

SURFACE EROSION STUDY ON CULTIVATED AND BARE LANDS USING ^7Be

ESTUDO DA EROSÃO SUPERFICIAL EM TERRAS CULTIVADAS E SEM COBERTURA VEGETAL UTILIZANDO O FALLOUT DO ^7Be

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Abstract: The monitoring of geological and hydrological phenomena presents a great environmental and financial interest, and several natural and artificial radioisotopes have been used for this purpose. In this study, Beryllium-7 was used to determine soil erosion in three areas: the first with soybean cultivation in direction of the topographic slope, the second with perpendicular soybean crop in the slope direction, and the last on bare land. Samples were analyzed by gamma ray spectrometry. The relaxation mass constant (h_0) was 4.71 ± 0.36 , similar to other studies. As predicted, bare soil had the highest erosion of all three areas studied, while the soil redistribution rate was lower when soybean was cultivated perpendicularly to the slope. The technique was helpful in order to identify the soil's path during the erosion process.

Keywords: Erosion, Soil, Environmental, Beryllium.

Resumo: O monitoramento de fenômenos geológicos e hidrológicos apresenta um grande interesse ambiental e financeiro e vários radioisótopos naturais e artificiais tem sido utilizados para este fim. Neste trabalho o ^7Be foi usado para determinar a erosão do solo em três áreas: uma com cultura de soja seguindo a direção de uma inclinação topográfica, uma com cultura

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de soja perpendicular à direção da inclinação e outra em terra sem cobertura vegetal. As amostras foram analisadas por espectrometria de raios gama. A constante de massa de relaxamento (h_0) foi de $4,71 \pm 0,36$, semelhante a outras pesquisas. Como previsto, o solo nu teve a maior erosão de todas as três áreas estudadas, enquanto a taxa de redistribuição do solo foi menor quando a soja foi cultivada perpendicular à inclinação. A técnica foi útil para se conseguir enxergar o caminho do solo durante a erosão.

Palavras Chave: Erosão, Solo, Meio Ambiente, Berílio.

1. Introduction

Soil erosion and sediment deposition are the most significant concerns distressing sustainable development of agricultural activities around the world, due to the reduction in soil fertility and the necessity of large investments to maintain certain levels of productivity. Besides, altogether these two issues may contribute in the siltation of water reservoirs, rivers and lakes, as well as eutrophication caused by the accumulation of biomass as a result of agricultural wastes (IAEA, 2001a). It has been estimated that human activities have accelerated soil erosion by approximately 7% in continental land (LAL, 1994; AGUIAR et al, 1958). Deforestation and inappropriate agricultural practices are responsible for about 30% of soil degradation, which indicates an economic impact of about US\$ 400 billion per year (OBALUM et al., 2017; ZAPATA, 2003).

Over the past 50 years, soil erosion has been extensively studied in order to clarify its causes and consequences. Conventional techniques for quantifying the soil erosion rate are very restricted and the results are mostly uncertain. Furthermore, they do not even consider spatial land redistribution. The usage of radionuclides for determining soil erosion rates is very promising, since the redistribution model of some radionuclides, such as caesium-137 (^{137}Cs), lead-210 (^{210}Pb) and beryllium-7 (^7Be), indicate soil redistribution in the area of interest. These radionuclides can be easily submitted to gamma ray spectrometry, in a lower cost when compared to conventional techniques and providing faster results, from which it is possible to determine the spatial redistribution of soil.

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Caesium-137 is the most commonly used radionuclide and its handling is well established (MOURI et al., 2014; PORTO; WALLING, 2015; VELASCO et al., 2018; IAEA, 1998; GOLOSOV et al., 2017; WALLING AND HE, 1998; 1999). Through the usage of this radionuclide it is possible to analyze the soil redistribution of the past 45 years.

As for Lead-210, it has a half-life of 22.26 years and it is kept in the atmosphere for a week as residence time. For that reason, ^{210}Pb has been frequently used to validate simulation of global transport models and aerosols' residence time in the atmosphere, sedimentary chronological time and the analysis of soil erosion's processes combined with ^{137}Cs .

By using ^{210}Pb , the redistribution rate of the last 100 years can be estimated and, similarly as by the use of ^{137}Cs , lead reveals itself advantageous in view of the constant annual erosion rate. However, after a short period of time, erosion cannot be observed through the use of these radionuclides. Thus, it was possible to accomplish this study due to the use of ^7Be , considering its short half-life and the roughly constant deposition throughout the year (WALLING, 2015).

The objective of this study was to employ ^7Be in the model of simplified mass balance to verify soil redistribution, both in qualitative and quantitative terms. Considering that one of the greatest challenges to current agricultural praxis is to minimize production costs, this study reveals itself as very relevant, since it considers the differentiation of soil redistribution and the process of erosion under different situations during the cultivation period of a soybean crop from November of 2005 to May of 2006.

1.1 *Beryllium-7* (^7Be)

Beryllium-7 has a half-life of 53.3 days. It occurs both in the upper troposphere and lower stratosphere, being naturally produced by spallation reactions of cosmic rays and solar energy particles with nitrogen, oxygen and carbon atoms (YOSHIMORY et al., 2003). The nuclear reactions produce ^7BeO and $^7\text{Be}(\text{OH})_2$ which are quickly associated with atmospheric aerosols.

Furthermore, this radionuclide's residence time in the stratosphere is calculated in years, while in the troposphere, in days. As a consequence of its small half-life, much of the ^7Be found in the soil is originated from tropospheric deposits. The concentration level of ^7Be is influenced especially by the following atmospheric processes: wet and dry deposition, mass exchange between the troposphere and stratosphere, vertical transport in the troposphere and horizontal transport of subtropical and middle latitudes to the tropics and polar regions (TALPOS; RIMBU; BORSAN, 2005). The mass exchange between troposphere and stratosphere increases the concentration of ^7Be in the troposphere and the near-surface air. According to Stohl (2003), the maximum mass exchange between troposphere and stratosphere usually takes place in middle latitudes during spring and summer.

As Yoshimory et al., 2003 points out, ^7Be decays to ^7Li emitting a gamma ray of 477.8 keV, through which it can be easily measured by gamma ray spectrometry. This radionuclide has been recognized as a useful tool in the study and description of environmental processes, such as transit and residence time of aerosols in the troposphere, the speed of aerosols' deposition (DUEÑAS et al., 2005), imprisonment by vegetation, transit and the residence time of sediment in rivers as well as evaluation of erosive surface processes (VELASCO et al., 2018; WALLING et al., 1999b; SCHULLER et al., 2006). In the latter two cases, beryllium-7's short half-life offers a way to identify newly deposited sediment. The main fallout process of ^7Be is precipitation, from which 95% of the total occurs through the processes of washout and rainout. Thus, it was assumed that the whole deposition of this radionuclide is due to wet precipitation.

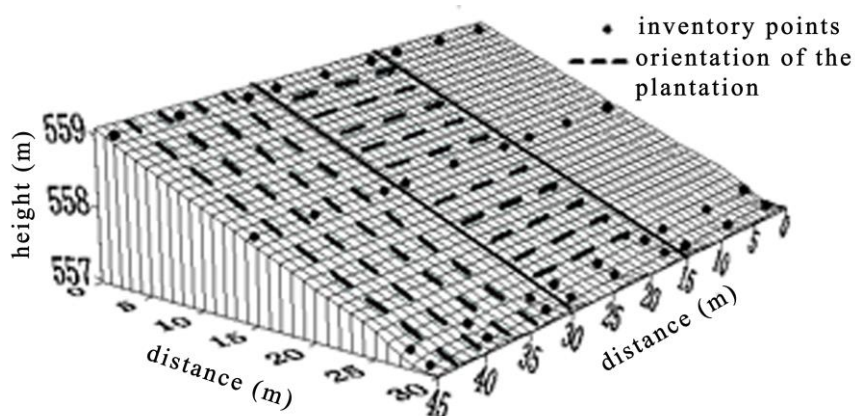
2. Materials and method

2.1 Description of the studied area and samplings

The experiment was conducted in three areas located in Londrina, a city in the North of Paraná, a Brazilian state, located at 23°20'34,0''S and 51°12'34,0''W. The size of the area corresponds to 15m × 30m, with a 10%
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slope. It was ploughed with (a) soybeans planted in the slope's direction, (b) soybeans planted perpendicular to the slope's direction and (c) bare land. The sampling was carried out on a 4x3 grid, as shown in Figure 1. According to the classification elaborated by the Brazilian Agricultural Research Corporation – Embrapa (1999), the soil in study is identified as *Latossolo vermelho distroférico* (Oxisol). The samples were collected in increments of 1cm to the depth where ⁷Be activity was negligible (≈ 3 cm). In order to draw a digital terrain model, the software SURFER Golden, Inc. was used.

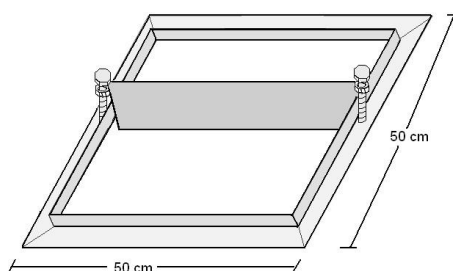
Figure 1. The three studied areas, the sampling points and the plantation direction.



Font: Authors (2017)

The soil samples for the beryllium-7 inventory were collected in a spot next to the studied area, approximately 300 meters away, at 23°20'25,7''S and 51°12'29,5''W, with a slope of 0%. The samples were gathered using a plate scraper (Figure 2) developed by the Applied Nuclear Physics Laboratory at State University of Londrina (LFNA/UEL), which consists of one metal base with total area of 2,500 cm² and a 50cm-rectangular plate in length.

Figure 2. Plate scraper developed at LFNA/UEL.



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The samples were air-dried for a 48-hour period, sieved to 2 mm, weighted down and stored in a 1L Marinelli beaker for further analysis. All samples were analyzed by employing a hyper pure germanium detector (HPGe) with a 10% relative efficiency (model GEM10185-P) and another one with a relative efficiency of 66% (model GEM-M-7080-P-S), both subjected to electric tension of 3,000V. Standard of low background shields were used for both. Detectors and data acquisition were carried out using a Multi Channel Analyser (MCA) with a 4096-channel card and the MAESTRO™ software. The spectra acquisition time was 86,400s for the 66% efficiency detector and 172,800s for the 10% efficiency detector.

3. Results and Discussion

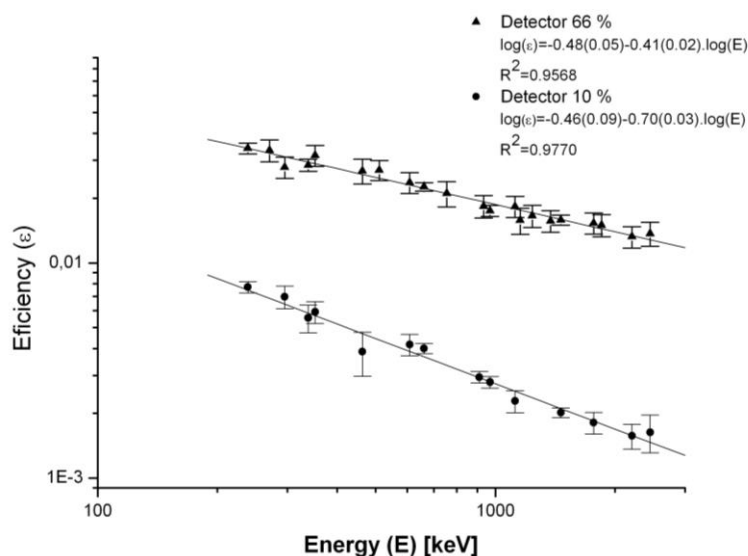
3.1 Efficiency curve

The energy calibration detector was performed using standard sources of ^{137}Cs and ^{60}Co . After the energy calibration, a spectrum for each sample with mass m (kg) was obtained, during the acquisition time t (sec). From the analysis of the spectrum, the net count (N) area under the peak of interest was established. As each gamma ray line presents absolute probability transition P_y , effectiveness on the detection system was determined using,

$$\varepsilon = \frac{N}{A \cdot P_y \cdot m \cdot t} \quad (1)$$

where the absolute efficiency curves (Figure 3) were obtained through certified standard IAEA-375 Soil (IAEA, 1996) and Equation 1.

Figure 3. Absolute efficiency curves for 66% and 10% detectors.



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A certified soil sample IAEA 327 (IAEA, 2001b) was used to validate the ⁷Be efficiency curves results (Table 1).

Table 1. Validation data for efficiency equations using the IAEA 327 soil. All results are presented with 95% confidence interval.

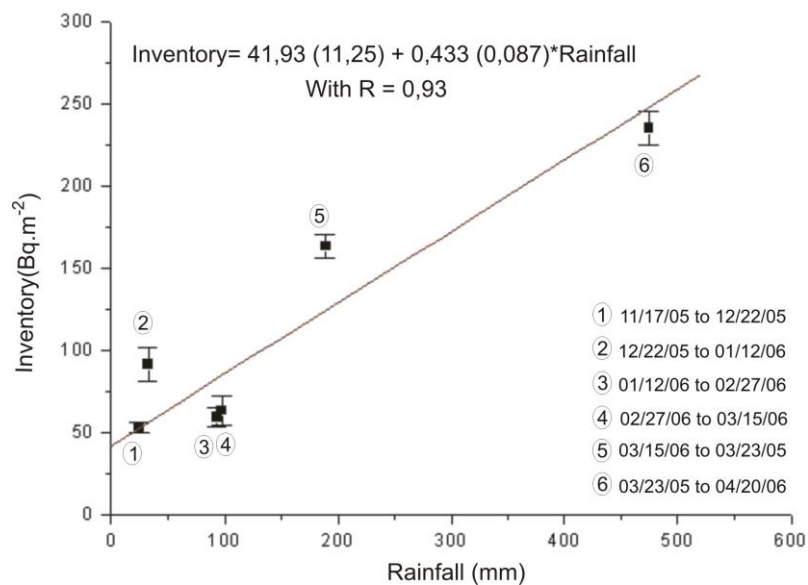
Radionuclide	Energy (keV)	Reference activity (Bq.kg ⁻¹)*	Measured activity (Bq.kg ⁻¹)	
			10% detector	66% detector
²¹² Pb	238.63	4.7 - 7.7	7.54 - 9.02	6.43 - 7.69
²¹⁴ Pb	295.21	3.8 - 6.6	5.2 - 7.2	4.78 - 6.36
²²⁸ Ac	338.32	4.7 - 7.7	7.2 - 10.4	5.26 - 7.14
²¹⁴ Pb	351.92	3.8 - 6.6	6.6 - 8.6	6.9 - 9.0
²²⁸ Ac	463.00	4.7 - 7.7	5.4 - 8.8	5.4 - 7.9
²⁰⁸ Tl	583.14	4.7 - 7.7	4.70 - 6.20	6.14 - 7.72
²¹⁴ Bi	609.31	3.8 - 6.6	6.09 - 8.03	5.20 - 6.80
¹³⁷ Cs	661.62	2.7 - 3.3	2.52 - 2.94	2.71 - 3.11
²²⁸ Ac	911.07	4.7 - 7.7	5.26 - 6.69	5.15 - 6.55
²²⁸ Ac	969.11	4.7 - 7.7	7.3 - 9.6	6.00 - 7.68
²¹⁴ Bi	1120.30	3.8 - 6.6	8.5 - 11.4	5.1 - 7.2
⁴⁰ K	1460.78	90 - 108	85.1 - 97.9	86.0 - 99.2
²¹⁴ Bi	1764.50	3.8 - 6.6	5.5 - 7.9	6.3 - 8.4
²¹⁴ Bi	2204.20	3.8 - 6.6	6.2 - 11.9	5.5 - 9.0
²¹⁴ Bi	2447.90	3.8 - 6.6	6.6 - 21.8	6.6 - 17.7

*Reference activity supplied by IAEA (2001a). The sample was consisted of 178.4g of the studied soil and 937.7g of IAEA standard soil.

3.2 Monthly inventory

The correlation between rainfall and the beryllium-7 inventory retained in the soil during the period of study is a valuable data. According to Blake et al. (1999), this information can be implied through the reference inventory. Samples were collected monthly in increments of 1 cm in depth down to 3 cm at the reference area. The measure of precipitation was carried out by the Agronomic Institute of Paraná – IAPAR, two kilometers far from the studied areas. Registers of the monthly inventory of ^7Be as a function of the rainfall along the study period can be seen on Figure 4.

Figure 4. ^7Be inventory associated to rainfall.



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Each measure of the monthly inventory (I_m) was done in different points within the reference area. Thus, to determine the inventory of each month it was necessary to subtract the inventory of the previous months (I_{am}). In order to make it possible, the measure of the inventory in the beginning of this research was assumed as zero, for reference's terms. After that, Equation 2 was applied to determine the monthly inventory.

$$I_m = I_{me} - I_{am} \cdot e^{-\lambda \cdot T} \quad (2)$$

Where I_{me} is the measured inventory, λ is the constant of beryllium-7's radioactivity disintegration, and T is the elapsed time between inventories I_m and I_{am} .

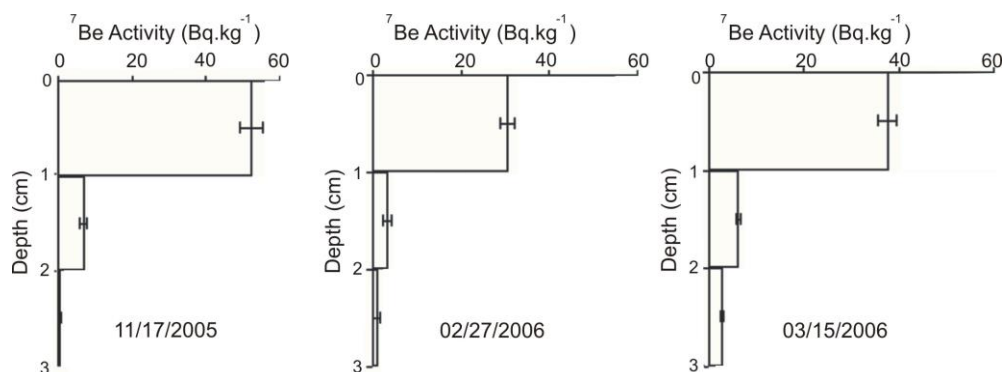
3.3 Determination of soil redistribution rate

The soil redistribution model of Blake *at al.* (1999) was applied in order to convert the measured inventory variation in soil redistribution. Thus, the estimated values both of erosion and soil deposition provided by the ^7Be inventory are strongly dependent on the coefficient of mass relaxation (h_0) as well as the initial concentration of ^7Be on the soil surface ($C_{(0)}$). The establishment of the mentioned parameters was only possible due to the knowledge of the distribution profile of beryllium-7 in the soil, according to Equation 3.

$$C_{(x)} = C_{(0)} \cdot e^{-x \cdot h_0^{-1}} \quad (3)$$

Where $C_{(x)}$ ($\text{Bq} \cdot \text{kg}^{-1}$) is the ^7Be activity at mass depth x ($\text{kg} \cdot \text{m}^{-2}$). The samples used to describe the ^7Be profile in the soil were the identical to establish the monthly inventory. Figure 5 presents three distribution profiles, which represent the studied soil.

Figure 5. ^7Be profile distribution in soil samples collected from the reference area.



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The vertical distribution also allows analysis of layers below a certain depth, since the ^7Be concentration is lower than the detection limit, discarding soil analysis below a given depth. Assuming that ^7Be profiles (Figure 5) are representative of this element's distribution in the studied soil and adjusting it to an exponential function, h_0 and $C_{(0)}$ can be determined by each data. The average value of h_0 was 4.71 kg m^{-2} with a standard deviation of 0.22. Table 2 shows the results of this study in comparison with data from literature.

Table 2. Relaxation mass depth.

Reference	Soil	h_0 (kg m^{-2})
Blake et al, 1999	Not mentioned	5.4
Schüller, 2006	Ultisol	2.14
Present work	Oxisol	4.71

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The difference between Schüller (2006) and this study (Table 2) is explained by the edaphic factors (Table 3) as well as their influence on ^7Be adsorption. According to Table 3, the clay content presents a discrepancy in values. Considering that the ^7Be adsorption is mainly due to the clay soil, it may justify the difference in the h_0 values found in this study. The initial ^7Be average activity observed on the soil surface was $C_{(0)m} = 39 \text{ Bq m}^{-2}$, with a standard deviation of 11 Bq m^{-2} .

Table 3. Physical and chemical properties of the soils.

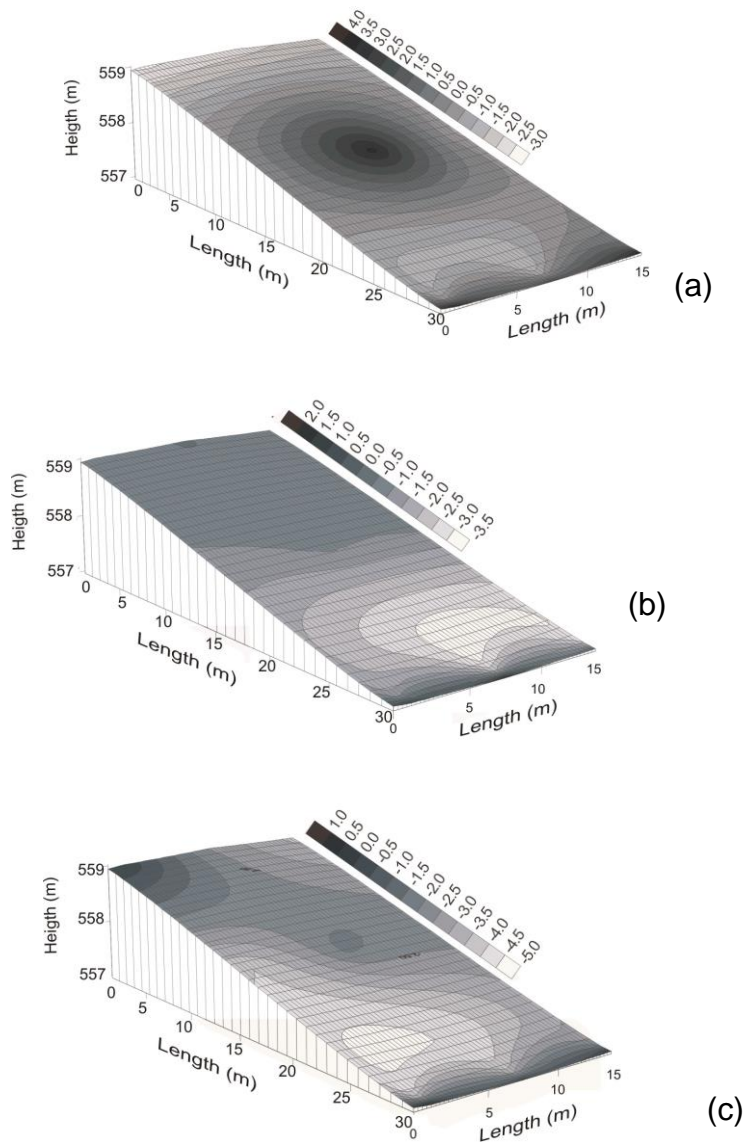
Reference	Soil	OC ¹ (g kg^{-1})	pH	Soil texture (g kg^{-1})		
				Sand	Silt	Clay
Schüller, 2006	Ultisol	29.6	5.51	800	120	80
Present work	Oxisol	29.2	4.93	400	300	300

¹Organic Carbon Content. ²Soil properties data were obtained from Rosadi et al, 2007.

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To determine the values of soil redistribution rate in the studied area, samples were collected before the harvest. In the points where a large amount of soil deposition was observed, the samples were collected at a greater depth, reaching about 10 cm. The magnitude of values on soil redistribution rate (kg m^{-2}) is presented in Figure 6.

Figure 6. Soil redistribution in bare land (a), planted perpendicular to the direction (b) and in the same direction of the slope (c).



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Negative values indicate the occurrence of soil erosion, since positive values suggest the incidence of soil deposition, and the zero value implies absence of movement or even that soil erosion rates are identical to deposition rates.

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Erosion was observed for almost the entire length of the areas, except in lower points, where soil accumulation took place. However, some points indicated an anomalous behavior as shown both in Figure 6a, where a certain amount of soil was accumulated in the middle of the field, and in Figure 6c, which in the upper left corner a point with no soil movement can be seen. A possible explanation is the occurrence of microtopographies that interfere in the final result of soil redistribution. These microtopographies were not represented in the digital model of land due to small erosion changes and the reduced number of points that were used for its construction. It would be necessary to refine the sample grid and considerably increase the number of samples to be analyzed in order to comprehend the microtopographies' effect, which are beyond the scope of this study.

In Figure 6b, the upper half of the terrain revealed a slight soil movement, probably due to the way soybean was planted on the ground. This area had the lowest soil redistribution, followed by the area where the soybean was planted in the direction of the slope. A large amount of soil was observed in the uncultivated area, described as bare land due to its exposure to weather.

4. Conclusions

The results presented in this study revealed the potential of the ^7Be fallout technique to analyze soil redistribution as a valuable tool to complement the technical use of ^{137}Cs and ^{210}Pb . The possibility of determining soil redistribution for a short period of time has been constantly increased according to its relevance in studies of environmental impacts related to climate change, plantations and other forms of human intervention. It can be inferred that the Beryllium-7's deposition through the correlation between the inventory and precipitation mostly occurs due to wet deposition, fact that has been evidenced by the appropriate data adjustments presented in this research.

Soil redistribution was lower for the soybean cultivation perpendicular to the topographic slope's direction, which consequently reveals an economically advantageous aspect, due to the low loss of soil nutrient. The land without

vegetation cover was severely exposed to the erosion phenomenon, since the absence of barriers to retain the flows towards the slope had left the ground unprotected to the kinetic impact against raindrops. In fact, this can be confirmed by the greatest soil redistribution values among the three areas.

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