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Application of the ^{137}Cs technique to quantify soil redistribution rates in paleohumults from Central-South Chile

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ABSTRACT

The objective of the present study was to evaluate the applicability of the ^{137}Cs technique in obtaining spatial distributed information on mean soil redistribution rates in Central-South Chile. For this purpose four fields of Palehumult soil and contrasting land use and management were selected in the Coastal Mountain Range of the 9th Region: Crop fields under subsistence and commercial management and non-permanent prairies under subsistence and commercial management. The spatial distribution of the soil redistribution rates obtained by the ^{137}Cs method was similar to the one obtained by pedological observations. Also, annual sediment fluxes measured at experimental plots were similar to the erosion rates determined by the ^{137}Cs method at adjacent points. The ^{137}Cs technique is seen as an efficient method to obtain long-term soil redistribution rates under the climatic conditions and the soil type selected in Chile. In the future, it is necessary to study the applicability of the method under other climatic conditions and soil types occurring in Chile in which erosion is not so evident, and to adjust the method to optimise costs and benefits.

Key words: ^{137}Cs. Fallout. Soil. Erosion. Sedimentation. Chile. South America.

RESUMEN

Con el objeto de estudiar el uso potencial de la técnica del ^{137}Cs en estimación de tasas medias de redistribución de suelo y su distribución espacial en la zona Centro-Sur de Chile, se aplicó este método en un Palehumult de la Cordillera de la Costa, situado en la IX Región. Para ello se seleccionaron cuatro sitios sometidos a diferentes sistemas de explotación y manejo: Cultivos en rotación con manejo de subsistencia y tradicional y praderas no permanentes con manejo de subsistencia y tradicional.

La distribución espacial de tasas de redistribución de suelo obtenida utilizando la técnica del ^{137}Cs es similar a la determinada mediante observaciones pedológicas. Por otra parte, tasas locales calculadas resultaron similares a las determinadas con parcelas de escurrimiento. Ello hace que la técnica del ^{137}Cs se evidencie como una herramienta rápida y eficaz para cuantificación de tasas de redistribución de suelo bajo las condiciones climáticas y el tipo de suelo seleccionado en Chile. En el futuro debe estudiarse la aplicabilidad del método bajo otras condiciones climáticas y tipos de suelo que presentan menor erodabilidad y, además, ajustarlo para optimizar costos y beneficios.

Palabras Clave: Cesio 137. Suelo. Erosión. Sedimentación. Chile. Sudamérica.

INTRODUCTION

Soil conservation and sustainability is of maximum relevance to guarantee the increasing demand for food and raw materials in the world. Therefore, soil degradation and deterioration occurring during the past need to be evaluated. For this purpose, reliable techniques for quanti-fying soil erosion and sedimentation have to be improved.

The objective of the present research is to evaluate the applicability of ^{137}Cs technique in obtaining spatially distributed information on mean soil erosion and sedimentation rates in soils from Central-South Chile. With this aim, the ^{137}Cs technique was first applied to quantify soil redistribution rates in a Palehumult of the 9th Region, Chile, adapting three mathematical models proposed by Walling and He (1998) to the time-course of the ^{137}Cs fallout inputs and to the climatic and soil properties of the selected area.

MATERIAL AND METHODS

Four study areas, located in the Coastal Mountain Range of the 9th Region of Chile (38º 40´S, 72º 30´W) were selected. The main characteristics of the sites are summarised in Table 1. The areas are constituted of Palehumult soil, having contrasting land use and management: Crop fields under subsistence management (A) and commercial management (B), and non-permanent prairies under subsistence management (C) and commercial management (D). The high ^{137}Cs retention in the Palehumults and the relative low annual rainfall rate at the selected area (1160 mm y^{-1}) guarantee that most of the ^{137}Cs inventory is retained in a shallow depth layer of the studied soils (Schuller et al. 1997).

To estimate the ^{137}Cs reference inventory, reference sites were chosen near to each study field, on a flat area with minimal intervention, located at some altitude with respect to the study field, not affected by soil erosion or sedimentation, and exhibiting a full grass cover during the whole year.

The plough depth and/or penetration depth of the radionuclide in the soil were determined by depth incremental sampling at the reference sites, and at the upper, middle and low sector of the sampling fields. For measuring ^{137}Cs inventories at the reference sites, and along the transects of the fields, bulk samples were collected with metallic cylinders of 0.072 m in diameter, introduced down to the ^{137}Cs penetration depth. In the reference sites they were collected in a 6x6 m grid, and at the study area the separation was larger, from 6x6 to 16x20 m grids, according to the size and topography of the field. The coordinates of each sampling point were defined on a topographic map of the sampling areas.

^{137}Cs activity was measured by gamma spectrometry with an HP Ge detector of 26% relative efficiency associated with Nuclear Data acquisition system and Accus-Spec B program for spectral analysis.

Soil redistribution rates were estimated using three mathematical models proposed by Walling and He (1998) for cultivated soils, adapted to the site specific conditions of the studied fields: Proportional Model (PM), Mass Balance Models 1 and 2 (MBM1 and MBM2, respectively). The time-course of the ^{137}Cs deposit within the study area

Table 1. Characteristics of the studied fields, and estimated soil redistribution rates.

Site code	A	B	C	D
Use	Crop land	Crop land	Prairie	Prairie
Management	Subsistence	Commercial	Subsistence	Commercial
Surface (ha)	2.2	0.4	0.5	0.2
Mean slope (%) U; M; L*	6; 19; 7	13; 16; 3	9; 13; 7	36; 48; 17
Plough depth (cm)	12	17	12	15
Mean soil redistribution rates				
PM (t ha^{-1} y^{-1}) U; M; L*	-5.2; -10.6; 3.2	-5.2; -8.5; 3.2	-1.1; -4.3; 14.8	0.3; 11.6; 6.2
MBM2 (t ha^{-1} y^{-1}) U; M; L*	-7.7; -12.8; 3.5	-4.8; -8.1; 3.0	-0.9; -4.4; 14.5	0.2; 9.9; 5.7

* determined at the upper (U), middle (M) and low (L) sector of the field.

was estimated based on the annual deposit of ^{90}Sr and ^{137}Cs reported for the nearest site, situated at the geographical position 41º 26´S, 73º 07´W (Health and Safety Laboratory, 1977; Juzdan, 1988; Larsen, 1985; Larsen and Juzdan, 1986; Monetti and Larsen, 1991; UNSCEAR, 1982). The activity ratio ^{137}Cs/^{90}Sr in deposition was considered constant at 1.6, for this purpose (UNSCEAR, 1982).

In order to examine the validity of the results obtained by the ^{137}Cs method, they were compared with redistribution rates obtained by pedological observations (comparing the depths of the horizon of the area affected by soil redistribution with the one of a reference area with scarce intervention). In addition, experimental plots of 10 m^2 were installed at the upper sector of fields A and C in order to obtain reference values of the annual sediment flux at the corresponding sampling points. The sediment flux from the erosion plots was measured during three years, from 1996 to 1998. To obtain the mean annual sediment flux, only values obtained during 1996 and 1997 were considered, because during 1998 the annual rainfall rate was 50% lower than the normal.

RESULTS AND DISCUSSION

The determined reference inventory for all studied sites was (525±12) Bq m^{-2} (reference date: January 1998). The plough depth varied according to the employed ploughing technique (Table 1), and the ^{137}Cs penetration depth fluctuated additionally according to the position along the transects, from 12 cm at eroded points up to 30 cm at sedimentation points.

The soil redistribution rates obtained using MBM1 were systematically higher than the ones obtained using the other mathematical models. This model also predicted higher annual erosion rates than the sediment flux measured with experimental plots at adjacent points. Based on these facts, and considering that MBM1 does not take into account the removal of freshly deposited ^{137}Cs, before its incorporation into the plough layer by cultivation, the results obtained by this model were excluded from the following discussion.

Almost all analysed fields show a small slope at the upper sector of the analysed area, a more pronounced slope at the middle sector and a slight slope at the foothill. In order to characterise the predominant soil redistribution process at each of these sectors, mean values of the erosion rates (negative values) or sedimentation rates (positive values) obtained using the PM and MBM2 at these three sectors of the fields are summarised in Table 1. The redistribution rates and their spatial distribution estimated by the two models are similar for each field.

Considering that the postulates of MBM2 were more realistic than the ones of the PM, the results obtained by MBM2 were selected to compare the soil redistribution processes at the four study areas (Fig. 1).

In the crop area under subsistence management (A) high erosion rates were observed at the upper border (30-45 t ha^{-1} y^{-1}), due to reiterated ploughing normal to the downslope direction and due to the obstruction of sediment flux from the adjacent area into this field by a dense shrub fence. The other sector of high erosion rates (10-30 t ha^{-1} y^{-1}) is situated in the area of maximal slope. The sedimentation area is positioned at the hillfoot (8-14 t ha^{-1} y^{-1}). The high erosion rates observed in this field could be the outcome of intensive annual cultivation processes and frequent transit of animal plough systems across this field (Schuller et al., 1999).

Similar spatial distribution of soil erosion rates were observed in the crop field site under commercial management (B): The highest erosion rates were measured at the top of the field (up to 9 t ha^{-1} y^{-1}) and at the sector of maximal slope (up to 14 t ha^{-1} y^{-1}). The highest sedimentation rates (up to 7 t ha^{-1} y^{-1}) were determined at a concavity situated at the hillfoot. The erosion rates in field B are lower than in field A, possibly due to a more adequate technology used during the cultivation processes at the commercial managed field.

At the semi-permanent prairie under subsistence management (C) the areas showing the highest erosion rates (up to 10 t ha^{-1} y^{-1}) are located in the middle sector of the field, where the slope is steepest. At this field high sedimentation rates (up to 44 t ha^{-1} y^{-1}) were observed at the hillfoot, caused by sediment flow into an adjacent stream.

In the non-permanent prairie under commercial management (D) the predominant process caused by soil redistribution was sedimentation. This area was affected by deposition of sediments running from an upper flat adjacent cultivated area, which was ploughed perpendicular to the hillslope of the pasture, throughout a long number of years. The highest sedimentation areas were located at mid- (7 to 14 t ha^{-1} y^{-1}) and footslope (up to 19 t ha^{-1} y^{-1}), probably in water flow concentration sites.

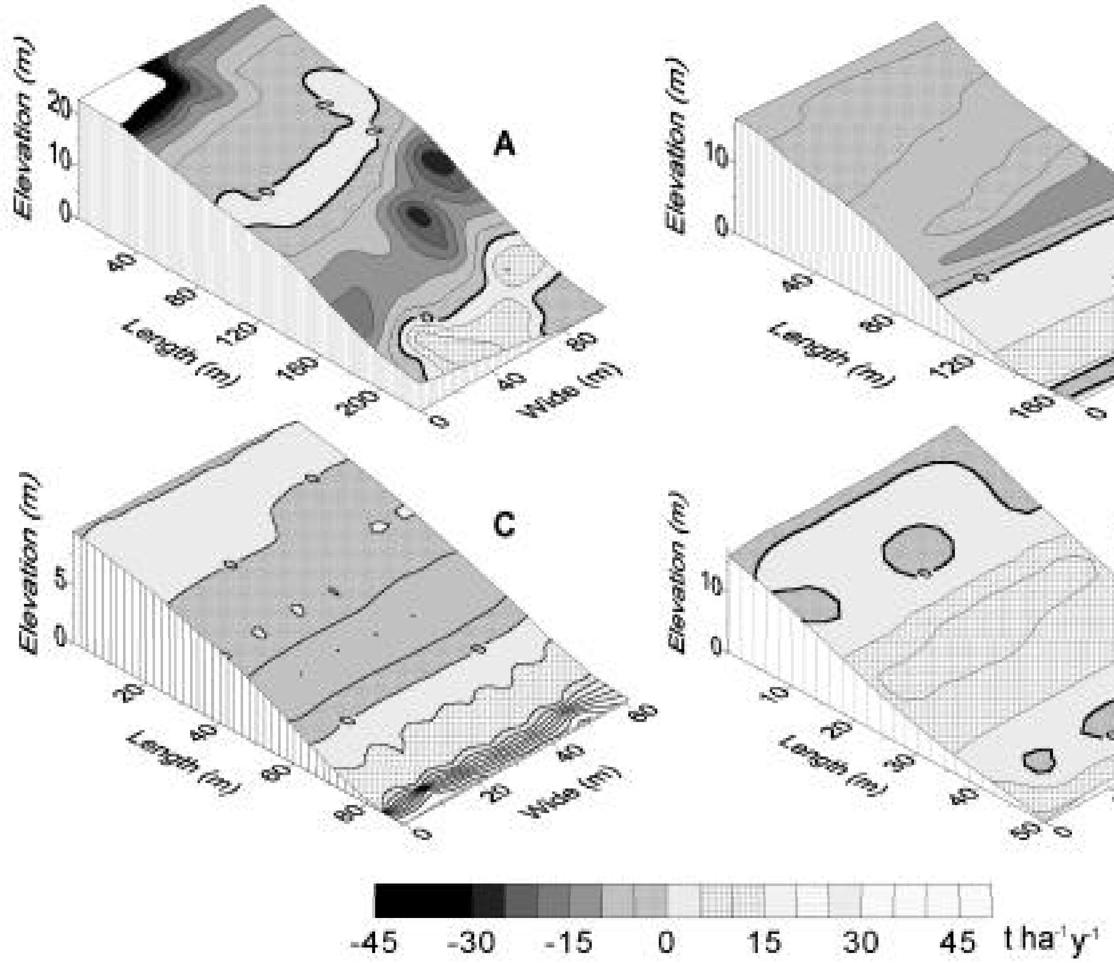

Figure 1. Soil redistribution rates as a function of field topography: Crop fields under subsistence management (A) and commercial management (B), non-permanent prairies under subsistence management (C) and commercial management (D).

The mean annual sediment flux determined with an experimental plot at the upper sector of site A was (2.8± 0.8) t ha^{-1} y^{-1}. The calculated erosion rate at four adjacent sampling points varied from 0.7 to 4 t ha^{-1} y^{-1} (mean value of 2.3 t ha^{-1} y^{-1}). The sediment flux determined with the experimental plot simulating the management conditions of prairie C was (1.0 ± 0.3) t ha^{-1} y^{-1} and the calculated erosion rates at sampling points of similar slope in prairie C fluctuated between 0.4 and 1.9 t ha^{-1} y^{-1} (mean value 1.1 t ha^{-1} y^{-1}). The sediment fluxes obtained with experimental plots are in good agreement with the estimated erosion rates at adjacent positions in the fields. Nevertheless, the experimental flux represents net soil export from the plots, because of their isolation from the processes operating in the adjacent areas. Moreover, sediment flux is time specific and therefore valid for the period for which it is calculated, because soil loss varies through time.

The soil redistribution rates estimated by the ^{137}Cs technique represent an average for the last 40-45 years, and are therefore less influenced by extreme events. Additional redistribution rates obtained by pedological observations, which also consider the accumulative effect of past soil redistribution processes, are represented in Fig. 2. The values of erosion and sedimentation rates obtained by this method are expressed on relative scales, because of the difficulty in determining the period of cultivation of each field and the depth of the reference horizons. Nevertheless, the rates estimated by the pedological observations reflect a similar pattern of spatial distribution, in relation to the soil redistribution rates quantified by the ^{137}Cs technique.

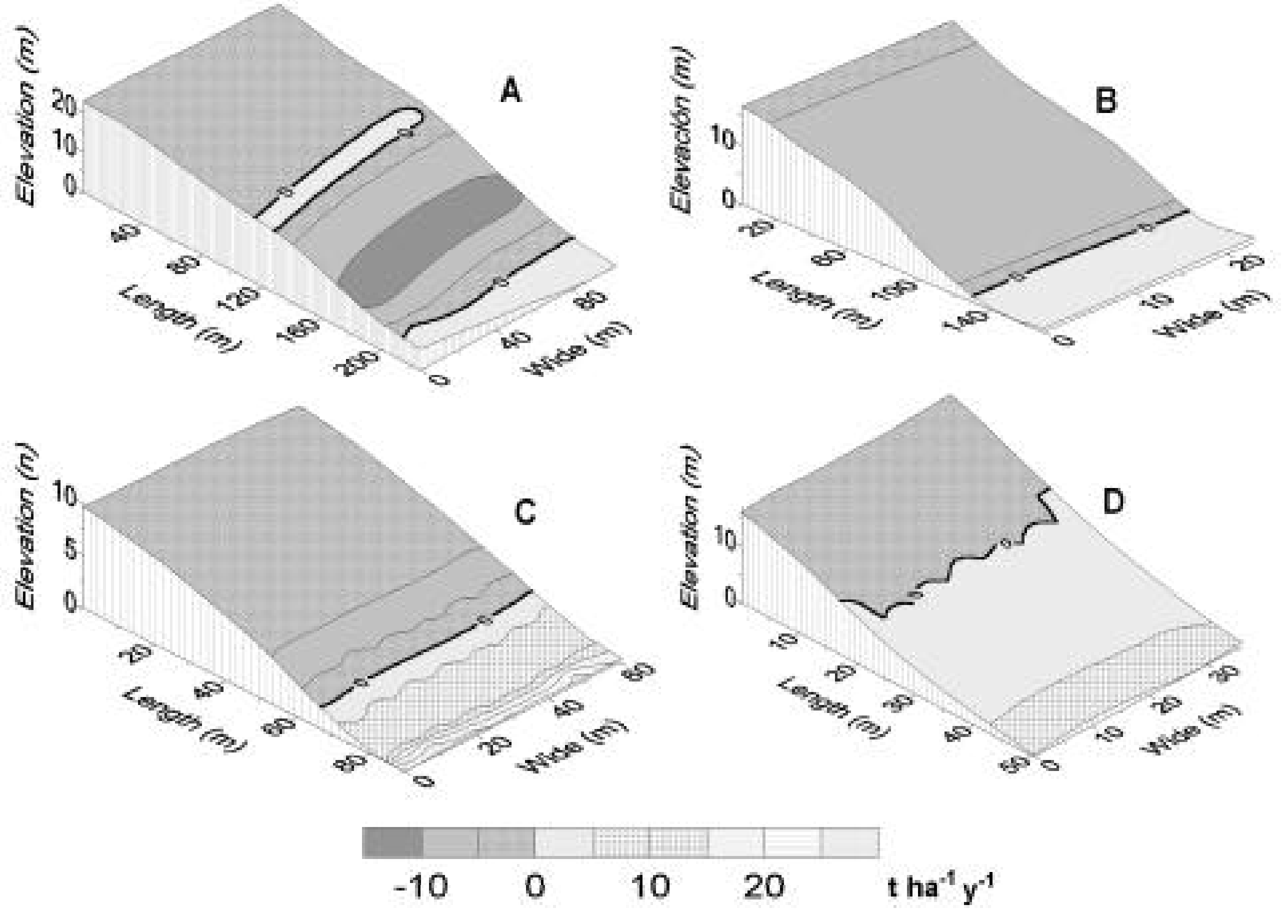

Figure 2. Soil redistribution rates estimated by pedological observations as a function of soil topography: Crop fields under subsistence management (A) and commercial management (B), non-permanent prairies under subsistence management (C) and commercial management (D).

CONCLUSIONS

The soil redistribution rates and their spatial distribution estimated using the PM and MBM2 are very similar at each studied field. Considering the similarity between the pattern of spatial distribution of the soil redistribution rates estimated by ^{137}Cs technique and by pedological observations, and due to the fact that the measured annual sediment fluxes were in good agreement with the local erosion rates predicted by the ^{137}Cs technique, the rates obtained by this method can be considered as good estimates for the studied areas.

The ^{137}Cs method is seen as a rapid and efficient method to obtain long-term soil redistribution rates under the climatic conditions and for the soil type selected in Chile. In the future, it is necessary to study the applicability of the method under other climatic conditions and soil types in which erosion is not so evident, in order to prevent it. To make the method accessible for potential users, it needs to be adjusted to optimise costs and benefits.

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REFERENCES

Health and Safety Laboratory, 1977. Final tabulation of monthly 90Sr fallout data: 1954-1976. U. S. Energy Research and

Development Administration. New York, USA. In HASL-329 Report, UC-11. 323 p.

Juzdan, Z.R., 1988. Worldwide deposition de 90Sr through 1985. USA; Department of Energy. New York, USA. In Environmental Measurements Laboratory Report. EML-515. 34 p.

Larsen, R.J., 1985. Worldwide deposition de 90Sr through 1983. USA; Department of Energy. New York, USA. In Environmental Measurements Laboratory Report. EML-444. 159 p.

Larsen, R.J., Juzdan, Z.R., 1986. Worldwide deposition de 90Sr through 1984. USA; Department of Energy. New York, USA. In Environmental Measurements Laboratory Report. EML-457. 159 p.

Monetti, M.A., Larsen, R.J., 1991. Worldwide deposition de ^{90}Sr through 1986. USA; Department of Energy. New York, USA. In Environmental Measurements Laboratory Report. EML-533. 31 p.

Schuller, P., Ellies, A., Handl, J., 1997. Influence of climatic conditions and soil properties on ^{137}Cs vertical distribution in selected Chilean soils. Z. Pflanzenernähr. Bodenk., 160, 423-426.

Schuller, P. Sepúlveda, A., Ellies, A., Castillo, A., 1999. Utilización de ^{137}Cs en cuantificación de erosión y sedimentación en un Palehumult de la IX Región. Agro Sur 27, 29-36.

United Nations Scientific Committee on the Effects of Atomic Radiation, 1982. Ionizing radiation: Sources and biological effects. United Nations. 773 p.

Walling, D.E., He, Q., 1998. Models for converting ^{137}Cs measurements to estimates of soil redistribution rates on cultivated and uncultivated soils. Department of Geography, University of Exter, UK. 33 p.