Loss and Soil Deposition Estimate by Means of the Cesium 137 Concentration in the Rio das Ondas Basin, BA

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Abstract. Erosion is the most harmful form of soil degradation, it affects plants' productivity and causes severe environmental damage, such as sediment accumulation and pollution of water sources. With the purpose of obtaining significant information about losses and soil deposition on the *Rio das Ondas* basin, a study of the losses caused by erosion by means of cesium 137 (^{137}Cs) concentration in the soil was conducted. Soil samples were collected for reference in four places, in vertexes and in the center of a triangle with five meters edges in a soil under native vegetation. Thus, samples in two perpendicular transects to the pendant were collected, one (transect A) under soy crops and another (transect B) under corn crops. The samples of the triangle's vertexes and of the transects were collected at a depth varying from 0.00 m to 0.60 m, with intermission of 0.10 m between them and the samples collected in the triangle's center varied between 0.00 m to a 1.00 m depth, distributed between layers from 0.05 m to 0.50 m and, from this value on, a sample at a 1.00 m depth was collected. After being air-dried, these samples were reduced to bran and passed through a 2 mm sieve, they were bagged and sent to Nuclear Physics Applied Laboratory (LFNA) of the State University of Londrina (UEL)" so as to analyze the ^{137}Cs concentration in soil. The results obtained from the activity of ^{137}Cs in the three places of the transects A and B varied between 0.14 e 0.42 Bq.kg^{-1} (soy crop) and between 0.12 and 0.24 Bq.kg^{-1} (corn crop), showing a variation of ^{137}Cs according to the position of the place on the downgrade. It was observed in the results 22.52 t.ha^{-1}.year^{-1} soil losses on the transect located in the soy crop (A) and 38.13 and 21.18 t.ha^{-1}.year^{-1} in the transect B located in the corn crop. These results indicate great deposition of sediments in the valley, mainly in the soil under soy crop.

Key words: ^{137}Cs, erosion, soil deposition.

1. Introduction

The prediction of soil loss models through erosion were greatly used for the erosive process evaluation in soil under crops. Among these models the USLE (Universal Soil Loss Equation) is the most used. However this model requires information about rain, spacial distribution of areas under crops, ground declivity, downriver length, soil "erodibility", conservationist treatments and management. It is therefore often hard to apply this model (De Jong *et al*., 1983).

Measurements of soil losses by erosion can be also obtained by portions maintained on fields for many years. It is possible too make use of rain simulators to study the factors that affect the erosion process, however the data extrapolation in these conditions is very difficult (Mech, 1965).

With the thermonuclear tests made from the beginning of 1950 to the end of 1970, ^{137}Cs was introduced into the environment. When this element is in the soil it is strongly absorbed by clay, so its side distribution is associated to physic process (Levens & Loveland, 1988), and its transport and deposition is linked to soil particle displacement. Therefore the variation of ^{137}Cs concentration can be used to determine the movement of soil by erosion (Rirchie & MacHenry, 1978).

Knowledge about the amount of ^{137}Cs in undisturbed soils compared to other soils that have suffered human action indicate a loss or gain of this element. In addition, the study of distribution and behavior of the radioactive elements inside the soil profile is important to the evaluation of its impact in the environment and its availability to plants.

The ^{137}Cs is a radioactive kernel, produced by nuclear fission of the ^{238}Uranium with ^{239}Plutonium. It is an unstable atom with 30.2 half-life years that decay by beta emission (β^-) to 137-Barium half-stable, with 2.55 half-life minutes, and became stable after emission of gamma ray (Y) with 661.6 keV, that, although it is emitted by ^{137}Barium, characterizes the ^{137}Cs.

Guimarães & Andrello (2001) describe that the armament race that started in 1945, provided the environment contamination caused by the *fallout* of the radioactive precipitation. In the more powerful atomic explosions (higher than 1 megaton) a great deal of the clouds produced enter the stratosphere, lengthening the dwelling time of the frag-

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ments from nuclear fission. The fragments' crossing through the troposphere were responsible for the global *fallout.* The time that elapses between the injections of products from nuclear fission into the stratosphere and the subsequent *fallout* vary from five months to five years, mainly depending on latitude, altitude and seasonal period of injection.

According to Rogowski & Tamura (1970), particles derived from the *fallout* are, in part, intercepted by plants, which retain them in their leaves. The radiokernells that reach the soil's surface are perhaps under movement by lixiviation or by superficial flow off and erosion. A large quantity of soils are able to absorb ^{137}Cs in small amounts, just as what happens during *fallout*. So, ^{137}Cs is strongly absorbed and attached to the soil, which limits its movement to lixiviation process or other natural chemical natural processess. The cation Cs^+ strongly act in soil due to its hydratation level and its high polarization. Cations with low hydratation energy cause dehydration of the clay particles interlayers causing these layers to collapse, so they became attached in interplanar positions.

The soil losses (or gains) are measured appraising ^{137}Cs activity in soil samples. If this activity is smaller (or larger) than the reference ^{137}Cs activity, soil loss or gain will occur in its place. The reference ^{137}Cs activity is equal to the total of ^{137}Cs deposited by radioactive precipitation (*fallout*), determined by evaluation of a soil sample collected on an undisturbed area, that is, without evidence of soil loss or gain (deposition). In such cases, the ^{137}Cs movement also means soil movement, ^{137}Cs accumulation brings into relation with soil deposition, and ^{137}Cs depleting indicates soil erosion.

The objective of this study is to evaluate soil loss or gain (deposition) under climate and edaphic conditions of the hydrographic Rio das Ondas basin, Bahia, Brazil, using the ^{137}Cs concentration appraisal method.

2. Material and Methods

2.1. Location and climate and edaphic characterization of the studied area

The area of the hydrographic basin of Rio das Ondas belongs to the basin of the Rio Grande river, and surrounds the cities of Barreiras and Luiz Eduardo Magalhães. It is located in the southwest region of the State of Bahia, between the parallels 11°59'11.95" and 12°32'9.16" of south latitude and the meridians 45°00'54.68" and 46°20'3.52" of west longitude. The altitude varies from 400 to 900 m and the total area contains a surface of 5,141.94 km2. This Basin includes the affluent rivers: Rio das Pedras, Rio Borá and Rio Vereda das Lages. On Fig. 1 there are the points where the samples were taken and the location of the studied area.

According to the Köppen's classification, the climate of this area is of the Aw kind, a tropical savanna with dry winters and rainy summers. The annual average temperature is 24 °C, varying between 18 °C (minimum average temperature) to 32 °C (maximum average temperature). The annual pluvial precipitation varies from 1,121.9 mm on the seat of the Barreira, to 1,624.6 mm on the Goiás and Tocantins state boaders, around 150 km west of Barreiras. It is estimated that approximately 95% of pluvial precipitation occurs during October and April.

The predominant soil types of the hydrographic basin of Rio das Ondas are: Red-Yelow Latosoils and Quartz Newsoils, which occur on 63 and 25 percent of the area, respectively (Soares Neto 2005). Table 1 illustrates the values of the physic-chemical attributes of the sampled points, in the reference area as in the two evaluated transects. These soils in their native states offer erosion resistance, however the continuum use of agricultural implements, specially the heavy grade, can compact the superficial layers, favoring erosion.

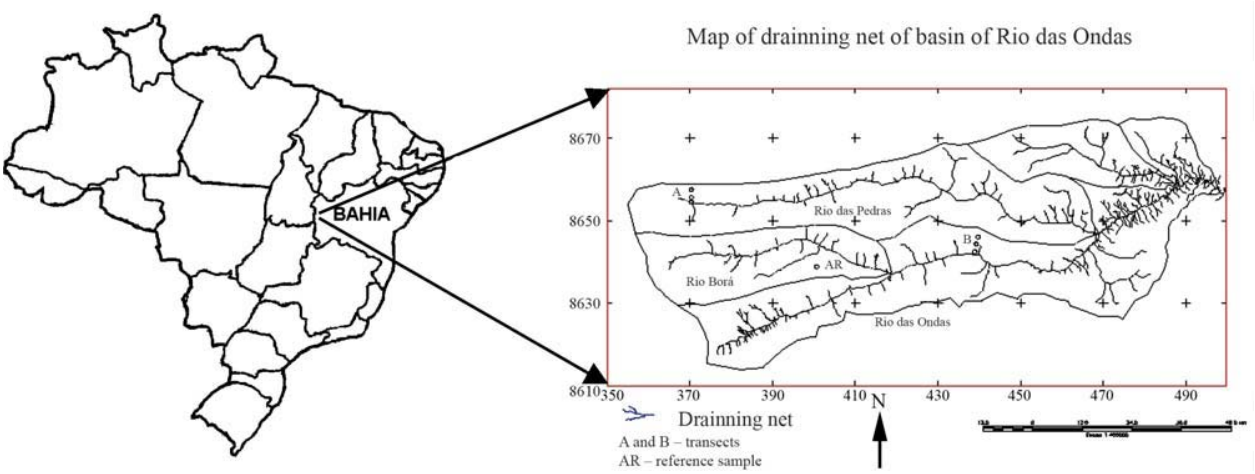

Figure 1 - Location of sampling points and studied area in the hydrographic basin of Rio das Ondas.

Table 1 - Results of grain size distribution, organic contents (OC), specific mass of the grains (ρ_s) and dry unit mass (ρ_d).

Sample	Depth (m)	Clay (%)	Silt (%)	Slim sand (%)	S. thick (%)	OC (%)	ρ_s (Mg.m^{-3})	ρ_d (Mg.m^{-3})
AR	0.00-0.10	8.0	0.7	31.0	59.0	1.48	2.50	1.48
AR	0.10-0.20	10.0	0.3	30.0	59.0	0.93	2.56	1.55
AR	0.20-0.30	11.0	1.0	30.0	58.0	0.81	2.60	1.62
AR	0.30-0.40	12.0	0.8	31.0	55.0	0.67	2.53	1.51
AR	0.40-0.60	11.0	0.8	28.0	59.0	0.50	2.56	1.58
A	0.00-0.10	5.0	2.3	40.0	51.0	1.04	2.60	1.62
A	0.10-0.20	7.0	1.5	43.0	46.0	0.72	1.63	1.66
A	0.20-0.30	9.0	1.0	43.0	45.0	0.72	2.53	1.56
A	0.30-0.40	9.0	3.5	40.0	44.0	0.60	2.47	1.50
A	0.40-0.60	13.0	2.5	41.0	41.0	0.74	2.47	1.49
B	0.00-0.10	9.4	2.4	51.8	35.1	0.93	2.53	1.55
B	0.10-0.20	9.0	2.9	49.7	37.0	0.84	2.67	1.69
B	0.20-0.30	12.8	2.7	50.7	32.7	0.64	2.60	1.60
B	0.30-0.40	13.0	1.2	51.8	33.0	0.45	2.47	1.50
B	0.40-0.60	13.1	2.6	51.7	31.6	0.38	2.56	1.55

AR = reference samples; A = samples of transect A on the mean position; B = samples of transect B on the mean position.

2.2. Procedure

The radioisotope activity average per sampled kilogram is determined by the following equation:

$$C_n = N_n(\varepsilon.m_a.P_\gamma)^{-1}, \quad (1)$$

where C_n = average of the activity of the radioisotope n (Bq.kg^{-1}); Nn = net tax of counting to gamma ray energy (γ) of the radioisotope n (counting per second - cps); m_a = mass of the sample (kg); ε = counting efficiency to gamma ray energy (γ) of the radioisotope n and P_γ = absolute probability of transition by gamma decay to gamma ray energy (γ).

The variables N_n and ε are determined by using standard sample with known activity (570 kBq ± 2.5%). The samples used in this study were prepared with a ^{137}Cs chloride solution to determine the calibration equation related to the activity of this radiokernell, according to what was described by Andrello (2004).

To determine soil losses by erosion, as recommended by Andrello (2004), the proportional model was used, which, according to the author, apart from being easier to apply, in relation to simplified models of mass balance, refined mass balance and mass balance incorporating the soil movement by crop, its results fall within acceptable deviation ranges (arising discrepancy from 70% of ^{137}Cs loss) in comparison with the most refined models. This model is represented by the following equation:

$$Y = 10.\rho_d.d.X(100.T.p)^{-1} \quad (2)$$

where Y = annual soil loss average (t.ha^{-1}.year^{-1}); ρ_d = dry unit mass (layer's average)(kg.m^{-3}); X = percentage reduction in the total inventory of ^{137}Cs; d = depth of cropped layer (m); T = time elapsed from the last deposition of ^{137}Cs, (year when the great fallout occurred,1964) and p = the correction factor for the particle size with respect to the position where the soil loss takes place.

The variable X (percentage reduction in the total inventory of ^{137}Cs) is calculated by the equation:

$$X = \left(\frac{A - A_{ref}}{A_{ref}}\right) \times 100 \quad (3)$$

where A_{ref} = inventory of ^{137}Cs in the reference sample (Bq.m^{-2}) until the depth of 0.30 m and A = inventory of ^{137}Cs in the evaluated sample of the area under antropic influence (Bq.m^{-2}) until 0.30 m in depth.

In addition, variable A, of Eq. (3), is calculated by the equation:

$$A = \Sigma 100.Ci.\rho_d.Li \quad (4)$$

where Ci = activity of level i (Bq.m^{-2}); ρ_d = soil density of level i (g.cm^{-3}); Li = soil layer thickness corresponding to the considered level (cm) and i = 1, 2 and 3 soil layers.

When the inventory of ^{137}Cs to a sampled point was larger than the local reference inventory (A_{ref}), then sediment deposition has occurred, if not, erosion has occurred.

The value of "p" expresses the size composition of the sediment grain that was mobilized in the original soil. As the mobilized sediment is usually increased with slim particles compared to the original soil, the "p" factor as-

sumes values larger than 1.0 due to the intense affinity of ^{137}Cs with slim particles of soil.

For the estimate of the "p" value, information about grain size distribution of the original soil, of the mobilized sediment and of the deposited sediment are needed. According to He & Walling (1996) mentioned by Andrello (2004), the "p" value can be determined by the knowledge of the superficial specific area of the grains, by the following equation:

$$p = (S_{sm}/S_{so})^{\nu} \quad (5)$$

where S_{sm} ($m^2.g^{-1}$) is the superficial specific area of the mobilized sediment; S_{so} ($m^2.g^{-1}$) is the original soil area; and ν is a constant with value approximately equal to 0.65.

2.3. Sampling

The determination of ^{137}Cs was executed by samples collected from soil with native plants coverage (reference value), plotted on top of a slope and in two transects with three points located in the top third, in the middle and on the base of the slope, one of these under soy crop (transect A) and the other under corn crop (transect B). The samples used to determine the reference value (AR) were collected in the center and in the vertexes of a triangle, whose sides are equal (5 m of edges), as is shown in Fig. 2. In each sampling point three soil specimens were collected, for each depth in an area of 1.0 m^2, as illustrated in the detail of Fig. 2. These samples contents were mixed in pails, and then a new sample was formed composed by 1.5 L of soil, which was sent to the Nuclear Physics Applied Laboratory of the University (LFNA) of the State University of Londrina (UEL)", in order to obtain data of ^{137}Cs activity. These samples were collected at the following depths: 0.00 to 0.10; 0.10 to 0.20; 0.20 to 0.30; 0.30 to 0.40; 0.40 to 0.50 and 0.50 to 0.60 m. The samples located in the center of the triangle were collected from the layers ranging from 0 to 0.05; 0.05 to 0.10; 0.10 to 0.15; 0.15 to 0.20; 0.20 to 0.25; 0.25 to 0.30; 0.30 to 0.35; 0.35 to 0.40; 0.40 to 0.45; 0.45 to 0.50; 0.50 to 0.55; 0.55 to 0.60 on 1.00 m depth.

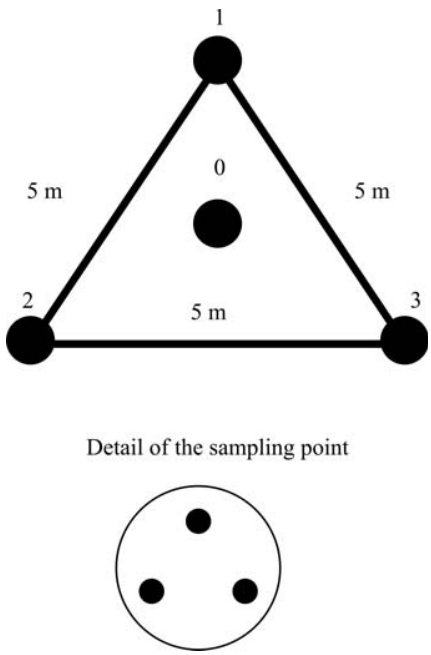

Figure 2 - Soil sampling points array for the evaluation of ^{137}Cs activity in an area under native vegetation (reference samples).

The ^{137}Cs activity readings were made by using a specific detector (GEM-M-7080-P-S model) to comply with the geometry of Marinelli bequer, with 69.9 mm germanium crystal diameter and 84.2 mm length.

3. Results and Discussion

The results obtained from the activity of ^{137}Cs on two transects (A and B) and the reference activities (AR) are shown in Table 2. By viewing this data, it is verified that the ^{137}Cs concentration measured on the three points of the transects A and B varied between 0.14 and 0.42 $Bq.kg^{-1}$ (A) and between 0.12 and 0.26 $Bq.kg^{-1}$ (B). This variation indicates that the distribution of ^{137}Cs in the soil depends of the sampling point position on the slope (Fig. 3). These results show the loss and gain points of this element in relation to the value found in the reference sample, which represents the ^{137}Cs concentration deposited by *fallout*, on this hydrographic basin.

As is shown in Table 2, on transect A ^{137}Cs loss has only occurred in higher positions, while on the central and on the lower positions gain has occurred in relation to the reference value. In conformity, it was verified after the samples were collect that this occurred because the sampling point on the mean position was located close to the terrace basis, which is the soil deposition point. On the other hand, the lower point naturally occurs in a deposition zone. Guimarães (1988) also found similar results for points located next to terrace waterways. On transect B ^{137}Cs losses were found on the higher and central positions of the slope.

Analyzing the results of soil losses and gains, Fig. 4 shows that sampled points on the transect A (soy under con-

Table 2 - Values of ^{137}Cs activity on soil in the samples of transects A and B, according to the position in the slope and the reference sample, Barreiras, BA.

Transect	Position on the slope	Activity ($Bq.kg^{-1}$)
A 1	Top	0.14 ± 0.03
A 2	Mean	0.42 ± 0.04
A 3	Lower	0.39 ± 0.03
B 1	Top	0.12 ± 0.06
B 2	Mean	0.13 ± 0.04
B 3	Lower	0.26 ± 0.03
Reference (AR)	Top of an area under native vegetation	0.24 ± 0.03

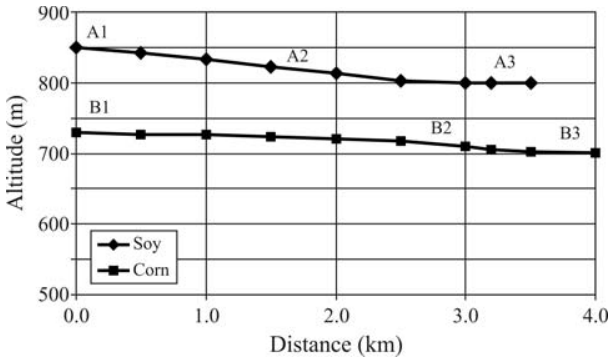

Figure 3 - Profile of sampled transects in soils under soy and corn crops in the hydrographic basin of Rio das Ondas.

ventional planting) presented soil loss by erosion only on the higher point (A1) of the slope (22.52 t.ha^{-1}.year^{-1}). The others sampled points of this transect showed behavior of deposition points, with gains of 86.10 t.ha^{-1}.year^{-1} (A2) and 75.50 t.ha^{-1}.year^{-1} (A3). For points B1, B2 and B3, sampled on the corn crop, also under conventional planting, large soil loss has occurred, except on B3 point, which presented gain of 4.24 t.ha^{-1}.year^{-1}, due to the fact that it is located in a sediment accumulation zone. These results indicate large soil movement in the Rio das Ondas basin, where there are areas under erosion and areas receiving sediments.

From this soil loss result one can deduce the need for using and developing conservational practice in order to guarantee the adequate control of erosion and, also, to discipline water movement by superficial flow off or torrent, as the maximum tax of erosion that can occur on Red-Yelow Latosoils and Quartz Newsoils (≈90% of the area), maintaining its sustainability is 12 t.ha^{-1}.year^{-1} and 15 t.ha^{-1}.year^{-1}, respectively (Soares Neto, 2005).

Besides soil loss in the erosive process, the losses of nutrients also are evident. Resk (1981), studying a Red-Dark Latosoil, with 5% declivity, applying rain with a simulator, verified that in an area under soy crop, the losses of calcium, magnesium and potassium were at least two times greater than the amount originally found in the soil.

In these draining basin conditions, it was verified that the soil loss average, on two transects, was 26 t.ha^{-1}.year^{-1},

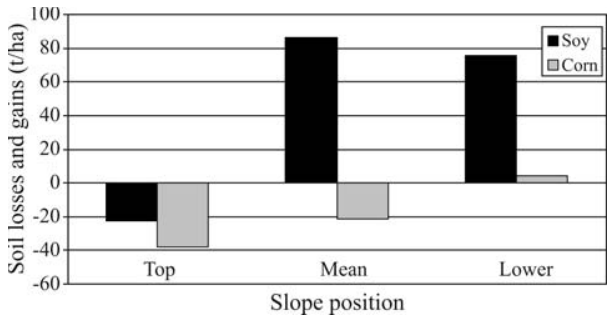

Figure 4 - Tax values of soil loss and gain (t/ha) on evaluated transects in the basin of Rio das Ondas, Barreiras, BA.

which corresponds to a layer of 1,67 mm.year^{-1}. On a similar study, using the same methodology, Andrello *et al.* (2003) evaluated the soil losses on a hydrographic basin on Paraná and found soil losses averaging 13.90 t.ha^{-1}.year^{-1} on areas under pasture and 15.80 t.ha^{-1}.year^{-1} on areas under annual crops, values that are lower than the ones found in this study. The soil losses on areas under pasture are always lower than those on areas under annual crops because pastures provide larger soil coverage. On the other hand, Kachanoski (1987), in Canada, and Andrello (1997) on the microbasin of Unda stream, in Paraná, Brazil, found soil loss values of 63 t.ha^{-1}.year^{-1} and 111 t.ha^{-1}.year^{-1}, respectively. These studies were carried out with soils with clay textures, which could favor the increase of losses by erosion. This variation of results is related to regional dissimilarities of the following factors: rain, soil, topography, coverage, management and conservational practices among the areas where these studies were conducted.

Comparing the result of soil loss average in the basin of Rio das Ondas with the results obtained by Maack (1981), in Paraná (28 to 34 t.ha^{-1}.year^{-1}) and Cogo *et al.* (2003), in Rio Grande do Sul, to a Red Latosoil under conventional planting system (30.94 t.ha^{-1}.year^{-1}), it was verified that these values are close to the ones found in this study.

4. Conclusions

The application of this methodology to calculate soil losses by erosion and the deposition by the measurement of ^{137}Cs activity seem to be quick and easy to be conducted. However, as far as the authors are aware, only the Nuclear Physics Applied Lab of the University "Universidade Estadual de Londrina (UEL)" has done this kind of analysis through scientific collaboration.

The results indicate large deposition of sediments in the valley, mainly on soils under soy crop.

This methodology can provide a better knowledge of soil movements in a hydrographic basin, and it can also allow the monitoring of soil movements in areas under different uses and management.

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