

## 7BE FALLOUT FOR SUPERFICIAL SOIL EROSION ASSESSMENT

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### ABSTRACT

Geological and hydrological phenomenon monitoring presents great environmental and financial interest and several radioisotopes, natural and artificial, have been used for this purpose. In the present work, <sup>7</sup>Be was used to determine the soil erosion in three areas: one ploughed with soy at the direction of the slope, one with it perpendicular to the slope and an area with bare land. Beryllium-7 (<sup>7</sup>Be) has half-life of 53.3 days and occurs in the upper troposphere and lower stratosphere and is produced naturally by spallation reaction of cosmic rays and solar energy particles with atoms of nitrogen, oxygen and carbon. The experiment was developed in three areas located at Londrina city, north of State of Parana - Brazil, around of the coordinates 23°20'34,0"S and 51°12'34,0"W. The size of the areas was 15 m x 30 m, with a 10 % of sloping. The samples were analyzed by gamma ray spectrometry nuclear electronic chain. The calculated relaxation mass constant ( $\lambda_0$ ) was 4.71 $\pm$  0.36, result that is in agreement with other works in the international literature.

### INTRODUCTION

Soil erosion and deposition of sediments are some of the main problems affect the sustainable development of agricultural activities around the world, since they are the main factors for reducing soil fertility, requiring larger investments to maintain the productivity. In addition, soil erosion and deposition of sediments may cause silting of water reservoirs, rivers, lakes and water pollution by the agricultural wastes absorbed in the sediments and eutrophication of water bodies [1]. Some works have estimated that a human activity has accelerated soil erosion in approximately 7% of the continental land [2,3]. Deforestation and inappropriate agricultural practices are responsible for about 30% of the soils degradation and the cost of the economic impact of soil erosion on-site and off-site has been estimated around US\$ 400 billion per year [4].

Over the past 50 years, soil erosion has been widely studied to determine its causes and consequences. The use of conventional techniques for quantifying soil erosion rate is very limited and high uncertainty are presented in the results and, in addition, it does not determine the spatial redistribution of land. The use of radionuclides for determining the soil erosion rates is very promising, since the model of redistribution of some radionuclides, such as caesium-137 (<sup>137</sup>Cs), lead-210 (<sup>210</sup>Pb) and beryllium-7 (<sup>7</sup>Be) reflects the model of soil redistribution in the landscape. These radionuclides are easily determined by gamma ray spectrometry, their cost is low related to conventional techniques and the results are fast, allowing determining the spatial soil redistribution.

Caesium-137 is the most used radionuclide and its use is well established [5, 6, 7, 8, 9, 10]. This radionuclide allows determining the history of soil redistribution over the past 45 years. The  $^{210}\text{Pb}$  has half-life of 22.26 years and its residence time in the atmosphere is around one week. Because of that,  $^{210}\text{Pb}$  has been frequently used to validate simulations of global transport models and residence time of aerosols in the atmosphere, the sediments chronological time and the assessment of soil erosive process in addition to  $^{137}\text{Cs}$ . By using  $^{210}\text{Pb}$ , the rate of soil erosion and redistribution during the last 100 years can be determinate and, as well as the  $^{137}\text{Cs}$ , it is also advantageous if the rate of erosion is constant each year. However, using these radionuclides, the erosion over a short time period can not be determined. Such study is possible using  $^7\text{Be}$  because of its short half-life and deposition roughly constant during the year.

The objective of this work was to use beryllium-7 in the model of simplified mass balance to determine the redistribution of soil erosion, qualitative and quantitatively. Considering that one of the greatest challenges of current agricultural practice is to minimize the costs of production, this work becomes very relevant, because allowed to differentiate the soil redistribution and the process of erosion under different situations during the season of cultivation of soybeans crop (11/2005 to 05/2006).

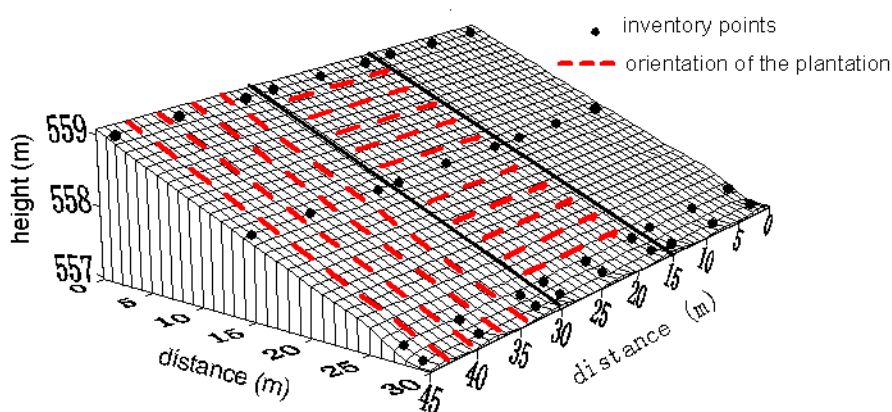
Beryllium-7 ( $^7\text{Be}$ ) has half-life of 53.3 days, occurs in the upper troposphere and lower stratosphere and is produced naturally by spallation reactions of cosmic rays and solar energetic particles with atoms of nitrogen, oxygen and carbon [11]. The nuclear reactions produce  $^7\text{BeO}$  and  $^7\text{Be}(\text{OH})_2$  which is quickly linked to atmospheric aerosols. The residence time of this radionuclide in the stratosphere is about a few years and in the troposphere, few days to weeks. Due to their small half-life, most of  $^7\text{Be}$  found in the soil is from the troposphere deposit. The concentration level of  $^7\text{Be}$  is influenced mainly 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 [12]. The mass exchange between the troposphere and stratosphere may increase the concentration of  $^7\text{Be}$  in the troposphere and the air that is near the land surface. The maximum mass exchange between the troposphere and stratosphere usually occurs during spring or summer in middle latitudes [13].

$^7\text{Be}$  decays to  $^7\text{Li}$  emitting a gamma ray of 477.8 keV, through which it is easily measured by gamma ray spectrometry [14].

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, speed of deposition of aerosols [15], imprisonment of aerosols by vegetation, transit and the residence time of sediment in rivers [16], evaluation of erosive surface processes [17, 7, 18, 19]. In the last two cases, the short half-life of  $^7\text{Be}$  offers a way of identifying newly deposited sediment. The main fallout process of  $^7\text{Be}$  is the precipitation, 95% of the total through the processes of washout and rainout. Thus, it was assumed that the whole deposition of  $^7\text{Be}$  is due to the wet precipitation.

## MATERIALS AND METHODS

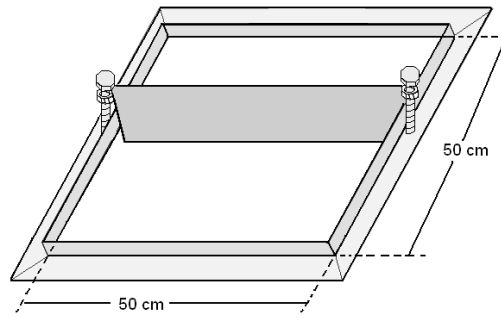
The experiment was developed in tree areas located at Londrina city, north of State of Parana - Brazil, around of the coordinates  $23^{\circ}20'34,0''\text{S}$  and  $51^{\circ}12'34,0''\text{W}$ . The size of the areas was  $15\text{ m} \times 30\text{ m}$ , with a slop of 10 %. It was ploughed with soybeans planted in the direction of the slope, soybeans planted perpendicular to the direction of the slope and bare land. The sampling was realized in a  $4 \times 3$  grid, as shown in Figure 1. The studied soil is classified as "Latossolo Vermelho distroférico" (Oxisol) according to Brazilian soil classification [20]. The samples were collected in increments of 1 cm to the depth where  $^7\text{Be}$  activity was negligible ( $\approx 3\text{ cm}$ ). In order to draw a digital terrain model, the software SURFER Golden, Inc. was used.



**Figure 1. Sketch of the three studied areas, sampling points and plantation direction.**

The soil samples for reference inventory of  $^7\text{Be}$  were collected in an area closed to the studied area, approximately 300 meters, located at coordinates  $23^{\circ}20'25,7''\text{S}$  and  $51^{\circ}12'29,5''\text{W}$ , with a 0% of sloping. The samples were collected using a plate scraper as shown in Figure 2. The plate scraper was constructed at LFNA/UEL (Nuclear Applied Physics Laboratory/State University of Londrina) and consists of one metal base with total area of  $2,500\text{ cm}^2$  and a rectangular plate with 50 cm in length.

The samples were air-dried for a period of 48 hours, sieved to 2 mm, weighed and conditioned into to 1L Marinelli beaker for posterior analysis. All samples were analyzed employing a hyper pure germanium (HPGe) detector with relative efficiency of 10%, model GEM10185-P and another one with a relative efficiency of 66%, model GEM-M-7080-P-S, both subject to tension of 3,000 V. Standard low background shield were used with both detectors and the data acquisition was realized by a MCA with 4096 channels card and the software MAESTRO<sup>TM</sup>. The spectra acquisition time was 86,400 s for the 66% efficiency detector and 172,800 s for the 10% efficiency detector.



**Figure 2. Plate scraper developed at LFNA/UEL.**

## RESULTS AND DISCUSSION

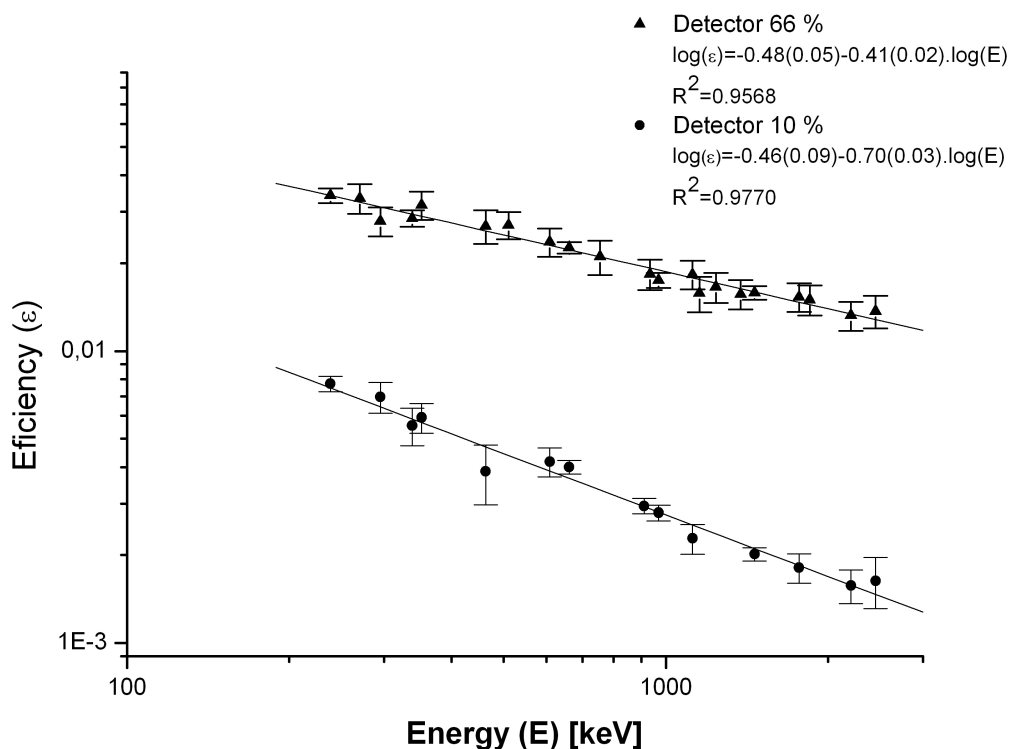
### 3.1. Efficiency curve

The energy calibration of the detector was performed using standards sources of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ . After energy calibration, it was obtained a spectrum for each sample with mass  $m$  (kg), during an acquisition time  $t$  (sec). From the analysis of the spectrum it was determined the net count ( $N$ ) area under the peak of interest. As each gamma ray line presents absolute probability transition  $P$ , efficiency of the detection system was determined using Equation 1.

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

Where the absolute efficiency curves (Figure 3) was obtained using certified standard IAEA-375 Soil [21] and Equation 1.

A certified soil sample IAEA 327 [1] was used to validate the  $^7\text{Be}$  efficiency curves results. Results are shown in Table 1. Good agreement between measured certified values can be observed.



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

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

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

\*Reference activity supplied by IAEA [22]. Sample was prepared mixing 178.4 g of studied soil with 937.7 g of IAEA standard soil.

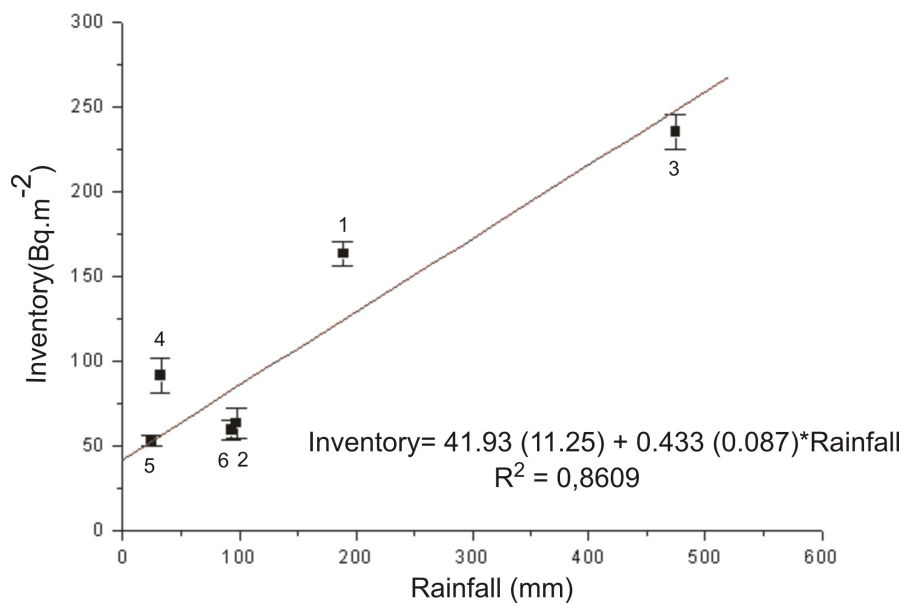
### 3.2. Monthly inventory

The correlation between rainfall and the  $^7\text{Be}$  inventory retained in the soil during the period of study is important information. Through this information the reference inventory can be determined according [17]. Samples were monthly collected in increments of 1 cm in depth down to 3 cm at the reference area. The measure of precipitation was realized by the Instituto Agronômico do Paraná (IAPAR), 2 km distant from the studied areas. The monthly inventory of  $^7\text{Be}$  as a function of the rainfall for the studied period is presented in Figure 4.

Each measure of the monthly inventory ( $I_m$ ) was done in different points inside the reference area. Thus, to determine the inventory of each month it was necessary to subtract the inventory of the previous months ( $I_{am}$ ). To turn it possible, the measure of the inventory in the beginning of the work research was assumed as the zero reference. After that it was applied Equation 2 to determine the monthly inventory.

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

Where  $I_{me}$  is the measured inventory,  $\lambda$  is the radioactivity disintegration constant of beryllium ( $^7\text{Be}$ ), and  $T$  is the elapsed time between inventory  $I_m$  and  $I_{am}$ .



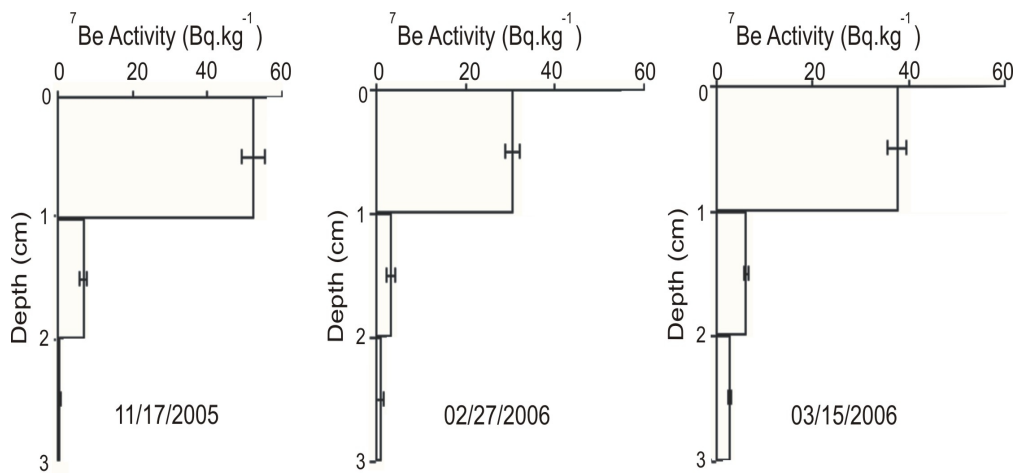
**Figure 4.**  $^7\text{Be}$  inventory associated to rainfall for the period: 1- 11/17/05 to 12/22/05; 2 – 12/22/05 to 01/12/06; 3 - 01/12/06 to 02/27/06; 4 – 02/27/06 to 03/15/06; 5 – 03/15/06 to 03/23/06; 6 – 03/23/06 to 04/20/06.

### 3.3. Determination of soil redistribution rate

To convert the measured inventory variation in soil redistribution, it was applied the model of soil redistribution presented by [17]. The estimated values of erosion and deposition soil provided by the  $^7\text{Be}$  inventory are strongly dependent on the mass relaxation coefficient,  $h_0$ , and the initial concentration of  $^7\text{Be}$  in soil surface,  $C_{(0)}$ . The determination of the cited parameter is only possible by the knowledge of the  $^7\text{Be}$  distribution profile in soil, according to Equation 3.

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

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



**Figure 5.**  $^7\text{Be}$  distribution profile in soil samples collected from the reference area according to the dates of sampling.

Vertical distribution also permits to determine the depth below which the  $^7\text{Be}$  concentration is lower than the detection limit, discarding soil analysis below that depth. Assuming that  $^7\text{Be}$  profiles at Figure 5 are representative of the distribution of this element in the studied soil and adjusting it to an exponential function,  $h_0$  and  $C_{(0)}$  can be determined for each date. The average value of  $h_0$  was  $4.71 \text{ kg m}^{-2}$ , with a standard deviation of 0.22. Table 2 shows the results of this work in comparison with data from the literature.

**Table 2. Results for the relaxation mass depth.**

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

**Table 3. Physical and chemistry properties of the soils.**

Reference	Soil	OC <sup>1</sup> (g kg <sup>-1</sup> )	pH <sub>H2O</sub>	Soil texture (g kg <sup>-1</sup> )		
				Sand	Silt	Clay
Schüller, 2006 [20]	Ultisol	29.6	5.51	800	120	80
Present work	Oxisol	29.2	4.93	400	300	300

Soil properties data were obtained from [23].<sup>1</sup> Organic Carbon Content

The difference between [19] and this work (Table 2) can be due to the soil properties (Table 3) and their influence on the <sup>7</sup>Be adsorption. According to Table 3, the clay content presents discrepancy of the values. Considering that the <sup>7</sup>Be adsorption is mainly due to the soil clay, it can explain the difference of the  $h_0$  values found in this work. The initial <sup>7</sup>Be average activity determined in the soil surface was  $C_{(0)m} = 39 \text{ Bq m}^{-2}$ , with a standard deviation of  $11 \text{ Bq m}^{-2}$ .

#### 4. CONCLUSIONS

The results presented in this work showed the goal potential of the technique for determining the soil redistribution as a valuable tool to complement the technical use of <sup>137</sup>Cs and <sup>210</sup>Pb. The possibility to determine the soil redistribution in a short period has been constantly increased its relevance in environmental impact assessments for climate changing, plantations and other forms of anthropological actions. Through the correlation between the inventory and precipitation it may be inferred that the <sup>7</sup>Be deposition is mainly due to wet deposition, which was proved by the proper adjustment of the data presented in this work.

#### ACKNOWLEDGMENTS

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#### REFERENCES

1. IAEA, *Assessment of Soil Erosion Through the Use of 137Cs and Related Techniques as a Basis for Soil Conservation, Sustainable Agricultural Production and environmental Protection*. IAEA, Vienna – Austria. (2001)
2. Lal, R., “Soil erosion by wind and water: problems and prospects”. In: Lal, R. (Ed.), *Soil erosion research methods*, 2<sup>nd</sup>. Ed. Soil and water conserve. Soc. Amer., Akeny, IA pp. 1-9. (1994)
3. Aguilar, J.; Araéz, E.G.; Villarroya, A., *Atlas universal Aguilar*. Ed. Aguilar, Madri.(1958)
4. Zapata, F, “The use or environmental radionuclides as tracers in soil erosion and sedimentation investigations: recent advances and future developments”. *Soil & Tillage Research* 69, pp.3-13. (2003)

5. Ritchie, J.C.; McHenry, J.R., "Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review". *J. Environ. Qual.* 19, pp.215-233.(1990)
6. Walling, D.E.; Quine, T.A. "The use of caesium-137 measurements in soil erosion surveys". In: *Erosion and Sediment Transport Monitoring Programmes in River Basins. IAHS* , 210, pp.143 -152. (1992)
7. Wallbrink, P.J.; Murray, A.S, "Determining soil loss using the inventory ratio of excess lead-210 to cesium-137". *Soil Sci. Soc. Am. J.* **60**, pp.1201-1208. (1996)
8. IAEA, *Use of <sup>137</sup>Cs in the study of soil erosion and sedimentation. IAEA-TECDOC-1028*, IAEA, Vienna – Austria.(1998)
9. Walling, D.E.; He, Q., "Use of fallout <sup>137</sup>Cs measurements for validating and calibrating soil erosion and sediment delivery models". *IAHS* 249, 267-278.( 1998)
10. Walling, D.E.; He, Q., "Improved models for estimating soil erosion rates from <sup>137</sup>Cs measurements". *J. Environ. Qual.* 28, 611-622.(1999)
11. Yoshimory, M.; Hirayama, H.; Mori, S.; Sasaki, K.; Sakurai, H, "<sup>7</sup>Be nuclei produced by galactic cosmic rays and solar energetic particles in the earth's atmosphere". *Pergamon* 32, pp.2691-2696.( 2003)
12. Talpos, S.; Cuculeanu, V, "A study of the vertical diffusion of <sup>7</sup>Be in the atmosphere." *J. Environ.* 36, pp. 93-106. (1997)
13. Feely, H.W.; Larsen, R.J.; Sanderson, C.G.. "Factors that cause seasonal variations in beryllium-7 concentrations in surface air". *J. Environ. Radioact.* 9, pp.223-249.(1989).
14. KNOLL, G. F., *Radiation detection and measurements*, John Wiley & Sons. 886p. (1979)
15. Dueñas, C.; Fernández, M.C.; Carretero, J.; Liger, E.; Cañete, S. "Deposition velocities and washout ratios on a coastal site (southeastern Spain) calculated from <sup>7</sup>Be and <sup>210</sup>Pb measurements." *Atmospheric Environment*, 39, pp. 6897-6908. (2005)
16. Bonniwell, E.C.; Matisoff, G.; Whiting, P.J. "Fine sediment residence times in rivers determined using fallout radionuclides (<sup>7</sup>Be, <sup>137</sup>Cs, <sup>210</sup>Pb)." *Geomorphology* 27(1-2), pp.75-92.(1999).
17. Blake, W.H.; Walling, D.E.; He Q. "Fallout beryllium-7 as a tracer in soil erosion investigations." *Applied Radiation and Isotopes*, 51, pp. 509-605 (1999).
18. Walling, D.E.; He, Q.; Blake, W. "Use of <sup>7</sup>Be and <sup>137</sup>Cs measurements to document short - and medium-term rates of water-induced soil erosion on agricultural land". *Water Resources Research*, **35**, pp.3865 - 3874.(1999)

19. Schuller, P.; Iroumé, A.; Walling, D.E.; Mancilla, H.B.; Castillo, A.; Trumper, R.E. “Use of beryllium-7 to document soil redistribution following forest harvest operations”. *J. Environ. Qual.* 35, pp.1756-1763.(2006)
20. Embrapa. *Sistema brasileiro de classificação de solos*. Rio de Janeiro: Embrapa Solos. 412pp. (2005).
21. IAEA, *Report on the intercomparison run IAEA-375: determination of radionuclides in soil sample IAEA-375*. IAEA, Vienna – Austria. (1989)
22. IAEA. *Report on the intercomparison run for the determination of radionuclides in soil IAEA-326 and IAEA-327*. IAEA, Vienna – Austria.(2001)
23. Rosadi, R. A. B., Afandi, Senge, M., Ito, K., Adomako, J. T. “The effect of water deficit in typical soil types on the yield and water requirement of soybean (*Glycine max* [L.] Merr.) in Indonesia”. *JARQ*, .41. pp.47–52. (2007)