NUCLEAR TECHNIQUES SUPPORT TO ASSESS EROSION AND SEDIMENTATION PROCESSES: PRELIMINARY RESULTS OF THE USE OF ^{137}Cs AS SOIL TRACER IN SLOVENIA

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Abstract
Most studies of erosion and sedimentation evaluation in Slovenia have focused on the use of conventional approaches. This paper highlights potential advantages of nuclear techniques to assess soil redistribution magnitude and presents assessment of the initial ^{137}Cs fallout in undisturbed site, located in Šalamenci, Eastern Slovenia. The ^{137}Cs background activity in the selected forested site was evaluated at 7316 ± 2525 Bq m^{-2} with a coefficient of variation of 34 % (n = 20). This information will be used in future investigations to assess erosion and sedimentation processes of adjacent agricultural fields with ^{137}Cs method.

Key words: agricultural land, soil degradation, water erosion, fallout radionuclides (FRN), ^{137}Cs method

UPORABA NUKLEARNIH TEHNIK ZA OCENO EROZIJE IN SEDIMENTACIJE: PRELIMINARNI REZULTATI UPORABE CEZIJA-137 KOT SLEDILA V SLOVENIJI

Izvleček
Dosedanje raziskave na področju erozije in procesov odlaganja talnih delcev v Sloveniji so uporabljale konvencionalne metode meritev. Prispevek predstavlja prednosti uporabe radionuklidov za oceno obsega prerazporeditve talne mase ter obravnava primer ocene izhodiščnega depozita ^{137}Cs na neporušenem talnem profilu v Šalamencih v vzhodni

Sloveniji. Ugotovljen izhodiščni depozit ^{137}Cs za izbrano gozdno parcelo je bil 7316 ± 2525 Bq m^{-2} (koeficient variabilnosti 34 %, n = 20). Ti podatki bodo uporabljeni pri aplikaciji ^{137}Cs metode v prihodnjih raziskavah o stopnji erozije in procesov odlaganja talnih delcev na okoliških kmetijskih zemljiščih.

Ključne besede: kmetijsko zemljišče, degradacija tal, vodna erozija, radionuklidi, ^{137}Cs metoda

1. INTRODUCTION

Conservation of soil and water resources has become a major agronomic and environmental concern. Degradation phenomena, such as erosion, desertification and salinization affect 65 % of the worldwide soil (Oldeman et al. 1990). Soil degradation is currently affecting 1.9 billion hectares and is increasing at a rate of 5 to 7 million hectares each year (Lal 2006). The degradation of arable lands affects especially arid areas with poor vegetation cover and tropical areas with high intensity rainfall, but it occurs under temperate and continental climate as well (Mabit et al. 2002a). Water erosion is by far the most common type of land degradation in both developed and developing countries. Accelerated erosion decreases soil productivity, increases sedimentation and is related to environmental pollution problems in agro-ecosystems (Pimentel et al. 1995; Boardman 2006).

In Europe, erosion by wind and water is a major threat to the soil resource and represents the main mechanism of landscape degradation. Around 12 % of the total area of Europe are highly affected by erosion processes (Commission of the European Communities 2006; Boardman and Poesen 2006) and, as an effect of climate change and global warming, water erosion risk is expected to increase in the European Union by the year 2050 for about 80 % of the agricultural areas (European Environmental Agency 1999; 2000).

Slovenia is not spared from this phenomenon, with more than 80 % of its territory affected by major soil degradation problems mainly linked to water erosion process (Komac and Zorn 2005; Zorn and Mikoš 2010). Arable land represents around 8.8 % of Slovenia's territory (Ministry for Agriculture, Food and Forestry 2010) and is subjected to heavy urbanization (Vrščaj 2008), therefore it is imperative that remaining arable land and cultural landscape are protected from land degradation, i.e. water erosion. Associated environmental impacts such as surface water eutrophication and groundwater pollution by nitrate are serious problems in the most intensive agricultural Slovenian regions (Matičič 1999; Drolc et al. 2007).

To control soil erosion there is a need to assess the impact of major land use and the effectiveness of specific soil conservation technologies using various approaches (Pimentel et al. 1995; Stroosnijder 2005). Effective erosion control starts with the knowledge of soil erosion rates and mechanisms.

Soil erosion processes and impacts on soil/water resources in Slovenia have been comprehensively addressed by Mikoš (1996) and Hrvatin et al. (2006a). Various research projects on water erosion processes and erosion risks assessment have been presented, i.e. involving various conventional techniques such as remote sensing, morphometric investigation combining GIS, DEM and radar photos, sediment transport models and sediment loading measurements, runoff plots and rainfall erosivity measurements (e.g. Ceglar et al. 2008; Hrvatin et al. 2006b; Komac and Zorn 2005; 2007; Mikoš et al. 2006; Petkovšek et al. 2003; Petkovšek and Mikoš 2004; Zorn and Petan 2007). However, only a few quantitative data on erosion and sedimentation magnitude under Slovenian agro-environmental condition are available (Zorn 2009).

Traditional monitoring and modelling techniques for soil erosion/sedimentation require many parameters and years of measurements of inter-annual and mid-term climatic variability and cropping practices evolution (Mabit et al. 2002a). Conventional erosion and sedimentation methods are limited to provide mid-term trends in soil erosion, however fallout radionuclides (FRN) have proven to be very powerful tools to trace soil erosion and sedimentation within the landscape from plot to basin scale and can complement the information provided by conventional erosion measurements and modelling (Mabit et al. 2008a).

Despite several environmental records and surveys (e.g. Brajnik et al. 1993; Jeršič 1972; 1974; 1975; Official Gazette of Republic of Slovenia 2007; Slovenian Nuclear Safety Administration 2007), FRN have never been used as soil redistribution tracer for assessment of erosion processes in physical geography and soil sciences researches under Slovenian agro-environment.

The purposes of this contribution are:

- To present a synthetic overview in using nuclear techniques, i.e. ^{137}Cs to assess erosion and sedimentation processes;
- To present a first investigation to assess the initial ^{137}Cs fallout to prepare future agricultural field investigations to quantify the magnitude of erosion processes in Slovenia.

2. THE USEFULNESS OF FRN APPROACHES TO INVESTIGATE SOIL REDISTRIBUTION IN AGRICULTURAL LANDSCAPE

Three FRN isotopes (^{137}Cs, ^{210}Pb and ^{7}Be) have been used worldwide to assess medium and short term soil erosion and deposition processes (Mabit et al. 2008a; Ritchie and Ritchie 2008):

I) Caesium-137 (^{137}Cs) with a half-life of 30 years, an artificial radionuclide originating from thermonuclear weapon tests and nuclear reactors releases (Figures 1 and 2);

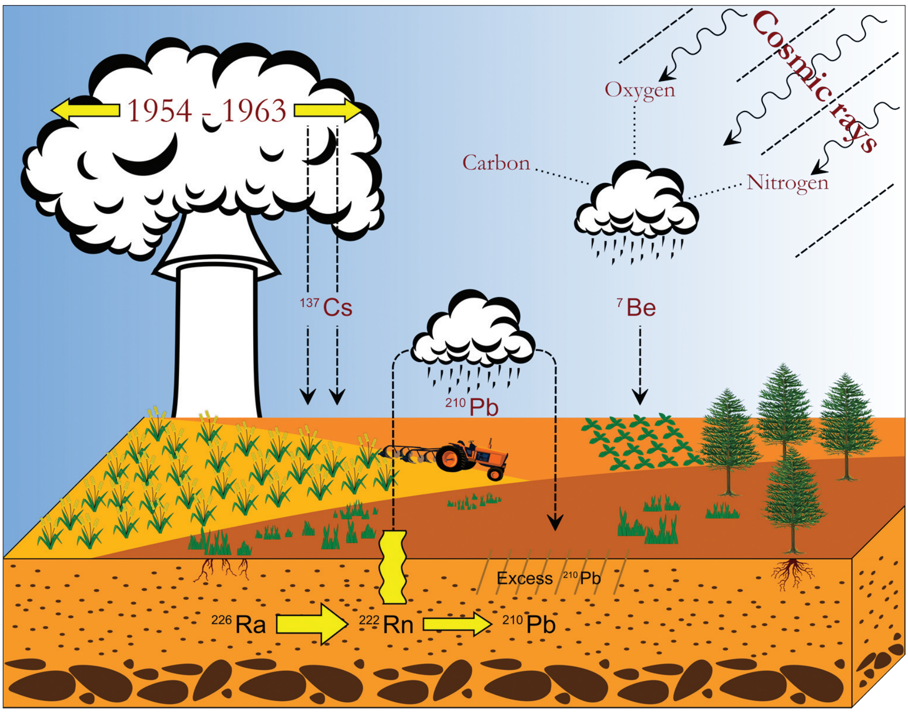
The spatial distribution of the ^{137}Cs fallout was determined by the location of the weapons testing, the pattern of stratospheric circulation and transport, and the annual precipitation amount. It shows a clear latitudinal zoning, with total fallout in the northern hemisphere being substantially greater than in the southern hemisphere. ^{137}Cs inventories in the southern hemisphere are, however, still measurable using appropriate detectors and counting times. However, at a small scale it can be assumed that the fallout was uniform.

The fallout of ^{137}Cs released into the troposphere by nuclear accidents – e.g. Chernobyl – had a more heterogeneous distribution, reflecting the atmospheric circulation and precipitation distribution immediately after the release.

II) Lead-210 (^{210}Pb) with a half-life of 22 years, is a geogenic radioisotope that originates from the decay of ^{226}Ra which produces short-lived gaseous ^{222}Rn (half-life = 3.8 days). Most of this ^{222}Rn decays to ^{210}Pb within the soil, producing supported ^{210}Pb, which is essentially in equilibrium with the parent ^{226}Ra. However, some of the ^{222}Rn diffuses upwards into the atmosphere, where it rapidly decays to ^{210}Pb. This ^{210}Pb is deposited as fallout, and, since it is not in equilibrium with the parent ^{226}Ra, it is commonly termed unsupported or excess ^{210}Pb ($^{210}Pb_{ex}$), to distinguish it from the supported ^{210}Pb in the soil which is in equilibrium with the parent ^{226}Ra (Figure 1);

III) Beryllium-7 (^{7}Be) is a short-lived cosmogenic radioisotope with a half-life of 53 days produced in the upper atmosphere by cosmic ray spallation on nitrogen and oxygen nuclei (Figure 1).

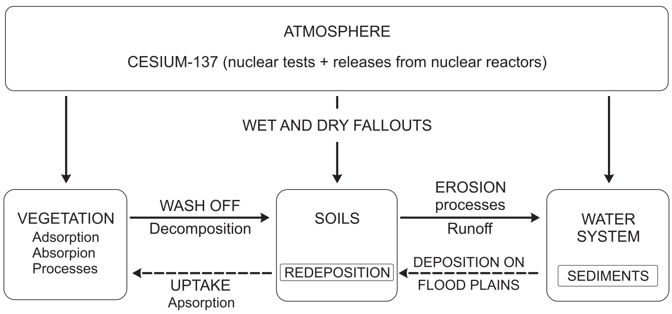
Figure 1: Origin of fallout radionuclides
Slika 1: Izvor depozita radionuklidov



Due to their rapid and strong adsorption by fine soil particles, ^{137}Cs, ^{7}Be and $^{210}Pb_{ex}$ are redistributed by mechanical processes of moving soil particles such as erosion (e.g. Figure 2 for ^{137}Cs). The use of these isotopes as well as their measurements is safe and they are already present in soil, one just measures the FRN soil activity background.

FRN techniques allow the estimation of short and medium-term rates of soil redistribution integrating land use and climatic variability. FRN can be used to obtain average soil redistribution figures for time scales ranging from single event to many years of erosion processes, while direct measurements on erosion plots are related to single rainfall event or rather short periods of time. FRN methodologies integrate all processes involving soil particle movements and allow quantification of soil loss and deposition associated with sheet erosion, which is difficult to assess using other conventional approaches. Sampling of individual points allows spatially distributed information on rates and patterns of soil redistribution.

Figure 2: Environmental ^{137}Cs cycle in the landscape
Slika 2: Kroženje ^{137}Cs v okolju



Source/vir: adapted from Ritchie and McHenry 1990

Also, one of the main advantages of the FRN is that time-consuming, costly maintenance, long-term monitoring programme and installations required by non-isotopic and conventional methods can be avoided. Soil sampling can be completed in a short time and the site disturbance during sampling is minimal and does not interfere with seeding and cultivation operations, which might occur with installation of bounded erosion plot. Since radionuclide-based measurements also provide information on the spatial distribution of erosion/sedimentation rates, they can be used to validate the results of distributed soil erosion models. The relative efficiency of soil conservation measures can also be assessed. Advantages and limitations in using the FRN as soil redistribution tracer compared to conventional methods have been summarized in Table 1.

The ^{137}Cs redistribution across the landscape is investigated to estimate soil redistribution rates and patterns based on the total ^{137}Cs areal activity in the eroding or depositing sites and comparing them with the ^{137}Cs initial fallout established at undisturbed area called also 'reference sites' where no soil erosion or deposition occurred (Mabit et al. 2008a; Walling and Quine 1993).

The ^{137}Cs method provides estimates of soil redistribution averaged over a period of several decades (i.e. from the beginning of global fallout in the mid 1950s until the time of sampling). It is therefore particularly useful for providing estimates of medium-term mean annual soil erosion and deposition rates. A full comparison of the advantages and limitations

Table 1: The main advantages and limitations of the use of FRNs versus conventional erosion and sedimentation techniques (adapted after Mabit et al. 2002b)
Preglednica 1: Glavne prednosti in omejitve pri uporabi radionuklidov v primerjavi s konvencionalnimi metodami merjenja erozije in sedimentacije (povzeto po Mabit in sod. 2002b)

	Main conventional methods	**Fallout radionuclides (FRN)** **^{137}Cs, ^{210}Pb, ^{7}Be**
Advantages	Modelling: • Plot to large watershed investigation • Assessment of erosion and sedimentation processes Erosion plots: • Plot investigation • Measurement of runoff and erosion • Evaluation of impact of particular cultivation methods and land use on erosion rate Watershed measurement: • Area studied small to large watershed • Off-site measurement of sediment transfer	• Plot to large watershed investigation • Short-term to mid-term assessment of erosion and sedimentation • Evaluation of impact of particular cultivation methods and land use on erosion rate using ^{7}Be • Soil redistribution mapping/pattern • No maintenance costs, only one sampling is needed • No climatic dependence, can be implemented worldwide
Limitations and requirements	Modelling: • Complexity, user friendliness • Advanced IT facilities are required • Precise information (e.g. Digital Elevation Model (DEM), climatic, soil and land-use data) is required • Realistic model should be validated by real data collected by other conventional approaches or FRN Erosion plots: • Need at least 10 to 15 years of measurement to integrate climatic variability • All the erosion forms not taken into account due to the short scale of measurement • Climatic dependence Watershed measurement: • No information obtained about the soil redistribution within the watershed as just the net erosion can be measured • Need at least 10 to 15 years of measurement to integrate climatic variability • Climatic dependence • Measures net sediment production, not erosion rates	• Not a measurement but assessment of erosion and sedimentation processes • Evaluation of initial fallout and finding reference site • Gamma detection facilities (HPGe γ detector) are required

of ^{137}Cs, $^{210}Pb_{ex}$ and ^{7}Be for documenting soil erosion and sediment redistribution has been recently reviewed and is summarized in Table 2.

Table 2: Advantages and limitations of the ^{137}Cs versus $^{210}Pb_{ex}$ and ^{7}Be (Mabit et al. 2008a)
Preglednica 2: Prednosti in omejitve ^{137}Cs v primerjavi z $^{210}Pb_{ex}$ in ^{7}Be (Mabit in sod. 2008a)

	Energy emission (keV)	**Time span**	**Erosion assessment**	**Sample collection**	**Area studied**	**Equipment needs**	**Laboratory measurement**	**In situ measurement**	**Sediment dating**
^{137}Cs	662	50 years	medium-term	simple	plot to large watershed	normal HPGe γ detector	easy*	easy	possible
^{210}Pb	46	100 years	long-term	simple	plot to watershed	broad energy range HPGe γ detector	**more difficult***	limited and unreliable	possible
^{7}Be	477	≤ 6 months	short-term	requires fine depth incremental sampling	local scale, plot to field	normal HPGe γ detector	easy	possible	possible

** For more information see Shakhashiro and Mabit 2009.*

3. REFERENCE SITE SELECTION

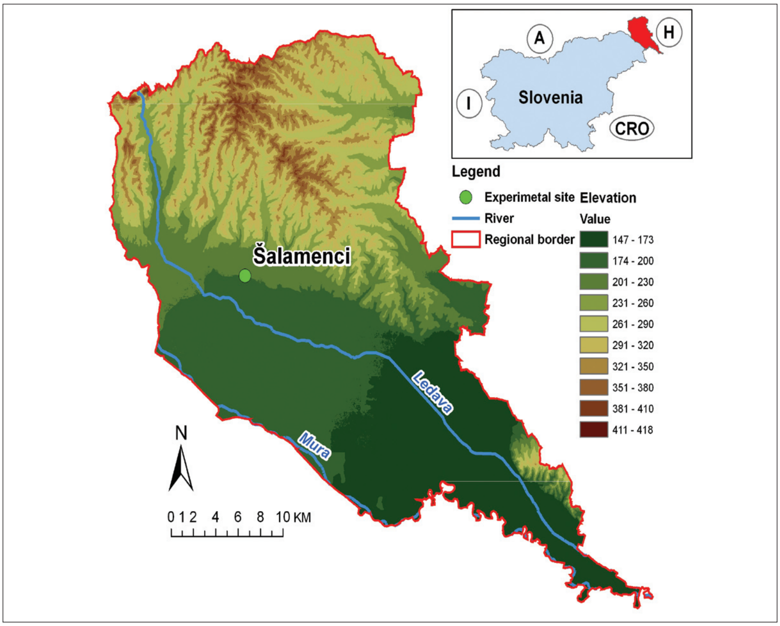
The measure of erosion assumes that the local fallouts of ^{137}Cs were originally uniform in the area under investigation. The commonly used approach involves comparison of measured inventories with a reference inventory, representing the inventory associated with a point experiencing neither erosion nor deposition. In view of its central importance to the reliability of the estimates of soil redistribution rates obtained, it is important to ensure that the sampling site, termed control site or reference site used to establish the reference inventory, provides a representative estimate of the local reference inventory (Sutherland 1996). These benchmark stations are localized near the studied sector, in areas without erosion or deposition since the first introduction of radiocaesium in the environment, e.g. old and stable pasture, permanent grassland, forested area (Mabit et al. 2008a).

4. MATERIAL AND METHODS

An undisturbed flat forest of 2 ha situated in Šalamenci (46°44'N, 16°7'E) located in Pomurje in Goričko in Eastern Slovenia was selected as reference site to assess the initial ^{137}Cs fallout for future investigations on erosion and sedimentation process affecting the neighborhood agricultural fields and areas (Figure 3). The climate is moderate inland continental with mean annual precipitation reaching 870 mm (Murska Sobota, 46°39'N, 16°11'E; Bat et al. 2008). Developed on non-carbonate rocks, the soil of the Šalamenci forest was described as a strongly acidic Haplic Stagnosol with a silt loam texture.

In the area under investigation, 20 soil profiles of 40 cm, divided into four increments of 10 cm were collected according to a 40 x 30 m grid, using bulk density cylinders based on the protocol proposed by Mabit et al. (2008b).

Figure 3: Location of the study area
Slika 3: Lokacija območje preučevanja



The soil samples (n = 80) were pre-treated (oven-dried 48 hours at 70 °C and sieved at 2 mm) prior to γ-spectrometry measurements using a high resolution HPGe coaxial detector (relative efficiency at 1.33 MeV, ^{60}Co = 115.6 %). Calibration and quality control were performed using sealed radioactive source FG 607 from Amersham and IAEA reference materials according to the protocol proposed by Shakhashiro and Mabit (2009). The Minimum Detectable Activity (MDA) for ^{137}Cs was 0.2 Bq kg^{-1} and the average error at 2 σ precision for 50,000 seconds counting times was 2.6 % ± 1.2 %, 6.5 % ± 3.3 %, 26 % ± 14 % and 46 % ± 24 % for the soil layers 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm, respectively.

After gamma measurement, the ^{137}Cs mass activity (Bq kg^{-1}) was converted into areal activity (Bq m^{-2}) using the bulk density of the different incremental samples. The total inventory at each sampling point was calculated as the sum of the depth interval areal activity. The ^{137}Cs areal activity data set was tested for normality by using Kolmogorov-Smirnov test at a confidence level of 95 %. All descriptive statistics calculus and statistical tests in this study were carried out by SPSS programme version 11.5 for Windows.

5. PRELIMINARY RESULTS AND FUTURE PERSPECTIVES IN THE APPLICATION OF THE ^{137}CS METHOD AS SOIL TRACER IN THE STUDY AREA

As expected in a forested soil with a fibric and organic matter enriched top soil, the bulk density increased with incremental depth reaching 1.5 t m^{-3} at 40 cm (Table 3). The activity of the ^{137}Cs measured in the layer 20–30 cm was close or even under the detection limit of our gamma detector (0.2 Bq kg^{-1}). Below the first 30 cm, ^{137}Cs soil content can be neglected (Table 4). The Kolmogorov-Smirnov test at a confidence level of 95 % confirmed that the ^{137}Cs content (total inventory 0–40 cm) is distributed along a normal distribution.

Table 3: Bulk density summary statistics per soil depth increments of the forested site (Šalamenci, Eastern Slovenia)
Preglednica 3: Pregled statističnih parametrov za surovo gostoto tal po globini za gozdno parcelo (Šalamenci, vzhodna Slovenija)

	Depth interval 0–10 cm	**Depth interval 10–20 cm**	**Depth interval 20–30 cm**	**Depth interval 30–40 cm**
	Bulk density (kg m^{-3})	**Bulk density (kg m^{-3})**	**Bulk density (kg m^{-3})**	**Bulk density (kg m^{-3})**
Mean	943	1354	1436	1500
SD	176	143	41	28.5
Kurtosis	0.9	3.9	1.2	0.9
Skewness	0.1	0.6	0.5	–0.6
Minimum	557	1050	1353	1426
Maximum	1352	1776	1539	1550
CV (in %)	18	11	3	2

SD = Standard Deviation; CV = Coefficient of Variation

The maximum ^{137}Cs mass activity was found in the first 10 cm with an average of 70 ± 33 Bq kg^{-1} (Table 4). In undisturbed and uneroded mineral or organic soils, the profile shape distribution of ^{137}Cs typically decreases with depth (Mabit et al. 2008a). In this forest also a clear exponential decrease in ^{137}Cs content was observed with 98 % of the ^{137}Cs in the first 20 cm.

Based on the 20 profiles collected (0–40 cm), the initial ^{137}Cs fallout was evaluated at 7316 ± 2525 Bq m^{-2} with a coefficient of variation (CV) of 34 %. The CVs of the ^{137}Cs initial inventory in undisturbed forested areas – if chosen as reference sites – are generally relatively high, from 5 % in the best case to 41 % (Sutherland 1996; Owens and Walling 1996). An acceptable CV should be around 25 %.

Under similar climatic conditions, e.g. in France (Bernard et al. 1998) and Austria (Mabit et al. 2008b) without a significant contribution of Chernobyl the base level in 2009 could be expected to be around 1800–2000 Bq/m^{-2}. A value three times higher in this study area in Slovenia suggests a major contribution of the Chernobyl fallout (April–May 1986).

Based on these preliminary results additional investigations and actions are needed:

- Firstly, the baseline ^{137}Cs evaluation should be improved in reducing the coefficient of variation, then an additional sampling in the reference site should be planned to collect 10 additional soil profiles to refine the value obtained;
- Secondly, the contribution of the Chernobyl accident to ^{137}Cs soil inventories should be estimated for future assessment of its contribution comparing to the nuclear test deposits occurring in the 1950 and 60's. This value will be included in the conversion model to convert the areal activity measured in the agricultural field to assess more accurately the soil redistribution magnitude (Walling et al. 2002);
- Thirdly, a sampling along a multi-transect design will be organized in an adjacent agricultural field to assess quantitatively the soil erosion and sedimentation magnitudes.

Table 4: ^{137}Cs summary statistics per soil depth increments of the forested site (Šalamenci, Eastern Slovenia)

Preglednica 4: Pregled statističnih parametrov za ^{137}Cs po globini za gozdno parcelo (Šalamenci, vzhodna Slovenija)

	^{137}Cs content Depth interval 0–10 cm		**^{137}Cs content Depth interval 10–20 cm**		**^{137}Cs content Depth interval 20–30 cm**		**^{137}Cs content Depth interval 30–40 cm**	
	(Bq kg^{-1})	**(Bq m^{-2})**	**(Bq kg^{-1})**	**(Bq m^{-2})**	**(Bq kg^{-1})**	**(Bq m^{-2})**	**(Bq kg^{-1})**	**(Bq m^{-2})**
Mean	70.1	6127	7.6	971.8	1.0	145	0.47	70.4
SD	33	2514	6.3	719	0.78	109	0.27	40
Kurtosis	0.2	–0.5	3.3	2.8	4.7	4.9	–0.16	–0.5
Skewness	0.7	0.5	2.0	1.9	2.0	2.0	0.9	0.8
Minimum	22	2230	2.6	369	0.3	41	0.1	20
Maximum	147	11302	24.7	2863	3.4	489	1.1	156
CV (in %)	47	41	84	74	76	75	58	56

SD = Standard Deviation; CV = Coefficient of Variation

6. CONCLUSIONS

To control water erosion processes and subsequent land degradation, impact assessment of major land uses is needed. FRN and especially ^{137}Cs provide very effective means of quantifying erosion and sedimentation rates and represent a valuable complement to validate conventional measurement techniques, especially computer models.

The methodology of ^{137}Cs can also be a useful and valuable technique to complement conventional runoff and sediment measurements when assessing soil redistribution in agricultural landscape.

A typical exponential distribution of ^{137}Cs in the soil profile was found and the baseline level in this undisturbed Slovenian forest was established at 7316 ± 2525 Bq m^{-2} with a coefficient of variation of 34 %. The variability of the fallout is rather high and before any additional agro-environmental investigation using ^{137}Cs as soil tracer in this area, the reference site should be refined to obtain an acceptable level of the initial baseline level.

A new sampling to assess a more reliable value for the initial ^{137}Cs fallout is planned and in the mean time a small agricultural field to evaluate the magnitude of soil redistribution will be investigated.

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UPORABA NUKLEARNIH TEHNIK ZA OCENO EROZIJE IN SEDIMENTACIJE: PRELIMINARNI REZULTATI UPORABE CEZIJA-137 KOT SLEDILA V SLOVENIJI

Povzetek

V Sloveniji je več kot 80 % površine podvrženo vodni eroziji. Kljub temu da raziskave o erozijskih procesih tal potekajo že iz sredine petdesetih let, je na voljo le malo meritev. Obstoječ pregled literature sicer jasno nakazuje mobilizacijo slovenske znanstvene sredine v zadnjih dvajsetih letih, vključno z geomorfologi, geografi, hidrologi in pedologi pri pridobivanju novih znanj na področju problematike erozije in sedimentacijskih procesov v različnih obsegih. Dosedanje raziskave na področju erozije in procesov odlaganja talnih delcev v Sloveniji so se osredotočile na rabo konvencionalnih pristopov meritev. Ti zahtevajo večletne meritve mnogih parametrov, hkrati pa so meritve močno odvisne od klimatskih pogojev. V svetu zelo razširjena metoda za kvantitativno določevanje stopnje erozije in posledično sedimentacije oz. odlaganja talnih delcev je merjenje vsebnosti ^{137}Cs v tleh. V Sloveniji radionuklidi kot sledila za raziskave erozijskih procesov še niso bili uporabljeni kljub mnogim okoljskim monitoringom in raziskavam.

Za raziskave erozije se najpogosteje uporabljajo trije radionuklidi, in sicer cezij-137 (^{137}Cs), svinec-210 (^{210}Pb$_{xy}$) ter berilij-7 (^{7}Be). Zaradi hitre in močne vezave na fine talne delce se ^{137}Cs, ^{7}Be in ^{210}Pb$_{ex}$ prerazporejajo zaradi mehanskih procesov ob premikanju talnih delcev, kot to poteka pri procesu erozije. Ti izotopi so že prisotni v tleh zaradi človekove aktivnosti (jedrski poskusi, nesreče). Uporaba kot tudi meritve količine teh izotopov je varna, izmerimo le ozadje radionuklidov. V primerjavi s ^{210}Pb$_{xy}$ ter ^{7}Be nam ^{137}Cs omogoča širok razpon glede velikosti območja raziskav – oceno erozijskih procesov lahko naredimo na nivoju posamezne parcele ali pa na nivoju celotnega porečja. Prav tako so vzorčenje kot tudi laboratorijske meritve preproste. ^{137}Cs je nereaktiven, njegova količina v tleh se spreminja zaradi fizikanih procesov (razpolovne dobe), tako da je zelo uporaben za oceno degradacije tal zaradi naravnih in antropogenih dejavnikov.

Uporaba nuklearnih tehnik, še posebej ^{137}Cs, lahko dopolni konvencionalne metode ocene erozijskih procesov. Ta metoda omogoča oceno kratko- in srednjeročne stopnje prerazporeditve talnih mas, pri tem zajema tako rabo tal kot tudi klimatsko raznolikost obravnavanega območja. S pomočjo radionuklidov lahko ocenimo prerazporeditev tal za posamezen dogodek ali pa obravnavamo premestitev talnih mas kot posledico procesov, ki so potekali prek daljšega časovnega obdobja.

Prednost radionuklidov je tudi v tem, da se z enkratnim vzorčenjem izognemo finančno zahtevnemu monitoringu ter namestitvi potrebnih merilnih naprav na terenu. Vzorčenje lahko opravimo tako, da se ne križa z obdelavo zemljišča, kar se nam pogosto zgodi pri konvencionalnih metodah. Dobljeni rezultati se lahko uporabijo pri validaciji modeliranja erozijskih procesov.

Metoda ocene erozijskih procesov tal ter stopnje sedimentacije talnih delcev s pomočjo ^{137}Cs je zasnovana na primerjavi vsebnosti ^{137}Cs na posameznih točkovnih mestih v pokrajini, kjer želimo te procese oceniti, z referenčnim mestom oziroma točko, kjer so bili ti fizikalni erozijski procesi zanemarljivi. S pomočjo referenčnega mesta, kjer ni bilo posegov v površinske plasti tal (npr. zemljišče ni bilo orano), se določi izhodiščno vsebnost oziroma porazdelitev vsebnosti ^{137}Cs v talnem profilu. Celokupna referenčna vsebnost ^{137}Cs je tako rezultat človeškega vnosa iz preteklosti ter kasnejše razpolovne dobe. Predpostavlja se, da se v neporušenenem talnem profilu vsebnost ^{137}Cs eksponencialno zmanjša z globino tal. Nasprotno je pričakovati, da bo na obdelovalnih tleh vsebnost ^{137}Cs znotraj orne plasti tal uniformna zaradi mešanja zemljine ob obdelovanju tal.

Omejitve uporabe ^{137}Cs metode so, da pri tem dobimo oceno in ne kvantitativnih meritev erozijskih in sedimentacijskih procesov. Potrebna je določitev začetnega depozita ter pazljivost pri izbiri referenčne parcele, kjer ni bilo posegov v talni profil (brez obdelave) v daljšem časovnem obdobju, vsekakor pa po vnosu ^{137}Cs v ozračje z jedrskimi poskusi oz. nesrečami. Referenčna parcela je tako osrednjega pomena za zanesljivost ocene o stopnji prerazporeditve talnih mas. Da lahko zanesljivo vljučimo tudi klimatske dejavnike, mora biti referenčna parcela v neposredni bližini preučevanega območja. Potrebne so meritve gama, kar zahteva določeno opremo (HPGe γ detector) in strokovno usposobljenost.

Prispevek predstavlja primer ocene izhodiščnega depozita ^{137}Cs na neporušenem talnem profilu v gozdu v Šalamencih v vzhodni Sloveniji.

Za oceno izhodiščne vrednosti ^{137}Cs je bilo izkopanih 20 talnih profilov, razporejenih v mrežo na referenčni parceli v gozdu v Šalamencih (46°44'N, 16°7'E) na Goričkem. S pomočjo meritev gama je bila določena celokupna referenčna vsebnost ^{137}Cs. Največja ^{137}Cs vsebnost je bila ugotovljena v prvih 10 cm. V neporušenih mineralnih ali organskih tleh, ki niso bila podvržena procesom erozije, porazdelitev ^{137}Cs v profilu z globino pade.

Surova gostota tal je z globino naraščala, in sicer do 1,5 t m^{-3} na 40 cm, kar je bilo pričakovati za gozdna tla, ki so bogata s humusom in organsko snovjo. Vsebnost ^{137}Cs, izmerjenega na nivoju 20–30 cm, je bila blizu ali celo pod mejo detekcije gama detektorja (0.2 Bq kg^{-1}). Pod prvimi 30 cm je vsebnost ^{137}Cs zanemarljiva. Kolmogorov-Smirnov test je potrdil normalno porazdelitev ^{137}Cs celokupne vsebnosti (0–40 cm). Največja ^{137}Cs vsebnost je bila ugotovljena na prvih 10 cm profila tal, in sicer 70 ± 33 Bq kg^{-1}. V neporušenem profilu tal, ki niso bila izpostavljena erozijskim procesom, vsebnost ^{137}Cs značilno eksponencialno pade. Za obravnavano referenčno parcelo je bila dobljena jasna eksponencialna porazdelitev ^{137}Cs v profilu tal, in sicer kar 98 % celokupne vsebnosti je bilo izmerjene v prvih 20 cm.

Na osnovi izbranih dvajsetih profilov tal, kjer so bili odvzeti vzorci (0–40 cm), je bil ugotovljen začetni depozit ^{137}Cs pri 7316 ± 2525 Bq m^{-2} s koeficientom variabilnosti 34 %. Koeficient variabilnosti je pri začetnem depozitu ^{137}Cs, dobljenem v neporušenih gozdnatih tleh, navadno relativno visok ter se giblje od 5 % v najboljšem primeru do celo 41 %. Zadovoljiv koeficient variabilnosti bi bil pri 25 %, zato predvidevamo na referenčni parceli dodatno vzorčenje.

V državah s podobnimi klimatskimi pogoji, kot sta Francija in Avstrija in kjer ni bilo ugotovljenega bistvenega doprinosa jedrske nesreče v Černobilu k osnovni vsebnosti ^{137}Cs, je bila le-ta 1800–2000 Bq m^{-2}. Za referenčno parcelo v Šalamencih je bila ugotovljena trikratna vrednost, kar nakazuje na znatne depozite v času jedrske nesreče v Černobilu (april–maj 1986).

Na osnovi teh predhodnih rezultatov so za ugotovitev stopnje erozije potrebne dodatne raziskave. Najprej je potrebno izboljšati podatke o izhodiščni ^{137}Cs vsebnosti, predvsem zaradi visokega koeficienta variabilnosti. Zavoljo tega bo potrebno dodatno vzorčenje na referenčnem mestu z vsaj desetimi dodatnimi profili. Nadalje je potrebno oceniti, kolikšen je bil vpliv nesreče v Černobilu na vsebnost ^{137}Cs v primerjavi z jedrskimi poskusi v 50. in 60. letih. Tako izboljšan podatek o izhodiščni referenčni vsebnosti bo uporabljen pri aplikaciji metode ^{137}Cs v prihodnjih raziskavah o stopnji erozije in procesov odlaganja talnih delcev na okoliških kmetijskih zemljiščih. Za kvantitativno oceno stopnje in obsega procesov erozije in sedimentacije bomo na kmetijskih zemljiščih, ki se nahajajo v neposredni bližini referenčnega mesta, izvedli vzorčenje v več presekih vzdolž nagiba polja.

Za uspešen nadzor vodne erozije tal in posledične degradacije potrebujemo presojo vpliva prevladujoče rabe tal. Metodologija porazdelitve ^{137}Cs v profilu tal je uporabna in koristna tehnika za dopolnitev konvencionalnih metod meritev površinskega odtoka vode in sedimentov pri oceni procesov erozije in odlaganja talnih delcev na kmetijskih zemljiščih.