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INDICATION OF EROSIVE-ACCUMULATIVE PROCESSES INTENSITY AT USING ^{137}CS PROFILE DISTRIBUTION ON SELECTED SOIL TRANSECT

INDIKÁCIA INTENZITY ERÓZNO-AKUMULAČNÝCH PROCESOV S VYUŽITÍM PROFILOVEJ DISTRIBÚCIE ^{137}CS VO VYBRANOM PÔDNOM TRANSEKTE

JÁN STYK

Soil Science and Conservation Research Institute, Bratislava
Výskumný ústav pôdoznalectva a ochrany pôdy, Bratislava

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The loss of the most fertile soil layers is induced by erosion from erosive parts of a transect. Production ability of soils goes often down in this way. In effort to assess its negative influence on the soil, it is very important to know the intensity of this process. It can be said that the negative influence of erosion is significant in case the intensity of soil loss is higher opposite its creation through the soil forming process. The paper is focused on assessment of water erosion intensity (on example of the monitored locality), using two methods and their comparison. The first one is the indication of erosive-accumulative processes intensity using ^{137}Cs activity determination in soil profiles (profile distribution). On the basis of this method, we can evaluate the amount of eroded (or accumulated) material directly (using proportional model) or indirectly (using of caesium profile distribution). The 2nd method is the average annual soil loss calculation using empirical model of the Universal soil loss equation (USLE) under the actual soil-climatic conditions.

The monitored locality (arable land) was situated in the erosively sensitive area (from the viewpoint of rainfall intensity, soil erodibility, gradient of slope, and land use), northeast from Detva town. The primary requirement for selecting the study locality was relief of surrounding area (erosive catena was located on the basis of terrain survey). Erosive catena is characterized by a typical line of pedological sites localized along the transect line (in direction of water erosion impact). The first one is on the top plateau of the slope (represents the soil uninfluenced by water erosion – referential soil profile), the second is in the erosive part of the slope (represents the soil strongly influenced by water erosion – eroded soil profile), and the last one is situated in the accumulative part of the slope (represents accumulated soil – accumulated soil profile).

We have achieved the extreme value of potential soil erosion (139.6 ton per hectare and year) by numerical calculation using the USLE. It can be said that potential soil erosion expresses an inherent susceptibility of bare soils to erosion (in case the soils are protective vegetation cover free). Actual soil erosion refers to the present endangerment, taking into account a contemporary vegetation cover (silage maize in this case). The mean annual soil loss, determined by this method, was 68.4 ton per hectare and year. This value is still too high, because maize belongs to the plants with not very good anti-erosive effect.

Profile distribution of ^{137}Cs in individual parts of erosive transect indicates the presence of intensive erosive-accumulative processes. The difference in the maximum depth of still measurable radioisotope concentration in the accumulative and referential soil profiles (100 mm) indicates the depth of accumulated layer in the base of the slope for approximately 40 year period (recent erosion). The mean annual soil loss has been calculated on the basis of a mass balance. This value is about 32.5 ton per hectare and year, which is a lower value in comparison with the USLE. The calculated value expresses the average soil loss during 40 year period, when annual intensity of erosion was either very high or very low (in dependence on rainfall intensity and actual vegetation cover).

Using calibration proportion model for the quantitative assessment of soil matter loss or accumulation is in this example limited by too high activity of caesium in the topsoil of referential part of the transect (in comparison with the other parts of erosive catena). Soil loss from erosive part (24.11 ton per hectare and year) was approximately similar to the soil loss achieved by using a mass balance, but the value of accumulated soil mass (from accumulative part of transect) is much lower (4.72 ton per hectare and year), what is not in correspondence with the results achieved in the eroded point.

Finally, it may be said that the proportional model is based on area expression of caesium activity (Bq.m^{-2}).

Ing. Ján Styk, PhD., Regional workplace of the SSCRI, 974 04 Banská Bystrica, Mládežnícka 36. E-mail: styk.vupop@bystrica.sk

Therefore the calculated value from accumulative part of the monitored locality was not very precise (in spite of caesium activity measured in deeper layers of soil profile). It is due to a quite high value of ^{137}Cs activity in the topsoil of referential part.

Key words: soil erosion, Cs activity, USLE, caesium profile distribution, proportion model

Soil erosion is a natural process and it belongs to the most significant forms of physical degradation of agricultural soils. It must be said that soil is a limited and irreplaceable natural source. The soil can be, in case of its progressive degradation, a limit for the next development of society in many parts of the world. The result of a negative influence of erosion on the soil is its irreversible or slowly reversible damage (above all its physical, mechanical, technological, and profile properties) [1]. The loss of the most fertile soil layers is induced by erosion and due to this loss the soil production ability is often going down. It is caused by translocation of the fine particles of soil matter from the erosive parts of slopes to accumulative ones (P, K nutrients and soil organic matter are relatively firmly fixed to these particles). According to Karniš [3], a 2–3 % decrease of soil fertility results form the loss of one-millimetre humus layer. It is influenced by the soil type, and production potential of soil as well.

Relating to elimination of soil erosion processes, we can decrease their intensity to the tolerable value by using appropriate soil protection measures. The effect of water on soil erosion can be minimized by a suitable using of soil protection measures.

To be able to assess the extent of soil erosion, we have to know the intensity of erosive-accumulative processes. It can be said that the negative influence of erosion is significant in case if the intensity of soil loss is higher than its creation during the soil forming process. On the assumption that 10 mm of soil will be created within approximately 100 years (0.1 mm soil layer will be created within a year) under climatic and geologic conditions of Slovakia, 1.4 $t.ha^{-1}$ of soil matter will be created in a year, if the soil has the average bulk density 1.4 $g.cm^{-3}$.

A tolerable intensity of soil erosion [10] has been determined, concerning soil protection requirements in Slovakia. It is defined as a maximum value of soil matter loss, which still maintains a high level of soil productivity. Malcolm [8] presented the extent of tolerable soil loss values ranging from 2.5 to 12 $t.ha^{-1}$ per year.

The paper is focused on assessment of water erosion intensity in particular conditions of the monitored site (transect), using the following methods:

- indication of intensity of erosive-accumula-tive processes by determination of ^{137}Cs activity in soil profiles (this technique can be helpful for the estimation of recent erosion development),
- calculation of average annual soil loss using the Universal Soil Loss Equation (USLE) under the actual soil-climatic conditions.

MATERIAL AND METHODS

Assessment of water erosion intensity, using particular methods, is quite popular in many countries. Concretely, the method of indication of recent erosive-accumulative processes by means of activity radioisotope ^{137}Cs determination (caesium was used as a tracer element in a soil profile) and the method of average annual soil loss calculation, using the empirical model USLE, were used.

Table 1

Tolerable soil loss values for variously deep soils
Tolerované hodnoty odnosu pôdnej hmoty pre rôzne hlboké pôdy

Soil (1)	Depth (5) (m)	Tolerable soil loss (6) (STN 754501) ($t.ha^{-1}$ per year)
shallow (2)	<0.30	1.0
medium deep (3)	30 – 60	4.0
deep (4)	>60	10.0

(1) Pôda, (2) plytká, (3) stredne hlboká, (4) hlboká, (5) hĺbka, (6) prijateľná strata pôdy

This technique is based on determination of ^{137}Cs activity in the soil profile (profile distribution) for the indication of erosive-accumulative processes. Caesium can be used as a tracer of erosion, because this element is not naturally distributed in the soils. The ^{137}Cs was emitted to the atmosphere from the thermonuclear explosions, or from nuclear power plants accidents. The presence of ^{137}Cs in soil dates back to the year 1945, when the first thermonuclear explosions started and later the testing of nuclear weapons. At present, caesium gets to the soil especially from the nuclear power plants accidents (Chernobyl in 1986 year).

This radioisotope is relatively stable in soil, because it is firmly fixed on a surface of colloidal components of soil (without leaching). The period of caesium disintegration is about 40 years. Vertical movement of this isotope in a soil profile is not possible, therefore its concentration going to the depth of soil is significantly decreasing. The ^{137}Cs has a relatively homogenous distribution in the topsoil (ploughing layer) of arable land (to the depth of 0.25 – 0.30 m). Caesium distribution is only to the depth of 0.05 – 0.10 m in the soils under the grassland. This scheme relates, of course, to the soils non-affected by erosion processes. Significant decrease (or increase) of caesium activity in a soil profile can be caused only by erosive or accumulative processes (soil matter loss in erosive parts of slope, and accumulation of translocated soil matter in accumulative parts of slope).

The amount of eroded or accumulated soil matter, indirectly or directly on the basis of caesium activity assessment in a soil profile, is evaluated in this paper. The indirect method is determination of caesium profile distribution and its differences in concentration (in percent) in individual parts of erosive catena (referential, erosive, accumulative) [7, 11]. This method can help us to get valuable information on soil erosion development during the period of the most intensive agricultural progress. Noticeable acceleration of soil erosion was induced by thoughtless human activities during this period. Recent erosion was determined on the basis of the difference between the depth of still measurable concentration of caesium in the soil profiles from accumulative and referential part of transect (mass and profile balance of erosive processes).

The direct method, using proportional model, was developed at the University of Exeter [12], and it is suitable for a quantitative assessment of erosion and accumulation. This model is based on the presumption that caesium is relatively homogenously distributed in the topsoil of arable land and the loss of soil matter is proportional to the loss of ^{137}Cs. The loss and/or accumulation of soil matter is stated in relation to the referential site, minimally affected by erosion.

Equation for proportional model only reflects caesium activity in the soil profile (area distribution in $Bq.m^{-2}$), time from the beginning of fallout, bulk density, depth of topsoil, and the factor of soil texture. This equation has two modifications [2]:

for eroded point $$Y = \frac{Bd\left(100\frac{Ar - A}{Ar}\right)}{10TP} \qquad [1]$$

for accumulated point $$Y = \frac{Bd\left(100\frac{A - Ar}{Ar}\right)}{10TP'} \qquad [2]$$

where
- Y – average annual soil loss ($t.ha^{-1}$)
- B – bulk density of soil ($kg.m^{-3}$)
- D – depth of topsoil (m)
- Ar – referential value of contamination ^{137}Cs ($Bq.m^{-2}$)
- A – contamination ^{137}Cs in investigated point ($Bq.m^{-2}$)
- T – time from the beginning of fallout ^{137}Cs (year)
- P – texture parameter in eroded point
- P' – texture parameter in accumulated point

Caesium analyses have been done by semiconductor gamma-spectrometric method in the Nuclear Power Plants Research Institute in Trnava city.

We have used the well-known empirical model of Wischmeier-Smith´s equation (USLE – Universal Soil Loss Equation) for the determination of potential water erosion influence on soil [14]. Universal soil loss equation is expressed by multiplication of two direct factors (rainfall, soil erodibility) and four indirect factors (length of slope, steepness of slope, cropping and management, conservation practices) (fig.

1). The results are numerical outputs giving the information about endangerment of agricultural soils by soil erosion processes.

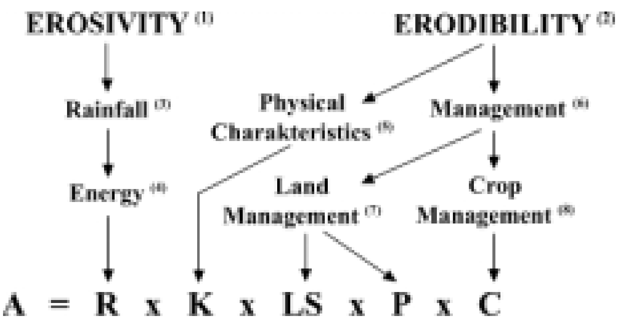

Fig. 1. Empirical expression of USLE [in ref. 6]
Obr. 1. Empirické vyjadrenie USLE [in cit. 6]
A – average annual soil loss ($t.ha^{-1}$) priemerná ročná strata pôdy ($t.ha^{-1}$),
R – rainfall erosivity factor faktor erozivity dažďa
K – soil erodibility factor faktor erodovateľnosti pôdy
LS – factor of relief – faktor reliéfu
C – cover management factor – faktor ochranného vplyvu vegetačného krytu
P – erosion control measures factor faktor účinnosti protieróznych opatrení

(1) Erozivita, (2) erodovateľnosť, (3) zrážky, (4) energia, (5) fyzikálne charakteristiky, (6) hospodárenie, (7) využitie pôdy, (8) využitie rastlín

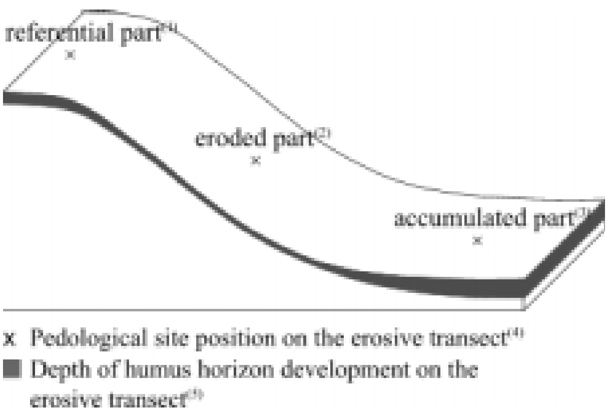

Fig. 2. Depth of humus layer on individual parts of transect
Obr. 2. Hĺbka humusovej vrstvy v jednotlivých častiach transektu
(1) Referenčná časť, (2) erodovaná časť, (3) akumulačná časť, (4) umiestnenie pedologických sond na eróznom transekte, (5) vývoj hĺbky humusového horizontu na eróznom transekte

RESULTS AND DISCUSSION

Characteristic of the studied locality

Erosive transect has been established north-east from Detva town, in the rolling hilly relief of Poľana mountains (volcanic origin). The monnitored catena is characterised by arable land and silage maize was cultivated there. This sub-region can be characterized as moderately warm and humid, hilly to highland, with the mean annual total precipitation 750 mm [4]. Medium deep to deep soils (medium heavy) developed from the weathered volcanic rocks are predominant in this region. Cambisols are characteristic for the whole monitored area (accumulative and erosive part of transect – Stagni Cambisols, referential part of transect – Eutric Cambisol) [5]. The length of transect is 390 m and its steepness is ranging from 8° to 12°. The thickness of humus horizon in individual parts of transect is following (fig. 2):
– referential part – 0.30 m,
– eroded part – 0.23 m,
– accumulated part – 0.60 m.

Results

Numerical expression of the average annual soil loss (potential and actual) in local conditions of the monitored locality was obtained by application of the USLE empirical model. For a potential soil loss (we did not take into account cover management factor and erosion control measures factor) the value 139.6 $t.ha^{-1}$ per year was calculated. When we took into account the grown plant (silage maize), the average actual soil loss was 68.4 $t.ha^{-1}$ per year. The achieved results confirm our presumption that soil in the monitored locality is extremely affected by erosion. This is significantly influenced by inclination and length of slope, soil properties, intensity and amount of precipitation, and the plant grown. Calculated value of actual soil loss highly exceeded the limit determined in the Act no. 220/2004 [9]. The limit value of soil loss for a deep soil is 30 $t.ha^{-1}$ per year.

A distinct profile distribution of radioisotope caesium in the soil demonstrates the presence of intensive erosive-accumulative processes. We have noticed a classic scheme of caesium profile distribution (^{137}Cs was only found out in the topsoil, 0 – 0.30 m) in the referential and erosive part of transect. Concentration of caesium was practically unmeasurable under the topsoil. The ^{137}Cs was only determined to a 0.45 m depth in the accumulation part of slope. This confirms accumulation of soil matter translocated by erosive processes from the erosive parts of transect (tab. 2).

We use the measured concentrations of caesium in the soil profile of individual parts of the monitored transect (profile distribution) for the estimation of recent erosion in the studied locality during the last 40 years approximately. The differences between the maximal depth of still measurable concentration of caesium in the soil profiles from the accumulative and referential part of transect indicate a thickness of accumulated layer (in this case 100 mm) in the accumulative part of transect [11]. Relations of caesium activity in the soil profiles of individual parts of erosive catena help us to make the mass balance of recent erosion development.

The average annual accumulation of soil matter is 2.5 mm and at the actual bulk density 1.30 g.cm^{-3} it represents about 32.50 t.ha^{-1} annually. Calculated value of the lost and/or accumulated soil matter is lower in comparison with the value calculated according to USLE. It represents the average annual soil loss and/or accumulation for a relatively long period (about 40 years). The loss of soil matter could or could not be observed, in dependence on intensity and amount of precipitation and actual vegetation cover, in individual years during this period. The layer of translocated soil matter is higher than the average accumulation in case of significant erosion events, e.g. if the intensity of precipitation is higher than 30 mm per hour.

Finally, we used proportional model for the quantitative assessment of soil loss and accumulation resulting from water erosion processes under the particular conditions of the studied locality. This model represents a suitable method for the quantitative expression of erosion and accumulation. For the assessment it is inevitable to have the data on area activity of caesium in the monitored locality, bulk density of soil, depth of topsoil, texture parameter, and time from the beginning of ^{137}Cs fallout (in our example 42 years, according to Walling and Quine, ref. 13). The average annual soil loss in the erosive part of transect has been calculated (24.11 t.ha^{-1} per year) after adding all concrete values to the equation. At the actual bulk density 1.23 g.cm^{-3} it represents the loss of approximately two-millimetre thick layer of soil matter from the erosive parts of catena (equation 1) every year (during 42 years). Calculated values of soil loss for the eroded point are quite similar to the values determined by the method based on a profile distribution of caesium

T a b l e 2

Profile distribution of radioisotope caesium ^{137}Cs in soil
Profilová distribúcia rádioaktívneho izotopu cézia ^{137}Cs v pôde

Depth of sampling (1) (m)	Referential profile (2)			Eroded profile (3)			Accumulated profile (4)		
	bulk density (5) (kg.m^{-3})	^{137}Cs		bulk density (kg.m^{-3})	^{137}Cs		bulk density (kg.m^{-3})	^{137}Cs–	
		Bq.kg^{-1}	Bg.m^{-2}		Bq.kg^{-1}	Bg.m^{-2}		Bq.kg^{-1}	Bg.m^{-2}
0.00 – 0.30	1230	15.2	5608.8	1230	11.7	4317.3	1300	12.3	4797.0
0.30 – 0.35	1230	1.5	92.3	1380	0.6	41.4	1450	11.0	797.5
0.35 – 0.40							1450	4.4	319.0
0.40 – 0.45							1450	0.5	36.25
in total (6)			5701.1			4358.7			5949.8

(1) Hĺbka odberu, (2) referenčný profil, (3) erodovaný profil, (4) akumulovaný profil, (5) objemová hmotnosť, (6) spolu

(annually 32.50 t.ha^{-1}, 2.5 mm). F u l a j t á r and J a n s k ý [2] achieved similar results.

The average annual value of soil matter accumulation (accumulation point) represents 4.72 t.ha^{-1}, what is approximately 0.4 mm thick soil layer (equation 2). These are really low values, which do not correspond with the results achieved by calculating the eroded point, neither with values determined by the method of caesium profile distribution and using the USLE empirical model. The average accumulation of soil matter should be approximately the same as the average value of soil loss. The differences between expected and calculated values were caused by the fact that in the topsoil of referential soil profile there was measured much higher activity of caesium as compared to caesium activity measured in the soil profile of accumulative part. We have achieved a relatively high value of area caesium activity (5701.1 Bq.m^{-2}) at the referential soil profile, though caesium is practically not measurable in the depth of 0.35 m. Caesium profile distribution in the accumulated soil profile was measured to the depth of 0.45 m, but area activity of caesium measured here was only slightly higher (5949.8 Bq.m^{-2}) in comparison with the referential part of transect.

This can misinterpret (if high values of caesium area activity were measured in the topsoil of referential point) calculated values of caesium area activity for remaining points of erosive transect (eroded, accumulated). Accumulated parts of slope can be influenced in this way, because calculated values of accumulated soil matter do not express a real accumulation, in spite of concentration of caesium, which was measured in deeper parts of soil profile (caesium profile distribution).

CONCLUSIONS

Soil erosion assessment, using two various methods and their comparison, has been evaluated in the presented paper. The first one is the indication of recent erosion intensity, using ^{137}Cs activity determination in the soil profile and the second method is the average annual soil loss calculation using the USLE empirical model.

No results of specific analyses are necessary for the calculation of potential and actual soil erosion in local conditions by means of the USLE empirical model. Individual inputs parameters (factors) can be derived from the existing digital data layers or databases of SSCRI. We have achieved extreme value of potential annual soil loss (139.6 t.ha^{-1}) by numerical expression (USLE model). It is only soil potential for erosion, because we did not take into account cover management factor and erosion control measures factor. The average actual soil loss (68.4 t.ha^{-1} per year) was calculated when we took into account the grown plant (silage maize). It is still a high value of soil loss, because maize belongs to the plants with not very good anti-erosive effect.

Indication of recent soil erosion using the ^{137}Cs technique was a relatively suitable tool in conditions of the studied locality. Relatively expensive caesium analyses from soil samples are disadvantage of this method. We can do the following conclusions on the basis of interpretation results achieved from the profile distribution of caesium activity in individual sites of transect (mass balance of recent erosion development) and using proportional model (quantitative expression of erosion and accumulation):

– Profile distribution of ^{137}Cs in individual parts of erosive catena documents the presence of intensive erosive-accumulative processes. The difference in the maximal depth of still measurable concentration of caesium in the soil profiles from accumulative and referential part of transect (in this case 100 mm) indicates a thickness of accumulated layer at the accumulative part of transect for the period of approximately 40 years (recent erosion).
– Average annual soil loss (32.50 t.ha^{-1}) was determined on the basis of mass balance. This value is lower in comparison with the value calculated according to the USLE empirical model. It represents the average annual soil loss and/or soil accumulation for a relatively long period. The loss of soil matter could or could not be observed in dependence on the intensity and amount of precipitation and actual vegetation cover, in individual years within this period.
– Using proportional model on the quantitative

assessment of soil loss and accumulation is in this case limited by too high caesium activity in the topsoil of referential soil profile, as compared to other parts of erosive catena. The soil loss calculated for the eroded point (24.11 $t.ha^{-1}$ per year) does not correspond with the value achieved in the accumulated part of erosive catena (it represents only 4.72 $t.ha^{-1}$ per year). Proportional model was developed on the basis of area expression of caesium activity, and when the values of caesium activity measured in the topsoil of referential point are quite high, it can misinterpret the values calculated for remaining points of erosive transect (eroded, accumulated).

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SÚHRN

Príspevok sa zaoberá stanovením intenzity vodnej erózie v konkrétnych podmienkach záujmovej lokality (erózneho transektu) metódou indikácie intenzity erózno-akumulačných procesov stanovením aktivity izotopu ^{137}Cs v pôdnych profiloch (profilová distribúcia) a metódou výpočtu priemernej ročnej straty pôdy využitím empirického modelu Univerzálnej rovnice straty pôdy (USLE).

Záujmové územie sa z hľadiska intenzity zrážok, erodovateľnosti pôdy, svahovitosti a pestovaných kultúr nachádza v erózne senzitívnej oblasti. Ide o lokalitu na ornej pôde nachádzajúcu sa severovýchodne od Detvy. Výber erózneho transektu vychádzal najmä z terénneho prieskumu, pričom hlavnou požiadavkou bol predovšetkým jeho reliéf.

Katéna je charakterizovaná typickým radom sond lokalizovaných po spádnici svahu. Ide o tri pôdne profily (sondy), ktoré sú umiestnené vo vrcholovej časti svahu (referenčný profil – neerodované alebo mierne erodované pôdy), v eróznej časti transektu (erodované pôdy) a v spodnej (akumulačnej) časti svahu (akumulované pôdy).

Transekt je orientovaný v smere spádnic kvôli vystihnutiu preferenčných smerov povrchového odtoku a transportu pôdnej hmoty.

Numerickým vyjadrením potenciálnej straty pôdnej hmoty (USLE) bola získaná extrémna hodnota erodovanosti (139,6 t.ha^{-1} za rok). Ide však len o potenciál pôdy na eróziu, keďže sa do úvahy neberie ochranný vplyv vegetačného krytu. Pri zohľadnení aktuálneho rastlinného pokryvu (kukurica na siláž) priemerná ročná strata pôdy poklesla na 68,4 t.ha^{-1} za rok. Stále však ide o vysokú hodnotu, nakoľko kukurica sa zaraďuje medzi plodiny so slabým protieróznym účinkom.

Profilová distribúcia ^{137}Cs v rámci jednotlivých častí eróznej katény dokumentuje prítomnosť intenzívnych erózno-akumulačných procesov. Rozdiel maximálnej hĺbky jeho ešte merateľnej koncentrácie v pôdnych profiloch sond akumulačnej a referenčnej časti transektu (v tomto prípade 100 mm) indikuje hrúbku akumulovanej vrstvy v báze svahu za obdobie približne 40 rokov (recentná erózia).

Na základe hmotnostnej bilancie sa stanovila priemerná strata pôdy, ktorá ročne predstavuje približne 32,50 t.ha^{-1} (priebeh recentnej erózie). Táto hodnota je v porovnaní s USLE nižšia. Treba však upozorniť, že vyjadruje priemer za obdobie približne 40 rokov, počas ktorého (v závislosti od intenzity zrážok a aktuálneho vegetačného krytu) mohlo, alebo vôbec nemuselo dochádzať k erózii.

Využitie kalibračného pomerného modelu na kvantitatívne stanovenie odnosu a akumulácie pôdnej hmoty je v tomto prípade limitované vysokou aktivitou cézia v ornici referenčnej časti svahu (v porovnaní s ostatnými časťami erózneho transektu). Strata pôdy pre erodovaný bod je síce podobná (ročne 24,11 t.ha^{-1}) ako pri hmotnostnej bilancii priebehu recentnej erózie, ale hodnota akumulácie pôdnej hmoty (akumulovaný bod) predstavuje len 4,72 t.ha^{-1} za rok čo nekorešponduje z výsledkami získanými v erodovanom bode.

Kalibračný pomerný model je postavený na plošnom vyjadrení aktivity cézia (Bq.m^{-2}), čo môže pri vyšších hodnotách obsahu tohto izotopu v ornici referenčného bodu skresľovať vypočítané hodnoty pre zvyšné časti erózneho transektu. Týka sa to najmä akumulačnej časti, v ktorej aj napriek stanoveniu aktivity cézia vo väčších hĺbkach pôdneho profilu vypočítané hodnoty nevyjadrujú priemernú akumuláciu.

Kľúčové slová: erózia pôdy, aktivita ^{137}Cs, USLE, distribúcia cézia v pôdnom profile, pomerný model