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Nutrient losses due to water erosion using simulated rainfall in southern Brazil

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Abstract
Erosion is the main form of degradation in the world, consequently of loss of soil, water and nutrients, provoking direct and indirect damages. The objective of this work is to quantify N, P and K losses by water erosion under simulated rainfall conditions by the application of six erosion tests in continuous cultivation of seasonal cycle species, including isolated and intercropped crops. The study was carried out in the field at the Experimental Station of Agronomy in Eldorado do Sul (RS), Brazil, in a typical Dystrophic Red Argisol. For the analysis of nutrient loss, six erosion tests with simulated rainfall were applied to the treatments between the end of October and mid-December, using the rain simulator with swivel arms of Swanson. The losses of N and P were influenced by surface conditions, with the partial removal of crop residues and the non-mobilization of the soil. The exception was K, due to its high solubility in the soil with a low colloidal activity, which was easily lost in the soil water surface runoff, regardless of total soil surface coverage by crop residues.

Keywords: erosive process; runoff; cultural sequences; ground cover.

Pérdidas de nutrientes debido a la erosión hídrica con la lluvia simulada en el sur de Brasil

Resumen
La erosión es la principal forma de degradación en el mundo, en consecuencia de la pérdida de suelo, agua y nutrientes, provocando daños directos e indirectos. El objetivo de este trabajo es cuantificar las pérdidas de N, P y K por erosión hídrica en condiciones de lluvia simulada mediante la aplicación de seis pruebas de erosión en cultivo continuo de especies de ciclo estacional, incluyendo cultivos aislados y cultivos intercalados. El estudio se llevó a cabo en el campo en la Estación Experimental de Agronomía en Eldorado do Sul (RS), Brasil, en un Argisol Rojo Distrófico típico. Para el análisis de la pérdida de nutrientes, se aplicaron seis ensayos de erosión con lluvia simulada a los tratamientos entre finales de octubre y mediados de diciembre, utilizando el simulador de lluvia con brazos giratorios de Swanson. Las pérdidas de N y P se vieron influenciadas por las condiciones de la superficie, con la eliminación parcial de los residuos del cultivo y la no movilización del suelo. La excepción fue K, debido a su alta solubilidad en el suelo con baja actividad coloidal, que se perdió fácilmente en la escorrentía superficial del agua del suelo, independientemente de la cobertura total de la superficie del suelo por los residuos de los cultivos.

Palabras clave: proceso erosivo; escorrentía; secuencias culturales; cobertura del suelo.

1. Introduction

The undue use of soil, including the removal of vegetation cover, stands out as one of the main factors associated with accelerated erosion, represented by soil loss rates by erosion that exceed the natural rates of renewal and replenishment of this resource. Soil loss rates in Brazil generally vary from 15 to 25 Mg ha^{-1} year^{-1}, while soil formation rates are in the range of 1 Mg ha^{-1} year^{-1} [1].

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Soil erosion is considered one of the major environmental problems in the world, as it causes soil and nutrient losses and is associated with flooding, sedimentation and pollution of water bodies [2,3] According to [4], an inadequate soil management may lead to erosive processes such as water erosion, whose sediment transport culminates in the loss of soil, water, nutrients and organic matter.

As there is an increase in soil losses, they are accompanied by losses of organic matter and nutrients, notably phosphorus, for example, which is very susceptible to losses in floods, and potassium [5]. Soil preparation methods vary in extent surface area of the land under of preparation and degree of mass fragmentation solo mobilized [6]. Notably, the loss of nutrients by erosion is affected by the method of preparation of the soil used in the growing process.

As for rainwater erosion, specifically, soils must fulfill their functions to freely let rainwater infiltrate its surface and resist degradation and transport of its particles by the action of rainfall and associated runoff.

Nutrients in the soil are those adsorbed to mineral or organic solid particles or dissolved in surface runoff water, which can be removed by water erosion processes [6].

[7] stated that with regard to nutrient losses caused by this type of erosion, they are more related to sediment losses than to water losses.

[8] quantified total water, soil and nutrient losses in the native field and verified that the removal of the vegetal cover by the burning of the native field phytomass decreased the infiltration of water in the soil, besides increasing the maximum rate of flood, water and soil losses due to water erosion and total nutrient losses (P, K and NH_4^+). For the quantification of losses of soil, water and nutrients, the use of the rainfall simulator is a tool that allows the control of rainfall characteristics, such as diameter and drop distribution, height and time of fall, terminal velocity, duration time, intensity and kinetic energy, which is not possible under natural rainfall conditions (Ribeiro et al. [9]).

The objective of this work is to quantify N, P and K losses by water erosion under simulated rainfall conditions by the application of six erosion tests in continuous cultivation of seasonal cycle species, including isolated and intercropped crops.

2. Material and methods

The study was conducted at the Experimental Erosion Area with Simulated Rain III at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul (EEA/UFRGS) in the municipality of Eldorado do Sul (RS) in the interval of six (6) months for six (6) rain simulation tests.

The EEA/UFRGS is located in the Central Depression, RS, between the geographic coordinates 30°00' and 30°15' S and 51°30' and 51°45' W, at an average altitude of 46 m. According to the Köppen classification, the climate is Cfa, subtropical humid with a hot summer and temperature of the coldest month oscillating between -3°C and 18°C and temperature of the hottest month higher than 22°C, with an annual mean rainfall around 1,400 mm and a monthly average of about 120 mm (BERGAMASCHI; GUADAGNIN [10]).

The soil is classified as a typical Dystrophic Red Argisol [11-13], presenting the following characteristics: sandy loam surface texture, A moderate to B moderate textural horizons, moderate depth and drainage, mean slope of 0.115 mm^{-1} and effective depth lower than 0.80 m [14].

The treatments consisted of seasonal crop species (autumn-winter and spring-summer) arranged in a continuous succession mode, including isolated cultivations and intercropped crops, most often in line and tratorized as for the sowing method (except for the first crop, depending on the soil adaptation operation in the experimental area, in which the grid was used).

The cultivars constituting the crop sequences of the autumn-winter period were *Avena strigosa* (black oat), *Vicia sativa* (vetch), *Raphanus sativus* L. (forage turnip), (*Trifolium alexandrinum*) (Alexandrian clover - cultivar Calipso), and *Lolium multiflorum* L. (ryegrass), while crops from the spring-summer period were *Zea mays* L. (maize), *Pennisetum americanum* (millet), *Euchlaena mexicana* Schrad (teosinte), *Vigna unguiculata* (kidney bean) and *Canavalia ensiformes* L. (jack bean).

For the analysis of nutrient loss, six erosion tests with simulated rainfall (T1 to T6) were applied to the treatments between the end of October and mid-December, with no more plants in the experimental plots (only their crop residues - dried - were used in this phase), using the rain simulator with swivel arms or Swanson. Each test consisted of a rainfall with a planned constant intensity of 64.0 mm h^{-1} and variable duration (60 to 180 minutes), depending on the behavior of the runoff, basically start and equilibrium times, in a given treatment, and were characterized as described below:

Test 1 (T1): unmoved soil, dead roots, natural crust, 100% surface cover (consisting of herbicide-dried plants, scrubbed with a costal scrubber and evenly scattered on the soil surface in experimental plots).

Test 2 (T2): unmoved soil, broken crust (manually and slightly, with a plastic rake, during the operation of removal of cultural residues from the experimental plots after T1), 18% (average values of 15% to 20%) of surface cover (remaining from the operation described immediately above, which could not be removed to avoid changing the soil surface in the experimental plots).

Test 3 (T3): unmoved soil, dead roots, thin or recent crust (naturally formed after T2), 18% (mean values between 15% and 20%) of surface cover (remaining from T2).

Test 4 (T4): recently scarified soil, dead roots, 100% of surface cover (added manually using the crop residues removed for the performance of T2).

Test 5 (T5): soil previously scarified (before T4), 18% (average values between 15% and 20%) of surface cover (remaining from the operation of removal of cultural residues after T4), which was not possible to remove so as not to change the soil surface in the experimental plots.

Test 6 (T6): recently gridded soil (after T5), 0% surface coverage (the small amount of remaining T5 cultural residue was incorporated into the topsoil during its harrowing operation), performed on December 13 and 14, 2007.

In the course of the research, several samplings and determinations were made in the field and in the laboratory, including soil management variables (measured in the experimental plots) and soil water erosion variables (measures in the runoff). For the elaboration of this study, only the results of measurements regarding the water erosion were used.

For the collection of runoff, directly under its flow, graduated test tubes of 500, 1,000 and/or 2,000 ml were used, according to the intensity of the flow. At the same time, samples were also collected for laboratory determination of sediment concentrations. For this, 1.0 L plastic pots were used, most of the time filled to the limit (except in cases where the flow was very small). At the end of the collection, the plastic pots were sealed, taken to the laboratory and weighed to later quantify the amount of nutrients lost in water and soil samples.

Subsequently, 3 to 5 ml (depending on the sediment charge in the sample) of the commercially available saturated solution (5%) of commercial potassium alum, used as a precipitant, were added to each pot and allowed to stand for 24 to 48 hours for decantation. After this time and using a small-diameter plastic hose, the supernatant from the plastic pots was sucked off and set to oven drying at 60°C for three to four days. Afterwards, the pots were weighed with and without sediments, and the appropriate subtractions were made. Once the sediments and the runoff were obtained, N, P and K determinations were performed on the samples using the methodologies described by [15]

3. Results and discussion

It was verified that, for soil nitrogen losses caused by rainwater erosion, the highest averages refer to Test 2, in which there was no soil mobilization regardless of the crop sequence. However, after the first erosion test, the surface cover of the soil was removed, which now represented about 18% of the total (Table 1), whereas for all treatments of the Test 1, for example, where the soil was 100% covered, the values of losses were much lower, being the soil cover by crop residues a condition of physical protection of its surface, essential with respect to the control of water erosion and the associated runoff. For all tests performed, the crop sequence 1Av,3Av+Er/3Fm presented the highest nitrogen losses in relation to the others (Table 1). [16], studying soil losses due to water erosion in corn crops in two erosion tests, observed that in treatments where the soil was completely covered by vegetation, there were no losses since the beginning of the experiment. This evidences the importance of maintaining the residues of crops on the surface for the conservation of the soil. For the nitrogen lost and quantified in the runoff water, the tests differed significantly from each other, and, in general, the lowest values were recorded for the Test 2. The Tests 1, 4 and 5 presented higher values of losses for the different cultural sequences, which are 1Av,Tr, Nf,Az/1Fm, 2Mi+Fm1Sc, Av+Er, Av+Nf, Av+Az/1Fm,2Mt. For the Test 2, the 4Av/1Fm,2Te was the only sequence that differed statistically from the others, with the lowest mean losses of nitrogen in the runoff (Table 2). [17], studying nutrient losses due to water erosion, observed that nitrogen losses (NH^{4+}) in the runoff water were higher in the treatment with burning, therefore, in a soil with absence of vegetal cover, corroborating values found in this study.

Phosphorus levels found in the soil lost due to rainwater erosion accompanied nitrogen losses, in which the highest averages were recorded in all cultural sequences for the Test 2, ranging from 0.35 to 0.62 kg ha^{-1}. For the remaining tests, these amounts were 0.02 to 0.45 kg ha^{-1} (Table 3).

[18] adds that the adoption of the no-tillage system is one of the main forms of soil P transfer through surface runoff. It can be observed that the losses of phosphorus in the runoff were higher when the cultural sequence 4Av/1Fm,2Te was used, differing

Table 1.
Nitrogen loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil.

Crop Sequence[1]	**Nitrogen losses (kg ha^{-1})**					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1Av,3Av+Er/3Fm	0.47	5.58	1.12	0.18	1.61	2.41
4Av/1Fm,2Te	0.09	1.35	0.14	0.08	0.72	0.47
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	0.70	1.32	0.53	0.10	0.75	0.30
1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt	0.37	3.09	0.99	0.23	0.64	0.27
1Av,3Er/1Fm,2Mi+Fp	0.31	4.24	0.99	0.29	0.64	1.25

Source: The authors

Table 2.
Nitrogen loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil at a 5% of significance according to the Tukey test.

Crop Sequence[1]	**Nitrogen (mg L^{-1})**					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1Av,3Av+Er/3Fm	5.400 aB	16.750 aA	6.225 aB	2.050 aB	6.975 aB	8.950 abA
4Av/1Fm,2Te	2.400 aB	5.355 bcB	3.125 aB	1.900 aB	6.525 aB	15.000 aA
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	4.575 aA	3.475 cA	3.050 aA	1.750 aA	5.325 aA	4.900 bA
1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt	3.475 aA	6.400 bcA	4.425 aA	2.375 aA	5.500 aA	6.075 bA
1Av,3Er/1Fm,2Mi+Fp	3.050 aB	12.100 abA	5.525 aA	1.700 aB	3.575 aB	9.175 abAB

[1]In the listed crop sequences, using no-tillage, the algorithm preceding the crop or combination of crops indicates the number of times it took part in the experiment, while the underlined crop or combination of crops means that it was the one that prevailed earlier to the moment of evaluation, being the following the conventions adopted: Av = Black oats, Er = vetch, Fm = Kidney beans, Te = Teosinte, Tr = Calypso clover, Nf = forage turnip, Az = rye grass, Mi = Corn, Sc = without cultivation, Mt = Millet and Fp = jack beans. [2]cs = cover only by cultural residue. 1 Means followed by the same uppercase letters in rows and lowercase letters in lines do not differ by Tukey test at 5% probability.
Source: The authors

Table 3.
Phosphorus loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil.

Crop Sequence[1]	Phosphorus losses (kg ha^{-1})					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1Av,3Av+Er/3Fm	0.26	0.41	0.21	0.05	0.23	0.16
4Av/1Fm,2Te	0.05	0.35	0.04	0.02	0.11	0.01
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	0.45	0.38	0.12	0.04	0.11	0.04
1Sc, Av+Er,Av+Nf,Av+Az/1Fm,2Mt	0.22	0.39	0.13	0.04	0.05	0.03
1Av,3Er/1Fm,2Mi+Fp	0.11	0.62	0.17	0.05	0.13	0.09

Source: The authors

Table 4.
Phosphorus loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil at a 5% of significance according to the Tukey test.

Crop Sequence[1]	Phosphorus					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1Av,3Av+Er/3Fm	2.925 aA	1.225 abB	1.115 aB	0.590 aB	0.990 aB	0.590 aB
4Av/1Fm,2Te	1.400 bA	1.370 abA	0.855 aA	0.535 aA	0.997 aA	0.460 aA
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	2.925 aA	0.992 abB	0.675 aB	0.605 aB	0.792 aB	0.592 aB
1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt	2.025 abA	0.812 bB	0.587 aB	0.415 aB	0.452 aB	0.687 aB
1Av,3Er/1Fm,2Mi+Fp	1.150 bAB	1.775 aA	0.912 aAB	0.285 aB	0.732 aB	0.657 aB

[1]In the listed crop sequences, using no-tillage, the algorithm preceding the crop or combination of crops indicates the number of times it took part in the experiment, while the underlined crop or combination of crops means that it was the one that prevailed earlier to the moment of evaluation, being the following the conventions adopted: Av = Black oats, Er = vetch, Fm = Kidney beans, Te = Teosinte, Tr = Calypso clover, Nf = forage turnip, Az = rye grass, Mi = Corn, Sc = without cultivation, Mt = Millet and Fp = jack beans. [2]cs = cover only by cultural residue. 1 Means followed by the same uppercase letters in rows and lowercase letters in lines do not differ by Tukey test at 5% probability.
Source: The authors

Table 5
Potassium loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil.

Crop Sequence[1]	Potassium Losses (kg ha^{-1})					
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
1Av,3Av+Er/3Fm	3.30	3.55	1.12	0.76	3.18	3.84
4Av/1Fm,2Te	0.83	2.35	0.29	0.32	1.34	0.15
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	7.86	2.23	0.82	0.69	1.41	0.61
1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt	6.63	5.94	1.45	1.21	1.64	0.54
1Av,3Er/1Fm,2Mi+Fp	2.48	3.56	0.89	1.6	2.00	1.96

Source: The authors

statistically from the other treatments, except for the Test 1, in which the phosphorus lost did not differ statistically between the sequences, and for the Test 2, where the phosphorus lost at 4Av/1Fm,2Te did not differ statistically from 1Av,3Er/1Fm,2Mi+Fp, and was higher than the others (Table 4). These results show that for all crop sequences, there was an efficient soil restoration, with emphasis on the cultural sequence that has a predominance of teosinte (grassy), 4Av/1Fm,2Te. [19], when assessing soil and water losses in cultural sequences, emphasizes that grasses, act as a soil builder, with positive impacts on minimizing soil and water losses, and, consequently, of nutrients.

The highest potassium losses in the soil were in the Test 1 for the crop sequences. In this test, the results were obtained for 1Av,Tr,Nf,Az/1Fm,2Mi+Fm and 1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt, which reached on average 7.0 kg ha^{-1}. This loss of K may be associated with a higher mobility of this ion in the soil, although the soil has 100% coverage. In the other evaluations, a loss pattern of this element was not observed (Tabla 5). This lack of pattern is linked to a starting time of the runoff that varied in both shape and magnitude [20]. Potassium lost in runoff was not influenced by the different crop sequences planted in the research and, for all of them, did not differ statistically (Table 6). Similar tendencies were observed by [21] in different plant cover conditions, where potassium losses were influenced by the magnitude of rainfall events. Potassium was easily lost in the soil condition without mobilization and with 100% coverage (Test 1). This is due to the soil class under study (typical Dystrophic Red Argisol) because it presents a low colloidal activity and a low affinity with ions, being easily released in runoff water (floodwater), which can be attributed to the low affinity of K with soil constituents.

4. Conclusions

- Soil preparation methods and crop sequences influenced losses of Nitrogen and Phosphorus due to water erosion with simulated rainfall.
- Potassium, in function of its high solubility in a soil condition of low colloidal activity, was easily lost in surface runoff water, regardless of the total cover of the soil surface by crop residues and the unmoved condition.

Table 6.
Potassium loss for crop sequences in six water erosion tests with simulated rainfall in southern Brazil at a 5% of significance according to the Tukey test.

Crop Sequence¹	Potassium					
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1Av,3Av+Er/3Fm	37.500 bcA	10.675 aB	6.225 aB	8.525 aB	13.750 aB	14.250 aB
4Av/1Fm,2Te	22.750 dA	9.275 aAB	6.775 aB	7.875 aB	12.175 aAB	9.550 aAB
1Av,Tr,Nf,Az/1Fm,2Mi+Fm	51.250 abA	5.850 aB	4.750 aB	11.725 aB	9.950 aB	10.050 aB
1Sc,Av+Er,Av+Nf,Av+Az/1Fm,2Mt	61.500 aA	12.325 aB	6.500 aB	12.250 aB	14.000 aB	12.350 aB
1Av,3Er/1Fm,2Mi+Fp	25.250 cdA	10.150 aB	4.075 aB	9.300 aB	11.175 aAB	5.250 aAB

¹In the listed crop sequences, using no-tillage, the algorithm preceding the crop or combination of crops indicates the number of times it took part in the experiment, while the underlined crop or combination of crops means that it was the one that prevailed earlier to the moment of evaluation, being the following the conventions adopted: Av = Black oats, Er = vetch, Fm = Kidney beans, Te = Teosinte, Tr = Calypso clover, Nf = forage turnip, Az = rye grass, Mi = Corn, Sc = without cultivation, Mt = Millet and Fp = jack beans. ²cs = cover only by cultural residue. 1 Means followed by the same uppercase letters in rows and lowercase letters in lines do not differ by Tukey test at 5% probability.
Source: The authors

- The 100% coverage in Test 1 and lack of soil preparation was effective in controlling nutrient loss for N and P by water erosion in all cultural sequences.
- The highest nitrogen loss occurred with the removal of cultural residues from the soil surface, with the same tendency for phosphorus. The highest losses occurred in Test 2 (18% coverage).

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