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The uncertainty given by the input parameters in the radiometric modelling of soil redistribution rates

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INTRODUCTION

The ^{137}Cs technique represents a worldwide instrument for assessing soil erosion and sedimentation rates in various agricultural and natural landscapes.

The methodology is based on a simple comparison between the fallout radionuclide inventory at a reference site and the inventories from the investigated area.

AIM OF RESEARCH

There is still a lack of information in the procedure needed for an accurate determination of the input parameters involved in these models, resulting in a noticeable source of uncertainty in erosion radiometric modelling.

Objectives of the study:

(i) to highlight the importance of the input parameter values involved in the **Diffusion and Migration Model** for assessing soil erosion in uncultivated fields.

(ii) to apply an alternative method to statistically derive the effective diffusion coefficient and the convective velocity of ^{137}Cs for undisturbed soil using the least square fitting procedure.

(iii) to assess the soil erosion and deposition rates on Romanian pasture land using ^{137}Cs inventories

METHODOLOGY

Study site

The site under investigation is situated in the ‘Somes’ watershed (N46°52’, E23°45’), north-west extremity of the Transylvanian Plain, Romania.

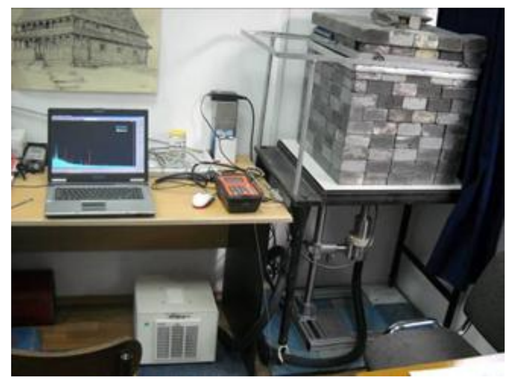
Sampling

Study site - twelve soil cores were taken to 40 cm along two parallel transects using a manually-operated cylindrical steel corer

Reference site - five soil cores (four bulks and one incremental) were collected from a flat terrace with low herb cover

Gamma spectrometry

Two high purity Germanium detectors with relative efficiencies of 34% and 30%, respectively, were used for ^{137}Cs determination in soil samples.



Physico-chemical properties of soil samples (texture, water content (%), bulk density (g cm^{-3}), humus) were analyzed according with national norms and standards.

DIFFUSION AND MIGRATION MODEL

It represents one dimensional transport model characterized by an effective diffusion coefficient D (kg^2 m^{-4} yr^{-1}) and a migration rate v (kg m^{-2} yr^{-1}) for ^{137}Cs within the soil profile.

Variation of the ^{137}Cs concentration $C_u(t)$ (Bq kg^{-1}) in surface soil with time *t* (yr) may be approximated as[1]:

$$C_u(t) \approx \frac{I(t)}{H} + \int_0^{t-1} \frac{I(t')e^{-R/H}}{\sqrt{D\pi(t-t')}} e^{-\frac{V^2(t-t')}{4D} - \lambda(t-t')} dt'$$

Key parameters used in the model:

1) Migration velocity v (kg m^{-2} yr^{-1}) and the Effective diffusion coefficient D (kg^2 m^{-4} yr^{-1})
2) Particle size correction factors (PS and PS')
3) Reference inventory (Bq kg^{-1})
4) Chernobyl contribution (%) to the total ^{137}Cs inventory in the study area
5) Relaxation depth (H) – **input value 5 kg m^{-2} (for undisturbed fields)[1]**

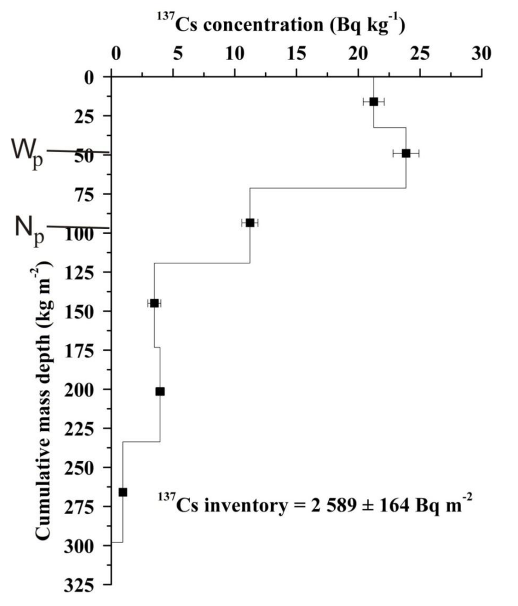
1) Estimation of v and D

“Easy” method

Values of v and D were determined from the distribution of ^{137}Cs concentration (Bq kg^{-1}) vs the cumulative mass depth (kg m^{-2}) in reference site.

$$v \approx \frac{W_p}{t-1963} = 1.043 \text{ kg m}^{-2} \text{ yr}^{-1}$$

$$D \approx \frac{(N_p - W_p)^2}{2(t-1963)} = 29.88 \text{ kg}^2 \text{ m}^{-4} \text{ yr}^{-1}$$



Applying the Convection-dispersion equation

The initial surface depositions from Chernobyl (J_{0Ch}), in 1986, and from the nuclear tests in atmosphere (J_{0Nt}), in 1963, v and D values were determined using the method of least squares to fit the function C(x,t) to the vertical distribution data of ^{137}Cs from reference site.

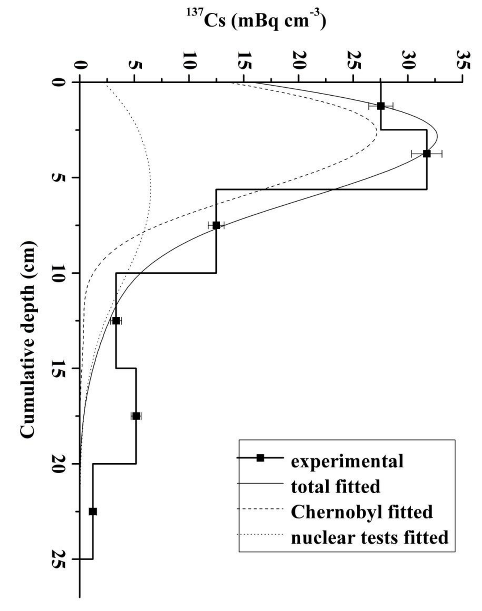
^{137}Cs concentration in soil is defined by the equation[2]:

$$C(x,t) = J_0 e^{-\lambda t}\left\{\frac{1}{\sqrt{\pi D t}} e^{-(x-vt)^2/(4Dt)} - \frac{v}{2D} e^{vx/D} \operatorname{erfc}\left(\frac{v}{2}\sqrt{\frac{t}{D}} + \frac{x}{2\sqrt{Dt}}\right)\right\}$$

We obtained the following fitting parameters:

v = 1.566 kg m^{-2} yr^{-1} **J_{0Ch} = 0.36 Bq cm^{-2}**

D = 44.29 kg^2 m^{-4} yr^{-1} **J_{0Np} = 0.24 Bq cm^{-2}**



2) Estimation of PS and PS'

- The granulometric analysis showed that the soils were clay, with a fine texture.
- Particle size correction factors had values between 0.333 and 1.674.

Pearson correlation between the radionuclide inventories and the soil physico-chemical parameters

	^{137}Cs activity (Bq m^{-2})	Clay (d<0.005 mm)	Silt (0.005<d<0.05 mm)	Sand (0.05<d<2 mm)	Stones (d>2 mm)	Humus content	Water content (%)	Bulk density (g cm^{-3})
^{137}Cs activity (Bq m^{-2})	1.00							
Clay (d<0.005 mm)	-0.30	1.00						
Silt (0.005<d<0.05mm)	0.55	-0.81**	1.00					
Sand (0.05<d<2mm)	-0.43	-0.24	-0.37	1.00				
Stones (d>2 mm)	-0.03	-0.04	0.15	-0.25	1.00			
Humus content	0.63*	-0.40	0.27	0.20	-0.12	1.00		
Water content (%)	-0.24	0.40	-0.34	-0.08	0.12	-0.34	1.00	
Bulk density (g cm^{-3})	0.33	-0.70**	0.65*	0.05	-0.27	0.39	-0.58*	1.00

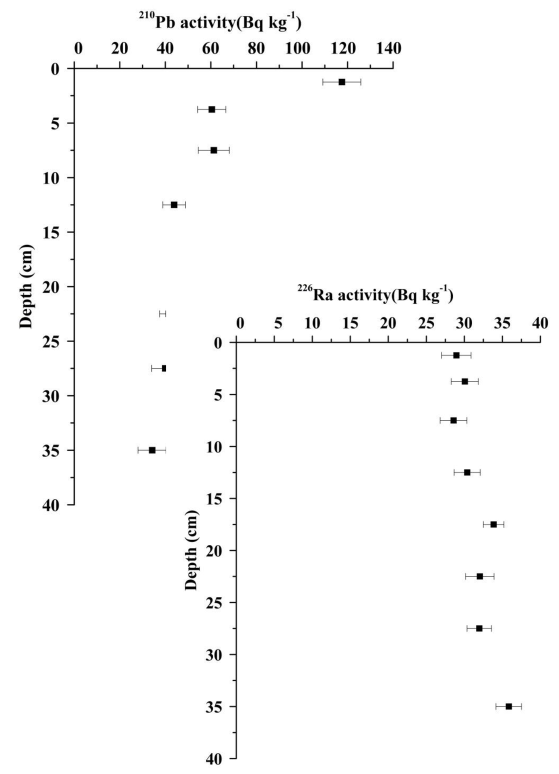
** *p<0.01* * *p<0.1*

DIFFUSION AND MIGRATION MODEL

3) Reference inventory

Averaged reference inventory of 5 soil cores: **3,160 ± 867 Bq m^{-2}** (given as areal inventory ± standard deviation), Coefficient of variation (CV) 27.44%.

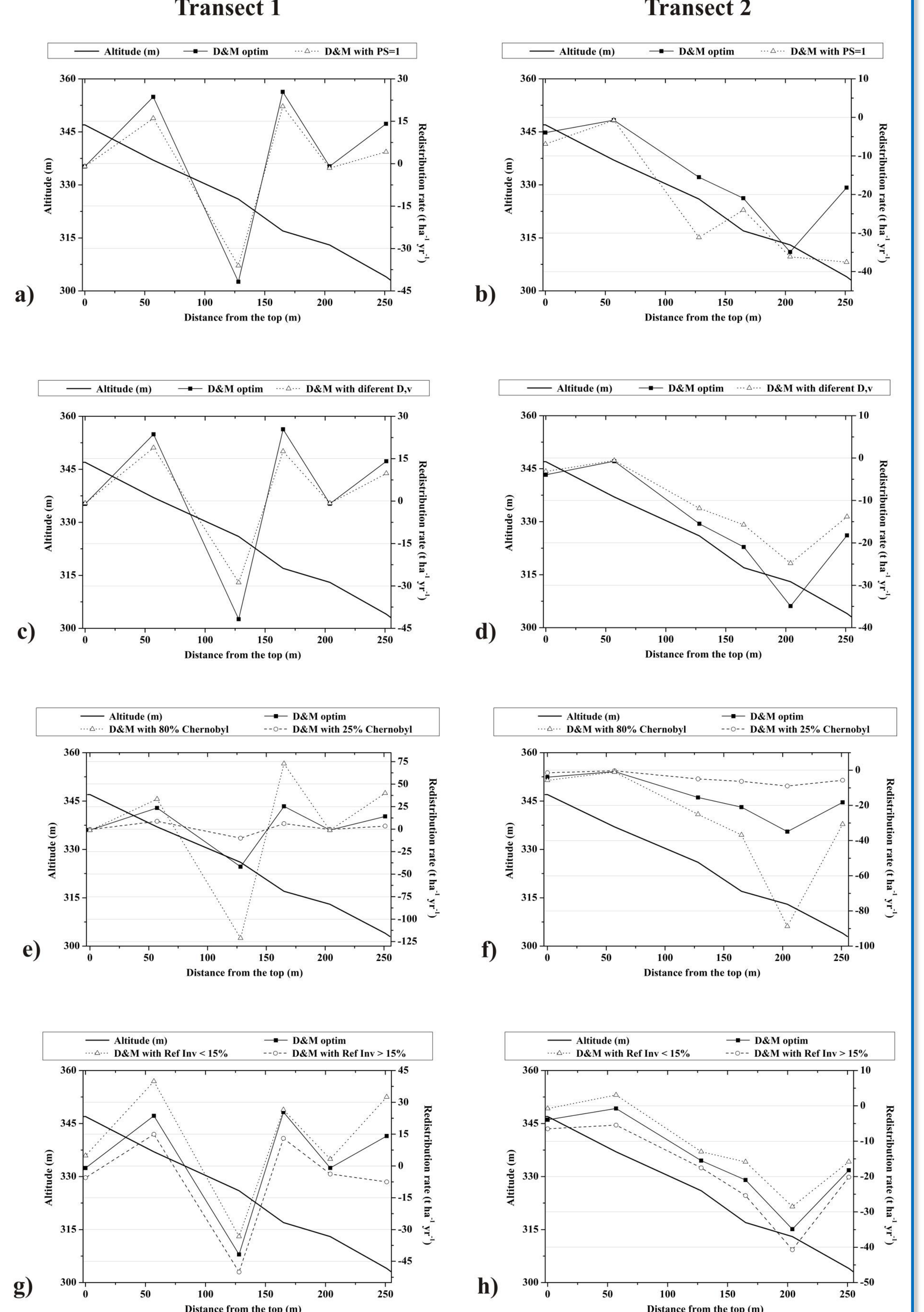
Additionally, the depth distributions of ^{210}Pb and ^{226}Ra activities for the incremental soil profile in the reference site were obtained.



4) Chernobyl contribution (%)

Using the initial ^{137}Cs areal depositions resulted from the Convection-dispersion equation as of 1963 and 1986, respectively, it could be estimated a Chernobyl contribution at the sampling time (2010) of **71.9%**.

Differences in resulted net erosion rates considering the different key parameters of Diffusion and Migration Model (D&M): a) particle size correction factors (PS) , b) D and v values, c) Chernobyl contribution (%), d) reference inventory (Ref Inv)



Estimation of soil redistribution rates for an uncultivated field using the D&M Model for ^{137}Cs	***Gross erosion rate: -11.5 t ha^{-1} yr^{-1}*** ***Net erosion rate: - 6.2 t ha^{-1} yr^{-1}*** ***Sediment delivery ratio: 92%***

CONCLUSIONS

- The effective diffusion coefficient and the convective velocity of ^{137}Cs for undisturbed soil, as well as the initial ^{137}Cs areal depositions and the Chernobyl contribution were statistically derived using the least square fitting procedure.
- The Diffusion and Migration Model is very sensitive when using different input parameters and particular care is required in their estimation, especially in the areas affected by the Chernobyl fallout.
- The predicted erosion rates are positively related to D, v and Chernobyl contribution (%), but inversely related to PS.
- If PS=1 for all soil profiles in the study area, the net erosion rate will increase with 80%, whereas for the values of v and D obtained using the “Easy method” the erosion rate will decrease by -27%.
- A maximum of 80% Chernobyl contribution will increase the erosion rate with 123% and an increase of only 15% for the ^{137}Cs reference value will increase the erosion rate with 108%.
- The net soil erosion rate on Romanian pasture land using D&M Model for ^{137}Cs is -11.5 t ha^{-1} yr^{-1} as of 2010.

References:

1. Walling, D.E., He, Q., 1999. Improved models for estimating soil erosion rates from cesium-137 measurements. J. Environ. Qual. 28, 611-622.

2. Bossew, P., Kirchner, G., 2004. Modleling the vertical distribution of radionuclides in soil. Part 1: the convection–dispersion equation revisited, J. Environ. Radioactiv. 73, 127–150.

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