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UTILIZATION THE NUCLEAR TECHNIQUES USE TO ESTIMATE THE WATER EROSION IN TOBACCO PLANTATIONS IN CUBA

Utilización de técnicas nucleares para estimar la erosión hídrica en plantaciones de tabaco en Cuba

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ABSTRACT. Soil erosion is a relevant factor in land degradation, causing several negative impacts to different levels in the environment, agriculture, etc. The tobacco plantations in the western part of the country have been negatively affected by the water erosion due to natural and human factors. For the implementation of a strategy for sustainable land management a key element is to quantify the soil losses in order to establish policies for soil conservation. The nuclear techniques have advantages in comparison with the traditional methods to assess soil erosion and have been applied in different agricultural settings worldwide. The tobacco cultivation in Pinar del Río is placed on soils with high erosion levels, therefore is important to apply techniques which support the soil erosion rate quantification. This work shows the use of ^{137}Cs technique to characterize the soil erosion status in two sectors in a farm with tobacco plantations located in the south-western plain of Pinar del Rio province. The sampling strategy included the evaluation of selected transects in the slope direction for the studied site. The soil samples were collected in order to incorporate the whole ^{137}Cs profile. Different conversion models were applied and the Mass Balance Model II provided the more representative results, estimating the soil erosion rate from –18,28 to 8,15 t ha^{-1}año^{-1}.

Key words: soil conservation, radioisotopes, land degradation

RESUMEN. La erosión del suelo es un elemento importante en la degradación de tierras, provocando impactos negativos a varios niveles (parcela, finca, cuenca, etc). El cultivo del tabaco en el occidente del país se ha visto negativamente afectado por la erosión hídrica asociado a factores naturales y antrópicos. Un elemento fundamental para implementar una estrategia de manejo sostenible de tierras es la cuantificación de las pérdidas de suelo, ya que permiten establecer políticas de conservación de suelos. Las técnicas nucleares en la evaluación de la erosión, poseen ventajas en comparación con los métodos tradicionales y han sido aplicadas en diferentes agrosistemas a nivel mundial. En la provincia Pinar del Río, los suelos dedicados al cultivo del tabaco, presentan elevados niveles erosivos, por lo que es importante utilizar técnicas que permitan la cuantificación de las tasas de erosión de suelos. El trabajo muestra el uso de la técnica del ^{137}Cs para caracterizar el estado de la erosión de suelos en dos sectores de una granja con plantaciones de tabaco, ubicadas en la Llanura Suroccidental de la provincia de Pinar del Río. La estrategia de muestreo incorporó la evaluación de transectas seleccionadas en dirección de la pendiente, siendo tomadas muestras de suelos que incluyeron todo el ^{137}Cs del perfil. Se emplearon varios modelos de conversión; el Modelo de Balance de Masa II proporcionó los mejores resultados, obteniéndose una tasa de redistribución de suelos con valores de -18,28 a 8,15 t ha^{-1}año^{-1}.

Palabras clave: conservación de suelos, radioisótopos, degradación de tierras

INTRODUCTION

Soil erosion is an important factor in land degradation, it causes negatives impacts on the environment and influence from yield reduction to eutrophication and asolvamiento in surface water bodies. In Cuba, land degradation is one of the main environmental problems in which both natural and human factors have caused accelerated erosion

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processes affecting 43 % of arable lands (1). In Pinar del Río province, the highest percentage of soils devoted to tobacco growing show an ondulated topography, in spite of being exposed to the repeated ocurrence of extreme meteorological events and wrong soil management which has led to high levels of water erosion and at the same time a high negative potential for the domestic economy[A].

For the application of a sustainable land management, it is necessary to quantify the losses of this natural resource in order to support the establishment of policies for soil conservation. Nuclear techniques have shown to be efficient as a calculation tool of this soil redistribution being widely used internationally with some successful experiences in different agroecosystems of the country (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14). These tools have some advantages (2) since they can be applied to different environments (agrosystems). They can be used to estimate erosion levels at short, medium and long term with a minimum of field visits to get the results. Their estimations can be spatially associated (by sampling sites) which makes easier their incorporation to maps and geographical information systems.

In order to quantify the redistribution soil levels (erosion/deposition) the ^{137}Cs technique was applied on a tobacco-growing cooperative, located at the South-Western Plain of Pinar del Río province.

MATERIALS AND METHODS

Location, experimental site

Within the framework of the National Project[B] an area of a highly degraded ecosystem was selected; with "Alitic soil type of low clay content" (Plinthustalf, Soil Taxonomy), at the "Jesús Suárez Soca" cooperative in the municipality of Consolacion Sur, Pinar de Río province (central coordinates N 22°30'46.1" and W 83°28'22.8").

Forty two percent of the total area was affected by soil erosion, a problem that is heavily influenced by different extreme meteorological events (heavy rains, hurricanes, etc).

In order to estimate the erosion of the soil by the application of environmental radionúclidos (^{137}Cs) from the radioactive "fallout", a tobacco growing site was selected and divided into two sectors (North-South) slightly ondulated, but with different redistribution soil levels.

Additionally, meteorological, geomorphological, edaphologhical and the use of land were evaluated which allowed the selection of a reference site and two study sectors of 4 hectares, specifically in the North sector where the highest levels were found.

Taking the topography of the site into account, as well as the volume of points to sample, the sampling strategy was made through different transects in the demostration area and the samples were measured with a gamma spectrophotometer detector. Methodologies (2, 15) were used as well as the models described[C] (3, 7, 9, 10, 11, 13, 14) to characterize the status of the soil erosion in the area.

Soil sampling strategy

The average value of the area density of activity was determined at the reference site for ^{137}Cs, making possible the application of the conversion models. The models complied with the essential requisites: absence of soil erosion, proximity to study sectors, low slope, absence of soil since the 50's and a perennial plant cover. Points on a uniform network with spaces of 5 m between one point and the other were set as recommended in previous studies (8, 9, 13) to evaluate the behavior of the reference variable. Sampling depth allowed to include all the inventory of ^{137}Cs present on the soil.

Study sectors were evaluated through eight transects in the maximum slope directions, the distance between points was variable and taken according to the topographic characteristics of the area, the variation was between 15 and 40 m. Sampling was made by a nucleus sampler, till a depth of 40 cm (location of the ^{137}Cs on the soil profile).

In each point, four samples were taken to make up a compound sample, for a total of 104. At the reference site, samples were taken at different depths (every 10 cm), to evaluate the distribution behavior of ^{137}Cs in depth.

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[C] Walling, D.; Zhang, X. y Quine, H. *Models for Converting Measurements of Environmental Radionuclide Inventories (137Cs, Excess 210Pb, and 7Be) to Estimates of Soil Erosion and Deposition Rates (Including Software for Model Implementation)*, Department of Geography, University of Exeter, Exeter, 2007, pp. 1-182.

Pretreatment of the samples

The objective of this stage was to prepare soil samples for spectrophotometric measurements of ^{137}Cs levels at the lab. It was done according to the procedure PR/LVRA/03 “Sample Treatment” from the Radiological and Environmental Vigilance Lab. The soil was mechanically desaggregated for its homogenization, drying and screening at 2 mm. Later on, weight measurements were done for the different fractions and the smallest one, of 2 mm, was placed in Marinelli beakers of 500 ml for spectrophotometric measurements.

Measurements of ^{137}Cs by gamma spectrometry

The mass activity density of ^{137}Cs in soil samples, were measured by a spectrophotometric gamma system “Silena”, using a hyperpure germanium detector (Type P) of 21 % relative efficiency.

The selected geometry for soil samples were the Marinnelli beakers of 500 mL. The detector was calibrated with an available soil standard at the lab records (PAT/LVRA/09) and the spectrum was analyzed through the software EMCAPLUS version 2.00.5.

According to the ^{137}Cs levels on the soil, the counting time for samples was fixed at 60 000 s which allowed a detection limit of approximately 0.2 $Bq.kg^{-1}$. The mass activity density ($Bq.kg^{-1}$) for each sample was converted to the activity area density ($Bq.m^{-2}$) to apply conversion models and estimate the soil redistribution rate ($t\ ha^{-1}year^{-1}$).

- For soil sample measurements the SILENA spectrometric chain was used, composed of the following elements:
- Low voltage source NIM POWER SUPPLY UNIT MOD. PS01-B
- Spectrometric amplifier MOD. 7611/L
- High-voltage source MOD. 7715
- Coaxial Detector of Intrinsic Germanium (HpGe) Type-p

The operational characteristics of the HpGe detector during the sample measurement ramained unchained. The main features are the following:

- Working voltage: + 3500 Volts DC
- Shaping time: 6 μsec
- Gain adjustment: 25
- Average resolution (FWHM): 3 keV at the second peak of Co-60 (1332.5 keV)
- Average position of the second peak of Co-60: 1332 keV.

For the efficient calibration of the measuring system, the soil pattern PAT/LVRA/09 was used. The activity of the pattern and other features of interest can be found at the Patterns Registry of the Lab RNP/PRA/LVRA/22.

The efficiency value reached for the energy of ^{137}Cs (662 keV) was 0.008. This efficiency value, from the calibration sample, was compared to the previous calibration (code: 110ML2000 by the software EMCAPLUS version 2.00.5) and the results coincided.

Conversion models used

Soil redistribution rates were estimated by the application of three conversion models[C]; the Proportional Model (PM), the Mass I Balance Model (MBM I) and the Mass II Balance Model (MBM II).

The Proportional Model has been widely used in cropped soils (2, 3, 5, 9, 10), it is based on the premise that rainfall of ^{137}Cs are totally mixed with the crop layer and the soil loss is directly proportional to the quantity of removed Cesium.

The main advantage of this model is the little information needed to use it; its major disadvantage is that if there was selective removal of the soil fine fraction, the redistribution rates will be overstimated, because ^{137}Cs is associated to the fine soil fraction.

The Mass I Balance Model I takes into account the income or losses of ^{137}Cs of the soil profile, during the period in which Cesium perecipitation took place. There is an evaluation of the reduced concentration of ^{137}Cs within the crop layer, due to the incorporation of soil with low ^{137}Cs from the original crop layer. Its main disadvantage is that it does not incorporate the removal of fresh ^{137}Cs from atmospheric precipitations before being incorporated to the soil layer through crop because of the rains.

The Mass II Balance Model incorporates the soil distribution due to tillage, which also redistributes the content of ^{137}Cs on the soil. This model surpasses the limitations of the previous ones, though it is necessary to know more parameters and its use turns complex.

The results of applying models were compared to the estimation of the potential erosion through the direct evaluation of the study sectors (soil guide horizons, organic matter, texture and other edaphological characteristics). A software (Complement of MSExcell) was used[C], for applying models to the evaluation of soil redistribution at the study sectors.

The main parameters used are summarized in (Table I), they were reached from the soil measurements under crop conditions; annual rainfall data were given by the closest weather station and were supplied to the growers.

Table I. Main parameters of the models

Parameters	Units	Value
Soil density	kg m^{-3}	1390
Annual rainfall	mm	1509
Plowing depth	cm	20
Aereal density of reference activity from 137Cs	Bq m^{-2}	1640
Relaxation depth	kg m^{-2}	4
Proportional factor	-	0,5
Sampling area	cm^{-2}	19,6

RESULTS AND DISCUSSION

The main results derived from the three models for both sectors under study are summarized in Figures 1 and 2, where positive and negative values account for the gain and loss of land respectively.

There is a qualitative coincidence for the different models; in spite there are quantitative variations in soil redistribution through these three models, they equally identified erosion and depositition for both sectors. The MP (-28,80 to 15,71 t ha^{-1}year^{-1}) and MBM I (-41,27 to 18,26 t ha^{-1}year^{-1}) recorded the highest quantitative variation. On the other hand, MBM II shows the lowest variation (-18,28 a 8,15 t ha^{-1}year^{-1}). These differences are associated to the different processes and premises incorporated into the models.

The results show predominance of erosive phenomena on the study sectors (80 %), in most of the evaluated points the estimated redistribution proportions are negative. From previous studies on area[A], soil redistribution rate should vary from 7,0 to -20,0 t ha^{-1}year^{-1}

The MBM II kept the results closer to the expected values for this type of soil, topography and harvests; values varied from 8.15 to -18.9 t.ha^{-1}year^{-1}. This is the most complete model compared to the other two (PM y MBM I), since it takes into account the temporal variation of the ^{137}Cs for its incorporation to radioactive precipitation and its initial distribution on the soil surface.

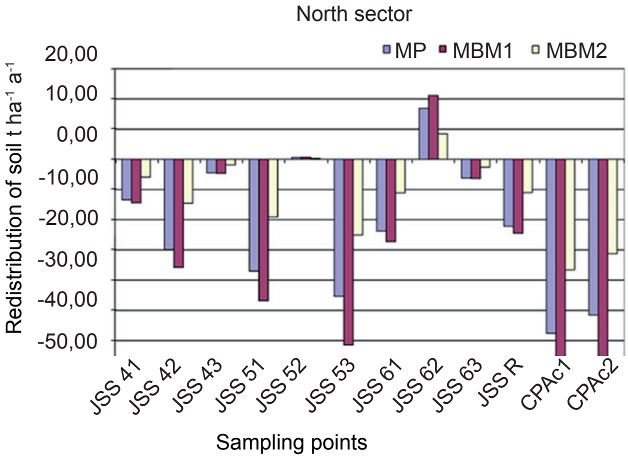

Figure 1. Soil redistribution estimation according to Conversion Models (North sector)

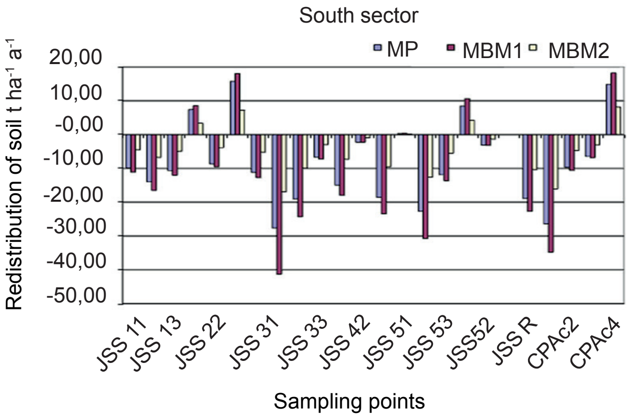

Figure 2. Soil redistribution estimation according to Conversion Models (South sector)

For the analysis of the results, different parameters were calculated for both sectors applying the above-mentioned models (MP, MBM I y MBM II); which allowed to comprehensively complete the quantitative analysis of the soil redistribution in the studied area. Most of these parameters are automatically calculated by the softwares used (Table II).

Though in both sectors with tobacco plots, erosive processes are predominant, results show that the North sector is the most affected one. Net erosion and the sediment loss rate were higher than in the south sector. Deposition values are also lower in the North sector. The difference could be mainly associated to the characteristics of the topography; the mean slope in the North sector is bigger (3,8 degrees) compared to the South sector (1,6 degrees).

Figure 3 shows for MBM II, a spatial representation of soil redistribution (including the topography of the studied area), being identified a close relationship with the soil forms. Models indicate an association between water erosion and topography, with a deposition in the areas whose figures are close to cero, and the erosion is associated to another soil form with the highest figures.

The application of this nuclear technique by using ^{137}Cs in the studied area, allows to efficiently characterize the soil redistribution rate. Preliminary research works confirmed the importance of this water erosion processes in the studied sectors and the difference identified between them. Some spatial distribution models of water erosion at the study site were also identified.

The results confirm the presence of high levels of soil losses associated to tobacco growing areas evaluated in this study and the need to implement a program of antierosive measures that permit prevent and/or mitigate negative impacts. The identified relationship between the levels of soil redistribution and topography allow to recommend the incorporation of other corrective actions as contour plantings, the use of live and dead barriers as a way to reduce the water erosion levels.

Table II. Summary of the main results

Parameters	North Sector	South Sector	Total
Affected area by erosion (m^2)	15472,53	15448,34	30920,8
Mid erosion of the affected area (t ha^{-1}year^{-1})	-14,56 MP -18,37 MBM I -7,95 MBM II	-14,74 MP -17,79 MBM I -7,62 MBM II	-
Affected area by sedimentation (m^2)	3656,98	3705,13	7362,1
Mid sedimentation in affected sites (t ha^{-1}year^{-1})	4,37 MP 5,45 MBM I 2,18 MBM II	12,66 MP 14,94 MBM I 6,26 MBM II	-
Total studied area(m^2)	19129,51	19153,47	38282,9
Total area fraction affected by erosion	0,8	0,8	0,8
Total area fraction affected by sedimentation	0,2	0,2	0,2
Net erosion (t ha^{-1}year^{-1})	-10,77 MP -13,61 MBM I -5,92 MBM II	-9,26 MP -11,24 MBM I -4,84 MBM II	
Loss rate of sediments/studied area (%)	89 (for all models)	77 MP 79 MBM I 80 MBM II	

MP: Proportional model MBM I: Balance Model of Mass I MBM II: Balance Model of Mass II

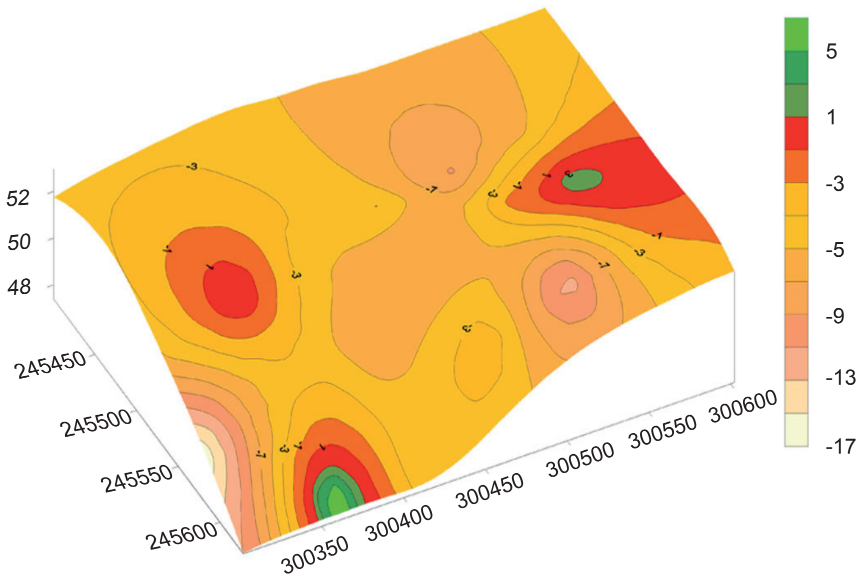

Figure 3. Soil redistribution rate expressed in (t ha^{-1}year^{-1}), according to the Balance Model of Mass II, in the study area (two sectors)

CONCLUSIONS

- ♦ The application of the nuclear technique with the use of ^{137}Cs allowed to make an effective characterization of the soil erosion status of the study site being the Balance Mass Model II the one showing the most representative results.
- ♦ Different soil redistribution rates were identified between the two sectors, being the North sector the most affected one by soil erosion, partially due to the slope and topography.

1. The study site was vulnerable to erosion, it greatly surpasses the 5 t ha^{-1} $year^{-1}$, considered within the permissible limit for these types of soil[A]. Preliminary results show the spatial behavior of soil redistribution rates.

- ♦ Different studies confirm the high erosion levels of tobacco plots in Western Cuba, which leads to urgent actions to revert this situation.

RECOMMENDATIONS

Complementary studies should be conducted to reach more detailed results on water erosion at the study site, for which the use of other radionuclidos (^{210}Pb, ^{7}Be) is needed.

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