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Preliminary study on the use of the ^{137}Cs method for soil erosion investigation in the pampean region of Argentina

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ABSTRACT

Soil erosion is the most important degradation process in Argentine. According to the estimation of 4.9 millon ha in Pampa Ondulada Region, 1.600.000 ha (36% of agricultural soils) are affected by the erosion. Field measurements of soil erosion and sediment deposition using classical techniques are difficult, time consuming, and expensive but indispensable to feed the prediction models for conservation practices design and farm planning.

Many authors have reported that the measurement of fallout nuclides is useful tool to characterize geomorphical processes. Walling and He proposes models for converting ^{137}Cs depletion/enrichment amounts to net soil loss/deposition. These models are based in the comparison between a reference ^{137}Cs profile in a long term undisturbed site (control site) and the ^{137}Cs profiles in the suspected eroded or deposited sites in the landscape.

The aim of this study is to provide a complete and well representative set of data on the erosion intensity in topographical conditions for the Pampa Ondulada Region in Argentine by using a tracer technique. The study area is a small watershed (about 300 ha), located in Arroyo del Tala medium basin, within Partido of San Pedro in Buenos Aires Province, Argentine. This paper presents a group of results from a detailed investigation of erosion and sediment delivery, within a 49 ha cultivated field study site in this watershed. The base of sampling strategy is the grid approach. A reference inventory, representing the local fallout input, was searched for at a site experiencing neither erosion nor deposition.

Radiocaesium analyses were made at the Nuclear Regulatory Authority Laboratory by a GE Hp detector. To make an interpretation of ^{137}Cs distribution of soil losses and sedimentation, the Mass Balance Model 2 was used (Walling and He 1997). The erosion/deposition rates from Mass Balance Model 2 are in the range of 0 to -30 $t \cdot ha^{-1} \cdot y^{-1}$ for erosion, and 0 to 19 $t \cdot ha^{-1} \cdot y^{-1}$ for deposition, and these values matched well, with the rates of erosion obtained by classical methods. The ^{137}Cs spatial and depth distribution are showed in a map, and enabled to study the relationship of the erosion to the topography, and a good discrimination in subclasses within moderate erosion class and sedimentation class.

Key words: Soil erosion. Sedimentation. Watershed. Mollisols. ^{137}Cs method. Pampean Region

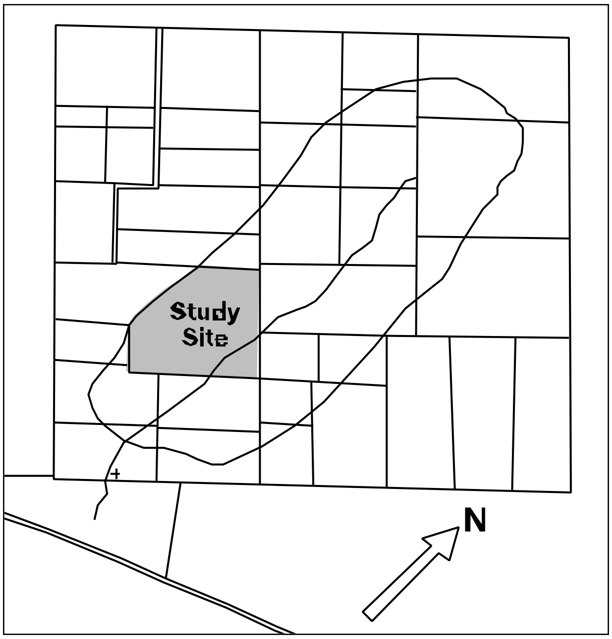

Figure 1. Subwatershed in the Arroyo del Tala basin.

INTRODUCTION

Soil erosion is the most serious degradation process in Argentina. It has been estimated that from 4.9 million ha of arable soils in the "Pampa Ondulada" region, 1.6 million ha or 32.6% are affected by erosion (Secretaría de Agricultura Ganadería y Pesca, 1995). Although it is known that water and wind are the main factors causing soil erosion, little information exists about their magnitude and actual erosion/sedimentation rates as well as soil and sediment redistribution across the landscape.

In a previous study, Santanatoglia et al. (1996a) carried out an erosion survey and mapping of the region based on measurements of the depth of B21 horizon. They found that 41, 21, and 18 % of the area was affected by severe, moderate and slight erosion respectively, and the remaining 20% by sedimentation. The length of the slope, in spite of its low gradient, had a great influence on the intensity of erosion. Other studies have been also conducted to investigate water erosion processes by using ^{59}Fe to label soil aggregates (Buján et al., 1986).

Many empirical and theoretical mathematical equation models have been developed to estimate soil erosion. The most widely used is the USLE (Universal Soil Loss Equation), which is an empirical equation developed with data collected from soil erosion plots on "typical" soils of the USA, in the eastern states of the Rocky Mountains (Wischmeier and Smith 1978).

Field measurements of soil erosion and sediment deposition using classical techniques are difficult, time consuming, and expensive but indispensable to feed the prediction models. Because of the important limitations of the classical techniques for monitoring soil erosion, many authors have reported that the use of fallout radionuclides is a powerful tool to estimate soil

Table 1. ^{137}Cs distribution (Bq·kg^{-1}) with depth and average values at the four reference inventories.

Depth. (cm)	P1	P2	P3	P4	Average
0-10	5.68	4.81	4.31	4.05	4.71 ± 0.36
10-20	4.40	2.65	3.35	2.49	3.22 ± 0.43
20-30	1.82	0.00	0.94	0.95	0.93 ± 0.37
30-40	0.00	0.00	0.00	0.00	0.00 ± 0
40-50	0.00	0.00	0.00	0.00	0.00 ± 0
50-60	0.00	0.00	0.00	0.00	0.00 ± 0
60-70	0.00	0.00	0.00	0.00	0.00 ± 0
70-80	0.00	0.00	0.00	0.00	0.00 ± 0
80-90	0.00	0.00	0.00	0.00	0.00 ± 0
Total Bq.kg^{-1}	11.91	7.46	8.59	7.49	8.86 ± 1.04
Total Bq.m^{-2}	1488	933	1074	937	1108±131

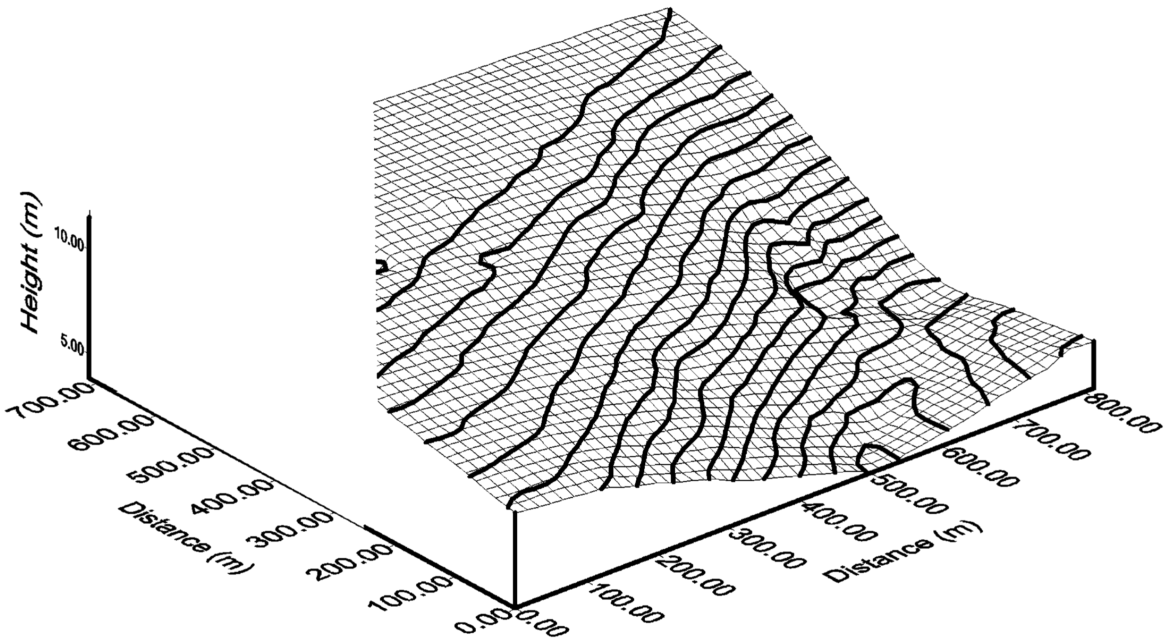

Figure 2. Landscape perspective of study site.

erosion/deposition on agricultural land. Among them, the ^{137}Cs is the most widely used. The ^{137}Cs technique is based on the comparison between the ^{137}Cs inventories, measured in the suspected eroded or deposition sites in the landscape and a reference ^{137}Cs inventory normally established at a long-term undisturbed site. Any reference site is only valid for areas studied at the same time and with identical land management strategies (Quine, 1995). The global pattern of ^{137}Cs inventories show a latitudinal variation and are much lower in the southern hemisphere than in the northern hemisphere (García Agudo, 1998). Rainfall regime also affects the local ^{137}Cs inventories.

Walling and He (1997) have developed several models for converting ^{137}Cs data to net soil loss/gain. They proposed different approaches taking into account the variation of the ^{137}Cs inventories (the most simple), or several other factors, such as non- uniform initial distribution of nuclides, ^{137}Cs concentration in the soil surface, variation in depth and extent of erosion, plough depth, land use and particle size. This paper describes a preliminary study of soil erosion and sediment delivery, in a small watershed of the river Tala basin using the ^{137}Cs method. The specific aim is to gather a reliable set of data on the erosion rates in conditions representative for the "Pampa Ondulada" region of Argentina.

MATERIALS AND METHODS

General characteristics of the study area and study site

Location

The study area was a small watershed, (about 300 ha) located in the northern slope of medium basin of the river Tala (Arroyo del Tala), within the "Partido of San Pedro" (330 50´ Latitude South, 590 52´ Longitude West) in the province of Buenos Aires Province, Argentina, approximately 200 km NW of Buenos Aires City.

An experimental field of 49 ha located in the lower part of the watershed was chosen as the study site for the application of the ^{137}Cs technique (Figure 1).

Topography

The study site is located 40 m above sea level and the general topography is undulated with slopes between 0,5 and 2% (Figure 2). The slope length is variable and sometimes is over 400 m. The study area was divided in landscape units with slope gradients of about 0-0.5%, 0.5-1% and 1-2% and a coverage of 22%, 35·% and 34% respectively. The remaining 9% was occupied by intermittent waterways.

Table 2. Soil erosion/sedimentation classes, ^{137}Cs inventories and topographical characteristics.

Class	Estimated Rates ($t.ha^{-1}.y^{-1}$)	^{137}Cs Inventory ($Bq.m^{-2}$)	Slope Gradient/Length (%/ m)	Area (ha)	Area (%)
Null to slight erosion	0 to -10	1120 to 858	0.5/100	18	36.7
Medium erosion	-10 to -20	858 to 655	1.5/300	19	38.7
High erosion	-20 to -30	655 to 389	2/400	3	6.1
Null to Slight sedimentation	0 to 10	1120 to 1340	1/200	8	16.3
Moderate sedimentation	>10	1340 to >1554	1/400	1	2.2

Land use

In the upper watershed, the predominant land use is agriculture, being soybean the most important crop rotated with cereals such as maize and wheat and pastures, whereas in the medium and low watershed, agriculture is alternated with grassland for livestock production.

Climate

The region has an annual average rainfall of 1069 mm (mean of 50 years) non-evenly distributed throughout the year (Santantoglia et al, 1996 a and 1996 b). The lowest rainfall period occurs in winter and the rainy season is normally distributed from early spring to autumn (INTA, 1996).

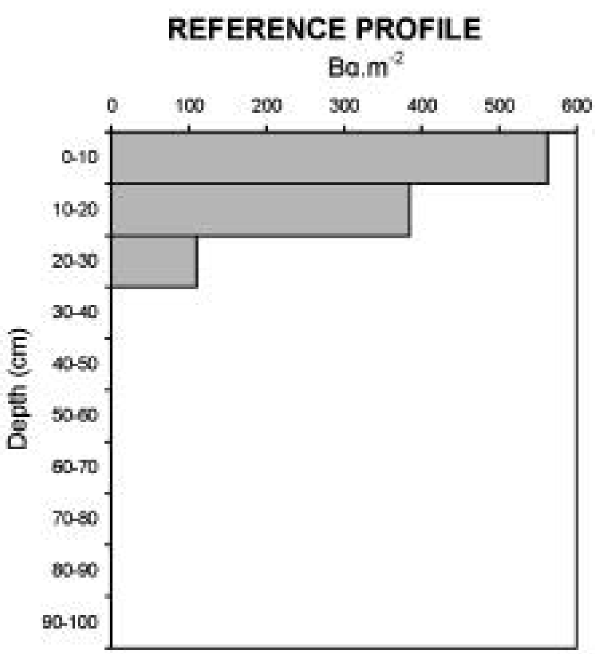

Figure 3. ^{137}Cs inventory in the reference profile.

Soils

The main soil type is classified as a Vertic Argiudoll, series Ramallo and its eroded phases (INTA, 1973). This soil has a silty clay loam top horizon containing: 15% sand, 60% silt and 25 % clay, and a medium content of organic mater (3% by weight). The internal drainage of the soil is classified as moderately well drained, according to Soil Survey Staff (1993). Due to these properties, it is very susceptible to the impact of the raindrops resulting in crusting and sealing of the soil surface (FAO, 1980).

Field application of the ^{137}Cs technique

Selection of reference sites

Potentially uneroded or undeposited sites were searched as reference sites in the study area (Bujan et al, 1999). A reference site was selected in a yard, not distant 1 km from the study area and with slope inclination of about 0,5 %. Four depth increments profiles samples were taken for the determination of the depth distribution of the ^{137}Cs in the soil profile. Subsamples were taken every 10 cm up to 90 cm.

Sampling network in the study site

A systematic sampling design based on the grid approach was used. The distance between sampling points

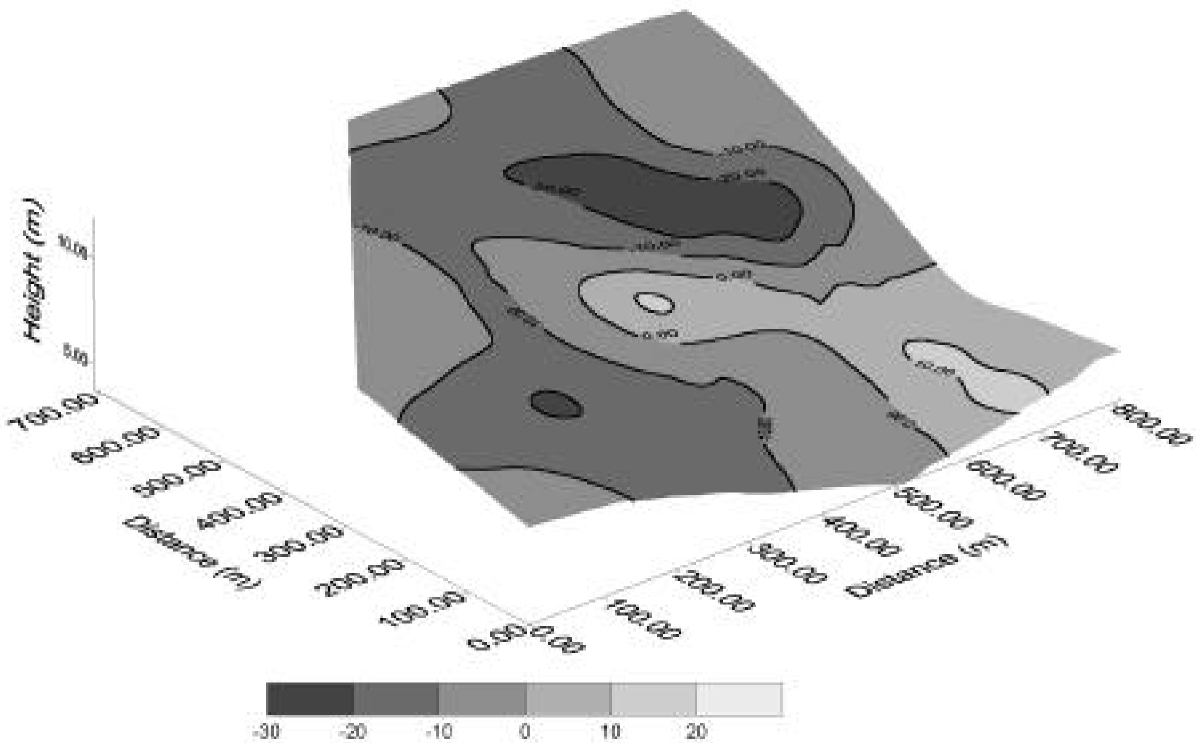

Figure 4. Soil erosion and sedimentation units' map.

was 140 m., corresponding to 2 ha., each one. Samples were collected with shovel, manually in blocks of rectangular cross section of approximately 120x150 mm and the thickness adjusted by knife. Incremental samples by depth were also taken in 10-cm intervals up to 90 cm.

^{137}Cs analysis

Samples were air dried, sieved through a 2 mm. mesh, and homogenized. The radiocaesium analyses were carried out at the Laboratory of the Nuclear Regulatory Authority, Ezeiza Atomic Center, National Atomic Energy Commission, Argentina. The measurements were made with a GE Hp detector in plastic containers of 7 cm. diameter and 4 cm height. Each sample was counted for 90000 seconds.

Calibration Models

From the calibration models proposed by Walling and He, 1997 to convert the ^{137}Cs data into estimates of soil loss and deposition rates, the Proportional Model, the Mass Balance Model 1 and the Mass Balance Model 2 were tested.

RESULTS AND DISCUSSION

An average value of 1108 Bq.m^{-2} was obtained for the local reference inventory. It is recommended to check these reference levels with the estimated value of global distribution of ^{137}Cs for the location. In this case, the measured reference inventory was slightly larger than the ^{137}Cs values of global distribution given by García Agudo (1998).

The ^{137}Cs activities of the reference profiles declined sharply from 4.71 Bq·kg^{-1} in the first 10 cm to 0.93 Bq·kg^{-1} at 30 cm. The ^{137}Cs profile distribution with depth showed a decrease down to 30 cm, except one core (P2) where the ^{137}Cs distribution depth was only to 20 cm. Below this depth no ^{137}Cs activities were found (Table 1).

The typical distribution with depth of the average reference inventory is shown in. Fig.3. An analysis of the data of ^{137}Cs profile in the reference site shows that the 0-

10 cm layer contains 53 % and the 0-20 cm layer 90 % of the total inventory.

To make an assessment of the spatial pattern of soil redistribution within the study site, the individual point estimates of erosion and deposition rates derived from the ^{137}Cs measurements were spatially integrated to produce a range of measures of the overall status of erosion and deposition in the study site. In a first instance the proportional model and mass balance model 1 were tested for calibration purposes but the obtained soil erosion and sedimentation rates were much higher than the rates previously reported by classical methods. Therefore the Mass Balance 2 was used to obtain such estimates.

The estimated points of erosion / deposition rates from Mass Balance Model 2 ranged from 0 to -30 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ for erosion, and from 0 to 19 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ for deposition. From the 30 sampling point estimates, five categories were established arbitrarily. In Table 2, it may be noted that first three categories do correspond to erosion classes and the last two to sedimentation categories. The first erosion class is "null to slight erosion" and includes areas with soil loss rates of 10 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ or less. The value of 10 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ is the maximum soil tolerance rate according to Wischmeier and Smith, 1978. Other two erosion classes (medium and high) were identified based on the estimated soil loss rates. The erosion classes represent 36.7%, 38.7%, 6.1% of the total area respectively.

Qualified like eroded zones, with the following ^{137}Cs activities: Class "Null to Slight Erosion" ranges between 1120 to 858 $Bq.m^{-2}$; Class "Slight erosion ranges" between 858 to 655 $Bq{\cdot}m^{-2}$; Class "Medium Erosion" ranges between 655 to 389 $Bq{\cdot}m^{-2}$ (Table 2).

Similarly two sedimentation classes (slight and moderate) were identified and they represent the 16.3% and 2.2 %, respectively, of the total area (Figure 4 and Table 2). The Class "Slight Sedimentation", ranged between 1120 to 1340 $Bq{\cdot}m^{-2}$, and Class "Moderate Sedimentation", ranged between 1340 to up to 1554 $Bq{\cdot}m^{-2}$, qualified like deposited areas.

The relationship between the measured ^{137}Cs inventories and the topographical features of the study site is well observable along the landscape. Overall the soil redistri-bution corresponds to general rule of water erosion dynamics. The erosion rates increase with the slope gradient and length. In the foot slope and intermittent waterway areas, the runoff intensity decreases and deposition occurs.

CONCLUSIONS

The application of ^{137}Cs technique enabled us to assess erosion/deposition rates in the study site. It showed good resolution to discriminate between erosion and deposition. In total, 5 categories were identified, which are related to topographical factors such as slope position, gradient and length.

The erosion / deposition rates estimated from Mass Balance Model 2 were in the range of 0 to - 30 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ for erosion, and 0 to 19 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ for deposition. These values matched well, with the erosion rates obtained by classical methods. A total of 45% of the study site is seriously affected by erosion with values higher than 10 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ which is considered as permissible soil loss tolerance rate.

^{137}Cs measurements were also used to assess the spatial patterns of soil redistribution within the study site. This information can be used to test and validate models to predict erosion and deposition rates within the catchment and to formulate appropriate soil conservation practices. Further studies using the ^{137}Cs technique are required to get representative erosion/sedimentation rates of the "Pampa Ondulada" region of Argentina. With regard to the ^{137}Cs technique a more refined application is needed with regard to the selection of reference sites, sampling design and calibration models.

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