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ISOTOPES: CESIUM-137 AND POTASSIUM-40 IN SOILS OF THE *POWIAT* OF GARWOLIN (PROVINCE OF MAZOWSZE)

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Abstract

In 2005, in the administrative district *(powiat)* of Garwolin (the Province of Mazowsze), the samples of forest, cropland and fallow land soils were collected from three depths: 0-3 cm, 3-7 cm, 7-12 cm. The litter from the sampling sites located in forests was also collected for studies. In the samples, the contents of isotopes ^{137}Cs and ^{40}K were measured. The highest amount of ^{137}Cs was measured in litter and the upper layer of forest soils; the content of the isotope decreased in deeper layers of the soil. Forest soils were the richest in ^{137}Cs; fallow and cropland soils contained less of this isotope. The content of ^{40}K in forest and fallow land soils did not depend on the depth from which the samples were collected. The highest amount of ^{40}K isotope was found in arable soil, the lowest – in forest soils. The content of ^{137}C in the soils decreased as the soil reaction increased but rose at higher organic carbon content. The content of ^{40}K isotope correlated negatively with the soil reaction and with the content of sand fraction but it correlated positively with the content of clay fraction.

Key words: radioactivity isotopes, cesium-137, potassium-40, forest soil, fallow land, field, Garwolin powiat.

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IZOTOPY CEZU-137 I POTASU-40 W GLEBACH POWIATU GARWOLIN (WOJEWÓDZTWO MAZOWIECKIE)

Abstrakt

W 2005 r., w glebach powiatu Garwolin (woj. mazowieckie) z trzech poziomów: 0–3 cm, 3–7 cm i 7–12 cm pobierano do badań próbki gleb leśnych oraz nieużytkowanych i użytkowanych rolniczo jako pola uprawne. Dodatkowo w punktach poboru gleb leśnych pobrano do badań ściółkę leśną. W próbkach oznaczono zawartość izotopów ^{137}Cs i ^{40}K. Największą zawartość ^{137}Cs zmierzono w ściółce i powierzchniowej warstwie gleb leśnych, w głąb gleby zawartość izotopu się zmniejszała. Najbardziej wzbogacone w ^{137}Cs były gleby leśne, gleby nieużytkowane rolniczo i pola uprawne zawierały mniejsze ilości tego izotopu. W wierzchnich warstwach gleb leśnych i nieużytków zawartość ^{40}K nie zależała od głębokości poboru prób, natomiast była zależna od sposobu użytkowania gleby. Największe ilości izotopu ^{40}K zmierzono w badanej warstwie gleb ornych, najmniejsze w glebach leśnych. Zawartość ^{137}Cs w badanych glebach zmniejszała się wraz z ze wzrostem odczynu gleby i wzrastała wraz z zawartością węgla organicznego. Zawartość potasu-40 była skorelowana ujemnie z odczynem gleby i zawartością frakcji piasku oraz dodatnio z zawartością frakcji iłu.

Słowa kluczowe: radioaktywne izotopy, cez-137, potas-40, gleba leśna, nieużytek rolny, pole uprawne, powiat Garwolin.

INTRODUCTION

^{137}Cs and ^{40}K isotopes are forms of the elements that differ only very slightly in their chemical properties but are of different origins. Cesium has one stable isotope (^{133}Cs) and 20 artificial radioactive isotopes (AVERY 1996). The latter group includes ^{137}Cs isotope, which escaped to the environment as a result of the 1986 Chernobyl disaster in the amounts estimated at 85 PBq. Due to its long half-time ($T_{1/2}$ = 30.1 years), the isotope persists in the environment. The content of ^{137}Cs isotope in soil depends on the level of radioactive contamination and the type of soil. In Poland, the Central Anti-Radiation Protection Laboratory reported the average concentration of ^{137}Cs in soil at 18.8 Bq kg^{-1} in 2004 (BIERNACKA, ISAJENKO 2006). Substantial amounts of ^{137}Cs are detected in the surface layers of soil (e.g. DOŁHAŃCZUK-ŚRÓDKA et al. 2002, KUBICA 2002, ZHIYANSKI et al. 2005, PACHOCKI et al. 2006), but particularly high concentrations of ^{137}Cs are present in forest soils, where the isotope is very well absorbed by organic matter (e.g. VAN BERGEIJK et al. 1992, ZGŁOBICKI 2002, DOŁCHAŃCZUK-ŚRÓDKA et al. 2005). Cesium is taken up by the root system of a plant, and its highest concentrations are observed in plants with roots in the upper layers of the soil, e.g. mosses and fungi (FALANDYSZ and CABOŃ 1992, AVERY 1996, WACŁAWEK et al. 2000).

Under natural conditions, potassium appears in three isotopic forms: ^{39}K (93.08%), ^{40}K (0.0119%) and ^{41}K (6.91%), with only ^{40}K being radioactive ($T_{1/2}$ = $1.32 \cdot 10^9$ years) (POLAŃSKI 1961). Potassium in soil mainly binds with inorganic particles (RACZUK 1990, BROGOWSKI, CHOJNICKI 2005).

The nuclei of ^{137}Cs and ^{40}K isotopes are subject to β-transformation, which is accompanied by the emission of γ-quanta with energies of 0.661 MeV and 1.46 MeV respectively.

The activity of ^{40}K isotope is directly proportional to the total content of potassium in soil – 1 g of potassium contains 31.7 Bq of ^{40}K (KUBICA 2002). The content of ^{40}K isotope depends on the type of soil (NIESIOBĘDZKA 1999, KUBICA 2002) as well as on human activity, e.g. spraying fields with potassium fertilizers. The mean activity of ^{40}K in soil is 400 Bq kg^{-1} (EISENBUD, GESELL 1997).

Following the breakdown of the Chernobyl power reactor in 1986, different regions of Poland became contaminated to a varied degree (BIERNACKA, ISAJENKO 2006). In 2004, particularly high activity of soil was observed in the following provinces: Opole, Silesia, Lower Silesia and Małopolska. The average concentration of ^{137}Cs in the soils of Masovia was slightly below the mean values marked for Poland (BIERNACKA, ISAJENKO 2006).

As ^{137}Cs and ^{40}K isotopes have similar chemical properties, it was interesting to determine their contents in the soils in the powiat of Garwolin, the Province of Mazowsze (Masovia) and establish the connection between their concentrations and soil use as well as soil physical and chemical parameters.

The scope of the research covered:

– determination of the activities of ^{137}Cs and ^{40}K isotopes in soils under forest, fields and fallow lands,
– assessment of the migration of the isotopes into the soil profile,
– correlation between the activities of ^{137}Cs and ^{40}K in soils and selected soil parameters (reaction, Corg content, granulometric composition)

The area of the research

The research was carried out in the *powiat* of Garwolin, situated in the Central-Masovian Lowlands (KONDRACKI 1988). In the area podzol soils are predominant. The *powiat* of Garwolin is an agricultural area (POLKOWSKI, JANISZEWSKA 2004). The samples were taken in four villages: Borowie, Samogoszcz, Skurcza and Wróble.

MATERIAL AND METHODS

The samples were picked up in October 2005. In each of the villages, samples of forest, fallow land and cropland soils were picked up. Additionally, forest litter was sampled to be analyzed. The samples came from the surface layers of soil to a depth of 12 centimeters. The forest and fallow land soils were collected so that the soil core 12 cm high could be obtained. The cores were then cut into three parts, the uppermost of which was taken from a maximum depth of 3 cm, the middle one – from a depth of 3 – 7 cm, and the bottom one – from a depth of 7 – 12 cm. Each subsample weighed *ca* 1 kg. Altogether, 12 samples of forest soil, 4 samples of litter, 12 samples of fallow land soil and 4 samples of arable land soil were picked up.

The samples were initially air-dried. Then they were dried at 60°C and finally sifted through a sieve with holes 2 mm in diameter. In the soil samples the following parameters were determined: reaction in 1 M KCL, Corg content with the use of Tiurin method, granulometric composition with the use of Bouyous aerometric method modified by Casagrande and Pruszyński (OSTROWSKA et al. 2001). The soils were classified into granulometric groups according to the Polish Standard PN–R –04033 (1998).

The activities of ^{137}Cs and ^{40}K isotopes were marked in the soil and litter samples with the use of ă-spectrometry method and a semi-conductor spectrometer with a coaxial germanium detector made by Canberra Company. The spectrum analysis was carried out with Genie 2000 Application Software. The measurement of each sample took 80.000 seconds.

The results of the analysis of the concentrations of ^{137}Cs and ^{40}K isotopes in the soils and of the chosen physical and chemical parameters of the soils were put to a statistical analysis. Pearson's linear correlation coefficients were calculated using a Statistica 5.0 software package.

RESULTS

The soils were sandy soils, mainly represented by weakly loamy sand and loamy sand. The soils were acid in reaction, with pH values ranging from 3.07 to 5.94. In forest soils, the surface layers (up to a depth of 3 cm) had the lowest pH values (3.33), the deeper into the soil (7–12 cm), the higher the reaction (up to pH = 4.00). No such regularities were observed in fallow land soils. Cropland soils had the weakest acid reaction.

In most soils, the content of organic carbon did not exceed 2%. The surface layers of forest soils contained most organic carbon (1.150% on average). Deeper into the soil, this percentage decreased to 0.418%. Fallow land soils did not reveal such a tendency. The average Corg content in the analyzed layer of ploughed soils was comparable with that in forest soils (Table 1).

The highest activity of ^{137}Cs was detected in litter – 62.84 Bq kg^{-1} on average. Its surface layer contained the largest amount of the isotope (mean activity – 37.72 Bq kg $^{-1}$). Deeper in the soil the value drastically decreased to 4.509 Bq kg^{-1} (the layer 7 – 12 cm deep) (Figure 1a). The mean concen-

Table 1
Tabela 1

Physical and chemical properties of the soils of the powiat of Garwolin
Właściwości fizyczno-chemiczne gleb powiatu Garwolin

Fractions of soil	(mm)		Soils			Range
			forests	fallow land	field	
Sand	2v0.05	%	84.8	82.3	76.0	69–93
Silt	0.05v0.002		12.6	14.5	19.7	7–28
Clay	<0.002		2.6	3.2	4.3	2-–6
Reaction		pH	3.33	4.43	5.14	3.07–5.94
Corg		%	0.662	0.393	0.677	0.055–2.271

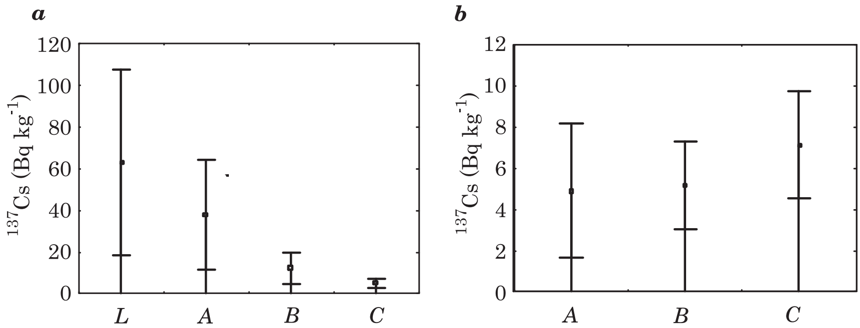

Fig. 1. The mean content of 137Cs (±SD) in the layers of forest (a) and wasteland soils (b) of the Garwolin county
L – litter, layers of soils: A – 0–3 cm, B – 3–7 cm, C – 7–12 cm
Rys. 1. Średnia zawartość 137Cs (±SD) w warstwach gleb leśnych (a) i nieużytków (b) powiatu Garwolin
L – ściółka, warstwy gleby: A – 0–3 cm, B – 3–7 cm, C – 7–12 cm

tration of ^{137}Cs isotope in forest soils at a maximum depth of 12 cm was 15.53 Bq kg $^{-1}$. The mean activity of ^{137}Cs in fallow land soils at a maximum depth of 12 cm was 5.915 Bq kg $^{-1}$. Unlike forest soils, fallow land soils contained slightly higher concentrations of ^{137}Cs – 7.124 Bq kg $^{-1}$ in their bottom layers (7-12 cm deep). In the uppermost (0-3 cm deep) and middle (3-7 cm deep) layers the activities of ^{137}Cs were 4.917 and 5.152 Bq kg $^{-1}$, respectively (Figure 1b). In cropland soils the mean concentration of ^{137}Cs isotope was 9.657 Bq kg^{-1} (Figure 2).

The activities of ^{40}K in the soil samples ranged between 97.15 and 215.0 Bq kg $^{-1}$. The samples of arable soil had the highest content of ^{40}K (173.7 Bq kg $^{-1}$ on average) – Figure 2) and the samples of forest soils – the lowest content (126.4 Bq kg^{-1} on average). The concentrations of po-

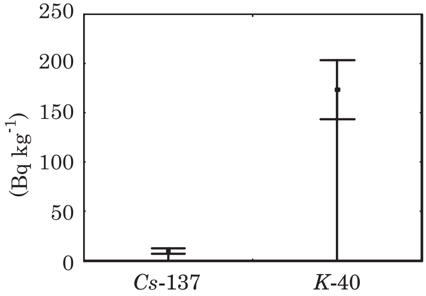

Fig. 2. The mean contents of 137Cs and 40K (±SD) in ploughland soils of the Garwolin county

Rys. 2. Średnia zawartość 137Cs i 40K (±SD) w glebach ornych powiatu Garwolin

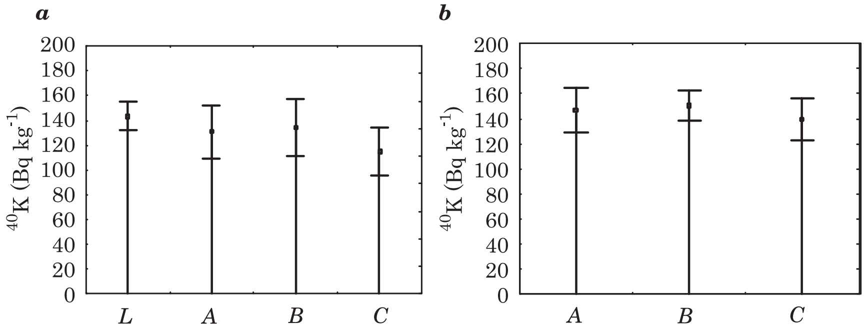

Fig. 3. The mean content of 40K (±SD) in the layers of forest (a) and wasteland soils (b) of the Garwolin county
L – litter, layers of soils: A – 0–3 cm, B – 3–7 cm, C – 7–12 cm

Rys. 3. Średnia zawartość 40K (±SD) w warstwach gleb leśnych (Rys. 2a) i nieużytków (b) powiatu Garwolin
L – ściółka, warstwy gleby: A – 0–3 cm, B – 3–7 cm, C – 7–12 cm

tassium in the individual layers of forest (Figure 3a) and fallow land soils (Figure 3b) did not differ considerably.

The concentrations of ^{137}Cs in the analyzed soils were significantly correlated: positively with Corg content and negatively with the soil reaction. The concentrations of ^{40}K were positively correlated with the soil reaction and the content of a clay fraction, but negatively correlated with a sand fraction (Table 2).

Table 2
Tabela 2

Pearson's correlation factors for ^{137}Cs and ^{40}K activity concentrations and some physical and chemical properties of soils (*p* - level of significance)
Współczynniki korelacji liniowej Persona między zawartością Cs-137 i K-40 w glebach a wybranymi właściwościami fizyczno-chemicznymi gleb

Isotopes	pH	% Corg	Fractions of soils		
			sand	silt	clay
Cs-137	-0.4923 p=0.008	0.5002 p=0.007	ns	ns	ns
K-40	0.6968 p<0.001	ns	-0.3800 p=0.046	ns	0.5609 p=0.002

DISCUSSION OF THE RESULTS

The mean activities of ^{137}Cs marked in the soil samples taken near Garwolin are reported (BIERNACKA, ISAJENKO 2006) to have been lower than the mean activities of the isotope elsewhere in Poland in 2004.

Out of the three types of soil it is the forest soil that contains the highest concentration of radioactive cesium, particularly in its surface layer. This fact is also pointed out by other authors, e.g. DOŁCHAŃCZUK-ŚRÓDKA i in. (2005, 2006), KUBICA (2002), ZGŁOBICKI (1992). The high activity of ^{137}Cs in a surface layer of the soil in forest areas results from the accumulation of the isotope in litter (ZGŁOBICKI 1992), which is confirmed by the author's study. Cesium is definitely better absorbed by plants from sandy soils than from clayey soils. Sand-rich soils are characterized by low retention of the element (CHIBOWSKI et al. 1994). The analyzed soils were represented by sands and they had a relatively low content of silt and clay fractions.

The concentration of cesium in arable soils was definitely smaller than in forest soils. Harvest of crops contributes to a decrease in the content of cesium in cropland soils (GRABOWSKI et al.1993). Moreover, cropland soils were less acidic than forest soils. The statistical analysis showed that the reaction of soils was reversely proportional to the concentration of ^{137}Cs, which is indicated by the Pearson's linear correlation coefficient between the activity of ^{137}Cs and the reaction of soil. The research also demonstrated positive correlation between the concentration of ^{137}Cs and organic carbon. The reports (e.g. DOŁCHAŃCZUK-ŚRÓDKA et al. 2005, 2006, VAN BERGEIJK et al. 1992, ZGŁOBICKI 2002) point out that the highest concentrations of radioactive cesium are found in the genetic layers of the soil, where humus is formed. Organic matter is a filter, in which various elements, including radioactive cesium, accumulate.

Potassium, represented by ^{40}K isotope, has chemical properties resembling those of cesium. Potassium mainly binds with inorganic parts of the soil (RACZUK 1990, BROGOWSKI and CHOJNICKI 2005), and the activity of ^{40}K isotope is directly proportional to the total content of potassium in soil, which depends on the type of soil and the soil use (NIESIOBĘDZKA 1999, KUBICA 2002). The author's research showed that more potassium was in cropland than in forest soils. This result was entirely predictable. Fields are sprayed, inter alia, with potassium fertilizer. The analyzed soils were mainly sandy soils. More potassium is washed away from sandy soils than from loess or clayey soils as the former type of soil has a low content of clay fraction and, consequently, demonstrates poor ability to soak up ions (TERELAK, SADURSKI 1981). CHIBOWSKI et al. (1994) point out the relationship between the potassium concentration and the content of a clay fraction in the soils. The present study confirmed such observations by establishing statistically significant positive correlation between the clay content and the activity of ^{40}K isotope in the soils.

The results of determination of the ^{137}Cs content in the soils are diverse in comparison with the ^{40}K content, which is due to the uneven contamination of the area after the breakdown of the power reactor in Chernobyl. The ^{40}K content in the soils depends on the composition of primary minerals. The results of determination of the ^{40}K content in the soils near Garwolin indicate that the soils, including the surface layers of field soils, are relatively poor in potassium. The potassium content in the soils in the *powiat* of Garwolin, derived from from the activity of ^{40}K isotope and corresponding to 0.55% of the potassium content in the soil, is below the mean values reported by PONDEL et al. (1979) for an arable layer of soils in Poland. A statistically significant positive correlation between the ^{40}K content in the soils and the content of a clay fraction confirms other reports (MERCIK 1982, ŁABĘTOWICZ and RUTKOWSKA 2001), indicating that the potassium content in soil is affected by the content of mineral fractions, including clay fractions, rather than by organic fractions of the soil.

^{137}Cs and ^{40}K isotopes in the soils in the *powiat* og Garwolin behave differently although they are forms of elements that have similar chemical properties.

CONCLUSIONS

1. The contamination of the soils in the powiat of Garwolin nearly 20 years after the breakdown of the power reactor in Chernobyl is below the average for Poland. The highest activities of ^{137}Cs were observed in forest soils. The isotope was less active in cropland and fallow land soils.

The largest amounts of ^{137}Cs isotope accumulate in the surface layers of forest soils (to a depth of 3 cm).

2. The soils in the *powiat* of Garwolin powiat contain relatively little potassium. Cropland soils are the richest and forest soils – the poorest in potassium. The surface layers of the soils contain similar amounts of potassium, independently from the depth from which samples are picked up.

3. The concentration of ^{137}Cs isotope is positively correlated with the Corg content and negatively correlated with the soil reaction.

4. The content of ^{40}K isotope is positively correlated with the soil reaction and the content of a clay fraction, but negatively correlated with the content of a sand fraction.

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