

NUTRIENT LOSSES BY WATER EROSION

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ABSTRACT: Water erosion causes soil degradation, which is closely related to nutrient losses either in the soluble form or adsorbed to soil particles, depending mainly on the adopted soil management system. This study was carried out in São José do Cerrito, SC, Brazil, between March 2000 and June 2001. The objective was to quantify available nitrogen, phosphorus, potassium, calcium and magnesium losses in water erosion obtained with simulated rainfall in the following soil management systems: conventional tillage with no-crop (bare soil) (BS), conventional tillage with soybean (CT), reduced tillage with soybean (RT), no tillage with soybean on a desiccated and burned natural pasture (DBNP), and no tillage with soybean on a desiccated natural pasture (DNP). A rotating boom rainfall simulator was used to perform three rainfall tests with constant intensity of 64 mm h⁻¹ and sufficient duration to reach constant runoff rate, on a clayey-loam, well-structured Typic Hapludox, with an average slope of 0.18 m m⁻¹. The first test was carried out five days before soybean emergence and the second and third at 30 and 60 days, respectively. The nutrient concentration in water and total losses of nitrogen, phosphorus, potassium, calcium and magnesium were higher under CT than in the other soil management systems.

Key words: nutrient concentration, water loss, simulated rainfall

PERDAS DE NUTRIENTES NA ÁGUA DA EROSÃO HÍDRICA

RESUMO: A erosão hídrica causa o empobrecimento dos solos, devido ao transporte de nutrientes, os quais são transportados tanto adsorvidos aos colóides do solo quanto solubilizados na água, podendo variar com o sistema de manejo solo. O trabalho foi conduzido em São José do Cerrito (SC), entre março de 2000 e junho de 2001, com o objetivo de quantificar as perdas de nitrogênio, fósforo, potássio, cálcio e magnésio na água da erosão hídrica sob chuva simulada, nos seguintes sistemas de manejo: aração+duas gradagens sem cultivo do solo (SSC), aração+duas gradagens com cultivo de soja (PCO), escarificação+uma gradagem com cultivo de soja (CMI), semeadura direta de soja em campo natural dessecado e queimado (SDDQ) e semeadura direta de soja em campo natural dessecado (SDD). Utilizando um simulador de chuvas de braços rotativos, foram aplicados três testes de chuva, com intensidade constante de 64 mm h⁻¹ e com durações suficientes para a enxurrada atingir taxa constante, sobre um Nitossolo Háplico aluminico, com 0,18 m m⁻¹ de declividade média. O 1º teste foi aplicado cinco dias após a semeadura da soja, e o 2º e 3º, 30 e 60 dias após o primeiro, respectivamente. A concentração e a perda total de nitrogênio, fósforo, potássio, cálcio e magnésio na água da erosão hídrica foram maiores no PCO do que nos demais sistemas de manejo do solo.

Palavras-chave: concentração de nutrientes, perda de água, chuva simulada

INTRODUCTION

The loss of nutrients by water erosion in crop fields contributes to soil degradation, especially under conventional tillage (Bertol, 1994; Schick et al., 2000). N and P are the main nutrients that restore soil fertility, and together with Ca, Mg, K and organic matter, are subject to losses by water erosion (Bertol & Miquelluti, 1993; Schick et al., 2000; Mello, 2002).

Nutrient losses can be expressed as concentration in the water or in the sediment and as amounts lost (Schick, 1999; Schick et al., 2000). These losses are affected by soil type, cover and fertility; slope of the ter-

rain; amount, method and time of fertilizers application; intensity, amount and moment of occurrence of rainfall (Gascho et al., 1998); as well as by soil management practices (Barisas et al., 1978; Schick et al., 2000; Mello, 2002).

Soil conservation tillage are characterized by the presence of more extensive ground cover and/or surface roughness than under conventional tillage. Therefore, soil and water losses are reduced, which could decrease nutrient losses by erosion under conservation tillage (King et al., 1996; Seganfredo et al., 1997; Schick et al., 2000). The concentrations of nutrients in water resulting from water erosion are, in general, similar or greater under

conservation tillage than under conventional tillage (Barisas et al., 1978; Schick et al., 2000), what can be explained by the reduction of the total sediment load in the outflow, with the consequent relative increase of the colloidal sediment load in the storm runoff under conservation tillage. It could also result from the use of soil tillage to incorporate fertilizers under these soil management systems (Gascho et al., 1998).

Nutrient losses are expected to be reduced in soil management systems that preserve plant residues. However, even under such conditions plant residues can be washed off (Burwell et al., 1975), becoming sources of soluble nutrients (Barisas et al., 1978; Johnson et al., 1979), which can be lost by water erosion.

Nutrient gain rates are usually inversely proportional to soil and water losses. As erosion decreases, an increase in the proportion of smaller particles is observed in the eroded material (Alberts & Moldenhauer, 1981), resulting in an increase of the proportion of mineral and organic colloids, and consequently the sediment becomes richer in nutrients (Freitas & Castro, 1983; Schick et al., 2000). Ca and Mg losses by water erosion are usually high (Bertol, 1994; Schick et al., 2000). This occurs because these elements are strongly adsorbed by colloids in the soil, which makes it easy for them to be transported with the sediment, and also because they occur in high concentrations in erosion water. The objective of this work was to quantify losses of P, K, Ca, Mg and N in water erosion, during soybean cultivation, in different soil management systems, using simulated rain.

MATERIAL AND METHODS

The study was developed on an Typic Hapludox, clayey textured, located in São José do Cerrito, SC, Brazil, at 27°39'47"S and 50°34'48"W, between March 2000 and June 2001. The mean slope of the experimental area was 0.18 m m⁻¹; Table 1 presents data on soil depth, granulometry and organic carbon content.

The experimental area was initially covered by natural pasture, improved in March 1999 with the introduction of ryegrass (*Lolium multiflorum*) and red clover (*Trifolium pratense*) and the surface application of 3 t ha⁻¹

dolomitic lime. In May 2000, the area that received the treatments corresponding to bare soil, conventional tillage and reduced tillage, was tilled with one plowing and two harrowing operations. The other part, which received treatments corresponding to reduced tillage and conventional tillage, was corrected with 11 t ha⁻¹ dolomitic lime and 230 kg ha⁻¹ triple superphosphate, in addition to 70 kg ha⁻¹ potassium chloride, which were incorporated to the soil with one harrowing operation. Plowing was performed with a disk plow, transversally to the slope, at a depth of approximately 0.20 m. Harrowings were carried out with a leveling disk harrow, also transversally to the slope, at a depth of approximately 0.15 m. The rest of the area, where treatments of no tillage on a desiccated natural pasture and of no tillage on a desiccated and burned natural pasture were installed, was not tilled nor received liming or fertilization at that time.

Black oat (*Avena strigosa*) was sown as a cover crop in May 2000, without fertilization, in the area where the reduced tillage and conventional tillage treatments were installed. In September 2000, during the oat bloom, the crop was chemically desiccated; yield was 5.4 t ha⁻¹ dry mass. The natural pasture was desiccated on the same date; yield was 1.4 t ha⁻¹ dry mass.

In November 2000 the following soil management treatments (n = 2) were installed over the oat and natural pasture dry mass residues: one plowing+two harrowings and no-cropping (bare soil) (standard Universal Soil Loss Equation plot - USLE) - BS; one plowing+two harrowings (conventional tillage) on the desiccated oat residue, with soybean - CT; one scarification+one harrowing (reduced tillage) on the desiccated oat residue, with soybean - RT; direct soybean sowing on the residue of the desiccated natural pasture - DNP; and, direct soybean sowing on the desiccated and burned natural pasture (no residue) - DBNP.

For treatments BS, CT and RT, tillage was performed parallel to the slope, five days before sowing soybean. Plowing was performed with a disk plow at a depth of approximately 0.20 m; harrowing was performed with a leveling harrow at a depth of approximately 0.15 m. Scarification was performed at a 0.20 m depth; the scarifier shanks were adjusted to a distance of 0.50 m between them. The soybean was sown with a punch-planter, in rows 0.50 m apart from each other. Desiccation of the natural pasture for treatments DNP and DBNP was performed five days before the application of the first simulated rainfall test. For treatment DBNP, the field was burned immediately before the application of the first simulated rainfall test.

Soybean fertilization was made with 80 kg ha⁻¹ KCl and 100 kg ha⁻¹ triple superphosphate, incorporated by one harrowing parallel to the slope, for CT and RT, at sowing time. For treatments DNP and DBNP, fertilizers were applied on the soil surface, at soybean sowing time, without incorporation.

Table 1 - Horizon depths and granulometric composition of the soil profile.

Horizon	Thickness cm	Clay	Sand	Silt	OC
		g kg ⁻¹			
A1	0 - 16	627	118	255	13.5
A2	16 - 32	733	102	165	7.6
AB	32 - 50	680	105	215	5.8
BA	50 - 68	706	113	181	3.7
B	68 - 115 ⁺	592	115	293	2.9

OC: organic carbon.

Three simulated rainfall tests were applied. The first test was performed five days after the soybean was sown and the others 30 and 60 days after the first, with a constant intensity of 64 mm h⁻¹ and variable duration, sufficient for the runoff to reach a steady rate.

Experimental units consisted of ten, 3.5 x 11 m plots, installed according to Embrapa (1975). The simulated rainfalls were applied with a rotating boom rainfall simulator (Swanson, 1975). The simulator covered simultaneously two plots, which were replicates of the soil management treatments.

Runoff sampling was performed by collecting samples inside 300 mL glass jars, according to the methodology described by Cogo (1981). Four jars were utilized per plot; two were collected when the runoff started to flow and two were collected when it reached a constant rate (those moments were variable for each treatment). In the laboratory, 3 to 5 droplets of hydrochloric acid (2.5 N) were added to each runoff jar, in order to flocculate and precipitate the soil particles in suspension, as recommended by Cogo (1981). After the solid particles were precipitated, an aliquot of approximately 10 mL of

sediment-free water was taken from each sample (jar), which was utilized to determine the soluble contents of P, K, Ca, Mg and N in the water, using the methodologies described by Tedesco et al. (1995). Data were interpreted by analysis of variance and compared by Duncan test ($P = 0.05$).

RESULTS AND DISCUSSION

Concentration of nutrients in the erosion water

The mean N concentration of the runoff water for the conventional tillage (CT) was approximately, 2.3; 3.0; 4.7; and 8.8 times greater than for bare soil (BS), reduced tillage (RT), desiccated and burned natural pasture (DBNP) and desiccated natural pasture (DNP), respectively, for the simulated rainfall tests (Table 2). In the case of BS, this can be explained by the absence of fertilization, while for DNP and DBNP, the differences can be probably attributed to the low N mineralization rate during that period and, for DBNP specifically, to plant mass burning in the natural pasture.

Table 2 - Concentrations of soluble N, P, K, Ca and Mg in water erosion, under different management systems of the soil and simulated rainfalls applied (means of two replicates).

Rainfall	BS	RT	CT	DBNP	DNP
Nitrogen (mg dm ⁻³)					
Test 1	3.36 Ba	3.50 Ba	6.30 Aa	1.86 Ca	0.70 Da
Test 2	2.24 Ab	0.90 Cb	1.11 Bb	0.73 Db	0.56 Eb
Test 3	0.76 Dc	0.43 Cc	7.11 Ac	1.11 Bc	0.39 Cc
Mean	2.12 B	1.61 C	4.84 A	1.04 D	0.55 E
Phosphorus (mg dm ⁻³)					
Test 1	0.01 Ca	0.01 Ca	0.01 Ca	1.88 Ba	2.19 Aa
Test 2	0.01 Aa	0.01 Aa	0.01 Aa	0.01 Ab	0.01 Ab
Test 3	0.01 Aa	0.01 Aa	0.01 Aa	0.01 Ab	0.01 Ab
Mean	0.01 C	0.01 C	0.01 C	0.64 A	0.74 B
Potassium (mg dm ⁻³)					
Test 1	3.88 Ea	29.58 Ba	34.60 Aa	21.60 Ca	16.68 Da
Test 2	2.73 Db	7.78 Ab	7.60 Ab	5.68 Cb	6.13 Bb
Test 3	3.88 Ea	6.60 Bc	7.18 Ab	5.63 Cb	4.15 Dc
Mean	3.50 E	14.65 B	16.45 A	10.97 C	9.00 D
Calcium (mmolc kg ⁻¹)					
Test 1	05.4 Ca	134.2 Aa	140.4 Aa	21.0 Ba	21.3 Ba
Test 2	15.9 Cb	78.8 Ab	77.5 Ab	27.5 Ba	28.8 Ba
Test 3	25.4 Ec	103.3 Ac	85.4 Bb	58.4 Db	68.4 Cb
Mean	15.6 C	105.4 A	101.1 A	35.6 B	39.5 B
Magnesium (mmolc kg ⁻¹)					
Test 1	26.5 Da	172.4 Ba	193.7 Aa	51.5 Ba	58.3 Ca
Test 2	21.9 Cb	83.0 Ab	84.5 Ab	33.1 Bb	31.3 Bb
Test 3	25.5 Da	82.1 Ab	68.7 Bc	46.5 Cc	49.0 Cc
Mean	24.6 C	112.5 A	115.6 A	43.7 B	46.2 B

BS: bare soil; RT: reduced tillage; CT: conventional tillage; DBNP: no tillage in desiccated and burned field; DNP: no tillage in desiccated field. Upper case letters in rows compare means between treatments; lower case letters in columns compare means between rainfall tests, by Duncan test at 5%.

For RT, which received the same fertilization as CT, the smaller concentration of N relative to CT partially disagrees with the reports of Barisas et al. (1978) and Johnson et al. (1979). The total incorporation of the cropping residue into the soil for CT, probably with greater decomposition, must have contributed to the greater concentration and release of N in that treatment. For all treatments, N concentrations were higher for rainfall test 1 than for tests 2 and 3, probably because of the greater soil organic matter mineralization and release of N in the initial stage of the experiment, which probably tended to decrease in the following stages.

The concentrations of P in the water were low in all treatments and rainfall sessions applied (Table 2), in agreement with other reports (Barisas et al., 1978; McIsaac et al., 1995; Schick et al., 2000), what can be explained by the low concentrations of this element in the soil and by its strong adsorption by colloids. DNP had the highest P concentration in water, followed by DBNP, in the means of applied rainfall tests, which is explained by the high concentrations of this element occurring in the first rainfall test. This probably occurred because, in these treatments, fertilization was performed by broadcasting fertilizer on the soil surface, allowing greater contact of the element with the runoff water, increasing its concentration in the erosion water, as verified by Gascho et al. (1998). Therefore, in the first applied rainfall, most of the soluble P on the soil surface was probably lost in the water erosion. On the other hand, phosphorus that had been applied to tillage treatments was incorporated to the soil, decreasing its contact with the runoff and consequently reducing its loss in the water erosion.

The highest concentration of K was found in CT water erosion (Table 2), with respect to the mean of the applied rainfall tests, because K is a relatively mobile element in the soil and when incorporated, as it is the case in CT, it behaves in a similar way in relation to its runoff concentration. The lowest K concentration, for the rainfall test means, occurred in BS, because of the absence of fertilization and plant residues in the soil. For CT, the concentration of K was 50 and 83% higher than in DBNP and DNP, respectively, for the rainfall test means. For the DNP treatment, the stubble in the desiccated field served as a source of nutrients, which were probably mineralized and made available for runoff transportation, as verified by Barisas et al. (1978) and Johnson et al. (1979). For DBNP, the same phenomenon probably occurred, with faster mineralization, since burning the desiccated field in this treatment accelerated the decomposition of organic compounds, making the soluble nutrients available for runoff transportation.

Treatments that received fertilization (RT, CT, DBNP and DNP - Table 2) had mean K concentrations fourfold greater in the runoff water of the first rainfall as

compared to the other applied rainfalls, in agreement with Pote et al. (1996) and Gascho et al. (1998), thus demonstrating the importance of a correct surface runoff management, especially for the first rain that falls after the application of fertilizers to the soil, or after surface plant residue management operations have been carried out, as it is the case with soil conservation tillage. This behavior is explained by the high solubility of K, which can be easily lost through water erosion.

The Ca and Mg concentrations were higher for RT and CT than for the other treatments, in relation to the mean of the applied simulated rain tests (Table 2), and attributed to the application of dolomitic lime in these treatments. For the no-tillage treatments (DBNP and DNP), the concentrations of these elements in the water erosion were smaller because these treatments only received 1/3 of the lime rate relative to the rate applied for RT and CT, which was applied about a year before. On the other hand, the smallest concentrations of Ca and Mg were verified in BS, resulting from the complete absence of liming in this treatment. For treatments RT, CT, DBNP and DNP, concentrations of Ca and Mg were higher for the first rainfall test than for the others, except for DBNP and DNP. Schick et al. (2000) and Mello (2002) emphasize the importance of controlling the runoff that occurs for open rain, especially when it is intense or large in volume. It is also important to take into account the moment of the rainfall occurrence in relation to the moment of lime application, with regard to the importance of runoff control.

Water total volume lost by erosion

Water losses caused by water erosion were relatively high in all treatments and simulated rainfalls applied (Table 3), with relatively small differences between treatments, as also verified by other authors (Cogo, 1981; Bertol, 1995; Bertol et al., 1997b). RT was the most effective treatment, with water loss equivalent to 25% of the applied rainfall, while the less effective was BS, which lost the equivalent to 42% of the rainfall.

This demonstrates that support conservation practices, such as terracing, capable of storing water in the

Table 3 - Total water volume lost in erosion, under different management systems of the soil and simulated rainfalls applied (means of two replicates).

Treatment	Test 1	Test 2	Test 3	Mean
	----- % of applied rainfall -----			
BS	40	44	43	42
RT	25	23	27	25
CT	35	40	40	38
DBNP	13	37	34	28
DNP	14	39	38	30

BS: bare soil; RT: reduced tillage; CT: conventional tillage; DBNP: no tillage in desiccated and burned field; DNP: no tillage in desiccated field.

cropping field, must be adopted, avoiding nutrient losses by water erosion. The total losses of nutrients by water erosion are directly related, among other factors, to the concentration of nutrients in the water and to the volume of water lost by erosion (Alberts et al., 1978; Schick et al., 2000; Mello, 2002).

Total nutrient losses in water erosion

Losses of N in water erosion were 2.6; 3.5; 6.2; and 10.4 times greater for the CT treatment than for BS, RT, DBNP and DNP, respectively (Table 4), and are proportional to the concentration of this element in the water (Table 2) and to water loss (Table 3). The smaller loss of N in RT, relative to CT, can be attributed to the combined effect of low concentration of the element in the runoff (Table 2) with smaller water loss (Table 3). In treatments CT, BS, DNP and DBNP, on the other hand, the differences in water loss were small and, therefore, N losses were more influenced by the concentrations of this element in the runoff water than by water losses.

RT was the most effective treatment in reducing P losses (Table 4), mainly because of the smaller water loss (Table 3). BS and CT did not differ between themselves with regard to P losses, which can be explained

both by water losses (Table 3) and by the concentrations of this element in the water (Table 2). The highest total P loss occurred for the DNP treatment, followed by DBNP, which presented values, on average 43 times greater than the mean for the other treatments. For these two treatments, the total losses of P were strongly influenced by the losses that occurred in the first rainfall test, similarly to what was observed for concentration (Table 2), because of the surface application of phosphate fertilizer in both treatments, as verified by Pote et al. (1996) and Gascho et al. (1998) and, in the case of the DBNP treatment, also because of the effect of plant residue burning.

K losses were relatively high, regardless of the management system (Table 4), in agreement with Schick et al. (2000). This occurred because K is naturally found in relatively high concentrations in the soil and also because it is highly soluble in water. K loss of the CT treatment was 1.4 time greater than for RT, considering the total rainfall applied (Table 4); this difference was strongly influenced by the difference in water loss (Table 3), with smaller influence of the concentration of this element in the water (Table 2); this fact was also verified by Schick et al. (2000). In relation to rainfall, K losses followed the same behavior observed for its concentra-

Table 4 - Losses of soluble N, P, K, Ca and Mg in erosion water, under different management systems of the Typic Hapludox and simulated rainfalls applied (means of two replicates).

Rainfall	BS	RT	CT	DBNP	DNP
Nitrogen (kg ha ⁻¹)					
Test 1	0.52 Ca	0.97 Ba	2.01 Aa	0.17 Da	0.13 Da
Test 2	0.85 Bb	1.90 Ab	0.33 Cb	0.24 CDb	0.18 Db
Test 3	0.28 Cc	0.90 Ba	2.03 Aa	0.29 Cc	0.11 Da
Total	1.65 B	1.25 C	4.37 A	0.70 D	0.42 E
Phosphorus (g ha ⁻¹)					
Test 1	1.56 Ca	2.75 Ca	3.15 Ca	273.59 Ba	413.29 Aa
Test 2	3.72 Ab	2.09 Db	3.05 Ca	3.27 Bb	3.26 Bb
Test 3	3.63 Ab	2.09 Db	2.45 Cb	2.99 Bb	2.99 Bb
Total	8.91 C	6.93 D	8.65 C	279.85 B	419.54 A
Potassium (kg ha ⁻¹)					
Test 1	0.61 Da	8.08 Ba	11.05 Aa	3.15 Ca	3.15 Ca
Test 2	1.00 Db	1.62 Cb	2.30 Ab	1.85 Bb	1.98 Bb
Test 3	1.40 Bc	1.38 Bc	1.82 Ac	1.69 Ab	1.28 Bc
Total	3.01 E	11.08 B	15.17 A	6.69 C	6.41 D
Calcium (kg ha ⁻¹)					
Test 1	17 Ea	738 Ba	890 Aa	62 Da	80 Ca
Test 2	115 Db	330 Bc	472 Ab	179 Cb	184 Cb
Test 3	189 Dc	432 Ab	433 Ac	343 Cc	410 Bc
Total	321 E	1500 B	1795 A	584 D	674 C
Magnesium (kg ha ⁻¹)					
Test 1	50 Ea	570 Ba	742 Aa	93 Da	132 Ca
Test 2	97 Db	209 Bb	309 Ab	130 Cb	120 Cb
Test 3	107 Dc	206 Ab	202 Ac	163 Cc	176 Bc
Total	254 E	985 B	1253 A	386 D	428 C

BS: bare soil; RT: reduced tillage; CT: conventional tillage; DBNP: no tillage in desiccated and burned field; DNP: no tillage in desiccated field. Upper case letters in rows compare means between treatments; lower case letters in columns compare means between rainfall tests, by Duncan test at 5%.

tion in the water erosion, i.e., the greatest losses in treatments that received fertilization occurred in the first simulated rainfall applied, and the lower losses were recorded in the subsequent rainfalls, due to the high solubility of this element, which easily causes loss by water erosion.

Ca and Mg losses by water erosion were high (Table 4), which is in agreement with the work of Schick et al. (2000), explained by the fact that these elements are relatively soluble in water and because they can be found in high concentrations in the soil, which received dolomitic lime. CT was the less effective treatment in controlling losses of these elements. With regard to RT, for example, this can be explained especially by the differences in water loss between the two treatments (Table 3), since the concentrations of those elements in the water were equal under these soil management systems (Table 3). Ca and Mg losses were greater in the first applied rainfall than in the others, according to the behavior observed for the concentration of these elements in water erosion (Table 2).

K, Ca and Mg losses were smaller for treatments BS, DNP and DBNP than for RT and CT (Table 4). This occurred because of the absence of fertilization and liming in BS and, in the case of DNP and DBNP, because these treatments received only 1/3 of the lime that to RT and CT received.

Nutrient losses were in general influenced by the concentrations of elements in the water, and especially by water losses. This demonstrates that support conservation practices that reduce water losses in cropping fields must be adopted, such as terracing, even when the crops are managed under soil conservation tillage, as recommended by Bertol (1995) and Bertol et al. (1997a; 2000).

CONCLUSION

The concentrations of N, P, K, Ca and Mg in the water lost by erosion are strongly influenced by the soil management system adopted and increase with increasing fertilization and soil tillage intensity. Highest concentrations of N, P, K, Ca and Mg in the water lost by erosion occur under conventional tillage and, in the case of P, under no tillage in natural fields.

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