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Water erosion in a Haplic Dystrudept soil after application of swine slurry

Erosão hídrica em um Cambissolo Háplico após aplicação de dejeto líquido de suínos

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ABSTRACT

Water (WL), soil (SL), phosphorus (P) and potassium (K) losses by water erosion and subsurface flow are influenced by soil management and by soil fertilization with swine slurry (SS). The study was conducted between 09/2014 and 11/2015, in a Haplic Dystrudept, to evaluate the 0 (zero), 50, 100 and 200 m³ ha^{-1} SS doses applied to millet (Pennisetum americanum), black oats (Avena strigosa) and crotalaria (Crotalaria ochroleuca), compared with a soil without cultivation and without SS. The soil total porosity (Tp) and macroporosity (Ma), the P and K concentration in the soil, in the runoff, and in the subsurface flow, the dry mass of the aerial part (DM) of crops, and the WL and SL were determined. The main results show the application of SS in the soil results in an increase in Tp and Ma, as well as in the concentration of P and K in the soil and the DM of the plants, in relation to the absence of SS. Water erosion decreases with an increased dose of SS applied to the soil in the interval between 50 and 200 m3 ha^{-1}. The increase in the dose of SS increases the concentration and total losses of P and K in the runoff and decreases the concentration of these nutrients in the subsurface flow in the interval between 50 and 200 m3 ha^{-1}. The increase of DM of the plants, in the interval between 13.75 and 22.82 t ha^{-1}, decreases SL at an average rate of 2.90 t ha^{-1}. The concentration of K in the subsurface flow water was negatively related to the concentration of the element in the subsurface flow.

KEYWORDS: soil and water losses, nutrient losses, lysimeter.

RESUMO

As perdas de água, solo, fósforo (P) e potássio (K) por erosão hídrica e escoamento subsuperficial são influenciadas pelo manejo e fertilização do solo com dejeto líquido de suínos (DLS). A pesquisa foi conduzida em 09/2014 e 11/2015, em um Cambissolo Háplico, para avaliar as doses 0 (zero), 50, 100 e 200 m³ ha^{-1} de DLS aplicado no milheto (*Pennisetum americanum*), aveia preta (*Avena strigosa*) e crotalária (*Crotalaria ochroleuca)*, em comparação ao solo sem cultivo e sem DLS. A porosidade total (PT) e macroporosidade (Ma) do solo, as concentrações de P e K no solo, na enxurrada e no escoamento subsuperficial, a massa seca da parte aérea das culturas (MS), e as PA e PS pela foram determinadas. Os principais resultados mostram que a aplicação de DLS no solo resulta em aumento da PT e Ma e da concentração de P e K no solo, além da MS das plantas, em relação à ausência de dejeto. A erosão hídrica diminui com o aumento da dose de DLS, no intervalo entre 50 e 200 m^3 ha^{-1} do dejeto aplicado no solo em relação à dose de 50. O aumento da dose de DLS faz aumentar a concentração e as perdas totais de P e K no escoamento superficial e diminuir a concentração desses nutrientes no fluxo subsuperficial, no intervalo entre 50 e 200 m^3 ha^{-1} de dejeto. O aumento de MS das plantas, no intervalo entre 13,75 e 22,82 t ha^{-1}, faz diminuir as PS a uma taxa média de 2,90 t ha^{-1}. A concentração de K na água do fluxo subsuperficial se relaciona negativamente com a concentração do elemento no escoamento superficial.

PALAVRAS-CHAVE: perdas de solo e água, perdas de nutrientes, lisímetro.

INTRODUCTION

The factors rainfall, soil, relief, soil coverage, and conservation practices influence water erosion (WISCHMEIER & SMITH 1978). Among these factors, soil coverage and management are the most important ones (SCHICK et al. 2017) and can be influenced by soil fertilization with swine slurry (SS). In no-tillage (NT), soil fertilization on surface is a part of soil management and influences water (WL), soil (SL), and nutrient losses due to water erosion, as well as the losses of some nutrients in the subsurface flow (GIROTTO et al. 2013).

A number of studies (ARRUDA et al. 2010, RAUBER et al. 2012, MAFRA et al. 2014) showed increasing the dose of SS improved some soil attributes and increased the dry mass (DM) of the aerial part of the crops. In the short term, the SS did not increase the organic carbon (OC) and did not improve the structure in NT. However, OC increased, its structure improved and soil density and resistance to root penetration decreased when the soil was submitted to SS application for a long time (RAUBER et al. 2012).

Abundant studies on the effect of SS on the chemical characteristics of the soil (SCHERER et al. 2010, COSTA et al. 2011, MAFRA et al. 2014) revealed accumulation of P and K in the surface layer in comparison with the lower layers in soil with continuous application of SS for 15 years.

On the other hand, few studies have evaluated the effect of SS on water and nutrient losses due to erosion and to subsurface flow (GIROTTO et al. 2013, LOURENZI et al. 2014, MECABÔ JÚNIOR et al. 2014). The increased dose of SS in soil increased DM and protected the soil from the erosive energy of the rains. However, the increase in the SS dose resulted in an increase in WL and SL and in the concentration of some nutrients in the subsurface flow (LOURENZI et al. 2014).

In light of the current state of the art, one can infer that SS increases DM because it improves the soil chemical characteristics and adds P, K, and other nutrients to it, reducing water erosion because of increased soil cover and OC addition to the soil. In addition, the concentration and total losses of P and K in the runoff increase with increasing SS dose applied cumulatively in the soil.

In the subsurface flow, for other side, the P and K concentration in the flow was less influenced than in the surface runoff. This study aimed to determine the effect of SS doses on total porosity (Pt) and Macroporosity (Ma), on the DM production of millet, oat, and crotalaria, and on the P and K concentration in the soil. Also, the objective was to quantify the WL and SL and the total losses of P and K in runoff and the concentration of these elements in the subsurface flow.

MATERIAL AND METHODS

The study was carried out between 09/2014 and 11/2015, in an experiment located in the southern Brazil (altitude 690 m, South latitude 27º 11'7' 'and longitude 49º 39’ 41´´ West of Greenwich), in a Haplic Dystrudept soil (SOIL SURVEY STAFF 2014), with mean slope of 0.23 m m-1. In the average layer 0-0.2 m, the soil presents 180 g dm-3 of clay, 420 g dm-3 of sand, and 400 g dm-3 of silt.

Each plot (15 m x 2 m) was delimited with galvanized sheets. At the lower end of the plot, a runoff collector system received the eroded material. This collector was connected through a pipe to a first sedimentation tank (500L), which was connected to a second tank (300L) through a discharge divider of the "Geib" type with seven windows. At the lower end of each plot, an Ebermayer lysimeter (GOSS & EHLERS 2009) was installed to collect the subsurface flow.

The experiment was initiated with soil preparation, carried out with a plowing followed by two harrows, in September 2014. The soil fertility and pH index were adequate for annual crops. In October/2014, the first crop (millet – Pennisetum americanum) was seeded, and the cut of the plants was carried out in March/2015. During this crop cycle, rainfall was 285 mm. In March/2015 the second crop was seeded (black oats – Avena strigosa), without soil mobilization, and the cut of the plants was made in August. During that crop cycle, the rainfall was 212 mm. In August/2015, the third crop was seeded (Crotalaria - Crotalaria juncea), without soil mobilizing. During this crop cycle rainfall was 313 mm, and this cycle finished in November/2015. At the end of each crop, the green mass of the aerial part of the crops was collected, in an area of 1 m2, and immediately dried, and the dry mass determined.

The treatments, with two replicates, consisted of doses of swine slurry (SS). The SS was applied manually three times on the soil surface, that is, 15 days after millet, 15 days after black oats, and 15 days after crotalaria crop seeding, without additional chemical fertilization. Thus, the treatments consisted of doses of 0 (SS0), 50 (SS50), 100 (SS100), and 200 m3 ha^{-1} (SS200) in each crop, totaling, in the period studies, 0 m3 ha^{-1} of SS in SS0 treatment, 150 m3 ha^{-1} in SS50 treatment, 300 m3 ha^{-1} in SS100 treatment, and 600 m3 h-1 in SS200 treatment. The slurry originated from a system of rearing pigs that involved raising and rearing animals. The SS contained, in average, 2.7% of dry matter and, in it, 0.57 mg dm-3 of P and 0.43 mg dm-3 of K. An additional treatment was control (C), consisting of bare soil that remained uncultivated, uncovered, and without manure application along the study period.

The collection of runoff samples and their processing for the determination of WL and SL by erosion followed the method described in SCHICK et al. (2017). Additional sample of water from this runoff was collected for later determination of P and K concentration. From the subsurface flow collected by the lysimeter, samples were collected for P and K analysis. The lysimeter was installed at a depth of 0.2 m from the soil surface. The water samples from the runoff and subsurface flow were filtered using 45 µm filter paper. For the runoff analysis, the samples were joined together during the cycle of each culture for composing, at the end of each cycle, a single sample per cycle and per plot, which was stored in a refrigerator until analysis. In the case of subsurface flow, the samples were joined together over the three crop cycles, composing a single sample of the three crops per plot, also stored in a refrigerator.

The physical and chemical characteristics of the soil were determined in samples collected in the 0-0.05 m and 0.05-0.1 m layer. The microporosity (Mi) was determined in a preserved sample of the soil after saturation and submitted to the tension of 6k Pa in sand tension table, according to REINERT & REICHERT (2006) and LIMA & SILVA (2008). The total porosity (Tp) was determined by the ratio between soil density and particle density, and the macroporosity (Ma) determined by the difference between Tp and Mi. MEHLICH (1953) was used for extracting P and K of the soil samples. P was determined using spectrophotometry; K, flame photometry. After filtering the runoff water using 0.45 µm filter paper, the P and the K were determined following the methodology described in MURPHY & RILEY (1965), and the P determined by spectrophotometry and the K by flame photometry. For the determination of the total losses of P and K in the runoff water, the concentration of each element found in water was multiplied by the total amount of water lost in the form of runoff in each plot. At the end of each crop cycle, a sample of the crop residues was collected in an area of 0.24 m² to quantify the DM after drying at 50º C.

An analysis of variance of the data considered the completely randomized design of the treatments and, when the means differed between them, the Tukey test was applied ($p \leq 0.05$). Relations were performed between the DM and SS dose using the model $y=a+aox^b$ between SL and DM, and using the model $y=a+bx$ between P and K concentration in the subsurface flow and runoff.

RESULTS AND DISCUSSION

The soil Tp and Ma did not vary between treatments and evaluation periods, with some exceptions (Table 1). The Tp increased at the end of the study in relation to the beginning in SS100 and SS200 in the 0-0.05 m soil layer, while the Ma was higher at the beginning in the control treatment in the layer of 0.05-0.1 m. These differences may be due to the soil moisture condition at the time of collection of soil sample, because the increase in the soil water content increases its volume. This confirms that improving soil physical characteristics such as Tp and Ma by application of SS in a short time period is difficult, which was also observed by RAUBER et al. (2012) and MAFRA et al. (2014).

Table 1. Values of total porosity and macroporosity determined at the beginning (begin) of the study (after soil preparation and before applying SS) and at the end of the study, in two soil layers, depending on the treatment.

Treatment	Begin	End	Average	CV (%)	Begin	End	Average	CV (%)
(SS)	Total porosity				Macroporosity			
m^3 ha^{-1}	---------------------------------- $dm^3 dm^{-3}$ ----------------------------------							
				0 –0.05m				
(0)	0.44	0.54	0.49	5.8	0.18A	0.15bB	0.17	3.1
0	0.47	0.58	0.53	6.8	0.16	0.13b	0.15	9.8
50	0.46	0.61	0.54	5.9	0.18	0.23a	0.21	10.9
100	0.46B	0.58A	0.52	2.7	0.16	0.18ab	0.17	5.9
200	0.44B	0.59A	0.52	4.4	0.17	0.17ab	0.17	8.3
Average	0.45	0.58	-		0.17	0.17	-	-
CV (%)	4.4	5.8	-		6.4	10.0	-	-
				0.05 –0.1 m				
(0)	0.50	0.52	0.51	5.6	0.11ab	0.11	0.11	9.1
0	0.46	0.48	0.47	3.0	0.07b	0.08	0.08	13.3
50	0.44	0.51	0.48	4.7	0.12a	0.07	0.10	14.9
100	0.47	0.48	0.48	6.0	0.08ab	0.07	0.08	18.1
200	0.46	0.49	0.48	2.1	0.08ab	0.07	0.08	18.9
Average	0.47	0.50	-	-	0.09	0.08	-	-
CV (%)	4.3	4.8	-	-	11.9	13.7	-	-

(0): Without slurry and without cultivation. SS: swine slurry. Equal lowercase letters in the column and uppercase in the row do not differ by Duncan ($p \leq 0.05$). The averages cover the treatments with 50, 100 and 200 m^3 ha^{-1} of SS. CV: coefficient of variation.

The soil concentration of P decreased by 46% from the beginning to the end of the study, on average of the SS doses and the soil layers (Table 2), probably due to the effect of the exportation by the plants and due to the losses by water erosion, which occurred during the period. At the beginning of the study, the P concentration in the soil layers of 0-0.05 m and 0.05-0.1 m were different between treatments, due to natural soil variation. Comparing SS50, SS100, and SS200, a 16% increase was observed from SS50 to SS100 and a 8% increase from SS100 to SS200, on average of the surface layers. These increases were influenced by the dose of P applied in the soil with manure. The nutrient recycling action of the plants that have incorporated the element probability, coming from a deeper layer into these soil layers, influenced at end of search, as determined by SCHERER et al. (2010).

Table 2. Values of soil phosphorus and potassium concentration, determined at the beginning (begin) of the study (after soil preparation and before applying SS) and at the end of the study, in two soil layers, depending on the treatment.

Treatment (SS)	Begin	End	Average	CV (%)	Begin	End	Average	CV (%)
	Phosphorus				Potassium			
	mg dm^{-3}							
	0 –0.05 m							
(0)	7.6cA	5.2bB	6.4	3.5	114ab	106b	110	3.3
0	7.5cA	4.5cB	6.0	2.6	110ab	105b	108	3.5
50	8.6bcA	5.2bB	6.9	3.2	126a	111a	119	4.0
100	9.9abA	5.1bcA	7.5	2.8	115abA	78cB	97	4.4
200	10.9aA	7.8aB	9.4	4.8	105bA	61dB	83	6.5
Average	9.8	6.0	-	-	115	83	-	-
CV (%)	3.8	3.1	-	-	4,5	3,9	-	-
	0.05 –0.1 m							
(0)	6.8cA	4.3bcB	5.6	2.6	100b	79a	90	7.2
0	6.6cA	4.1cB	5.4	2.6	105bA	82aB	94	4.8
50	8.4bA	4.3bcB	6.4	3.5	120bA	71aB	96	5.6
100	9.8aA	4.9bB	7.4	3.0	123bA	54bB	89	4.8
200	10.3aA	7.1aB	8.7	4.1	162aA	45bB	104	3.1
Average	9.5a	4.8	-	-	135	57	-	-
CV (%)	3.3	3.6	-	-	4,8	5,6	-	-

(0): Without slurry and without cultivation. SS: swine slurry. Equal lowercase letters in the column and uppercase in the row do not differ by Duncan (p≤0.05). The averages cover the treatments with 50, 100 and 200 m^3 ha^{-1} of SS. CV: coefficient of variation.

From the beginning to the end of the study, the K concentration of the soil decreased by 45%, on average of the doses of SS and soil layers (Table 2), explained in the same way as for P. In the comparison between treatments, the K concentration tended to decrease from 50 m3 ha^{-1} of SS to 200 m3 ha^{-1} at the beginning of the study in the soil surface layer. The K concentration increased from SS50 to SS200, at the same time in the 0.05-0.1m layer by influence of the nutrient contained in the SS applied to the soil, according to MAFRA et al. (2014). This possibly occurred due to the higher extraction of nutrients from the soil by the crops in this phase of the study and to the possible leaching of the element in the profile, considering that this soil is clayey.

The (O) and SS0 treatments showed almost the same values for both P and K in the two layers of the soil, in the two sampling time (Table 2). This means that the soil crop without manure did not influence the concentration of these nutrients down to the 0.1 m soil depth in relation to the absence of cultivation and manure, even after three crop cycles.

Crotalaria produced more DM than millet and oats, with a small numerical distinction between millet and oats (Table 3). This is due to the physiological and morphological distinction between the cultivated plant species and to the climatic distinction between the cultivation seasons (different times), as verified by SCHICK et al. (2017). The DM yield differed between the SS doses and the zero-dose. The crotalaria produced 1.6 and 1.7 times more than millet and oats, respectively, and the average of the treatments with the dose of SS produced 1.4 times more than zero-dose. Therefore, starting from the first crop, the SS application showed results in the production of DM only compared with the absence of SS, as also verified by RAUBER et al. (2012).

The WL did not vary between treatments with cultivation, except for oats in which they were higher at zero-dose than at the others (Table 4).

Table 3. Values of dry mass of aerial part of the crops, determined depending on the treatment.

Treatment (SS)	Millet	Oat	Crotalaria	Total
m^3 ha^{-1}	---------------------------------- t ha^{-1} ---------------------------------			
(0)	-	-	-	-
0	2.47c	1.73c	9.55b	13.75
50	3.53b	2.46b	12.38a	18.37
100	3.67b	2.89ab	13.72a	20.28
200	4.73a	3.28a	14.78a	22.79
Average	3.98	2.88	13.63	20.48
CV(%)	7.2	6.4	5.1	-

(0): Without slurry and without cultivation. SS: swine slurry. Equal lowercase letters in the column do not differ by Duncan ($p \leq 0.05$). The averages cover the treatments with 50, 100 and 200 m^3 ha^{-1} of SS. CV: coefficient of variation.

The SS dose did not influence the WL in the 1st and 3rd crop cycle in any way, comparing between treatments, influencing them only in the 2nd crop cycle. In that cycle, the WL was twice as high at zero-dose as on the average of the other treatments. In the control treatment, the WL was significantly higher (11.6 times) than in the zero-dose of SS in the 3rd cycle of culture; in the other cycles, only a trend was observed, with no statistical difference (Table 4). Thus, influence of the culture in the reduction in the WL was verified only in the crotalaria crop. This occurred because crotalaria produced more DM and improved the physical characteristics of the soil in relation to the other crops.

Table 4. Total water losses, rainfall volume (Rv), total soil losses, and sediment concentration in the runoff (Sc), depending on the treatments (T).

T (SS)	Water losses (m^3 ha^{-1})				Rv	Soil losses (t ha^{-1})				Sc
m^3 ha^{-1}	Millet	Oat	Crot	Total	$m^3 ha^{-1}$	Millet	Oat	Crot	Total	g L^{-1}
(0)	413	54a	324a	791	8.100	45.964a	11.507a	7.005a	64.476	81.51a
0	347	49ab	28b	424	8.100	17.456b	7.884b	0.066b	25.406	59.92b
50	357	22c	33b	412	8.100	17.236b	7.123b	0.048b	24.407	59.24b
100	392	28bc	44b	464	8.100	17.095b	0.231c	0.042b	17.268	37.22c
200	354	25bc	28b	407	8.100	10.982c	0.149c	0.040b	11.171	27.45d
Average	368	25	35	428	8.100	15.104	2.501	0.043	17.615	41.30
CV (%)	5.1	18.1	6.5	-	0	5.4	5.4	8.6	-	3.1

(0): Without slurry and without cultivation. SS: swine slurry. Equal lowercase letters in the column do not differ by Duncan ($p \leq 0.05$). The averages cover the treatments with 50, 100 and 200 m^3 ha^{-1} of SS. CV: coefficient of variation.

The expressive difference in the WL between treatments in crotalaria reflected in the total WL of the three crop cycles, which was 1.9 times higher in the control than in the (O) treatment. In general, the dose of SS does not influence the total WL by water erosion. These losses are generally more influenced by physical attributes of the soil, by the soil coverage and by the water content in the soil than by the dose of manure (MECABÔ JÚNIOR et al. 2014).

The dose 200 m3 ha^{-1} of SS was most effective in controlling SL (Table 4) in relation to other doses, due to the 40% increase in the total DM in this treatment in relation to the zero-dose (Table 3). Thus, in crotalaria, a 54% reduction in sediment concentration in the runoff was observed, also due to the effect of cultural residues accumulated on the soil surface. Water erosion decreases with increased dose of cultural residues on the soil surface (WISCHMEIER & SMITH 1978) and with the cultivation of plant species considered soil conservationists in relation to other species (MECABÔ JÚNIOR et al. 2014). The succession of cultures over time, from the second cultivation, decreased the differentiation between the treatments regarding the capacity of the SS to control the SL (Table 4). Thus, in the second crop, the doses of 100 and 200 m3 ha^{-1} of SS were differentiated from doses 0 (zero) and 50 m3 ha^{-1}, whereas in the 3rd crop only the dose 200 m3 ha^{-1} differed from the others. These differences were also influenced by the effect of the crops: oats in the 2nd and crotalaria in the 3rd cultivation. In NT, SL tended to decrease in crops over time, because soil coverage, when effective and permanent, is the main control factor of soil erosion.

In all three crops, the WL and SL were higher in the treatment without SS and without cultivation than in the others, driven mainly by the differences occurred in the cycle of crotalaria (Table 4). Thus, this culture stood out positively in the erosion control compared with the others, overlapping the effect of the SS dose, as also verified by MECABÔ JÚNIOR et al. (2014), who worked with corn, soybean, and forage turnip and whose work with corn stood out. In the case of SL control, oats were also more effective than millet.

The total SL was influenced by the sediment concentration in the runoff (Cs) (Table 4), due to influence of the SS on the yield of DM by the crops. Thus, the Cs decreased by 54% at the dose 200 m3 ha^{-1} of SS in relation to zero-dose, both with cultivation. The cultivation, in turn, also influenced the SL compared with the absence of cultivation (control) due to the reduction in the Cs, which was 44% on average of the crop cycles. Therefore, the SL was more influenced by the SS than by the cultivation, contrary to what was verified by MECABÔ JÚNIOR et al. (2014).

Between crops, the SL decreased by 85% from the 1st to the 3rd cropping cycle in the control treatment, in numerical terms (Table 4), influenced by soil consolidation and by the fact that most of the soil readily available for transport was eroded in the 1st cycle, as also verified by SCHICK et al. (2017). The rainfall did not influence, since the precipitated volume increased 10% in this period (2,850 m3 in the 1st crop, 2,120 m3 in the 2nd crop, and 3,130 m3 in the 3rd crop) (FONTANIVE 2016). In the treatment with crop and zero-dose, and on average of the treatments with doses of 50, 100, and 200 m3 ha^{-1} of SS, the mentioned reduction was of 99.7%. This is explained by the cumulative effect of the sequence of crops and application of SS. The accumulation of DM resulting from crops in sequence and soil consolidation in the NT condition increases the soil protective effect against erosive agents over time and soil erosion resistance (BERTOL et al. 2015, SCHICK et al. 2017).

The concentration and total P and K losses in the runoff were higher in the SS treatments, on average of the doses 50, 100, and 200 m3 ha^{-1} than in zero-dose, all with crops (Table 5); they were also higher with SS application than in the control, except for the total K losses in crotalaria cycle. In addition, concentration and total losses of the two elements by erosion increased from the zero-dose to SS200. Thus, SS provided soil conditions and increased DM production (Table 3). Therefore, the concentration and total P and K losses in the runoff increased due to the recycling of the elements, making them available for transport by the runoff. The SS improves some soil characteristics, especially P content, thus stimulating the production of DM and root mass (SCHERER et al. 2010, MAFRA et al. 2014), which recycle soil nutrients (COSTA et al. 2011). In the case of NT, the cultural residues are maintained on the soil surface where DM is decomposed releasing the nutrients recycled by the plant (SCHERER et al. 2010). Water erosion is a surface phenomenon and, therefore, the runoff easily transports the nutrients deposited there (SHARPLEY 2016).

The increase in the P and K concentration in the runoff water from the dose 200 m3 ha^{-1} to the zero-dose of SS was respectively 14.9 times and 4.7 times from the start to the end of search, on average of the crops (Table 5). This increase reflected the combined effect of the contribution of the elements to the soil, directly from the SS, the increase in DM and the recycling of the soil nutrients by the effect of SS, indirectly, according to GIROTTO et al. (2013). The recycling effect of crops must have been important in the case of the P. In that case, the runoff concentration of P was 2.4 times higher in the zero-dose of SS with crop than in the control, on average of the crops.

In the case of the total P and K losses in the runoff, the increase was insignificant with the SS dose, from 7.0 times and 3.4 times greater, respectively, from the start to the end of search from the 200 m3 ha^{-1} dose to the zero-dose, in the total of crops (Table 5). This increase reflected the combined effect of the concentration of elements in the runoff, particularly in the case of P, and the total WL by the mentioned runoff (SCHNEIDERS 2017).

In the case of the subsurface flow water, the P concentration decreased 29% and the K decreased 9% from the dose 50 m3 ha^{-1} of SS to the dose 200 (Table 6), contrary to what happened in the runoff. The increase in P and K losses by runoff with the increase in SS dose possibly resulted in a decrease in their concentration in the drainage water that reached the lysimeter, contrary to what happened in the SCHNEIDERS (2017) study. The possible higher adsorption of the elements by the soil in the higher doses of SS may have been caused by the increase in soil retention on the path traveled by the SS down to the depth in which the runoff reached the lysimeter.

The total DM responded significantly to the increase in SS dose applied in the soil ($p<0.05$) (Figure 1). The potential growth of DM with an increasing dose of SS means that, between the doses 0 (zero) and 50 m3 ha^{-1} of SS, DM increased at the rate of 4.65 t ha^{-1}. Between the doses 50 and 100, the increase rate of DM was 1.85 t ha^{-1} and was 2.57 t ha^{-1} when the interval between doses of SS was between 100 and 200 m3 ha^{-1}. The production of DM increases with the increased SS dose, due to the improvement in some characteristics of the soil. The effect of nutrients contributed to the soil by the SS (MECABÔ JÚNIOR et al. 2014) concentration in the drainage water that reached the lysimeter, contrary to what happened in the SCHNEIDERS (2017) study. The possible higher adsorption of the elements by the soil in the higher doses of SS may have been caused by possible increase in soil loads on the path traveled by the SS down to the depth in which the runoff reached the lysimeter.

Table 5. P and K concentrations and P and K total losses in the runoff, depending on the crops and treatments.

Treatment(SS)	Phosphorus and potassium un runoff			
	P	K	P	K
m³ ha⁻¹	----------- mg L⁻¹-----------		-------- g ha⁻¹ --------	
		Millet		
(0)	0.12e	3.22b	50e	1,330bc
0	0.31d	2.23b	108d	774d
50	0.80c	3.27b	286c	1,168c
100	0.99b	3.78a	388b	1,483b
200	1.40a	7.13a	496a	2,526a
Average	1.06	4.73	390	1,726
CV (%)	6.1	4.6	5.4	4.1
		Oat		
(0)	0.32c	3.22c	17d	174c
0	0.46c	2.78c	23d	136c
50	5.93b	1.88b	130c	284b
100	7.98b	1.14b	224b	396a
200	11.83a	17.56a	296a	439a
Average	8.58	14.86	217	373
CV (%)	10.8	6.5	4.5	8.6
		Crotalaria		
(0)	0.20d	4.37c	65c	1,416a
0	0.77d	3.99c	22d	113d
50	2.25c	5.20c	74c	172d
100	4.08b	8.12b	180b	357c
200	9.58a	17.24a	268a	483b
Average	5.30	10.19	174	337
CV (%)	6,4	4.2	5.7	4.2
		Average in crops		
(0)	0.21	3.27	132	2,920
0	0.51	3.00	152	1,023
50	2.99	7.12	490	1,624
100	4.35	8.68	791	2,236
200	7.60	13.98	1.060	3,448
Average	4.98	9.93	780	2,436
CV (%)	0.21	3.27	132	2,920

(0): Without slurry and without cultivation.SS: swine slurry. Equal lowercase letters in the column do not differ by Duncan ($p \leq 0.05$). The averages cover the treatments with 50, 100 and 200 m³ ha⁻¹ of SS. CV: coefficient of variation.

Table 6. P and K concentrations in subsurface flow in crops, depending on the treatments.

Treatament (SS)	Phosphorus	Potassium
m³ ha⁻¹	---------------- mg L⁻¹	------------------
(0)	0.076d	2.84a
0	0.233bc	2.42b
50	0.282a	2.34bc
100	0.243b	2.24bc
200	0.201c	2.14c
Average	0.242	2.24
CV (%)	4.5	2.3

(0): Without slurry and without cultivation. SS: swine slurry. Equal lowercase letters in the column do not differ by Duncan ($p \leq 0.05$). The averages cover the treatments with 50, 100 and 200 m³ ha⁻¹ of SS. CV: coefficient of variation.

The increased DM due to the increase in the dose of SS decreased the SL linearly in a significant way ($p<0.05$) (Figure 2).The DM protected the soil from the effect of the rain and runoff, so that the SL decreased at 2.90 t ha⁻¹ with an increase in DM between 13.75 t ha⁻¹ and 22.79 t ha⁻¹.The increase in DM increases the soil coverage, as verified by SCHICK et al.(2017), dissipating the energy of the rain and the runoff in NT condition, increasing the infiltration of water (BERTOL et al. 2015) and decreasing water erosion.

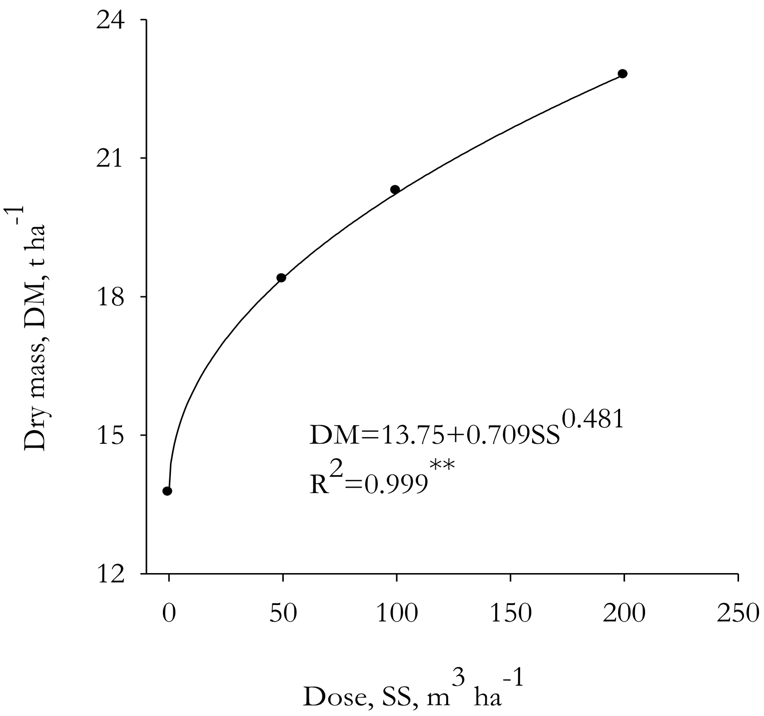

Figure 1. Relation between total dry mass of aerial part (DM) of the crops and dose of swine slurry (SS) applied to the soil (mean of the treatments).

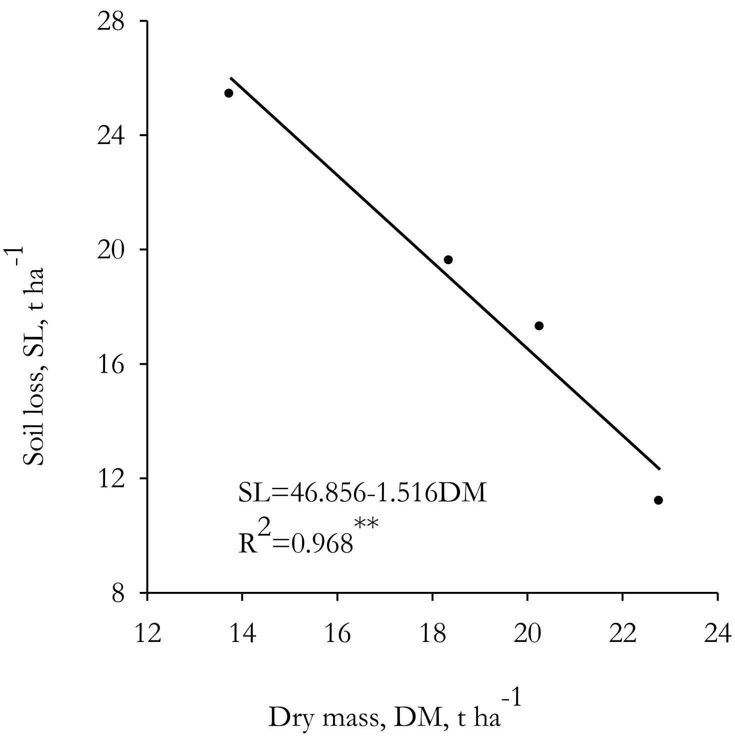

Figure 2. Relation between soil losses (SL) and total dry mass of the crops DM (mean of the treatments).

The P concentration in the subsurface flow was not influenced by P concentration in runoff, while the regression of Figure 4 shows significant decrease in K concentration in the subsurface flow with the increase in the K concentration in the runoff (Figure 3 - $p<0.05$), contradicting what SCHNEIDERS (2017) verified.

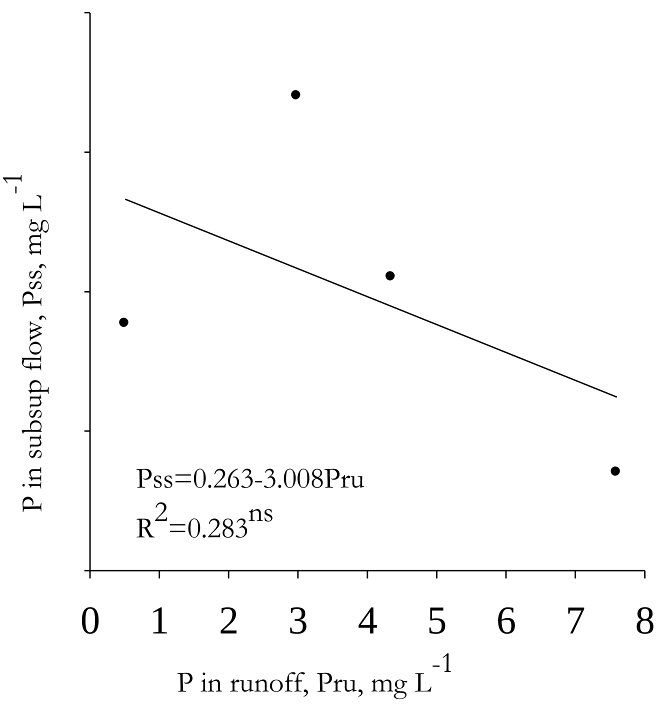

Figure 3. Relation between P concentrations in subsurface flow (Pss) and P in runoff (Pru) (mean of the treatments).

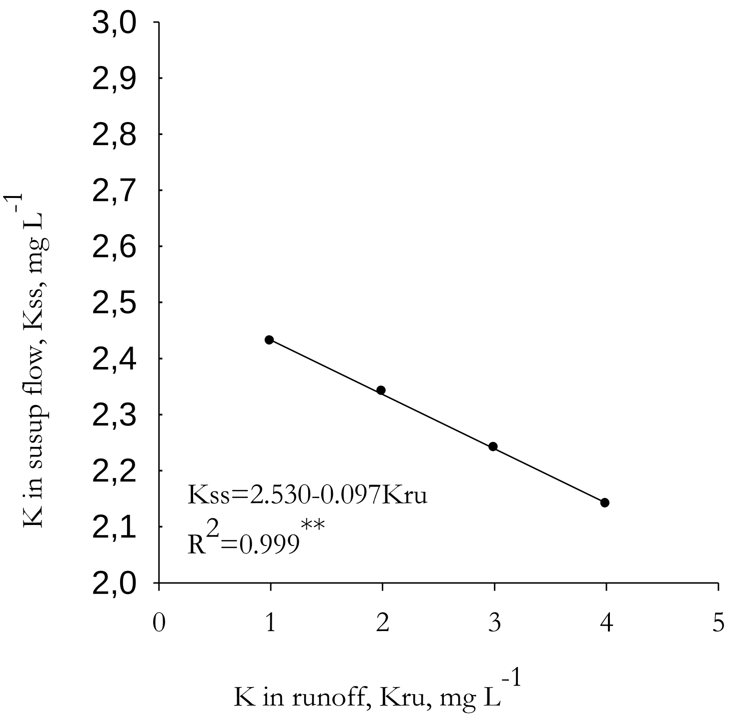

Figure 4. Relation between K concentrations in subsurface flow (Kss) and K in runoff (Kru) (mean of the treatments).

CONCLUSION

The main results allow us to conclude that the application of swine slurry in the soil increases its total porosity and macroporosity, the concentration of phosphorus and potassium in the soil, and the dry mass of the plants, compared with the absence of swine slurry. Water erosion decreases with an increase in the dose of swine slurry in the interval between 50 and 200 m3 ha^{-1}, in relation to the dose of 50. The increase in the swine slurry dose increases the concentration and total losses of phosphorus and potassium in the runoff and decreases the concentration of these nutrients in the subsurface flow in the interval between 50 and 200 m3 ha^{-1} of SS. The increase in the dry mass of the plants, in the interval between 13.75 and 22.82 t ha^{-1}, decreases soil loss at an average rate of 2.90 t ha^{-1}. The concentration of potassium in the subsurface flow water is negatively related to the concentration of the element in the runoff.

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