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Impact of pig slurry application on soil and water losses: Comparison with a historical series

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ABSTRACT: Water erosion in soil is influenced by several factors, including rain, relief, cover, and management and conservation practices. Also, erosion is affected by pig slurry (PS) applied to the soil as a fertilizer. The objectives of this research were i) to evaluate water erosion in a Humic Cambisol cultivated with *Zea mays* L., *Avena strigosa*, *Glycyne max* L., and *Raphanus sativus* in rotation after PS dispersal under different tillage treatments, namely: no-tillage (NT), minimum tillage (MT), rotation tillage (RT) and conventional tillage (CT), and ii) to compare erosion before and after PS application in a single dose of 50 m³ ha⁻¹ in each crop, soon after the germination of the crops. NT had lower soil and water loss, which were reduced by 81 and 13%, respectively, in relation to CT. Differences in soil and water losses were lower between MT and RT, than between other treatments. The contents of phosphorus (P) and potassium (K) in the superficial layers of the soil were higher under NT than under CT. The contents of P and K in the sediments were higher in the NT than in the CT treatment. Also, the contents of P and K were significantly higher in sediments than in water, especially under NT. The application of a single PS dose on the soil surface increased soil P and K contents and decreased water erosion compared to the 19-year historical series that preceded this research in different soil management systems without PS application.

Key words: conservation tillage, erosivity, crop rotation, organic fertilization

Impacto da aplicação de dejetos de suínos nas perdas de solo e água: Comparação com uma série histórica

RESUMO: A erosão hídrica no solo é influenciada por diversos fatores, incluindo chuva, relevo, cobertura, e manejo e práticas conservacionistas. Ainda, a erosão é afetada pelo dejetos suíno (DS) aplicado ao solo como fertilizante. Os objetivos desta pesquisa foram i) avaliar a erosão em Cambissolo Húmico, após aplicação de DS sob diferentes tratamentos: plantio direto (PD), cultivo mínimo (CM), rotação de preparos (RP) e plantio convencional (PC), cultivados com *Zea mays* L., *Avena strigosa*, *Glycyne max* L., e *Raphanus sativus* em rotação, e ii) comparar a erosão antes e após a aplicação de DS em dose única de 50 m³ ha⁻¹ em cada cultivo, logo após a germinação das culturas. O PD apresentou menor perda de solo e água, reduzindo em 81 e 13%, respectivamente, em relação à PC. Diferenças nas perdas de solo e água foram menores, entre CM e RP, do que nos outros tratamentos. O teor de fósforo (P) e potássio (K) nas camadas superficiais do solo foi maior em PD do que em PC. Os teores de P e K nos sedimentos foram maiores no PD que no PC. Ainda, os teores de P e K foram significativamente maiores nos sedimentos do que na água, especialmente PD. A aplicação da dose única de DS na superfície do solo melhorou os teores de P e K do solo e diminuiu a erosão hídrica em relação ao histórico de 19 anos que antecederam esta pesquisa, em diferentes sistemas de manejo do solo e sem aplicação de DS.

Palavras-chave: preparo conservacionista, erosividade, rotação de culturas, adubação orgânica



INTRODUCTION

Water erosion is caused by the action of rain on the soil, involving the disaggregation, transportation, and depositional phases of sedimentation. These phases may be distinct from each other or may occur concomitantly (Ellison, 1947). The increase in water erosion over time is derived from the intensification of soil management, especially in the condition of agricultural crops, with a close relationship between erosion and soil management (Vanwalleghem et al., 2017).

The use of pig slurry (PS) as fertilizer is an alternative practice used in agriculture. Therefore, this practice should be studied, taking into account the effects of PS on the soil, the benefits in erosion reduction, the influence on crop productivity, and possible environmental contamination outside the place of erosion (Gunkel-Grillon et al., 2015).

Phosphorous is a poorly soluble and slightly mobile element in the soil and, therefore, tends to concentrate on the surface in the absence of mechanical preparation, as in the case in no-tillage (NT) (Roberts et al., 2017). Thus, the element becomes available to be transported by runoff, mainly adsorbed to the sediments, in the event of water erosion.

Potassium is the element in the soil that present greater accumulation due to the use of PS, followed by calcium and magnesium (Kraaijvanger & Veldkamp, 2015). In the absence of mechanical preparation, it tends to concentrate on the soil surface, being easily captured by the runoff, both adsorbed to the sediments and soluble in water, and transported via water erosion.

The objective of this study was to evaluate water erosion by quantifying soil, water, and P and K losses in different types of soil management under PS application during four cultivations, and to compare the results with those obtained in a historical data series (19 years) obtained before the application of the PS.

MATERIAL AND METHODS

This study was developed in the south of the Santa Catarina Plateau, State of Santa Catarina, Brazil (27° 49' S; 50° 20' W; 923 m), between October 2012 and October 2014. The climate is of type Cfb according to the Köppen classification system, with mean annual precipitation of 1,503 mm. The soil is a clayey Inceptisols according to the Soil Survey Staff (2014), with a mean slope of 0.102 m m⁻¹.

The implantation of the experiment was in a completely randomized design, with two replicates in each treatment and factorial scheme (4 x 4). In Table 1 the factorial scheme comprised the four sample depths versus the four treatments and, in Tables 3, 4 and 5, the scheme comprised the fourth crops studied versus of the respective treatments.

The experiment was conducted in experimental unit of 3.5 x 22.1 m (77.35 m²), 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 experimental unit.

In the treatments, the crops and soil management were carried out twice a year. Once, at the time of the implantation of crops, soil preparation was done as follows: preparation with

one plowing + two harrowings (CT) and preparation with one scarification + one harrowing (MT). Another soil preparation occurred in each crop during the period of the research, including: one scarification + one harrowing, one plowing + two harrowings, no-tillage and two light harrowings (RT), and without tillage of the soil (NT). Mechanical operations of soil tillage, in the direction parallel to the slope for the treatments with tillage, were carried out in the following way: a reversible plow with three discs set to an operating depth of 0.20 m, a chisel plow with thirteen rods spaced at 0.25 m apart from each other with an operating depth of 0.15 m from the soil surface, and a 32-disc tandem harrow adjusted to operate at a depth of 0.12 m.

In each crop and in each treatment, 50 m³ ha⁻¹ of PS were applied to the soil immediately after the total germination of the crops, in a total of four applications during the research, that is, 200 m³ ha⁻¹ in the four crops, manually and with the aid of watering cans. The PS presented, on mean, 2.8% of dry matter, 1.14% of P, and 0.42% of K according to the methodology described in Tedesco et al. (1995). During the four crop treatments, no chemical fertilizer was applied. Corn (*Zea mays* L.), black oats (*Avena strigosa*), soybean (*Glycine max* L.), and wild radish (*Raphanus sativus*) were cultivated in this order. Corn and soybean were sown with the aid of a "saraquá" or "matraca" manual seeder, while oats and wild radish were hand sown.

Rainfall was monitored by pluviograms from a rain gauge installed at 600 m from the experimental area. For the determination of the erosivity factor (EI₃₀) of the rains, daily pluviograms, model IH-01-01, with a recording range of 10 mm of precipitation and of 24 h of duration were used, with intervals of 0.2 mm for the volume and 10 min for the time. The criterion adopted for the definition of erosive rain was that of Wischmeier & Smith (1958).

After the occurrence of erosive rains, sediments and water were quantified. Samples of the runoff were collected in glass vials with a capacity of 280 cm³ and weighed. After decantation of the sediments in the vials, caused by the addition of HCl, the water was siphoned and the vials with the wet sediments were oven dried at 55-60 °C for 24 to 48 h and then weighed. From these weights, the amount of water and the mass of soil contained in suspension in the vials were calculated and extrapolated to the flood volume of the tanks. Thus, total water and soil losses were calculated for each erosive rainfall. The procedures for collecting samples in the field, their processing in the laboratory, and the calculation of the total losses followed the methodology suggested by Cogo (1978). In the field, other samples of runoff were collected in vials of the same volume for further chemical analysis. After sedimentation without chemical addition, the water was siphoned, filtered, and conditioned in a refrigerator, and the sediments were air dried and conditioned for further chemical analysis.

In the central part of each plot, prior to the installation of the research and at its end, samples of the soil, deformed and non-deformed, were collected in the 0-0.025, 0.025-0.05, 0.05-0.10 and 0.10-0.20 m layers. In the deformed samples, the stability of soil aggregates in water and the extractable P and exchangeable K contents were determined. In the

non-deformed samples, collected in steel rings of 2.5 and 5 cm in height and 5 cm in diameter, the volume of macropores (Ma) and soil bulk density (BD) were determined according to Blake & Hartge (1986) methodology.

With the aid of a tension table with a sand column, the volume of Ma was determined by means of suction caused by a water column of 0.60 m. Afterwards, the samples were dried at 105 °C and weighed to calculate soil density. The stability of aggregates in water, expressed as the weighted mean diameter (WAD), was determined by wet balancing using the method proposed by Yoder (1936) and modified by Kemper & Chepil (1965), using a set of four open-sieve meshes of 4.76, 2, 1, and 0.25 mm with 40 vertical oscillations per minute for 10 min.

The contents of extractable P and exchangeable K in soil and erosion sediments were extracted by the Mehlich-1 double acid method, with P determined by colorimetry and K by flame photometry. The soluble P and K contents in the runoff water were determined directly and respectively by colorimetry and flame photometry.

The total quantities of P and K lost by water erosion were calculated as follows: the content of each element contained in the sediment and runoff water was multiplied by the total amount of soil and water lost by erosion. For each element, total loss was the result of the sum of the losses in the sediments and erosion water.

The data were submitted to analysis of variance and, when the applied treatment generated a significant effect on the measured variable, the mean comparison was performed through the Tukey test at 0.05 significance level. For this purpose, the statistical program SISVAR 5.6 (Ferreira, 2014) was used.

RESULTS AND DISCUSSION

The physical attributes of the soil presented better conditions after the application of the PS (end of the research) than before, in all treatments and layers (Table 1). The volume of Ma increased by 36%, from 0.11 to 0.15 m³ m⁻³, in the mean of treatments and soil layers. The soil BD decreased by 6.7%, from 1.35 to 1.26 kg m⁻³, while the weighted WMD increased by 13%, from 4.72 to 5.33 mm, in the mean of the treatments and soil layers. In particular, the improvement of these attributes occurred in the superficial layers of soil. Improvements in soil physical attributes by addition of PS were also verified by Mecabô Junior et al. (2014) and Rosa et al. (2017). The PS possibly stimulated the biological activity of the soil, being reflected in the increase of the stability of the aggregates and a decrease in the bulk density with a corresponding increase of the macroporosity. The increase in Ma, in turn, possibly contributed to an increase in the infiltration of water in the soil and a reduction in erosion during the period of this research in relation to the previous period.

The concentration of extractable P and exchangeable K increased after the application of PS, in comparison to the previous period without the PS, in all treatments and soil layers (Table 1). The P concentration increased by 37%, from 9.6 to 13.1 mg dm⁻³, while the K increased by 84%, from 115 to 212 mg dm⁻³, in the mean of treatments and soil layers. In particular, the improvement of these attributes occurred in the soil surface. The P increased by 46%, while the K increased by 83% in the mean of layers 0 to 2.5 and 2.5 to 5 cm of the soil, due to the effect of the PS. Similar results were also reported by Boitt et al. (2018), relating soil chemical attributes to PS

Table 1. Mean values of macropores (MA), bulk density (BD), weighted mean diameter (WMD) of aggregates, extractable P and exchangeable K before (27/10/2012) and after (22/10/2014) applying the pig slurry (PS), in treatments and soil layers in an Inteceptisol

Layers (cm)	Before research begins				After research is finished					
	NT	MT	RT	CT	Mean	NT	MT	RT	CT	Mean
Macropores (m ³ m ⁻³)										
0-2.5	0.13 aA	0.10 aA	0.15 aA	0.10 aA	0.12	0.15 aA	0.13 aA	0.13 aA	0.16 aA	0.14
2.5-5	0.12 aA	0.11 aA	0.08 aA	0.09 aA	0.10	0.16 aA	0.12 aA	0.10 aA	0.09 aA	0.12
5-10	0.10 aA	0.10 aA	0.12 aA	0.10 aA	0.11	0.18 aA	0.18 aA	0.20 aA	0.16 aA	0.18
10-20	0.11 aA	0.10 aA	0.11 aA	0.08 aA	0.10	0.20 abA	0.16 abA	0.16 abA	0.10 bA	0.16
Bulk density (kg dm ⁻³)										
0-2.5	1.25 aA	1.27 aA	1.31 abA	1.23 aA	1.27	1.09 aA	1.13 aA	1.16 aA	1.23 abA	1.15
2.5-5	1.29 aAB	1.34 aAB	1.39 aAB	1.31 aAB	1.33	1.14 aA	1.16 aA	1.19 aA	1.22 aA	1.18
5-10	1.33 aAB	1.39 aB	1.44 aAB	1.36 aBC	1.38	1.33 aA	1.30 aA	1.30 aA	1.43 aA	1.34
10-20	1.43 aB	1.36 aAB	1.39 aB	1.41 aC	1.40	1.32 aA	1.36 aA	1.38 aA	1.40 aA	1.37
Weighted mean diameter of aggregates (mm)										
0-2.5	5.04 aA	4.84 aA	4.65 aA	4.39 aA	4.73	5.91 aA	6.65 aA	5.76 aA	4.84 bA	5.79
2.5-5	5.19 aA	5.21 aA	4.17 bBC	4.45 cA	4.76	5.94 aA	5.56 aA	5.57 aA	4.81 aA	5.47
5-10	5.30 aA	5.01 abA	4.25 abAB	4.00 bA	4.64	5.85 aA	5.34 aA	5.09 aB	4.62 abA	5.23
10-20	5.04 aA	5.24 aA	3.88 bC	4.86 aA	4.76	5.21 aA	4.75 abA	5.15 aB	4.22 bA	4.83
Extractable P (mg dm ⁻³)										
0-2.5	22.9 aA	12.2 bA	15.1 bA	6.5 cA	14.2	43.4 aA	14.3 bcA	20.8 bA	7.1 cdA	21.4
2.5-5	16.4 aB	11.6 bA	9.6b AB	5.5 cAB	10.8	30.1 aB	13.9 bA	10.7 bB	6.1 bAB	15.2
5-10	7.6 abC	12.2 bA	10.3 abB	4.1 bcB	8.6	8.3 aC	16.9 bA	13.8 bB	4.1 cB	10.8
10-20	5.2 aC	3.0 aB	6.2 aB	4.0 aB	4.6	5.5 abC	3.6 abB	6.4 aC	4.1 abB	4.9
Exchangeable K (mg dm ⁻³)										
0-2.5	222 aA	157 bA	122 cA	95 cdA	149	371 aA	270 bA	248 bA	232 bA	280
2.5-5	133 aB	170 bB	109 cA	77 dAB	122	221 abAB	244 aA	199 bB	201 bAB	216
5-10	124 aB	121 bC	98 cA	62 dB	101	205 aAB	192 aA	177 aBC	167 aBC	185
10-20	101 aC	112 aD	68 bB	61 bcB	86	191 aB	176 abA	150 bC	145 bC	166

NT - No-tillage; MT - Minimum tillage; RT - Rotation tillage; CT - Conventional tillage; BS - Bare soil. Means followed by the same lowercase letter in the columns do not differ from each other and, in the lines, means followed by the same uppercase letter do not differ from each other, by Tukey test at $p \leq 0.05$

doses. The increase of these two chemical attributes due to the application of PS to the soil surface layer was beneficial.

NT generally presented higher values of Ma, WMD, P and K, and lower values of BD than CT, especially in the surface layer, both at the beginning and at the end of the research (Table 1). This confirms that NT improves the main attributes of the soil, especially on the surface, in relation to CT, as suggested by Montoya et al. (2017).

Soil losses (SL) during the soil PS application varied widely, from 0.11 to 2.26 Mg ha⁻¹, while in the period of the historical series without PS, the values varied, from 0.19 to 4.09 Mg ha⁻¹, including treatments and crop cycles (Table 2). This variation of values was influenced by soil management treatments, from NT to CT and, partly, by erosivity (EI₃₀). The EI₃₀ varied 2.4 times, considering the crop periods after the PS application, and 1.8 times considering the period of the historical series without PS, between the highest and the lowest value. The variation of SL values, normal in this type of experiment, was also influenced by the temporal variation of soil water content due to irregular distribution of rainfall. The ratio between SL and EI₃₀ values reflects the relative effect of cropping systems on reducing erosion in face of rainfall erosivity.

Thus, this ratio was 2.68 x 10⁻⁴ for the period in which the treatments received doses of the PS and 5.45 x 10⁻⁴ for the period of the historical series of data without the PS. This means that during the period of application of the PS, the different types of soil management were twice as effective as in the previous period, without PS, in the control of the SL, in the mean of treatments. The results of the present study were similar to those of other authors in such studies, using simulated rainfall and natural rainfall (Schick et al., 2000; Almeida et al., 2016).

Table 2. Erosivity (EI₃₀) of rainfall, soil loss (SL), precipitation, and water losses (WL) in crop and soil management treatments in an Inceptisol and mean historical series

Crops	EI ₃₀ (MJ mm ha ⁻¹ h ⁻¹)	NT	MT	RT	CT	Mean
		Soil loss (Mg ha ⁻¹)				
Maize	3.042	0.17	0.36	0.23	0.85	0.40
Historic ¹	3.514	0.41	1.17	-	2.47	1.35
Oat	1.766	0.43	0.73	1.24	1.91	1.08
Historic ¹	1.952	0.53	0.94	-	1.85	1.11
Soybean	4.224	0.11	0.23	0.54	1.44	0.58
Historic ¹	2.603	0.19	0.55	-	1.94	0.89
Wild radish	2.741	0.53	0.94	0.68	2.26	1.10
Historic ¹	2.346	1.05	1.76	-	4.09	2.30
Mean crops	2.943	0.31	0.57	0.67	1.62	0.79
Mean historical	2.604	0.55	1.11	-	2.59	1.42
	Precipitation (mm)	Water loss (% of rain)				
Maize	701	4	5	4	13	6.5
Historic ¹	760	5	11	-	24	13.3
Oat	852	4	8	6	14	8.0
Historic ¹	747	7	14	-	33	18.0
Soybean	822	5	7	7	22	10.3
Historic ¹	724	6	8	-	24	12.7
Wild radish	923	9	19	11	25	16.0
Historic ¹	908	11	19	-	33	21.0
Mean crops	825	6	10	7	19	10.5
Mean historical	785	7	13	-	29	16.3

NT - No tillage; MT - Minimum tillage; RT - Rotation tillage; CT - Conventional tillage.

¹Data of Schick (2014). (-) - Nonexistent

NT was the most effective treatment to decrease SL in relation to the other treatments, both before and after the application of PS (Table 2). These losses were reduced by 81% in NT compared to CT during the research, and by 79% in the period prior to the use of the PS in the historical series. Therefore, the relative efficacy of NT in relation to CT in erosion control was not influenced by the application of PS in the soil. MT and RT were similar to each other, but presented intermediate SL values to the others (NT and CT). The SL values in the mean of the MT and RT treatments were 1.8 times higher than in NT and 80% lower than in CT, in the mean of the moments (before and after the PS). The partial mobilization of soil in MT and RT, and to a greater extent in NT and a lesser degree in CT, partially explains the results.

In this research, where the treatments were under the influence of PS, the SL was 55% lower in spring-summer (maize and soybean) than in autumn-winter (oats and wild radish), in the mean of the treatments, whereas the EI₃₀ was 61% higher in spring-summer; this difference was respectively 34 and 42% in the period prior to the application of the PS (Table 2). This probably occurred because, in the spring-summer, the soil was drier and more able to infiltrate water, thus generating less runoff than in autumn-winter for both periods.

The results of SL and EI₃₀ mean that rainfall erosivity did not influence SL, especially in NT, RT and MT treatments, due to the present soil cover being the most important factor in the reduction of erosion, together with the roughness present in the RT and MT. In CT treatment, SL in spring-summer was 45% lower than in autumn-winter, while rainfall erosivity was 61% higher in the period with PS, meaning that, in this case too, erosivity had little influence on SL, despite the low surface coverage. This was due to the high roughness generated, as well as the incorporation of the residual mass of the crops in the soil and the increase of the internal porosity due to the mechanical preparation.

Water losses (WL) were less influenced than SL by the treatments and crop cycles, with a variation of 4 to 25% of the rain precipitated (Table 2), as verified by other authors in works of this nature (Almeida et al., 2016). According to Kohnke (1968), the soil presents a limit to infiltration of water and, when this limit is exceeded, the loss of water by runoff tends to equalize in different systems of crops and crop management.

NT reduced WL by 13% compared to CT, in the mean of crops and PS application, being characterized as the most effective treatment (Table 2). MT presented higher water losses than RT, due to the fact that during the four crops with PS application, in the RT, there was one no-tillage crop and one crop with only light harrowing, which mobilized the soil less than MT, promoting less impact on water losses. In the case of the treatment with complete mobilization of the soil (CT), the surface was exposed to the impact of raindrops and, therefore, there was surface sealing with consequent reduction of water infiltration in the soil. This phenomenon is common in uncovered soil, as found by Duley (1939). In the case of NT, without soil preparation, and MT and RT, with partial preparation, the surface cover was totally preserved in the NT and partially preserved in the MT and RT. However, in both treatments there was also an increase in the surface roughness, which contributed to a reduction in WL.

Among the crops, the variations in WL occurred according to the type of crop and the height of rain, in general (Table 2). In the spring-summer crops, WL were 4% lower than those of autumn-winter, in the mean of treatments, while rainfall was 14% lower, similar to that reported by Schick (2014) in the historical series in which the treatments were studied without PS. The rainfall was 5% higher in the mean of the crops than in the mean of the historical series without PS, while the WL was 5.8% larger in the historical series without PS than in the mean of the crops, which demonstrate the influence of the PS in the WL (Table 2).

The contents of extractable P in the 0-2.5 cm soil layer prior to the beginning of the research showed a variation among treatments, being classified as low, medium, high, and very high for CT, RT, MT, and NT, respectively (Table 3), according to the classification criteria of CQFS/RS-SC (2004). The highest values for NT, before and at the end of the research, are considered normal and are due to the fact that the soil was not tilled which, combined with the low mobility of the P, allows for greater surface accumulation. The increase of P extractable, in the soil in all treatments at the end of the research, is explained by the superficial fertilization (PS) and the mineralization of this element due to the decomposition of the cultural residues present on the soil surface. With the PS application sequence over time, the soil P content significantly increased in the NT treatment, as also verified by Tiecher et al. (2017). Based on the mean of the crops, the content of P in NT and MT was, respectively, 4.1 and 2.8 times higher than in CT. The increase of P concentration in the soil with the use of PS occurs with the passage of time as reported by Rauber et al. (2018), who found a high concentration of P along the soil profile after the continuous application of PS over seven years,

Table 3. Extractable P content in the 0-2.5 cm soil layer, in erosion sediments and in runoff water, for crop and soil management treatments in an Inceptisol

Crops	NT	MT	RT	CT
Extractable P content in soil layer - mg dm ⁻³				
Before	22.9 aA	12.2 bcA	15.1 abAB	6.3 cA
Maize	16.8 aA	16.6 aA	13.7 aA	4.9 bA
Oat	39.9 aB	16.7 bA	15.3 bAB	5.3 cA
Soybean	20.4 aA	19.1 aA	14.3 abA	7.9 bA
Wild radish	43.3 aB	20.2 bA	19.3 bB	7.1 bA
Mean	30.1	18.1	15.6	6.5
CV (%)	38	19	12	21
Extractable P content in erosion sediments - mg dm ⁻³				
Maize	23.1 aA	19.1 abAB	14.5 bA	17 bA
Oat	27.7 aA	15.5 bA	17.6 bA	12.5 bA
Soybean	43.2 aA	29.4 abB	23.1 abA	8.9 bA
Wild radish	33 aA	22.7 abAB	21.1 bA	15 bA
Mean	31.2	21.7	19.1	13.3
CV (%)	26.0	26.0	21.0	27.0
Extractable P content in runoff water - mg L ⁻¹				
Maize	0.66 aA	0.06 bA	0.02 bA	0.09 bA
Oat	0.77 aA	0.68 aB	0.35 bB	0.19 bA
Soybean	1.03 aB	0.39 bC	0.26 bB	0.22 bA
Wild radish	0.95 aB	0.36 bC	0.27 bB	0.57 cB
Mean	0.85	0.37	0.22	0.26
CV (%)	21.2	34.6	49.3	45.1

NT - No tillage; MT - Minimum tillage; RT - Rotation tillage; CT - Conventional tillage; CV - Coefficient of variation. Means followed by the same lowercase letter in the columns do not differ from each other and, means followed by the same uppercase letter in the lines, do not differ from each other, by Tukey test at $p \leq 0.05$

and over eight years as reported by Dal Bosco et al. (2008).

In general, the contents of P in erosion sediments were 50 times greater than those of runoff water (Table 3), in the mean of treatments and crops, because this element is practically non-soluble in water, but adsorbed by the sediments. This indicates that P can become a serious problem of environmental contamination, in addition to contributing to an increase in the cost of production, especially if soil losses are high. In addition, sediments lost by NT erosion were probably colloidal with a higher adsorption capacity of P than CT, as found by Bertol et al. (2007).

The P content in runoff water was low, especially in RT, on the mean of the crops (Table 3). In the NT and MT treatments, the P contents in the runoff water were 3.26 and 1.42 times higher than in the CT, respectively, in the mean of the crop. The highest contents of P in runoff water in the NT and MT treatments were due to higher soil surface levels. This is a consequence of plant residues kept on the surface and the PS added on the soil during the experimental period, as well as the residue of the chemical fertilizations carried out before this research.

In the 0-2.5 cm layer, the exchangeable K content in the mean of the NT and MT treatments was 1.9 times higher than in the CT (Table 4), while in the case of P the increase was 2.8 times higher (Table 2). This shows that the K is more mobile in the soil and concentrates less on the surface than the P in the conservation preparations. The high K content in the soil surface in the conservation preparations explains, in part, the high contents of this element in the runoff, especially when adsorbed to the sediments.

Before the beginning of this research, the contents of K in the soil surface layer varied from medium to high (Table 5),

Table 4. Exchangeable K content in the 0-2.5 cm soil layer, in erosion sediments, and in runoff water, for crop and soil management treatments, in an Inceptisol

Crops	NT	MT	RT	CT
Extractable K content in soil layer - mg dm ⁻³				
Before	222 aA	157 bA	122 cA	95 dA
Maize	286 aB	269 aB	122 cA	206 bB
Oat	292 aB	220 bC	265 abB	251 abC
Soybean	268 aB	276 aB	287 aB	161 bD
Wild radish	271 aB	270 B	248 abB	232 bC
Mean	279	259	230	212
CV (%)	9	19	47	47
Extractable K content in erosion sediments - mg dm ⁻³				
Maize	337 aA	290 bA	256 bA	252 bA
Oat	272 aB	281 aA	220 bAB	165 cB
Soybean	189 abC	277 cA	201 aBC	159 bB
Wild radish	183 aC	159 aB	158 aC	182 aB
Mean	245.2	251.7	208.7	189.5
CV (%)	26.0	21.0	17.0	19.0
Exchangeable K content in runoff water - mg L ⁻¹				
Maize	12.7 aA	11.5 aA	9.1 abA	5.3 bA
Oat	5.7 aB	4.2 aB	3.6 aB	6.3 aA
Soybean	7.3 aB	4.9 bB	4.1 bB	3.3 bB
Wild radish	7 aB	5.9 abB	3.7 abB	2.2 bB
Mean	8.2	6.6	5.1	4.2
CV (%)	34.0	45.0	47.0	38.8

NT - No-tillage; MT - Minimum tillage; RT - Rotation tillage; CT - Conventional tillage; BS - Bare soil; CV - Coefficient of variation. Means followed by the same lowercase letter in the columns do not differ from each other and, means followed by the same uppercase letter in the lines, do not differ from each other, by Tukey test at $p \leq 0.05$

Table 5. Total losses of P and K considering the sum of losses in erosion sediment and in runoff water in crops and soil management treatments, in an Inceptisol

Crops	NT	MT	RT	CT
	(g ha ⁻¹)			
Total losses of P				
Maize	189 aD	28 cD	9 cC	96 bD
Oat	274 bC	475 aA	201 cB	250 bcC
Soybean	428 aB	231 bB	162 cB	410 aB
Wild radish	807 bA	152 dC	288 cA	1348 aA
Total	1,698	886	660	2,104
CV (%)	55	73	61	92
Total losses of K				
Maize	3618 cB	7126 aB	2594 cB	4984 bC
Oat	2065 cB	3067 bB	2183 cC	4239 aD
Soybean	3028 bB	2979 bC	2580 cB	6194 aA
Wild radish	5947 bA	10326 aA	3864 dA	5338 cB
Total	14,658	23,498	11,221	20,755
CV (%)	41	52	22	13

NT - No-tillage; MT - Minimum tillage; RT - Rotation tillage; CT - conventional tillage; CV - Coefficient of variation. Means followed by the same lowercase letter in the columns do not differ from each other and, means followed by the same uppercase letter in the lines, do not differ from each other. by Tukey test at $p \leq 0.05$

according to the classification of CQFS/RS-SC (2004), and NT treatment presented the highest concentrations, 2.3 times larger than CT. The high content of K in the soil before starting the research, together with the K applied by the PS and the one released by the decomposition of the cultural residues present on the surface, caused the content to be higher at the end of the research, than before research in all treatments (Table 4).

The contents of K in erosion sediments, in the mean of treatments and crops, were about 37 times higher than those found in runoff water (Table 4). This is due to the high contents of this element in the soil, mainly due to the application of PS, the maintenance of vegetal residues in the soil, and the application of chemical fertilizers before this research.

The contents of K in runoff water (Table 4) were significantly higher than those of P (Table 3) in all treatments, agreeing with Schick et al. (2000) and Rosa et al. (2017). The higher content of K than that of P in runoff water is explained by the fact that K content is high in soil, in addition to being more soluble and mobile than P. In NT and MT treatments, K contents in runoff water were 1.9 and 1.5 times higher than in CT, respectively, in the mean of crops (Table 4). This can be explained by the high contents of the element in the soil surface layer in NT and MT, due to the fertilization and the accumulation of vegetal residues on the surface. The data obtained in relation to K agree with those of Schick et al. (2000) and Mecabô Junior et al. (2014).

The total losses of P by erosion were higher in the CT (Table 5), despite the low element content in erosion sediments and runoff water. Thus, the amount of P losses were influenced, mainly, by the high loss of soil and runoff water in this treatment. The contrary was observed in NT. Despite the low soil losses in NT, the total loss was high due to the high element content in the sediments.

The total losses of K by erosion were high in relation to the stock present in the soil (Table 5) due to the high contents of the element in the runoff water and the high losses of water by erosion. In NT, the losses of this element were 30% smaller than in CT. This is mainly explained by the higher water losses that occurred in CT, although the contents of the element in

the runoff were higher in NT. These losses varied significantly between the crops due to the oscillations in water losses and in the contents of the element in the water.

CONCLUSIONS

1. Soil management influences water erosion, so that no-tillage reduces the loss of soil and water in relation to conventional tillage.
2. P and K contents in soil and runoff water are influenced by soil management, being higher in direct seeding than in conventional tillage, while the total erosion losses of these elements are higher in conventional tillage.
3. The application of 50 m³ ha⁻¹ of pig slurry to the soil surface, once in the beginning of each crop, during four cultivations, improves the physical and chemical attributes of the soil and decreases water erosion in comparison to that before the application of the pig slurry.

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LITERATURE CITED

- Almeida, W. S. de; Carvalho, D. F. de; Panachuki, E.; Valim, W. C.; Rodrigues, S. A.; Varella, C. A. A. Erosão hídrica em diferentes sistemas de cultivo e níveis de cobertura do solo. Pesquisa Agropecuária Brasileira, v.51, p.1110-1119, 2016. <https://doi.org/10.1590/s0100-204x2016000900010>
- Bertol, O. J.; Rizzi, N. E.; Bertol, I.; Roloff, G. Perdas de solo e água e qualidade do escoamento superficial associadas à erosão entre sulcos em área cultivada sob semeadura direta e submetida às adubações mineral e orgânica. Revista Brasileira de Ciência do Solo, v.31, p.781-792, 2007. <https://doi.org/10.1590/S0100-06832007000400018>
- Blake, G. R.; Hartge, K. H. Bulk density. In: Klute, A. (ed.). Methods of soil analysis - Part 1: Physical and mineralogical methods. Madison: Soil Science Society of America, 1986. Chap.14, p.363-375.
- Boitt, G.; Schmitt, D. E.; Gatiboni, L. C.; Wakelin, S. A.; Black, A.; Sacomori, W.; Cassol, P. C.; Condon, L. M. Fate of phosphorus applied to soil in pig slurry under cropping in Southern Brazil. Geoderma, v.321, p.164-172, 2018. <https://doi.org/10.1016/j.geoderma.2018.02.010>
- Cogo N. P. Uma contribuição à metodologia de estudo das perdas de erosão em condições de chuva natural: I - Sugestões gerais, medição dos volumes, amostragem e quantificação de solo e água da enxurrada. In: Encontro Nacional de Pesquisa sobre Conservação do Solo, 2, 1978, Passo Fundo. Anais... Passo Fundo: Embrapa Trigo, 1978. p.75-98.
- CQFS/RS-SC - Comissão de Química e Fertilidade do Solo. Manual de adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina. 10.ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo, 2004. 400p.

- Dal Bosco, T. C.; Sampaio, S. C.; Iost, C.; Silva, L. N.; Carnellosi, C. F.; Ebert, D. C.; Schreiner J. S. Utilização de água residuária de suinocultura em propriedade agrícola: Estudo de caso. *Irriga*, v.13, p.139-144, 2008. <https://doi.org/10.15809/irriga.2008v13n1p139-144>
- Duley, F. L. Surface factors affecting the rate of intake of water by soils. *Soil Science Society of America Journal*, v.4, p.60-64, 1939. <https://doi.org/10.2136/sssaj1940.036159950004000C0011x>
- Ellison, W. D. Studies of raindrop erosion. *Agricultural Engineering*, v.25, p.131-181, 1947.
- Ferreira, D. F. Sisvar: A guide for its bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, v.38, p.109-112, 2014. <https://doi.org/10.1590/S1413-70542014000200001>
- Gunkel-Grillon, P.; Roth, E.; Laporte-Magoni, C.; Mestre, M. L. Effects of long-term raw pig slurry inputs on nutrient and metal contamination of tropical volcanogenic soils, Uvéa Island (South Pacific). *Science of the Total Environment*, v.533, p.339-346, 2015. <https://doi.org/10.1016/j.scitotenv.2015.06.110>
- Kemper, W. D.; Chepil, W. S. Size distribution of aggregates. In: Klute, A. (ed.). *Methods of soil analysis - Part 1: Physical and mineralogical methods*. Madison: Soil Science Society of America, 1965. Chap.39, p.499-510.
- Kohnke, H. *Soil physics*. New York: McGraw Hill Inc., 1968. 224p.
- Kraaijvanger, R.; Veldkamp, T. Grain productivity, fertilizer response and nutrient balance of farming systems in Tigray, Ethiopia: A multi-perspective view in relation to soil fertility degradation. *Land Degradation & Development*, v.26, p.701-710, 2015. <https://doi.org/10.1002/ldr.2330>
- Mecabô Junior, J.; Bertol, I.; Barbosa, F. T.; Oselame, G. de S. Erosão hídrica influenciada por uma aplicação de dejetos líquidos de suínos no solo cultivado em semeadura direta. *Revista Brasileira de Ciência do Solo*, v.38, p.1601-1611, 2014. <https://doi.org/10.1590/S0100-06832014000500025>
- Montoya, T. S. R.; Paredes, F. A.; Dalurzo, H. C.; Lopez, C. F.; Kersting, R. M. Propiedades físicas de un argiudol ácuico bajo diferentes sistemas de manejo. *Ciencia del Suelo*, v.35, p.171-180, 2017.
- Rauber, L. P.; Andrade, A. P.; Friederichs, A.; Mafra, Á. L.; Baretta, D.; Rosa, M. G. da; Mafra, M. S. H.; Correa, J. C. Soil physical indicators of management systems in traditional agricultural areas under manure application. *Scientia Agricola*, v.75, p.354-359, 2018. <https://doi.org/10.1590/1678-992x-2016-0453>
- Roberts, W. M.; Gonzalez-Jimenez, J. L.; Doody, D. G.; Jordan, P.; Daly, K. Assessing the risk of phosphorus transfer to high ecological status rivers: Integration of nutrient management with soil geochemical and hydrological conditions. *Science of the Total Environment*, v.589, p.25-35, 2017. <https://doi.org/10.1016/j.scitotenv.2017.02.201>
- Rosa, D. M.; Sampaio, S. C.; Pereira, P. A. M.; Mauli, M. M.; Reis, R. R. Swine wastewater: Impacts on soil, plant, and leachate. *Engenharia Agrícola*, v.37, p.928-939, 2017. <https://doi.org/10.1590/1809-4430-eng.agric.v37n5p928-939/2017>
- Schick, J. Fatores R e K da USLE e perdas de solo e água em sistemas de manejo sobre um Cambissolo Húmico em Lages, SC. Lages: UDESC, 2014. 149p. Tese Doutorado
- Schick, J.; Bertol, I.; Balbinot Júnior, A. A.; Batistela, O. Erosão hídrica em Cambissolo Húmico aluminico submetido a diferentes sistemas de preparo e cultivo do solo: II - Perdas de nutrientes e carbono orgânico. *Revista Brasileira de Ciência do Solo*, v.24, p.437-447, 2000. <https://doi.org/10.1590/S0100-06832000000200020>
- Soil Survey Staff. *Keys to soil taxonomy*. 12.ed. Washington: United States Department of Agriculture, 2014. 360p.
- Tedesco, M. J.; Ianello, C.; Bissani, C. A.; Bohnen, H.; Volkweiss, S. J. *Análise de solos, plantas e outros materiais*. 2.ed. Porto Alegre: UFRGS, 1995. 174p.
- Tiecher, T.; Minella, J. P. G.; Caner, L.; Evrard, O.; Zafar, M.; Capoane, V.; Gall, M. le; Santos, D. R. dos. Quantifying land use contributions to suspended sediment in a large cultivated catchment of Southern Brazil (Guaporé River, Rio Grande do Sul). *Agriculture, Ecosystems & Environment*, v.237, p.95-108, 2017. <https://doi.org/10.1016/j.agee.2016.12.004>
- Vanwallegghem, T.; Gómez, J. A.; Amate, J. I.; Molina, M. G. de; Vanderlinden, K.; Guzmán, G.; Laguna, A.; Giráldez, J. V. Impact of historical land use and soil management change on soil erosion and agricultural sustainability during the Anthropocene. *Anthropocene*, v.17, p.13-29, 2017. <https://doi.org/10.1016/j.ancene.2017.01.002>
- Wischmeier, W. H.; Smith, D. D. Rainfall energy and its relationships to soil loss. *EOS, Transactions of the American Geophysical Union*, v.39, p.285-291, 1958.
- Yoder, R. E. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal of the American Society of Agronomy*, v.28, p.337-351, 1936. <https://doi.org/10.2134/agronj1936.00021962002800050001x>