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NATURAL FACTORS OF ^{137}Cs DISTRIBUTION IN SOIL ON THE EXAMPLE OF FORESTED SLOPE IN THE CARPATHIAN FOOTHILLS

INTRODUCTION

Radioactive caesium-137 was introduced into atmosphere as a result of nuclear test explosions and the failure of the Chernobyl power plant in April 1986. Test explosions took place in various areas of the world mostly in the fifties and the sixties. It can be assumed that the resulting total fallout of ^{137}Cs onto the Earth surface has been almost uniform even within large regions. On the contrary the fallout resulting from the single power-plant accident differed greatly as it depended on the migration of the radioactive cloud in the subsequent days after the power-plant failure and the occurrence of rainfalls introducing the radioisotope directly onto the Earth surface (Higgitt *et al.* 1992). There have been several attempts to assess the spatial differentiation of the radioactive caesium contamination in Poland (Królas *et al.* 1987, Biernacka *et al.* 1991, Mietelski *et al.* 1992). The map (Fig. 1) shows the areal distribution of the radioisotope in the soils of the south-east Poland in the summer 1986, which followed the Chernobyl accident.

Radiocaesium is strongly bound to clay minerals in the soil. The empirical evidence suggests that the isotope can be washed out, transported and then redeposited together with the finest soil particles. Many authors claim that soil erosion, transportation and redeposition are the main factors contributing to the local differences in ^{137}Cs spatial distribution in soils (Ritchie, McHenry 1975, Mc Callan *et al.* 1980, Brown *et al.* 1981, Campbell *et al.* 1982, Walling, Quine 1990). That is why ^{137}Cs is being applied as a tracer in examining areal extent and intensity of soil erosion and deposition, as well as in investigations of sources of suspended sediment delivered to rivers (Froehlich, Walling 1992). In areas undergoing soil loss the ^{137}Cs content is low, even in superficial soil layers. On the contrary in the areas where the soil matter is accumulated the ^{137}Cs content is high, even within deep soil layers. The depth of ^{137}Cs occurrence in soil depends on the intensity and

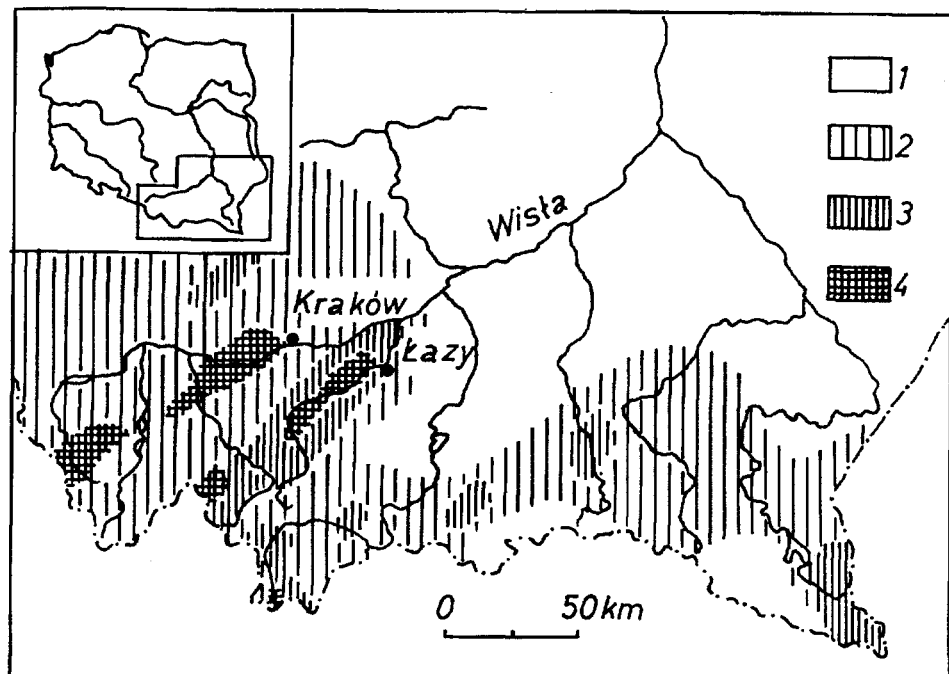


Fig. 1. Spatial distribution of ^{137}Cs concentration in soils of south-east Poland in summer 1986 (after Królas *et al.*, 1987) 1: <0.2 Bq/g; 2: $0.2-0.5$ Bq/g; 3: $0.5-1.0$ Bq/g; 4: >1.0 Bq/g

Ryc. 1. Przestrzenne zróżnicowanie zawartości ^{137}Cs w glebach południowo-wschodniej Polski w lecie 1986 r. (wg Królasa i in. 1986) 1: <0.2 Bq/g; 2: $0.2-0.5$ Bq/g; 3: $0.5-1.0$ Bq/g; 4: >1.0 Bq/g

duration of erosion and deposition. The question is, to what extent factors other than just soil loss or accretion are responsible for differences in vertical and areal distribution of the isotope.

The aim of this paper is to present the results of the investigation on some natural factors of ^{137}Cs distribution in soil, on a single forested slope situated in the Carpathian Foothills as an example. The following factors have been considered: slope morphology, organic matter content in soil, grain-size distribution and soil infiltration capacity (permeability).

DESCRIPTION OF THE EXAMINED SLOPE

The slope is situated in the outer zone of the Carpathian Foothills, 5 km east of the town of Bochnia, close to the Łazy Field Station of the Institute of Geography, Jagiellonian University, Cracow (Fig. 1). According to the map the investigated slope, while compared with the other parts of the Polish Carpathians is situated in the area of medium ^{137}Cs contamination.

The examined slope is 60 m long from the top of the local water divide (250 m a.s.l.) to the valley bottom (234 m a.s.l.). It is convex-shaped

and S-exposed. The upper and middle parts of the slope are covered by birch- and beech-dominated forest. The lowest part is covered by meadow—type vegetation with hydrophilous communities dominating in the valley bottom. The soil has been developed on fine-grained loess-like deposits, which are typical of the Carpathian Foothills. These very fine-grained deposits can strongly bind the ^{137}Cs radionuclide.

METHODS

SOIL SAMPLING

The samples of soil for radiometric analysis were collected in summer 1991 at 8 sites which covered the whole slope profile (Fig. 2) Site 1 was situated on the almost flat, forested hilltop. Sites 2–6 were situated on the forested part of the slope, site 7 — at the grass-covered footslope, and the site 8 — at the bottom of the undrained valley.

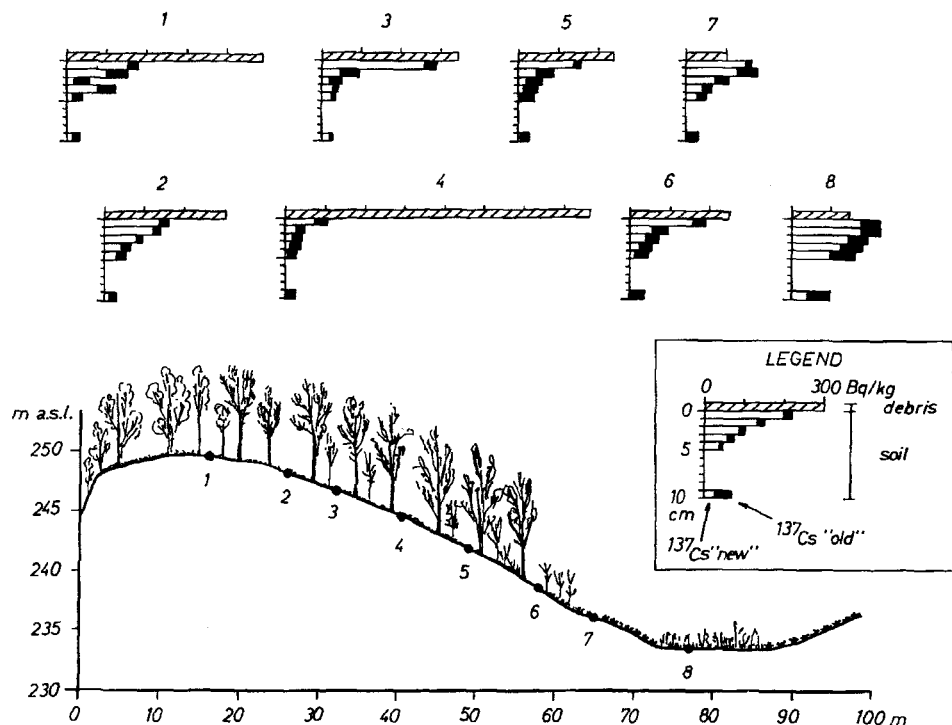


Fig. 2. Distribution of ^{137}Cs concentration in soil and superficial organic debris on the forested slope in Łazy; 1–8 — site numbers

Ryc. 2. Rozkład koncentracji ^{137}Cs w glebie i ściółce na zalesionym stoku w Łazach; 1–8 — numery stanowisk

At each site the soil samples were scraped to obtain five consecutive one centimetre thick slices, within a square frame (30×30 cm). Additional samples were taken from the depth of 10 cm. All samples came from planes parallel to the slope surface. The samples were dried (105°C), cleaned of undecomposed organic remains, disaggregated in a mortar and sieved (1 mm mesh). After completion of all samplings and measurements, including radiometric procedure, the additional samples of partly decomposed superficial organic debris (litter), derived from leaf mould were collected to check whether the high or low ^{137}Cs content in soil is supported by the respectively high or low content of caesium in overlying debris. The debris samples were only dried and homogenized before the radiometric measurements.

RADIOMETRIC PROCEDURE

The ^{137}Cs as an ordinary fission-product is obtained in nuclear reactors as well as in nuclear weapons explosions. The ^{134}Cs is, however, produced in the nuclear reactors only, not as a result of uranium or plutonium fission but as a result of neutron activation of the ^{133}Cs , the daughter of the fission-product ^{133}Xe . During the Chernobyl failure, in April-May 1986, the ratio of ^{134}Cs to ^{137}Cs activities in the air and in the fallout at Cracow was nearly constant in time and equal to approximately 0.48 (Mietelski *et al.* 1988). As the half-lives of those two isotopes are different the $^{134}\text{Cs}/^{137}\text{Cs}$ ratio at the time of sampling (1 September, 1991) was equal to 0.09. In case the ^{134}Cs activity is known it is possible to determine which part of the total ^{137}Cs activity has originated from the pre-Chernobyl fallout (so called ^{137}Cs "old") and which part has originated from the post-Chernobyl fallout (so called ^{137}Cs "new"). The formula for ^{137}Cs "old" calculation is following:

$$^{137}\text{Cs} \text{ "old"} = ^{137}\text{Cs} \frac{1}{\alpha} - ^{134}\text{Cs} \quad (1)$$

where:

- ^{137}Cs „old” is the activity of ^{137}Cs originated from nuclear explosions,
- ^{137}Cs is the total activity of ^{137}Cs in the sample,
- ^{134}Cs is the total activity of ^{134}Cs in the sample,
- α is $^{134}\text{Cs}/^{137}\text{Cs}$ ratio (taken as equal to 0.09).

Concentrations of ^{137}Cs and ^{134}Cs were determined for each sample. All measurements were performed with the low-background gamma spectrometers with germanium detectors, shielded by Pb walls plus Cd and Cu additional shielding. The spectra obtained were evaluated using the P. I. M. P. computer code (Mietelski 1989). The method of the calibration of spectrometers was described in detail in another paper (Mietelski *et al.* 1992).

All measurements were performed in May 1992. The activities were decay corrected for September 1st, 1991 (Tab. 1-4). The formula for the activity calculations was following:

$$A = \frac{n \exp(\lambda d) \mu(\rho, x, E)}{Y(E) \mathcal{E}(E, V) m} \quad (2)$$

where: A is the activity of sample in Bq/kg; n is the number of counts per one second in a given peak area corrected for background peaks; λ is the decay constant for a given isotope; d is a number of days from 1 September 1991 to the day of analysis; $\mu(\rho, x, E)$ is the experimentally obtained function for self-absorption correction for different densities ρ , thickness of sample x and energy of photon E; Y(E) is the intensity of a given peak in % (photons per 100 disintegrations); $\mathcal{E}(E, V)$ is the spectrometer efficiency function value for given photon energy E and volume of sample V; m is the sample dry mass.

Table 1

^{137}Cs activities in soil and superficial organic debris (d); decay corrected for September 1, 1991

Aktywność ^{137}Cs w glebie i ściółce (d); skorygowana ze względu na rozpad na dzień 1 września 1991

Depth. Głęb. cm	Site number Stanowisko			
	1	2	3	4
d	484.8 ± 39.6	303.5 ± 16.0	336.1 ± 11.2	766.5 ± 37.0
1	177.0 ± 12.0	162.9 ± 13.4	284.7 ± 27.7	101.6 ± 7.0
2	152.0 ± 11.0	143.3 ± 12.0	94.3 ± 7.6	52.8 ± 3.4
3	50.8 ± 3.5	97.4 ± 8.1	49.1 ± 4.0	43.4 ± 2.7
4	102.3 ± 7.1	67.8 ± 4.2	39.6 ± 3.5	41.1 ± 2.7
5	34.4 ± 2.3	57.8 ± 3.7	33.9 ± 2.6	33.4 ± 2.1
10	30.8 ± 2.3	28.6 ± 2.0	24.7 ± 7.0	27.5 ± 1.8

cm	5	6	7	8
d	242.3 ± 4.8	252.3 ± 14.7	96.5 ± 4.4	146.1 ± 7.6
1	161.8 ± 13.5	187.4 ± 14.4	162.3 ± 13.0	219.0 ± 20.9
2	89.8 ± 5.6	91.4 ± 5.8	179.7 ± 15.0	220.8 ± 21.9
3	63.1 ± 3.9	69.2 ± 4.8	106.7 ± 9.0	185.7 ± 19.2
4	49.9 ± 3.5	52.9 ± 3.4	61.4 ± 4.1	176.1 ± 15.8
5	42.9 ± 2.9	46.1 ± 3.2	44.0 ± 2.9	153.6 ± 12.8
10	31.2 ± 2.2	35.7 ± 2.3	29.3 ± 2.0	92.4 ± 6.8

^{134}Cs activities in soil and superficial organic debris (d); decay corrected for September 1, 1991

Aktywność ^{134}Cs w glebie i ściółce (d); skorygowana ze względu na rozpad na dzień 1 września 1991

Depth Głęb. cm	Site number Stanowisko			
	1	2	3	4
d	43.9 ± 22.0	27.0 ± 10.0	30.5 ± 9.3	78.4 ± 31.5
1	13.9 ± 1.2	12.6 ± 2.3	23.4 ± 4.3	7.2 ± 0.8
2	8.9 ± 2.7	11.3 ± 1.3	4.3 ± 0.7	2.8 ± 1.0
3	1.8 ± 0.5	7.3 ± 1.6	1.8 ± 0.6	1.8 ± 0.8
4	4.8 ± 0.8	4.1 ± 1.2	2.6 ± 1.1	1.1 ± 0.5
5	1.4 ± 0.9	3.3 ± 1.1	0.1 ± 0.7	0.9 ± 0.9
10	1.4 ± 0.6	1.2 ± 0.5	0.1 ± 0.6	0.4 ± 0.3

cm	5	6	7	8
d	22.3 ± 4.7	27.2 ± 12.4	7.3 ± 4.1	10.5 ± 5.3
1	13.0 ± 1.3	14.7 ± 1.3	13.8 ± 1.3	15.8 ± 1.6
2	4.6 ± 1.3	5.3 ± 1.3	11.5 ± 2.4	15.6 ± 3.2
3	2.4 ± 1.2	3.5 ± 0.6	6.9 ± 2.0	12.9 ± 2.9
4	1.5 ± 0.6	2.2 ± 0.8	3.7 ± 1.1	10.8 ± 1.2
5	0.7 ± 0.5	1.4 ± 0.7	2.6 ± 1.1	8.8 ± 2.0
10	0.8 ± 0.5	0.6 ± 0.6	0.1 ± 0.6	4.2 ± 0.7

One sigma error σA in the activity determination was given by the following formula (errors due to self-absorption correction factors were neglected as small values of second order):

$$\sigma A = A \left[\left(\frac{\sigma N}{N} \right)^2 + \left(\frac{\sigma n_0}{n_0} \right)^2 + \left(\frac{\sigma m}{m} \right)^2 + \left(\frac{\sigma \mathcal{E}(E,V)}{\mathcal{E}(E,V)} \right)^2 \right]^{0.5} \quad (3)$$

where:

A is the activity of the sample in Bq/kg, $\sigma N = (N + 2B)^{0.5}$: N is the net peak area in sample spectrum, B is the area below the peak in sample spectrum, $\sigma n_0 = (n_0 + 2B_0)^{0.5}$: n_0 is the net given peak area in the background spectrum, (0 for Cs-134 lines), B_0 is the area below the peak in background spectrum, σm is the error of mass m determination, $\sigma \mathcal{E}(E,V)$ is the error of the efficiency function $\mathcal{E}(E,V)$ value.

Table 3

^{137}Cs „old” activities in soil; decay corrected for September 1, 1991
 Aktywność ^{137}Cs „old” w glebie skorygowana ze względu na rozpad na dzień 1 września 1991

Depth Głęb. cm	Site number Stanowisko			
	1	2	3	4
1	21.7 ± 15.0	22.3 ± 22.2	23.3 ± 43.0	20.9 ± 9.1
2	52.5 ± 23.5	16.5 ± 15.4	46.0 ± 9.3	21.2 ± 8.7
3	30.6 ± 5.5	15.8 ± 15.0	28.9 ± 6.0	23.1 ± 7.1
4	48.8 ± 9.5	21.9 ± 10.0	11.1 ± 9.1	28.3 ± 4.5
5	18.9 ± 7.2	21.1 ± 9.0	32.5 ± 6.3	23.3 ± 7.0
10	15.6 ± 5.1	15.1 ± 4.3	23.0 ± 5.0	23.2 ± 3.0

cm	5	6	7	8
1	16.8 ± 16.7	23.2 ± 17.3	7.5 ± 16.3	42.8 ± 24.3
2	38.6 ± 11.4	32.2 ± 11.8	51.2 ± 24.1	46.1 ± 33.2
3	36.8 ± 9.9	30.4 ± 6.5	30.0 ± 17.6	41.5 ± 29.7
4	33.6 ± 5.5	28.2 ± 7.4	20.5 ± 9.4	55.0 ± 18.5
5	35.3 ± 4.7	30.7 ± 6.0	14.8 ± 9.3	55.5 ± 20.0
10	22.5 ± 4.5	28.7 ± 4.9	28.7 ± 5.1	45.9 ± 8.8

The measurements were performed in the Radioactive Contamination of Environment Research Laboratory, Institute of Nuclear Physics, Cracow.

HUMUS CONTENT MEASUREMENTS

Soil organic matter (humus) content was measured using method of Tiurin modified by Oleksynowa. The 0.5 g of each soil samples were disaggregated, then digested in chromic acid and titrated with copperas ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$). The humus content was expressed in per cent of dry soil weight (Tab. 5). The measurements were performed in the laboratory of the Field Station in Łazy.

GRAIN-SIZE MEASUREMENTS

For the grain-size measurements the laser Fritsch particle sizer *Analysette 22* was applied. The grain-size distribution was measured for the material from the 3-rd centimetre of soil at each site. The measurements were performed in the laboratory of the Department of Geomorphology and Hydrology of Mountains and Uplands, Polish Academy of Sciences, Cracow.

Table 4

^{137}Cs „new” activities in soil; decay corrected for September 1, 1991
 Aktywność ^{137}Cs „new” w glebie; skorygowana ze względu na rozpad na dzień 1 września 1991

Depth Głęb. cm	Site number Stanowisko			
	1	2	3	4
1	155.3 ± 19.2	140.6 ± 25.9	261 ± 51.2	80.7 ± 11.4
2	99.8 ± 25.9	126.8 ± 19.5	48.4 ± 12.0	31.7 ± 9.4
3	20.2 ± 6.5	81.7 ± 17.1	20.2 ± 7.2	20.3 ± 7.5
4	53.6 ± 11.9	45.9 ± 10.9	28.5 ± 9.8	12.8 ± 5.2
5	15.5 ± 7.5	36.7 ± 9.8	1.3 ± 6.8	10.1 ± 7.3
10	15.2 ± 5.6	13.6 ± 4.8	1.7 ± 5.3	4.3 ± 3.5

cm	5	6	7	8
1	145.0 ± 21.5	164.2 ± 22.5	154.8 ± 20.9	176.2 ± 32.1
2	51.2 ± 12.7	59.2 ± 13.2	128.5 ± 28.4	174.7 ± 39.8
3	26.3 ± 10.6	38.8 ± 8.1	76.8 ± 19.7	144.2 ± 35.4
4	16.3 ± 6.5	24.7 ± 8.1	40.9 ± 10.2	121.1 ± 24.3
5	7.6 ± 5.6	15.4 ± 6.8	29.1 ± 9.7	98.1 ± 23.8
10	8.7 ± 5.0	7.0 ± 5.4	0.6 ± 5.5	46.4 ± 11.1

Table 5

Humus content in soil samples; in % of dry soil weight
 Zawartość humusu w glebie; w % masy suchej gleby

Depth Głęb. cm	Site number Stanowisko							
	1	2	3	4	5	6	7	8
1	4.8	4.7	6.0	2.9	4.3	4.0	4.8	11.7
2	4.1	3.7	3.0	1.5	2.5	2.6	5.6	11.0
3	1.6	3.0	2.1	1.2	1.5	2.2	4.5	9.8
4	3.0	2.1	1.7	1.0	1.2	2.0	2.9	9.4
5	0.9	1.6	1.3	1.0	1.0	1.6	1.9	8.7
10	0.8	0.9	1.0	0.8	0.9	1.4	1.3	6.6

SOIL INFILTRATION CAPACITY MEASUREMENTS

Soil infiltration capacity at each sampling site was measured by means of cylindrical infiltrometer. At each sampling site the infiltrometer was hammered into the soil, filled with water and then the speed of infiltration was measured until it became constant. The soil infiltration capacity (permeability) was expressed in cm per minute (Tab. 6).

Table 6

Infiltration capacity (permeability) of soil; in cm/min.
Pojemność infiltracyjna (przepuszczalność) gleby; w cm/min.

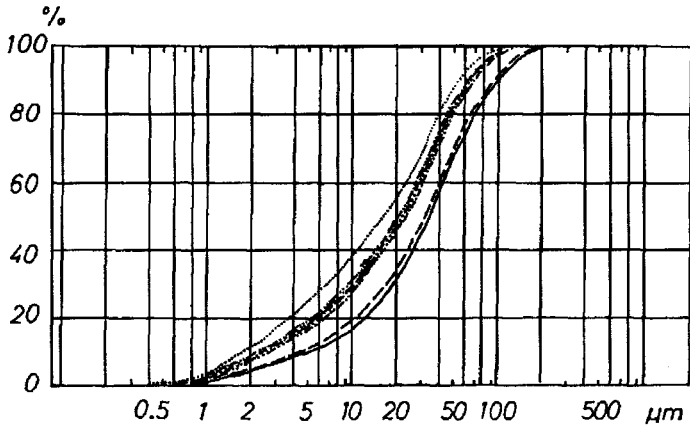
Site number Stanowisko							
1	2	3	4	5	6	7	8
1.04	2.95	4.62	0.12	0.06	0.07	0.78	0.06

RESULTS AND DISCUSSION

The ^{137}Cs distribution in soil (the surface debris will be discussed later in the paper) shows the substantial variations within the whole slope profile (Fig. 2). In terms of spatial and horizontal patterns these variations will be analyzed for the total as well as for the pre-Chernobyl and the post-Chernobyl ^{137}Cs concentrations (^{137}Cs "old" and ^{137}Cs "new" respectively).

The total ^{137}Cs shows the general pattern with the relatively high concentration for the upper section of the profile as well as for the valley bottom, and the relatively low concentration for the midslope section. This is similar to the results obtained for the grass-covered slope situated several hundred metres away from the forested slope (Chełmicki, Świąchowicz 1992, Chełmicki, Świąchowicz, Araszkiwicz 1992). In case of the forested slope the pattern is well expressed for the upper four centimetres of the soil, whilst for the 5th and 10th centimetres the radioisotope concentrations are almost the same for each site with the exception of the valley bottom. There the concentrations for all depth slices are higher than those for the corresponding depths at the remaining sites. The general pattern is disturbed by the abnormally high ^{137}Cs concentration for the top centimetre at the site 3, and the relatively low concentration for the 3rd centimetre at the site 1. These abnormalities are difficult to explain.

In case of the post-Chernobyl caesium (^{137}Cs "new") the distribution of the radioisotope in soil is similar to that of the total ^{137}Cs . The general pattern is repeated and the slight differences do not play a significant role. On the contrary the pre-Chernobyl caesium (^{137}Cs "old") shows the pattern somewhat different, however the relatively high ^{137}Cs concentration for the valley bottom



Site numbers

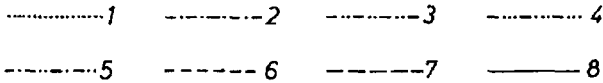


Fig. 3. Grain-size distribution for the 3rd centimetre of soil at each sampling site (1-8)

Ryc. 3. Skład granulometryczny gleby pobranej z głębokości 3 cm na każdym ze stanowisk (1-8)

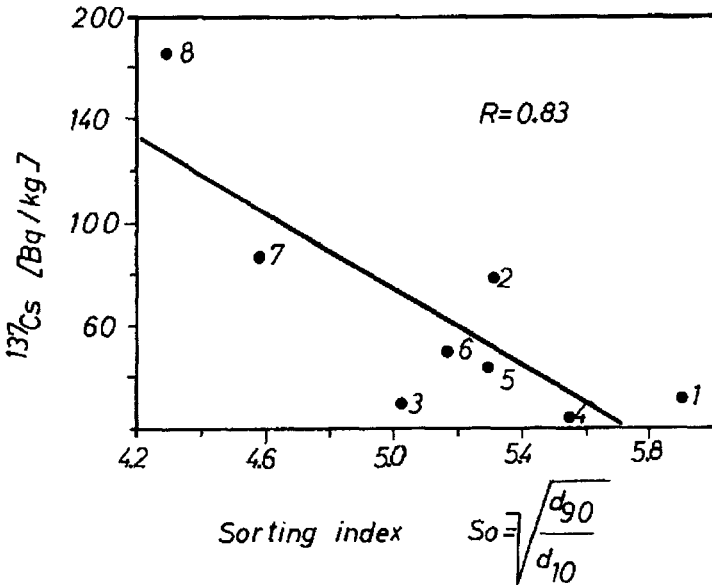


Fig. 4. Relationship between ^{137}Cs concentration and sorting index of soil taken from the depth of 3 centimetres at each sampling site

Ryc. 4. Zależność między koncentracją ^{137}Cs i wskaźnikiem wysortowania gleby pobranej z głębokości 3 cm na każdym ze stanowisk

is still detected, and the lower concentration values tend to appear in the midslope. What makes the pre-Chernobyl caesium distribution different from that of the post-Chernobyl (except lower activities due to the decay), is the vertical pattern of the isotope concentration. There is no constant reduction of the pre-Chernobyl caesium with depth. Moreover, except for the site 2, the pre-Chernobyl caesium concentration for the first centimetre is even lower than that for the next one. In case of two sites (4 and 8) the differences between the two depths are too small and the errors of estimation are too large to pay much attention to them. Generally for the uppermost 2 centimetres of soil, the post-Chernobyl caesium dominates over the pre-Chernobyl isotope, whilst at the depth of 10 centimetres the pre-Chernobyl caesium dominates over the post-Chernobyl one. In case of the valley bottom the concentrations of the "old" and "new" isotopes at the depth of 10 centimetres are virtually the same.

The results presented above may lead to the conclusion, that the post-Chernobyl caesium has not yet migrated substantially to the depth of 10 centimetres, and the pre-Chernobyl caesium has been mostly removed from the uppermost centimetres of the soil. The only exception is the valley bottom, where the pre-Chernobyl and post-Chernobyl caesium have been detected in large amounts, even at the depth of 10 centimetres. This suggests that the downward migration of the post-Chernobyl caesium in the valley bottom has been relatively intensive or the high ^{137}Cs content at the depth of 10 centimetres is due to the deposition of the material removed from the slope, especially from the convex midslope showing the relative loss of caesium.

The slope processes (removal, transport and deposition of the material) can be only one of the factors leading to the local differentiation of the ^{137}Cs content in soil. The other factors can be grain-size differentiation and humus content. Fine-grained soils as well as those containing much humus can bind the caesium radionuclide more effectively than the coarse-grained and containing less humus ones.

The grain size diagrams (Fig. 3) evidence good uniformity of the soil material, especially for the slope section (sites 2–6). At the site 1, situated at the top of the catena, the sorting of the soil particles is poorer than that for the lower sections. In the valley bottom the sorting is the best. The coefficient of correlation between the caesium content and the sorting index is 0.83 (Fig. 4). The best sorting of the bottom sediments and the poorer sorting of the top and slope sediments may confirm the erosional-depositional origin of the valley bottom material.

In terms of the relationship between humus and caesium contents in soil there is very well expressed correlation between them; the more humus, the more caesium (Fig. 5). This correlation to some extent seems to be misleading, as both ^{137}Cs and humus contents tend to decrease with depth as a rule. On the other hand, humus is conducive to ^{137}Cs sorption in soil and we may expect some relationship between the two for the samples taken

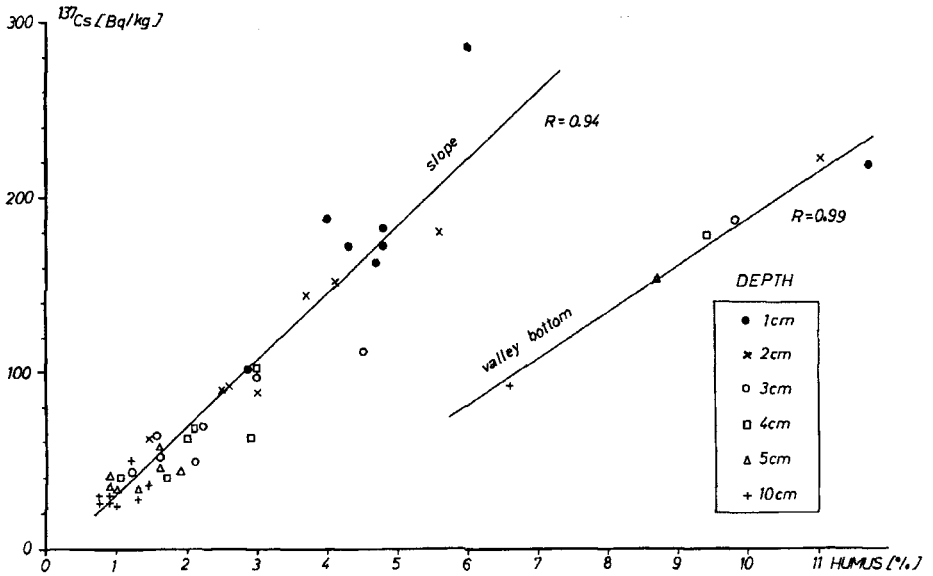


Fig. 5. Relationship between ^{137}Cs and humus content in soil

Rys. 5. Zależność między koncentracją ^{137}Cs i zawartością humusu w glebie

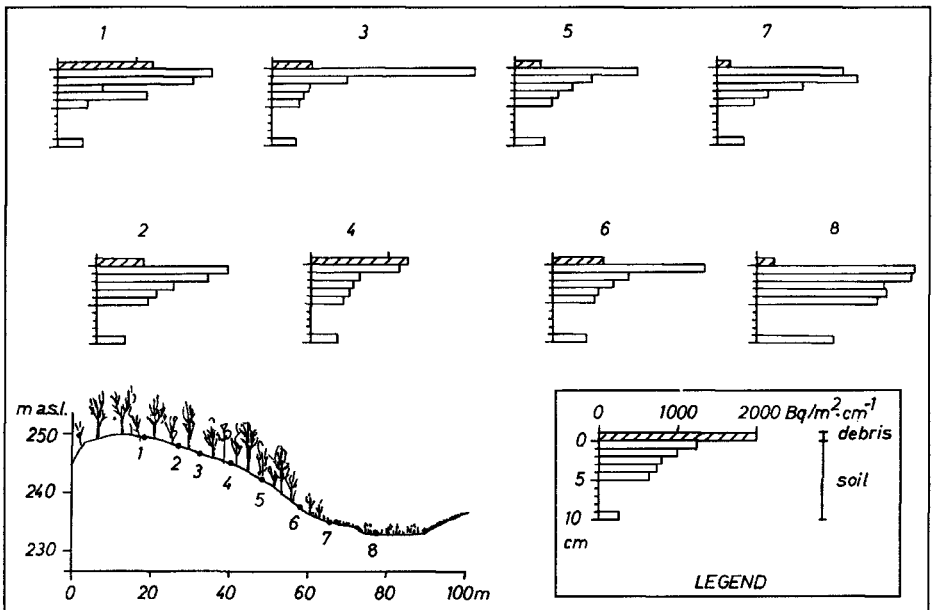


Fig. 6. Distribution of ^{137}Cs in soil and superficial organic debris expressed in $\text{Bq/m}^2 \text{cm}^{-1}$ (^{137}Cs "old" and ^{137}Cs "new" undivided)

Ryc. 6. Rozkład aktywności ^{137}Cs w glebie i ściółce wyrażony w $\text{Bq/m}^2 \text{cm}^{-1}$ (^{137}Cs „old” i ^{137}Cs „new” — nierozdzielone)

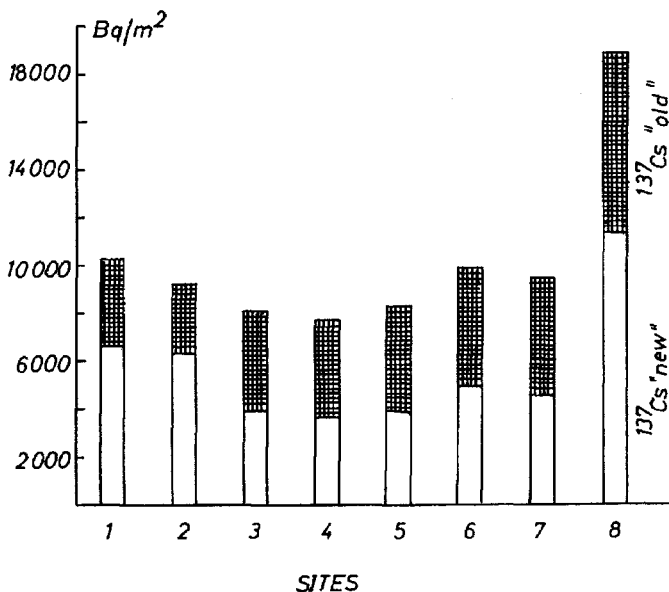


Fig. 7. Total ^{137}Cs content at each sampling site (1-8) expressed in Bq/m^2

Ryc. 7. Całkowita zawartość ^{137}Cs na poszczególnych stanowiskach (1-8) wyrażona w Bq/m^2

from the same depth. In fact for the same depth slices the correlation still exists. The question arising now is to what extent the ^{137}Cs differences between the particular parts of the slope result from the removal of the material and its deposition, and to what extent they result from the humus content differentiation.

There are at least two factors which can be responsible for the different erosional potential within the analysed slope: the shape of the slope and the differentiated soil permeability at different slope sections.

In terms of the shape the slope convexity seems to be favourable for the most intensive soil loss in the middle part of the slope. Moreover, the soil of the mid-slope is less permeable than that in the upper parts of the slope (Tab. 6). As relatively less water can infiltrate the surface, the resultant runoff of water may cause more intensive soil wash down the slope. As the organic as well as mineral soil particles are washed down, the humus content in the midslope becomes lower. In the bottom of the valley, where the washed matter is deposited, one can observe the relatively high humus content.

A separate point for discussion is the role of the superficial organic debris in trapping and transferring caesium to the underlying soil. The measurements of the ^{137}Cs content in the organic debris show the lack of the pre-Chernobyl caesium. High or low post-Chernobyl ^{137}Cs content in soil is not supported by the respectively high or low content of isotope in the respective overlying

debris (see Fig. 2). Moreover, at the site 4 the lowest ^{137}Cs content in the soil layer is accompanied by the highest ^{137}Cs content in the overlying debris cover. It looks like the debris at the site 4 have trapped the caesium fallout, what results in the relatively low caesium content in the soil below. If this interpretation is correct the removal and deposition of the soil can not be recognized as a major factor responsible for the caesium redistribution.

The situation is getting more clear if we express the caesium activities as inventories (Bq/m^2), instead of concentrations (Bq/kg). Then the importance of the debris layer as a storage medium for caesium seems to be smaller (Fig. 6). The difference between the total ^{137}Cs inventories in central part of the slope and the rest of the profile is well expressed (Fig. 7). As the pre-Chernobyl caesium inventories for the sites 1–7 are almost the same, it can be assumed that the spatial differentiation of total ^{137}Cs activities results from the redistribution of the post-Chernobyl ^{137}Cs fallout. The question is to what extent the redistribution was caused by the slope processes taking place over the time since May 1986, and to what extent this resulted from the redistribution of caesium before it was absorbed by fine soil particles (Higgitt *et al.* 1992). In case of the pre-Chernobyl caesium the long term fallout from the test explosions caused more even distribution of caesium than the single, short-term Chernobyl fallout. The essential problem to explore seems to be the length of time which was needed to bind caesium to the soil particles. The studies led in England (Linsley *et al.* 1981) have shown that it may take even 3 years until the majority of fallout caesium is bound to soil particles. The length of the time depends on physical and chemical properties of soil. Exchangeable K^+ and pH are two of them (Schuller *et al.* 1988). Caesium ions, which remain unattracted by the soil particles are accessible for roots of plants and then the ways of caesium circulation are getting more and more complex.

CONCLUSIONS

The study of caesium distribution in soil was undertaken for a single forested slope. Despite the simplicity of the case (small area, uniform geology, soils and vegetation) the substantial differentiation of ^{137}Cs content in soil was detected. In spite of many factors which can influence the ^{137}Cs redistribution in soil, geomorphic slope processes: soil erosion, transport and redeposition seem to play an important role in caesium migration on slopes.

However both humus content and granulometry of the deposits can influence the ability of soil to bind ^{137}Cs particles, in case of the discussed slope the correlation between ^{137}Cs content, humus content and the sorting index of the deposits seem to be the result of the same geomorphic processes taking place on the slope, rather than the result of influence of the soil characteristics on caesium storage. Because of its convexity the central part of the slope is subject to more intensive soil wash than the other parts. Soil wash, even it is generally

unintensive, which is a rule for the forested areas, may lower humus content which in turn may lower the permeability of soil. Then the natural conditions are becoming more and more favourable for the surface runoff of water, which may increase the degradation of the mid-slope soil cover and agradation of the bottom deposits. It is still unclear what the role of the redistribution of caesium is before it is bound to soil particles and then redeposited by slope processes. What is a role of diffusion of the isotope in soil as well as the role of plants and soil fauna in caesium redistribution? These problems has not yet been discussed in literature concerned on ^{137}Cs applications to soil erosion studies.

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STRESZCZENIE

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WPLYW CZYNNIKÓW NATURALNYCH NA ZAWARTOŚĆ ¹³⁷Cs W GLEBIE NA PRZYKŁADZIE STOKU LEŚNEGO POŁOŻONEGO NA POGÓRZU KARPACKIM

Na przykładzie zalesionego stoku położonego na Pogórzu Karpackim dokonano analizy wpływu rzeźby, zawartości humusu w glebie, granulometrii gleby i jej przepuszczalności na rozkład izotopu cezu-137, w tym cezu pochodzącego sprzed i po katastrofie w Czarnobylu (kwiecień 1986). Zawartość ¹³⁷Cs jest znacznie zróżnicowana (Tab. 1–4, Ryc. 2, 6 i 7), przy czym najwyższą koncentracją odznaczają się utwory glebowe znajdujące się w dnie doliny u podnóża stoku, a najniższą — utwory środkowej części stoku. Koncentracja ¹³⁷Cs w wysokim stopniu koreluje ze stopniem wysortowania utworów (Ryc. 3, 4) oraz zawartością w nich humusu (Ryc. 5). Korelacja ta spowodowana jest tym, iż zróżnicowanie wszystkich trzech charakterystyk badanych utworów (zawartości cezu, stopnia wysortowania i zawartości humusu) wynikać może z zachodzących na stoku procesów erozji i transportu materiału oraz deponowania go w dnie doliny. Nasuwa się jednak pytanie, w jakim stopniu zróżnicowanie zawartości cezu wynikać może z jego redystrybucji na stoku, zanim został on związany z cząsteczkami gleby. Wobec generalnie niewielkiego tempa erozji gleby, co stanowi regułę w odniesieniu do stoków zalesionych, proces ten wraz z przemieszczaniem cezu z cząstkami gleby przez organizmy zwierzęce, jego migracja spowodowana procesami życiowymi roślin oraz dyfuzją, mogą stanowić czynnik utrudniający oszacowanie natężenia procesów stokowych.