a Geib-type flow divisor, which allowed the passage of 1/7, 1/9, or 1/11 of the total runoff, discarding the remaining runoff. Runoff volume was measured by reading the water level in the tanks. Sediment samplings were taken to quantify soil losses in each natural rainfall and erosive runoff event. The samples were taken to the laboratory for weighing, drying, and final quantification of solid mass (g). Subsequently, the remaining material in tanks 1 and 2 (composed of suspended sediments) was homogenized again to sample the suspended sediments. These samples were collected using 300-mL vials, placing two for each treatment per tank (1 and 2).

The vials were weighed, and Kal $(SO_4)_2$ was added to each one to precipitate sediments and determine suspended sediment volumes. After 48h, the supernatant liquid was removed from the vials using a siphon with a plastic hose, leaving about 1.0 cm of water covering the sediment. The vials were then taken to a ventilated air-forced oven at 55 – 60°C until reaching a constant mass.

Some soil and water samples were collected in more than one rainfall event. Thus, rainfall and rainfall erosivity data were aggregated. A total of 276 individual and aggregate rainfall events were analyzed, of which 139 refer to the winter period (June to November) and 137 to the summer period (December to May).

Data processing

Erosivity indices

Based on the rainfall intensity, we could calculate the kinetic energy (KE) of each individual and erosive rainfall event according to Equation (1) of Foster, McCool, Renard and Moldenhauer (1981) for each rain segment. The erosivity indices (EI_{30}, EI_{20}, and EI_{10}) were calculated based on the method proposed by Wischmeier and Smith, (1958). EI_{30} was used to calculate the maximum rainfall intensity for 30 consecutive minutes. Likewise, EI_{20} and EI_{10} were calculated using the maximum rainfall intensity in 20 and 10 minutes, respectively (Equation 2) (Wischmeier & Smith, 1958).

$$\mathrm{KE} = 11.87 + 8.73\mathrm{LOG}_{10}\mathrm{I} \quad (1)$$

$$\mathrm{EI}_{30,20,10} = \mathrm{I}_{30,20,10} \times \mathrm{KE} \quad (2)$$

where in: KE is the kinetic energy expressed in J m^{-2} mm^{-1}; *I* is the rain intensity of each segment in mm h^{-1}; EI_{30}, EI_{20}, and EI_{10} are expressed in MJ mm ha^{-1} h^{-1}; and I_{30}, I_{20}, and I_{10} are the maximum intensities at 30, 20, and 10 min., respectively (expressed in mm h^{-1}).

Water determination

Where in: Q_{runoff} is the runoff volume for each rainfall event (mm), and rainfall is the rainfall amount (mm).

Data analyses

Data between the years 1978-1986 were used. The first year (1977) was excluded since it was when all experimental plots were tilled. Averages were grouped into periods referring to each agricultural year, between tillage and sowing of winter/ spring crops (oat, barley, and vetch) and summer/ autumn crops (soybeans and maize), and tillage for the next crops. The data were separated into winter/ spring periods (called winter periods) and summer/autumn periods (called summer periods).

With the 8-year series of data, simple regression analyses were performed between (I) soil losses (t ha^{-1}) and rainfall amount (mm), (II) soil losses and 30-min. rain erosivity index (EI_{30}, MJ mm ha^{-1} h^{-1}), (III) water losses (mm) and rainfall amount (mm), and (IV) water losses (mm) and 30-min. rain erosivity index (EI_{30}, MJ mm ha^{-1} h^{-1}). These analyses were performed per (agricultural) season and divided into summer and winter periods due to their climatic differences. Subsequently, simple regression analyses were also carried out between (V) soil losses (t ha^{-1}) and rainfall erosivity indices (EI_{30}, EI_{20}, and EI_{10}, MJ mm ha^{-1} h^{-1}), and (VI) water losses (mm) and rain erosivity indices (EI_{30}, EI_{20}, and EI_{10}, MJ mm ha^{-1} h^{-1}). The analyses (V) and (VI) were also performed per (agricultural) season, but disregarding winter and summer differences, distinguishing the treatment referred to as standard plot (BS) from those where maize and soybeans were included as summer crops. This way, we could effectively analyze the effects of both crops on the results and of conventional and no-tillage systems on the relationship between the different indices and soil and water losses.

Results and discussion

Rainfall analysis between 1978 and 1986

The annual average rainfall was 1,673.1 mm (Table 1), which is close to the historical average for Santa Maria (1,722.0 mm). Erosivity indices (EI_{30}, EI_{20}, and EI_{10}) are also detailed in Table 1, reflecting how total energy and peak intensity interact in a particular rainfall event. In total, 839 rainfall events occurred in the 8-year series, considering erosive and non-erosive rainfall, 421 in the winter, and 418 in the summer. Erosive rainfall totaled 370, with 168 in the winter and 202 in the summer. Unsurprisingly, when comparing the three indices, EI_{10} generated the highest values per period (winter and summer). Within the eight years, the R factor was 8,486.5 MJ mm ha^{-1} h^{-1} (Table 1), oscillating between 8,000.0 and 10,000.0 MJ mm ha^{-1} h^{-1} year^{-1} for the 1980-2013 period (Almagro, Oliveira, Nearing, & Hagemann, 2017).

Table 1. Rainfall and energy of events (erosivity indices EI_{30}, EI_{20}, EI_{10}, and maximum energy – E) between June 1978 and June 1986.

Year/period	Rainfall			Energy			
	Winter	Summer	Annual	EI_{30}	EI_{20}	EI_{10}	Maximum E
	-------------mm-------------			------MJ mm ha^{-1} h^{-1}-----			MJ ha^{-1}
78/79	772.4	429.9	1202.3	5768.4	6989.4	10742	26.6
79/80	846.3	672.3	1518.6	6402.5	7786.5	10888.7	19.3
80/81	560.0	594.8	1154.8	4240.9	5326.7	7207.8	16.2
81/82	502.1	1233.6	1735.7	10825.6	13141.8	16076.5	21.0
82/83	1183	1116.8	2299.8	12755.7	14440	16185.4	52.4
83/84	747.9	936.3	1684.2	9184.8	10508.3	14825.8	31.1
84/85	970.6	896.3	1866.9	8909.1	10679.6	13513.2	23.9
85/86	808.0	1114.3	1922.3	9804.7	11081	14614.8	26.6
Mean	798.8	874.3	1673.1	8486.5*	9994.2	13006.8	-
SD	202.4	266.0	355.4	2642.4	2899.9	2935.2	-
CV	25.3	30.4	21.2	31.1	29	22.6	-
Number of events	421	418	839	-	-	-	-

SD = Standard deviation; CV = Coefficient of variation; E = energy. R factor of the USLE * = 8486.5 MJ mm ha^{-1} h^{-1}.

Figure 3 describes the monthly averages for rainfall and erosivity indices. The months with the highest rainfall amounts may unnecessarily have the highest yearly erosivity. July had the highest volume of rainfall (190 mm), while October, February, and April showed the highest erosivity indices (EI_{30}, EI_{20}, and E_{10}, respectively) (Figure 2). In Rio Grande do Sul State, the most significant rainfall erosivity was found in periods of low soil cover. In October (the month with the highest EI_{30}), the soil tillage and sowing of the main commercial crops, such as maize and soybean, occurs (Panizzi, 2013).

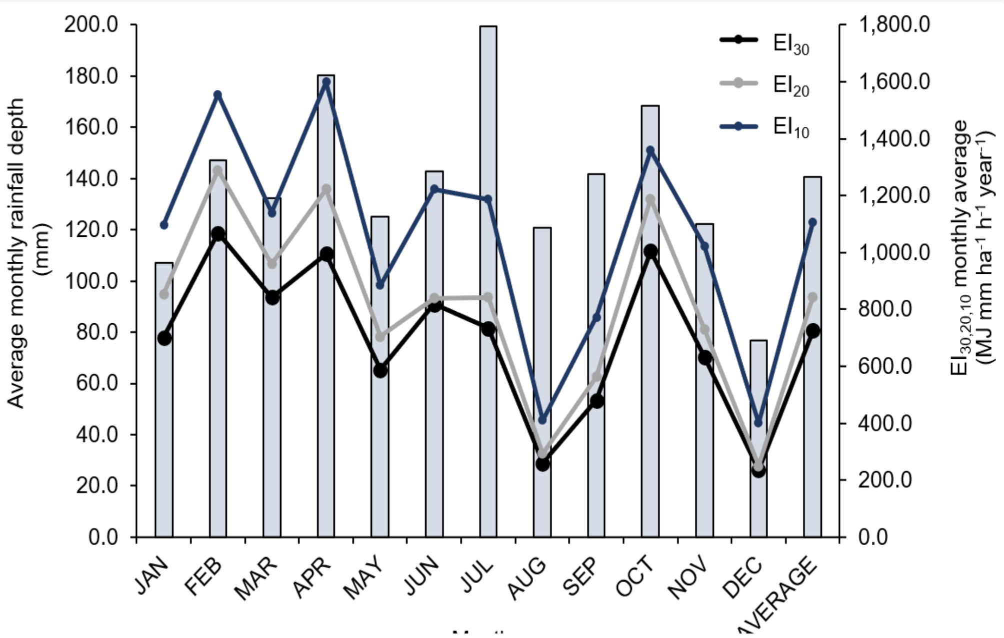

Figure 2. Average monthly rainfall distribution and EI_{30}, EI_{20}, and EI_{10} from June 1978 to June 1986.

Runoff

Effects of soil management and cover on runoff

Runoff decreases, on average, only 1.5 times from CT to NT treatments (Table 2). This result reveals that NT treatments partially controlled runoff because the efficiency in reducing runoff was lower than in reducing soil loss, which was reduced by 3.4 and 2.8 times for maize and soybeans, respectively, from CT to NT treatments (Table 2). Table 2 shows the runoff coefficients – C (%), which were obtained as the ratio between runoff and rainfall.

Table 2. Runoff depth (mm) and runoff coefficient C (%).

Year	BS		Maize CT		Soy CT		Maize NT		Soy NT	
	Runoff	C	Runoff	C	Runoff	C	Runoff	C	Runoff	C
78/79	318.5	26.5	206.5	17.2	151.8	12.6	168.1	14	233.9	19.5
79/80	297.5	19.6	135.1	8.9	177.5	11.7	117.5	7.7	191.5	12.6
80/81	347.1	30.1	242.6	21	165.1	14.3	186.4	16.1	185.8	16.1
81/82	622.4	36.1	362.1	21	483.6	28.1	215.2	12.5	277.5	16.1
82/83	676.4	28.2	764.6	31.9	866.8	36.1	375.1	15.6	418.5	17.5
83/84	544.1	32.3	483.1	28.7	531.7	31.6	394.3	23.4	445.3	26.4
84/85	594.6	31.5	566.4	30	616.7	32.7	358.4	19	393	20.8
85/86	749.1	39.1	464.6	24.3	716.2	37.4	150.2	7.8	360	18.8
Mean	518.7	30.4	403.1	22.9	463.7	25.6	245.6	14.5	313.2	18.5
SD	163.4	-	195.4	-	255.7	-	104.6	-	97.3	-
CV	31.5	-	48.5	-	55.1	-	42.6	-	31.1	-

SD = Standard deviation; CV = Coefficient of variation; BS = Bare Soil. Maize CT = Oat-Lupine-Vetch/ Maize Conventional Tillage. Soybeans CT = Barley-Oat/ Soybeans Conventional Tillage. Maize NT = Oat-Lupine-Vetch/ Maize No-Till. Soybeans NT = Barley-Oat/ Soybeans No-Till.

The highest C values were found in CT treatments, with the highest one under soybeans (25.6%) (Table 2). When rainfall intensity increased, the effects of soil management decreased. Besides, other soil features, including bulk density, had a more substantial influence. In a simulated rainfall trial with high intensity (120 mm h^{-1}), Lemos, Cassol, and Barros (2020) obtained a C value of 77% for maize under NT, which was about 1.71 times higher than that for CT.

Effects of rainfall amount and EI_{30} on runoff

Table 3 displays the regression analyses between runoff and rainfall amount (PPT) and EI_{30}. The analysis for the summer period was best explained by BS by PPTR (R^2 = 0.72). The summer PPT also revealed a good relationship with maize and soybeans under CT (Table 3), unlike NT, where winter rainfall amount was most related to runoff for maize and soybeans (Table 3). This result might be due to soil management and rainfall characteristics during winter. In other words, voluminous and prolonged rains, characteristic of the winter period in Rio Grande do Sul State, added to low evapotranspiration and the presence of soil cover may have kept soil moisture closer to saturation. Thus, rains of lower intensity, but that can be voluminous, generate surface runoff in conservation systems.

Table 3. Equation fits from runoff regression analysis.

Regression analyses	Annual runoff		Winter runoff		Summer runoff	
	Equation	r^2	Equation	r^2	Equation	r^2
BS vs PPT	0.3476(R) - 34.451	0.52	0.2516(R) + 22.194	0.26	0.3818(R) - 44.307	0.72
Maize CT vs PPT	0.3653(R) - 107.66	0.57	0.4327(R) - 170.61	0.49	0.3165(R) - 55.945	0.71
Soybeans CT vs PPT	0.5146(R) - 201.72	0.72	0.5608(R) - 234.97	0.62	0.4917(R) - 185.37	0.82
Maize NT vs PPT	0.173(R) - 22.98	0.29	0.3231(R) - 125.43	0.45	0.1047(R) + 19.299	0.39
Soybeans NT vs PPT	0.2372(R) - 43.539	0.34	0.4043(R) - 151.15	0.54	0.1681(R) - 8.9731	0.34
BS vs EI_{30}	0.038(EI_{30}) + 95.145	0.54	0.0239(EI_{30}) + 142.12	0.20	0.0473(EI_{30}) + 48.697	0.77
Maize CT vs EI_{30}	0.0386(EI_{30}) + 33.918	0.55	0.0501(EI_{30}) + 4.9812	0.54	0.0342(EI_{30}) + 46.572	0.59
Soybeans CT vs EI_{30}	0.0533(EI_{30}) + 2.7969	0.66	0.0605(EI_{30}) + 7.6732	0.60	0.0583(EI_{30}) - 52.524	0.81
Maize NT vs EI_{30}	0.0181(EI_{30}) + 44.986	0.27	0.0371(EI_{30}) + 6.6415	0.49	0.0141(EI_{30}) + 39.253	0.49
Soybeans NT vs EI_{30}	0.0268(EI_{30}) + 41.175	0.37	0.0459(EI_{30}) + 15.862	0.58	0.0273(EI_{30}) - 0.8743	0.62
BS vs EI_{20}	0.0313(EI_{20}) + 99.877	0.50	0.0179(EI_{20}) + 152.78	0.13	0.0392(EI_{20}) + 52.026	0.75
Maize CT vs EI_{20}	0.0315(EI_{20}) + 40.619	0.50	0.0426(EI_{20}) + 7.4325	0.47	0.0282(EI_{20}) + 49.567	0.56
Soybeans CT vs EI_{20}	0.0431(EI_{20}) + 13.445	0.59	0.0505(EI_{20}) + 14.301	0.50	0.0479(EI_{20}) - 45.961	0.77
Maize NT vs EI_{20}	0.0145(EI_{20}) + 49.458	0.24	.0324(EI_{20}) + 5.4667	0.45	0.0121(EI_{20}) + 37.693	0.51
Soybeans NT vs EI_{20}	0.0214(EI_{20}) + 48.201	0.32	0.0404(EI_{20}) + 13.06	0.54	0.0223(EI_{20}) + 2.5206	0.59
BS vs EI_{10}	0.0255(EI_{10}) + 90.653	0.44	0.0124(EI_{10}) + 157.51	0.08	0.0314(EI_{10}) + 46.646	0.68
Maize CT vs EI_{10}	0.0245(EI_{10}) + 38.293	0.40	0.0322(EI_{10}) + 4.9682	0.32	0.0225(EI_{10}) + 46.789	0.50
Soybeans CT vs EI_{10}	0.034(EI_{10}) + 7.6473	0.49	0.036(EI_{10}) + 22.798	0.31	0.0394(EI_{10}) - 59.761	0.73
Maize NT vs EI_{10}	0.0114(EI_{10}) + 47.841	0.19	0.0259(EI_{10}) - 4.0128	0.34	0.0103(EI_{10}) + 31.103	0.53
Soybeans NT vs EI_{10}	0.018(EI_{10}) + 37.525	0.31	0.0348(EI_{10}) - 11.936	0.48	0.0194(EI_{10}) - 12.022	0.63

*BS = Bare Soil. Maize CT = Oats-Lupine-Vetch/ Maize Conventional Tillage. Soybeans CT = Barley-Oats/ Soybeans Conventional Tillage. Maize NT = Oats-Lupine-Vetch/ Maize No-Till. Soybeans NT = Barley-Oats/ Soybeans No-Till.

When runoff was related to EI_{30}, the same results were found for CT concerning rainfall amount (Table 3). However, the results are different for NT, as erosive rainfall occurring in the summer best explains its runoff (Table 3). The coefficients of determination improved for rainfall amount and EI_{30} when runoff was related to EI_{30}, both in NT and CT systems.

EI_{30} best correlated with runoff in all CT and NT treatments (Table 3). In Jiangxi (China), Chen, Liang, Zhang, and Zhang (2020) monitored 66 rainfall events in experimental plots and reported that soil and water losses increased significantly as I_{30} increased in treatments with bare-soil, leveled, slope-direction, and mulched crops.

Nevertheless, the results were different when the winter and summer periods were evaluated separately (Table 3). EI_{10} was the best to explain runoff in NT treatments in the summer, matching the soil loss results (Table 5, Figure 4). When comparing the KE effects of rainfall with I_{30} on the hydrological variables peak flow and runoff depth during 81 rainfall events, KE explained these variables in a small rural catchment (Ramon, Minella, Merten, Barros, & Canale, 2017).

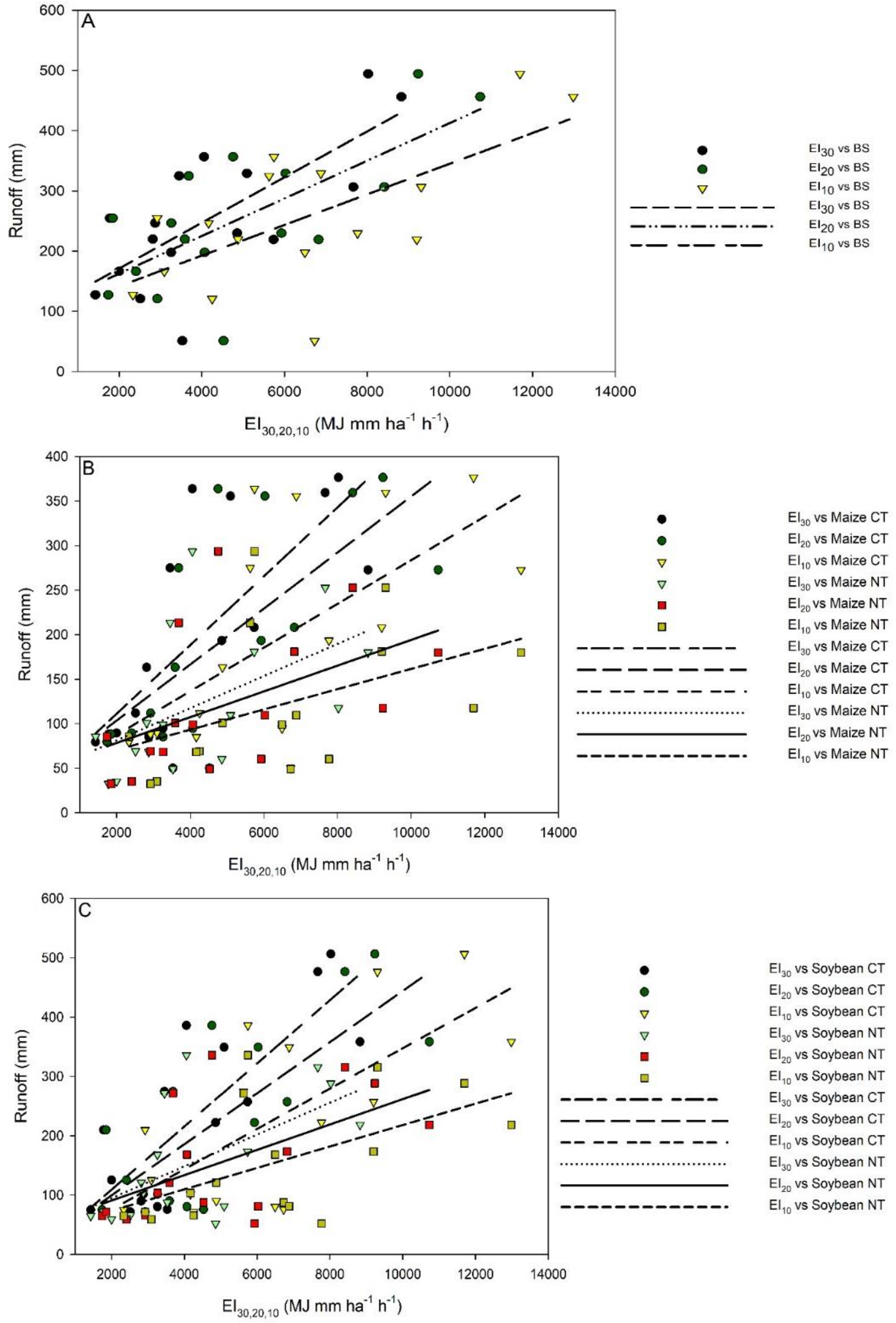

Figure 3. Influence of erosivity indices on runoff in the bare soil plot (A) and NT and CT treatments, evaluated with maize (B) and soybeans (C).

Soil losses

Effects of soil management and cover on soil losses

Table 4 lists the soil loss averages in agricultural years for each treatment. Bare soil (BS) had the highest soil losses every year, with an annual average of 330.8 t ha^{-1}, which was already expected due to tilling in this treatment and the absence of protective cover crops. In conventional tillage (CT) treatments, soil losses were also more significant than in no-tillage (NT) treatments. On average, soil losses decreased by 3.4 times from Maize CT to Maize NT succession treatments (Table 4). As for soybeans succession, losses decreased by 2.8 times from CT to NT (Table 4). These results demonstrate the beneficial effects of conservation systems in controlling soil erosion (Didoné et al., 2017; Le Gall et al., 2017) and corroborate the literature regarding their efficiency for soil losses in subtropical climate regions (Bertol et al., 2008).

The highest averages of soil losses in NT occurred in the agricultural years 1983–1984, with 107.4 and 103.5 t ha^{-1} for maize and soybeans, respectively (Table 4), five years after experiment installation (considering 1977 as year zero). This fact can be explained by a liming operation incorporated with one plowing and two harrowings in all experimental plots, according to recommendations so far known, including limestone incorporation every five years (Eltz et al., 1984). However, the effects of conservation systems could be evaluated, since soil losses were much lower in the 1982-1983 agricultural years than in the following year, even with more significant rainfall volumes and erosivity among all study periods (Tables 1 and 4).

In addition to the difference in soil losses, when comparing CT and NT, it is noteworthy that soil loss was higher in treatments where soybeans were introduced as summer crops instead of maize (Table 4). This outcome can be attributed to the different contributions and quality of residues added to the soil both for winter and summer crops. Soybeans have a decomposition rate that exceeds that of grasses, which is characteristic of leguminous species known for their low plant C/ N ratios (Rossi, Pereira, Giácomo, Betta, & Polidoro, 2013; Acosta, Amado, Silva, Santi, & Weber, 2014). This feature helps quickly reduce soil cover and protection by soybeans residues, baring the soil and leaving it more susceptible to erosion. Notwithstanding, maize crop residues are more persistent because of their higher carbon, cellulose, and hemicellulose contents, which is typical of species of the Poaceae family (Redin et al., 2014), reducing decomposition rates (Watthier, Peralta Antonio, Gomes, Rocha, & Santos, 2020).

Table 4. Annual soil losses in each treatment in t ha^{-1}.

Year	Soil loss (t ha^{-1})				
	BS	Maize CT	Soybeans CT	Maize NT	Soybeans NT
78/79	108.6	11.5	11.7	9.6	11.5
79/80	243.8	17.7	11.2	4.1	5.8
80/81	248.1	62.5	46.5	14	12.7
81/82	408.4	50.3	49.5	12.6	22.3
82/83	527.6	165.8	105.1	8.7	9.7
83/84	386.2	138.2	143.4	107.4	103.5
84/85	449.3	95.2	95.8	13.2	40.1
85/86	274.7	45.2	137.6	1.1	6
Mean	330.8	73.3	75.1	21.4	26.5
SD	126.9	51.9	49.3	32.8	31
CV	38.4	70.9	65.7	153.5	117.2

SD = Standard deviation; CV = Coefficient of variation; BS = Bare Soil. Maize CT = Oat-Lupine-Vetch/ Maize Conventional Tillage. Soybeans CT = Barley-Oat/ Soybeans Conventional Tillage. Maize NT = Oat-Lupine-Vetch/ Maize No-Till. Soybeans NT = Barley-Oat/ Soybeans No-Till.

Effects of rainfall amount and EI_{30} on soil losses

Table 5 demonstrates the soil losses in the different treatments and their relationship with rainfall amounts (PPT) and EI_{30}. PPT and EI_{30} could explain soil losses in BS. By isolating the individual effects of each period (winter and summer), both rainfall depth and EI_{30} evidenced a more substantial relationship in the summer, with r^2 values of 0.81 (BS x PPT) and 0.75 (BS x EI_{30}), respectively (Table 5). BS, unlike the others, had no vegetation cover at any time of the year. This way, no physical barriers protected the soil against raindrop impacts, breaking particles down and starting the erosion process faster (Carvalho, Eduardo, Almeida, Santos, & Sobrinho, 2015; Panachuki, Bertol, Sobrinho, Oliveira, & Rodrigues, 2011).

Table 5. Equation fits from regression analysis Soil loss.

Regression analyses	Annual soil loss		Winter soil loss		Summer soil loss	
	Equation	r^2	Equation	r^2	Equation	r^2
BS vs PPT	0.3337(R) - 115.5	0.70	0.3517(R) - 143.82	0.60	0.3084(R) - 79.487	0.81
Maize CT vs PPT	0.0732(R) - 32.354	0.32	0.147(R) - 81.674	0.57	0.0395(R) - 11.718	0.46
Soybeans CT vs PPT	0.0856(R) - 40.634	0.38	0.0905(R) - 44.857	0.46	0.0825(R) - 37.722	0.33
Maize NT vs PPT	0.004(R) + 0.665	0.07	0.0046(R) + 1.1141	0.09	0.0046(R) - 0.5661	0.10
Soybeans NT vs PPT	0.0101(R) - 2.9915	0.21	0.0032(R) + 3.0364	0.03	0.0143(R) - 7.211	0.35
BS vs EI_{30}	$0.036(EI_{30}) + 10.876$	0.70	$0.0391(EI_{30}) + 4.3359$	0.61	$0.0352(EI_{30}) + 10.645$	0.75
Maize CT vs EI_{30}	$0.0075(EI_{30}) - 2.7238$	0.29	$0.0174(EI_{30}) - 22.16$	0.67	$0.005(EI_{30}) - 2.4365$	0.51
Soybeans CT vs EI_{30}	$0.0101(EI_{30}) - 11.703$	0.45	$0.0094(EI_{30}) - 3.6625$	0.41	$0.0122(EI_{30}) - 27.838$	0.52
Maize NT vs EI_{30}	$0.0005(EI_{30}) + 1.6369$	0.12	$0.0007(EI_{30}) + 2.3707$	0.18	$0.0008(EI_{30}) - 0.5242$	0.21
Soybeans NT vs EI_{30}	$0.0013(EI_{30}) - 0.1158$	0.30	$0.0005(EI_{30}) + 3.8035$	0.09	$0.0022(EI_{30}) - 5.7955$	0.56
BS vs EI_{20}	$0.0308(EI_{20}) + 9.9103$	0.70	$0.0349(EI_{20}) - 0.2277$	0.59	$0.0302(EI_{20}) + 6.7037$	0.78
Maize CT vs EI_{20}	$0.0059(EI_{20}) - 0.7792$	0.25	$0.0153(EI_{20}) - 23.784$	0.62	$0.0042(EI_{20}) - 2.5922$	0.52
Soybeans CT vs EI_{20}	$0.0083(EI_{20}) - 10.566$	0.41	$0.0082(EI_{20}) - 4.5537$	0.38	$0.0098(EI_{20}) - 25.095$	0.47
Maize NT vs EI_{20}	$0.0005(EI_{20}) + 1.4182$	0.14	$0.0007(EI_{20}) + 2.0743$	0.20	$0.0007(EI_{20}) - 0.9088$	0.25
Soybeans NT vs EI_{20}	$0.0012(EI_{20}) - 0.5306$	0.34	$0.0005(EI_{20}) + 3.4591$	0.11	$0.0019(EI_{20}) - 6.1866$	0.60
BS vs EI_{10}	$0.0248(EI_{10}) + 2.2003$	0.60	$0.028(EI_{10}) - 10.454$	0.45	$0.0242(EI_{10}) + 2.8836$	0.70
Maize CT vs EI_{10}	$0.0039(EI_{10}) + 3.6312$	0.14	$0.0109(EI_{10}) - 19.955$	0.37	$0.0033(EI_{10}) - 2.7487$	0.45
Soybeans CT vs EI_{10}	$0.0067(EI_{10}) - 12.45$	0.36	$0.0056(EI_{10}) - 1.114$	0.21	$0.0085(EI_{10}) - 30.913$	0.49
Maize NT vs EI_{10}	$0.0004(EI_{10}) + 1.0748$	0.14	$0.0006(EI_{10}) + 1.4012$	0.22	$0.0006(EI_{10}) - 1.2284$	0.25
Soybeans NT vs EI_{10}	$0.001(EI_{10}) - 1.4224$	0.35	$0.0006(EI_{10}) + 2.6272$	0.14	$0.0016(EI_{10}) - 6.9123$	0.59

*BS = Bare Soil. Maize CT = Oats-Lupine-Vetch/ Maize Conventional Tillage. Soybeans CT = Barley-Oats/ Soybeans Conventional Tillage. Maize NT = Oats-Lupine-Vetch/ Maize No-Till. Soybeans NT = Barley-Oats/ Soybeans No-Till.

Soil losses in CT, both under soybeans and maize crops, were better explained by PPT in the winter; however, it could not explain soil losses in NT, which had a low r^2, even when winter, summer, and agricultural seasons were isolated (Table 5). When relating soil loss to EI_{30}, it better explained the dependent variable (soil loss) in CT than did PPT, which explains the soil losses under NT (Table 5), mainly when isolating winter and summer periods. In other words, erosive rainfall occurring in the summer, for both soybeans and maize, could better explain these losses (Table 5). Notably, in treatments under CT, soil losses were better described by EI_{30} in the winter for maize crops and in the summer for soybeans (Table 5).

Ramon et al. (2017) reported that I_{30} is limited in explaining sediment yields, while its concentration (suspended sediments concentration) shows a better relationship with this variable (I_{30}) in a small rural catchment in RS, Brazil. Nevertheless, the rainfall amount variable better-elucidated sediment yield (Ramon et al., 2017).

EI_{30} is globally recognized and used to relate rainfall energy with soil losses (Alewell, Borrelli, Meusburger, & Panagos, 2019). Conversely, this study revealed that depending on soil use and management, EI_{10} and EI_{20} are better suited to explain soil losses, as they are more related to the dependent and explanatory variables (Table 5, Figure 3). EI_{30} was the best to explain soil losses in BS, as it was developed based on these plot conditions (Table 5, Figure 4A). Between 2015 and 2018, the maximum rainfall intensity in 30 min (I_{30}) was considered the best indicator of soil losses in bare soil and runoff depth (Chen et al., 2020). Apart from BS, CT treatments with vegetation cover (i.e., maize and soybeans - CT) also showed the best relationship between soil losses and EI_{30} (Figure 4B and C, respectively).

When the results of NT with maize (Figure 4B, Table 5) and soybeans (Figure 4C, Table 5) were observed, EI_{10} was the best explanation for soil losses. These findings corroborate (Stocking & Elwell, 1973), wherein, for plots with vegetation, EI_5 and EI_{15} were better correlated with soil losses than EI_{30}. These results were also found when analyzing the periods (Table 5). We observed the same behavior: EI_{10} during the winter better explained soil losses regardless of the crop for NT. However, the results were different for the summer period, when EI_{20} was the best to explain NT treatments, in addition to the two treatments under BS and Maize CT (Table 5). Evaluating the effects of different rainfall intensities (10, 20, 30, 40, 50, 60, and 90 min.) on soil losses in experimental plots with an average 18–23% slope and soil covered by spontaneous vegetation, the maximum intensity in 20 min. was better related to soil losses for 12 erosive rainfall events (Mohamadi & Kavian, 2015).

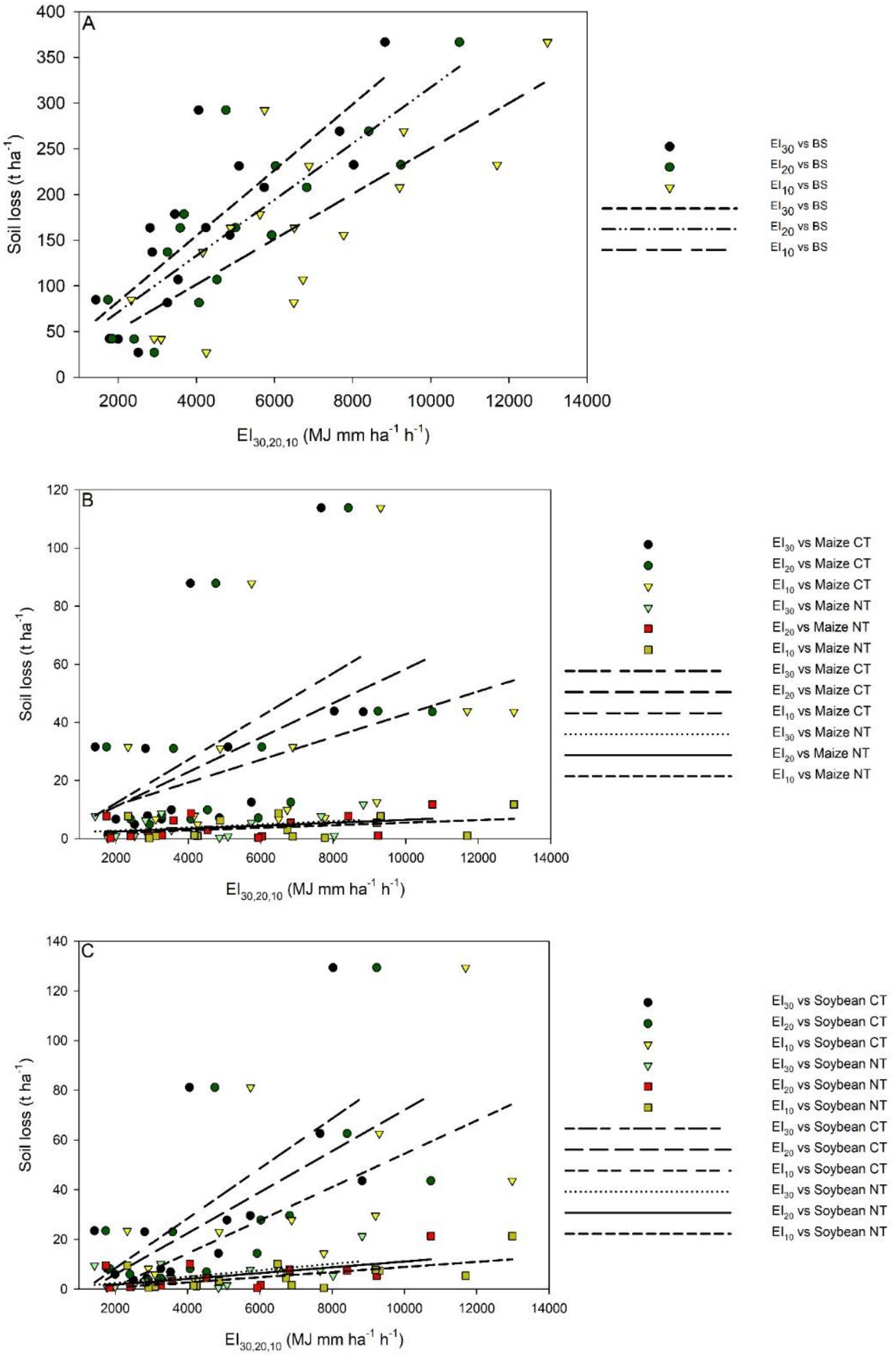

Figure 4. Influence of erosivity indices on soil loss in BS plot (A) and NT and CT systems, evaluated with maize (B) and soybeans (C).

Conclusion

Conservation systems based on soil cover (disregarding crop rotation) and no-tillage have been efficient in controlling soil losses over the years. This result is mainly based on studies in experimental plots with natural and simulated rainfall. Nonetheless, the same efficiency was not observed in controlling runoff, as demonstrated by our findings. In other words, soil loss decreases, on average, by 3.4 times from oat-lupine-vetch/ maize succession under conventional tillage to the same succession under no-tillage. In the barley-oat/ soybeans succession, losses decreased by 2.8 times from conventional to no-tillage. Runoff decreases, on average, only by 1.5 times from conventional to no-tillage. When rainfall amount and erosivity index (EI_{30}) were related to soil losses, both explained them for bare soil and treatments under conventional tillage, both for summer and winter rainfall events. However, plots under no-tillage were better correlated with winter rainfall, both in energy (EI_{30}) and volume (mm). Moreover, different soil management and cover types were observed by evaluating rainfall energy through erosivity indices (EI_{30}, EI_{20}, and EI_{10}) under annual soil losses. That is, EI_{30}, as expected, is the variable that best describes soil losses for bare soil and conventional tillage. However, EI_{10} best explains soil losses in no-tillage systems. For runoff, less rainfall intensity is required for starting, showing that EI_{30} was the best related to an annual runoff under both conventional and no-tillage systems.

References

Acosta, J. A. A., Amado, T. J. C., Silva, L. S., Santi, A., & Weber, M. A. (2014). Decomposição da fitomassa de plantas de cobertura e liberação de nitrogênio em função da quantidade de resíduos aportada ao solo sob sistema plantio direto. *Ciência Rural*, *44*(5), 801-809. DOI: https://doi.org/10.1590/S0103-84782014005000002

Alewell, C., Borrelli, P., Meusburger, K., & Panagos, P. (2019). Using the USLE: Chances, challenges and limitations of soil erosion modelling. *International Soil and Water Conservation Research*, *7*(3), 203-225. DOI: https://doi.org/10.1016/j.iswcr.2019.05.004

Almagro, A., Oliveira, P. T. S., Nearing, M. A., & Hagemann, S. (2017). Projected climate change impacts in rainfall erosivity over Brazil. *Scientific Reports*, *7*(1), 1-12. DOI: https://doi.org/10.1038/s41598-017-08298-y

Amado, J. T., Bayer, C., Eltz, F. L. F., & Brum, A. C. R. (2001). Potencial de culturas de cobertura em acumular carbono e nitrogênio no solo no plantio direto e a melhoria da qualidade ambiental. *Revista Brasileira de Ciência do Solo*, *25*(1),189-197. DOI: https://doi.org/10.1590/S0100-06832001000100020

Anache, J. A. A., Wendland, E. C., Oliveira, P. T. S., Flanagan, D. C., & Nearing, M. A. (2017). Runoff and soil erosion plot-scale studies under natural rainfall: A meta-analysis of the Brazilian experience. *Catena*, *152*, 29-39. DOI: https://doi.org/10.1016/j.catena.2017.01.003

Barcelos, A. A., Cassol, E. A., & Denardim, J. E. (1999). Infiltração de água em um Latossolo Vermelho-escuro sob condições de chuva intensa em diferentes sistemas de manejo, *Revista Brasileira de Ciência do Solo*, *23*(1), 35-43. DOI: https://doi.org/10.1590/S0100-06831999000100005

Bertol, I., Barbosa, F. T., Fabian, E. L., Pegoraro, R., Zavaschi, E., González, A. P., & Vázquez, E. V. (2008). Escoamento superficial em diferentes sistemas de manejo em um Nitossolo Háplico típico Surface runoff in different soil management systems on Typic Hapudox soil. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *12*(3), 243-250.

Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Yang, J. E., Alewell, C., ... Ballabio, C. (2020). Land use and climate change impacts on global soil erosion by water (2015-2070). *Proceedings of the National Academy of Sciences of the United States of America*, *117*(36), 21994-22001. DOI: https://doi.org/10.1073/pnas.2001403117

Cabeda, M. S. V. (1976). *Computation of storm EI Values*. West Lafayette, IN: Purdue University.

Chen, X., Liang, Z., Zhang, Z., & Zhang, L. (2020). Effects of soil and water conservation measures on runoff and sediment yield in red soil slope farmland under natural rainfall. *Sustainability*, *12*(8), 1-19. DOI: https://doi.org/10.3390/SU12083417

Chowaniak, M., Głąb, T., Klima, K., Niemiec, M., Zaleski, T., & Zuzek, D. (2020). Effect of tillage and crop management on runoff, soil erosion and organic carbon loss. *Soil Use and Management*, *36*(4), 581-593. DOI: https://doi.org/10.1111/sum.12606

Cogo, N. P., Levien, R., & Schwarz, R. A. (2003). Perdas de solo e água por erosão hídrica influenciadas por métodos de preparo, classes de declive e níveis de fertilidade do solo, *Revista Brasileira de Ciência do Solo*, *27*(4), 743-753. DOI: https://doi.org/10.1590/S0100-06832003000400019

Cunha, G. R., Pires, J. L. F., Dalmago, G. A., Santi, A., Pasinato, A., Silva, A. A. G., ... Rosa, C. M. (2011). El Niño/La Niña - Oscilação Sul e seus impactos na agricultura brasileira: fatos, especulações e aplicações. *Revista Plantio Direto*, *121*, 18-22.

Carvalho, D. F., Eduardo, E. N., Almeida, W. S., Santos, L. A. F., & Sobrinho, T. A. (2015). Water erosion and soil water infiltration in different stages of corn development and tillage systems. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *19*(11), 1072-1078. DOI: https://doi.org/10.1590/1807-1929/agriambi.v19n11p1072-1078

Debarba, L., & Amado, T. J. C. (1997). Desenvolvimento de sistemas de produção de milho no sul do Brasil com características de sustentabilidade. *Revista Brasileira de Ciência do Solo*, *21*, 473-480.

Deuschle, D., Minella, J. P. G., Hörbe, T. A. N., Londero, A. L., & Schneider, F. J. A. (2019). Erosion and hydrological response in no-tillage subjected to crop rotation intensification in southern Brazil. *Geoderma*, *340*, 157-163. DOI: https://doi.org/10.1016/j.geoderma.2019.01.0103

Didoné, E. J., Minella, J. P. G., & Evrard, O. (2017). Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-tillage of Southern Brazil. *Soil and Tillage Research*, *174*(1000), 24-33. DOI: https://doi.org/10.1016/j.still.2017.05.011

Didoné, E. J., Minella, J. P. G., Reichert, J. M., Merten, G. H., Dalbianco, L., Barrros, C. A. P., & Ramon, R. (2014). Impact of no-tillage agricultural systems on sediment yield in two large catchments in Southern Brazil. *Journal of Soils and Sediments*, *14*(7), 1287-1297. DOI: https://doi.org/10.1007/s11368-013-0844-6

Eltz, F. L. F., Cassol, E. A., Guerra, M., & Abrão, P. U. R. (1984). Perdas de solo e água por erosão em diferentes sistemas de manejo e coberturas vegetais em solo "São Pedro" (Podzólico vermelho-amarelo) sob chuva natural. *Revista Brasileira de Ciência do Solo*, *8*(2), 245-249.

Empresa de Assistência Técnica e Extensão Rural [EMATER]. (2012). *Relatório do acompanhamento da safra 2011-2012*. Retrieved on Jan. 24, 2012 from http://www.emater.tche.br/site/arquivos_pdf/safra/safraTabela_12012012.pdf

Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA]. (2023). *Soja no mundo*. Retrieved on September 7, 2023 from https://www.embrapa.br/soja/cultivos/soja1/dados-economicos

Grimm, A. M., Almeida, A. S., Beneti, C. A. A., & Leite, E. A. (2020). The combined effect of climate oscillations in producing extremes: the 2020 drought in southern Brazil. *Revista Brasileira de Recursos Hídricos*, *25*, 1-12. DOI: https://doi.org/10.1590/2318-0331.252020200116

Foster, G. R., McCool, D. K., Renard, K. G., & Moldenhauer, W. C. (1981). Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation*, *36*(6), 355-359.

IUSS Working Group WRB. (2015). *World reference base for soil resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps.* Rome, IT: FAO. (World Soil Resources Reports No. 106).

Le Gall, M., Evrard, O., Dapoigny, A., Tiecher, T., Zafar, M., Minella, J. P. G., ... Ayrault, S. (2017). Tracing sediment sources in a subtropical agricultural catchment of southern Brazil cultivated with conventional and conservation farming practices. *Land Degradation and Development*, *28*(4), 1426-1436. DOI: https://doi.org/10.1002/ldr.2662

Lemos, A. M., Cassol, E. A., & Barros, C. A. P. (2020). Losses of water, soil, and nutrients during high-intensity simulated rainfall in two soil management systems different sources of fertilization. *Ciência Rural*, *50*(10), 1-11. DOI: https://doi.org/10.1590/0103-8478cr20190306

Merten, G. H., Araújo, A. G., Biscaia, R. C. M., Barbosa, G. M. C., & Conte, O. (2015). No-tillage surface runoff and soil losses in southern Brazil. *Soil and Tillage Research*, *152*, 85-93. DOI: https://doi.org/10.1016/j.still.2015.03.014

Miranda, R. B., Scarpinella, G. D., Silva, R. S., & Mauad, F. F. (2015). Water erosion in Brazil and in the world: A brief review. *Modern Environmental Science and Engineering*, *1*(1), 17-26. DOI: https://doi.org/10.15341/mese(2333-2581)/01.01.2015/003

Mohamadi, M. A., & Kavian, A. (2015). Effects of rainfall patterns on runoff and soil erosion in field plots. *International Soil and Water Conservation Research*, *3*(4), 273-281. DOI: https://doi.org/10.1016/j.iswcr.2015.10.001

Nóia Júnior, R. S., Fraisse, C. W., Karrei, M. A. Z., Cerbaro, V. A., & Perondi, D. (2020). Effects of the El Niño Southern Oscillation phenomenon and sowing dates on soybean yield and on the occurrence of extreme weather events in southern Brazil. *Agricultural and Forest Meteorology*, *290*, 1-6. DOI: https://doi.org/10.1016/j.agrformet.2020.108038

Panachuki, E., Bertol, I., Sobrinho, T. A., Oliveira, P. T. S., & Rodrigues, D. B. B. (2011). Perdas de solo e de água e infiltração de água em latossolo vermelho sob sistemas de manejo. *Revista Brasileira de Ciência do Solo*, *35*(5), 1777-1785. DOI: https://doi.org/10.1590/S0100-06832011000500032

Panizzi, A. R. (2013). History and contemporary perspectives of the integrated pest management of soybean in Brazil. *Neotropical Entomology*, *42*(2), 119–127. DOI: https://doi.org/10.1007/s13744-013-0111-y

Ramon, R., Minella, J. P. G., Merten, G. H., Barros, C. A. P., & Canale, T. (2017). Kinetic energy estimation by rainfall intensity and its usefulness in predicting hydrosedimentological variables in a small rural catchment in southern Brazil. *Catena*, *148*(Part 2), 176-184. DOI: https://doi.org/10.1016/j.catena.2016.07.015

Redin, M., Recous, S., Aita, C., Dietrich, G., Skolaude, A. C., Ludke, W. H., ... Giacomini, S. J. (2014). How the chemical composition and heterogeneity of crop residue mixtures decomposing at the soil surface affect C and N mineralization. *Soil Biology and Biochemistry*, *78*, 65-75. DOI: https://doi.org/10.1016/j.soilbio.2014.07.014

Rossi, C. Q., Pereira, M. G., Giácomo, S. G., Betta, M., & Polidoro, J. C. (2013). Decomposição e liberação de nutrientes da palhada de braquiária, sorgo e soja em áreas de plantio direto no cerrado goiano. *Semina: Ciencias Agrarias*, *34*(4), 1523–1534. DOI: https://doi.org/10.5433/1679-0359.2013v34n4p1523

Schick, J., Bertol, I., Batistela, O., & Júnior, A. A. B. (2000). Erosão hídrica em Cambissolo Húmico alumínico submetido a diferentes sistemas de preparo e cultivo do solo: I. Perdas de solo e água. *Revista Brasileira de Ciência do Solo*, *24*(2), 427-436. DOI: https://doi.org/10.1590/S0100-06832000000200019

Silva, T. S., Cassol, E. A., Levien, R., Eltz, F. L. F., & Schmidt, M. R. (2020). Long-term wheat-soybeans successions affecting the cover and soil management factor in usle, under subtropical climate. *Revista Brasileira de Ciência do Solo*, *44*, 1-13. DOI: https://doi.org/10.36783/18069657rbcs20190180

Stocking, M. A., & Elwell, H. A. (1973). Prediction of subtropical storm soil losses from field plot studies. *Agricultural Meteorology*, *12*, 193-201. DOI: https://doi.org/10.1016/0002-1571(73)90019-8

Strohmeier, S., Laaha, G., Holzmann, H., & Klik, A. (2016). Magnitude and occurrence probability of soil loss: a risk analytical approach for the plot scale for two sites in lower Austria. *Land Degradation and Development*, *27*(1), 43-51. DOI: https://doi.org/10.1002/ldr.2354

Theisen, G., Vernetti Jr., F., & Silva, J. J. C. (2009). *Cultivo de soja em terras baixas em ano de El-niño*. Pelotas, RS: Embrapa Clima Temperado. Retrieved on Mar. 7, 2012 from https://ainfo.cnptia.embrapa.br/digital/bitstream/CPACT-2010/12306/1/soja-giovani.pdf

Watthier, M., Peralta Antonio, N., Gomes, J. A., Rocha, S. B. F., & Santos, R. H. S. (2020). Decomposition of green manure with different grass: legume ratios. *Archives of Agronomy and Soil Science*, *66*(7), 913-924. DOI: https://doi.org/10.1080/03650340.2019.1644622

Wischmeier, W. H. (1959). A rainfall erosion index for a universal soil-loss equation. *Soil Science Society of America Journal*, *23*(3), 246-249. DOI: https://doi.org/10.2136/sssaj1959.03615995002300030027x

Wischmeier, W. H., & Smith, D. D. (1958). Rainfall energy and its relationship to soil loss. *Eos, Transactions American Geophysical Union*, *39*(2), 285-291. DOI: https://doi.org/10.1029/TR039i002p00285

Yang, X., Sun, W., Li, P., Mu, X., Gao, P., & Zhao, G. (2019). Integrating agricultural land, water yield and soil conservation trade-o ff s into spatial land use planning. *Ecological Indicators*, *104*, 219-228. DOI: https://doi.org/10.1016/j.ecolind.2019.04.082

Zhuang, Y., Du, C., Zhang, L., Du, Y., & Li, S. (2015). Research trends and hotspots in soil erosion from 1932 to 2013: A literature review. *Scientometrics*, *105*(2), 743-758. DOI: https://doi.org/10.1007/s11192-015-1706-3