Leaching of strontium from *Albic Retisol* limed with Sr-containing industrial waste

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Abstract

To study the intensity of migration of stable strontium (Sr) from the light-textured *Albic Retisol* with different levels of humus content, a column experiment was carried out. As the Sr-containing lime, conversion chalk (CC) as a by-product of nitrogen fertilizer production containing 90% $CaCO_3$ and 1.5% Sr was used. The experiment included 8 washings, where the eluates of each leachate were analysed for the content of Sr leached from the light-textured *Albic Retisol* from meadow and forest soils. In a native high-humus soil, complete removal of mobile Sr was achieved by the 3rd washing; in the low-humus soil, Sr leaching began only after the 3rd washing and did not end after the 8th washing. The total amount of Sr washed out from the low-humus soil exceeded that of Sr removed from the soil with a high-humus content by 1.3 times and amounted to 0.21 and 0.16 mg, respectively. Liming of the soil with the waste CC led to its increased leaching of Sr 6.1 mg from low-humus soil and 3.8 mg from high-humus soil. The share of CC-Sr leached from limed soils was 24.3% from high-humus soil and 39.2% from low-humus soil of the amount applied with chalk. Empirical equations developed adequately explained the processes of elution of Sr from native and limed soils. Average rates of the Sr leaching under the simulated precipitation were: for the native low-humus soil −0.29 lg(mg) per year, for the calcareous low-humus soil −0.24 lg(mg) per year and for the calcareous high-humus soil −0.17 l lg(mg) per year.

In the agricultural systems, where systematic and prolonged liming of soils with an ameliorant containing Sr, in order to prevent the ingress of excessive amounts of Sr into the human body, a systematic monitoring of the content of Sr in food chains is required.

Key words: stable strontium, migration, *Albic Retisol*, empirical equations, liming.

Introduction

Strontium (Sr) is an alkaline earth metal that is widespread in nature (Koshy, Pathak, 2020). The average content of stable Sr in the Earth's crust is 0.04%, and in soils not contaminated with Sr it ranges from 0.01% to 0.28%. Naturally occurring Sr is abundant in the Earth's crust – ranking 15th at 340 ppm (Burger, Lichtscheidl, 2019) in a form of nonradioactive celestite ($SrSO_4$) and strontianite ($SrCO_3$) (Sharma, 2020). Strontium occurs naturally in the Earth's mantle as a mixture of four stable isotopes, i.e., Sr-84, Sr-86, Sr-87 and Sr-88 (Gupta et al., 2018). The stable and radioactive Sr isotopes act identically in most physical, chemical and biological processes (Nedobukh, Semenishchev, 2020). In addition, due to similar characteristics of Sr with calcium (Ca), it enters bodies of organisms via accumulation onto the tissues and bones (Pathak et al., 2020).

In agricultural systems, anthropogenic sources of Sr are fertilizers and ameliorants made from phosphate raw materials (phosphorites and apatites), where Sr is in an isomorphic admixture (Лаврищев, Литвинович, 2019). One of such sources of Sr is a conversion chalk (CC) that is a waste by-product of nitric acid processing

of phosphate raw materials in the production of nitrogen fertilizers. The content of stable Sr in CC is about 1.5%. Thomsen and Andreasen (2019) found that the use of agricultural lime was the largest source of anthropogenic Sr in the Karup catchment area, Denmark.

Recently, researchers particularly have focused their interests on Sr found in soil-groundwater systems (Pathak et al., 2020; Sharma, 2020), since it is highly reactive (Srivastava, Ilyas, 2020), and in aqueous solution it can be bioavailable (Chatterjee et al., 2020; Ilyas et al., 2020).

The available literature data on the migration capacity of Sr are contradictory. In the studies of Маковский et al. (2008), two years after liming of *Albic Retisol* with conversion chalk at a dose of 9.9 t ha^{-1}, the presence of Sr in drainage waters sampled from a depth of 1 m was not established. On the contrary, irrigation of oasis-gray soil during cotton cultivation led to the movement of Sr to a depth of 110–120 cm (Литвинович, Павлова, 1999). Strontium migrating through soil stratum leaches into groundwater and surface water. Content of carbonates significantly affects the ratio of $^{87}Sr/^{86}Sr$ in surface water bodies affected by liming of agricultural soils (Thomsen, Andreasen, 2019).

Currently, the literature recognizes such mechanisms responsible for the movement of Sr in soil: (1) convective transport with water flow (Cameron, Klute, 1977; Novák, Hlaváčiková, 2019) during infiltration of atmospheric precipitation in the form of soluble salts and complex compounds with organic ligands (Лаврищев, Литвинович, 2019) or mechanically transported solid particles; and (2) due to diffusion in the soil solution (Isermann, 1981; Cole et al., 2000; Kudzin et al., 2020).

The predominant form of vertical migration of Sr is migration in ionic form (Dubchak, 2018; Sharma, 2020). Earlier studies established that some soil humic substances can fix Sr preventing from leaching (Лаврищев, Литвинович, 2019), but the different fractions of soil humus can have different effect on releasing and fixing Sr in soil solution (Burger, Lichtscheidl, 2019). Generally, organic complexation allows Sr to bind and reduce its mobility. However, the scale of migration of Sr in soils with a percolation type of water regime of different levels of humus content remains unclear.

Studies on migration capacity of Sr in *Albic Retisol* limed with Sr-containing industrial wastes are scarce (Lavrishchev et al., 2021). Empirical equations that adequately describe the processes of leaching of Sr in native and reclaimed soils have also not been developed. As a working hypothesis of the present experiment, it was suggested that the migratory mobility of stable Sr in soils of different levels of humus content should differ.

The aim of the research was to conduct a coupled study of the intensity of migration of stable Sr from light textured *Albic Retisol* with different levels of humus content in the column experiment. The tasks included: (1) to establish the scale of migration of Sr in native low-humus and reclaimed soils; (2) to reveal the proportion of soil Sr migrating in reclaimed soil; (3) to develop leaching empirical equations that adequately describe the leaching of Sr during repeated soil wetting, simulating the annual amount of moisture seeping from atmospheric precipitation; (4) to establish the rate of decrease of Sr content in eluates as the experiment proceeds.

Materials and methods

Description of studied soils. The column experiment was conducted at the St. Petersburg State Agrarian University, Russia in 2020 on a light-textured *Albic Retisol* (WRB, 2015). Soil No. 1 was sampled from the native perennial meadow, and soil No. 2 – from native forest.

Table 1 shows basic physicochemical characteristics of the studied soils.

The data from Table 1 indicate that the soils were acidic and had almost the same pH$_{KCl}$ value and hydrolytic acidity (Hy): 5.4 and 5.6 mmol (eq) 100 g^{-1}. The total strontium (Sr) content in the soils was close to the background level (156 mg kg^{-1}) of *Albic Retisol* in the North-West of the non-Chernozem zone of Russia (Муравьёв и др., 2015). The soils had a similar content of the particles <0.001 and <0.01 mm in size.

Table 1. Physicochemical characteristics of the studied *Albic Retisol*

Humus %	pH$_{KCl}$	Hydrolytic acidity	Exchangeable acidity	Sr mg kg^{-1}	Soil particles %	
		mmol (eq) 100 g^{-1}			<0.001 mm	<0.01 mm
Soil No. 1 (meadow)						
3.02 ± 0.02	4.1 ± 0.1	5.4 ± 0.05	2.5 ± 0.04	135 ± 2.10	6.86 ± 0.04	18.6 ± 0.60
Soil No. 2 (forest)						
1.76 ± 0.01	4.2 ± 0.1	5.6 ± 0.03	0.75 ± 0.03	112 ± 1.30	8.98 ± 0.05	21.6 ± 0.32

$\bar{x} \pm s$, where $\bar{x}$ – sample mean, s^2 – sample variance, calculated by replicates

The total chemical composition of the soils was determined by the sintering method (Новицкий и др., 2009). The content of soil humus was determined by the Tyurin wet-digestion method (Новицкий и др., 2009). The content of Sr in the leachates was determined by X-ray fluorescence spectral analyser ORTEC-6111-TEFA (ORTEC Inc., USA). The total content of Sr was determined on an atomic absorption spectrophotometer (Shimadzu, Japan). The hydrolytic acidity (Hy) was determined according to Kappen (1929): 0.5 M dm^{-3} Ca-acetate solution adjusted to pH 8.2 was added to the soil in the ratio of 1:2.5. After 1 hour of shaking the suspension was filtrated and followed by titration with 0.1 M dm^{-3} NaOH solution. The Hy values were calculated from the amount of alkali consumed (0.1 M dm^{-3} NaOH cm^3 for 50 g soil). Exchangeable acidity was determined by the extraction of exchangeable hydrogen and aluminium ions from the soil with a solution of KCl with a concentration of 1 mol dm^{-3} at a soil-to-solution ratio of 1:2.5 and subsequent potentiometric titration of the filtrate with sodium hydroxide to pH 8.2 (GOST 26484-85. Soils. Method for determining exchangeable acidity). The soil texture was determined by the Kachinsky method (Новицкий и др., 2009); the texture of the conversion chalk was determined by the sieve method.

The total chemical composition of soils is given in Table 2. The soil from meadow vegetation was characterized by a significantly higher humus content.

Description of liming material conversion chalk (CC). As the Sr-containing material, CC containing 90% CaCO$_3$ and 1.5% Sr was used. It has been used as a liming material for more than 20 years in the Novgorod region, Russia. The reclamation properties of CC are described in detail by Литвинович et al. (2013) and Лаврищев and Литвинович (2019). The bulk of the chalk is represented by particles with a size of <0.25 mm (99.8%). This predetermines its high reactivity and rapid dissolution in soils (Table 3).

Experimental design and calculations. The experimental design included two treatments with four replications on the meadow and forest soils with a low- and high-humus content: 1) washing of native soil (control) and 2) washing of limed soil. The height of the soil layer in the funnel was 17 cm, and the weight was 350 g. The density of the filling was 1.0–1.1 g cm^{-3}. In total, 8 washings were performed for both soils (Figure 1).

The effect of different levels of humus on the migration ability of Sr was studied in treatments No. 1 and No. 2 using separating funnels. Before filling the

Table 2. The total chemical composition (%) of the studied *Albic Retisol*

Loss on ignition	SiO$_2$	R$_2$O$_3$	Fe$_2$O$_3$	Al$_2$O$_3$	CaO	MgO	P$_2$O$_5$	SO$_3$	MnO
6.15 ± 0.02	81.09 ± 0.08	9.28 ± 0.04	1.19 ± 0.01	7.97 ± 0.06	0.44 ± 0.03	0.47 ± 0.04	0.11 ± 0.02	0.51 ± 0.03	1.50 ± 0.06
4.75 ± 0.01	82.27 ± 0.06	9.12 ± 0.05	1.89 ± 0.02	8.38 ± 0.05	0.29 ± 0.02	0.30 ± 0.03	0.09 ± 0.01	0.38 ± 0.02	1.47 ± 0.08

$\bar{x} \pm s$, where $\bar{x}$ – sample mean, s^2 – sample variance, calculated by replicates

funnels, the soils were limed with the chalk at a full dose of 1000 mg Hy per column and composted at 28°C temperature in a thermostat for 30 days, stirring regularly. Humidity during composting was maintained at 60% field moisture capacity. After composting, the soils were dried and ground by passing through a sieve with a mesh diameter of 1 mm.

Washing was carried out with a strictly calculated amount of distilled water simulating the volume of moisture seeping through the soil layer annually. The calculations were based on the following data: (1) the annual precipitation in the North-West of the Non-Chernozem zone of Russia ranges from 600 to 650 mm (https://en.climate-data.org/asia/russian-federation/saint-petersburg/saint-petersburg-456/); (2) about 400 mm is spent on transpiration by plants and evaporation from the soil surface (Пестряков, 1977). Thus, 200 mm of precipitation per year seeps through the soil stratum.

Table 3. Particle size distribution (%) of conversion chalk

>2	2–1	1–0.25	0.25–0.16	0.16–0.09	0.09–0.063	<0.63
			mm			
0	0.3 ± 0.02	0.16 ± 0.02	4.3 ± 0.04	24.3 ± 0.08	41.3 ± 0.12	21.6 ± 0.1

$\bar{x} \pm s$, where $\bar{x}$ – sample mean, s^2 – sample variance, calculated by replicates

Figure 1. Laboratory experiment to study the migration ability of stable strontium (Sr) in the soil (photo by A. Lavrishchev)

The amount of water required for a single washing of one column was calculated by the formula:

$$V = \frac{\pi \times r^2 \times 200}{1000}$$, where π = 3.14; r is column radius, mm; 1000 – conversion to millilitre.

According to calculations, 400 ml of distilled water was used for one washing. In total, 8 washings were carried out simulating 8 annual soil wetting with atmospheric moisture. The Sr content in the leachates was determined using an atomic adsorption spectrophotometer (Shimadzu). Considering the fact that one wash simulates the annual volume of percolating moisture and a year passes between washings in nature, the time is measured in years. Since we logarithm the data using the generalized regression, therefore the unit of measure for rate of leaching (v_1, v_2 and v_3) is lg(mg) per year. This appproach is often used in data analysis and empirical modeling to avoid negative values in the models. Construction of mathematical equations was carried out according to Буре (2007).

Results and discussion

The data given in Table 4 show that Sr was washed out of the soil due to wetting. The maximum content in the eluates removed from the native meadow soil was found in the filtrate of the 1st washing (0.12 mg). In the eluates of the 2nd washing, the amount of migrating Sr decreased three times and amounted to 0.04 mg. In the wash water of 3–8 washings, the presence of Sr was not established. This implies that complete removal of the mobile compounds of Sr was achieved by the 3rd washing. The total amount of leached Sr from the native meadow soil was 0.16 mg. The pool of stable Sr compounds capable of migrating in high-humus soil was not high and was equal to 0.18% of its total content. Due to the rapid removal of Sr from the high-humus soil, an empirical equation could not be created.

A different nature of migration was established in native forest soil with a low-humus content. No Sr was found in the filtrates of the first 3 washings. In the filtrate of the 4th washing, the Sr content was 0.09 mg, in the 5th washing it is decreased to 0.04 mg and then it ranged from 0.02 to 0.03 mg until the end of the experiment. Due to the termination of the experiment, it was not possible to establish whether all soil Sr capable of migration in low-humus forest soil was removed after 8 washings. However, in general, the amount of Sr migrating in native forest soil with a low-humus content was 1.25 times higher than that from high-humus soil.

Since empirical equations cannot take negative values and must correspond to the dynamics of the studied indicator with an increase in the number of washings, the logarithm of the initial data was used to construct
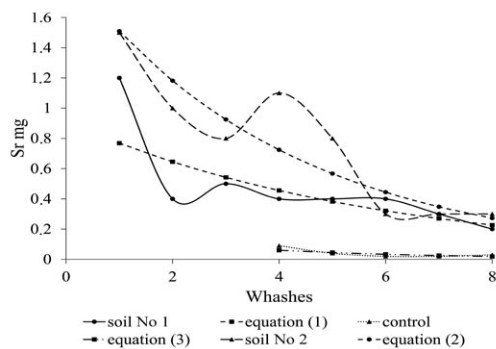
Table 4. The amount (mg) of leached strontium (Sr)

Washing	Soil No. 1 (meadow)		Soil No. 2 (forest)	
	native (control)	limed with 1 Hy	native (control)	limed with 1 Hy
1	0.12 ± 0.03	1.2 ± 0.2	0	1.5 ± 0.3
2	0.04 ± 0.01	0.4 ± 0.1	0	1.0 ± 0.2
3	0	0.5 ± 0.15	0	0.8 ± 0.2
4	0	0.4 ± 0.15	0.09 ± 0.02	1.1 ± 0.3
5	0	0.4 ± 0.1	0.04 ± 0.01	0.8 ± 0.15
6	0	0.4 ± 0.09	0.02 ± 0.004	0.3 ± 0.07
7	0	0.3 ± 0.1	0.02 ± 0.004	0.3 ± 0.06
8	0	0.2 ± 0.04	0.03 ± 0.005	0.3 ± 0.06
Σ	0.16	3.8	0.2	6.1
%	0.12	24.3	0.18	39.3

% – in native soil from the initial content (control) and in limed soil from the applied with conversion chalk (CC); $\bar{x} \pm s$, where $\bar{x}$ – sample mean, s^2 – sample variance, calculated by replicates; Hy – hydrolytic acidity

empirical equations. The paired linear regression after logarithm of the experimental data (starting from the 4th washing, t = 4) of leaching of Sr from the low-humus forest soil according to the empirical equation:

$$\ln (y_1) = -1.66 - 0.29 \times t, \qquad (1)$$

where t is conditional time (number of washings). Empirical equation (1) is significant by the F-test at a not high level of significance P-value $(F) = 0.158$ with the coefficient of determination $R^2 = 0.53$.

The average decay rate for the logarithmic data over the entire observation interval: $v_1 = -0.29$ lg(mg). The graph of equation (1), function $y_1'(t) = \exp(-1.66 - 0.29 \times t)$ is shown in the Figure 2.

Note. Soil No. 1 – meadow, soil No. 2 – forest; control – the native soil without liming; equation is an empirical description of Sr leaching.

Figure 2. Dynamics of strontium (Sr) content in leachates of the native soil without liming and with a conversion chalk (CC) limed soil

Liming the soils with CC increases the loss of Sr by leaching due to washings. The maximum amount of Sr in the limed meadow soil was also found in the filtrate of the 1st washing. In the eluates of the 2nd washing its content decreased to 0.4 mg (i.e., three times) and then until the end of the experiment ranged from 0.5 to 0.2 mg. Consequently, starting from the 2nd washing, the curve of Sr content in the washing waters was smooth. The total amount of leached Sr over the 8 washings (8 experimental years) was 3.8 mg. Considering that the amount of soil Sr leached in native and ameliorated soils is a constant value, then the share of leached CC-Sr was 24.3%. Thus, the complete removal of Sr due to washing did not occur. None of the eluates exceeded the maximum permissible concentration of Sr established for drinking water that is 7 mg L^{-1} (GOST 2874-82. Drinking water. Hygiene requirements and quality control).

The paired linear regression after logarithm of the experimental data of leaching of Sr from the limed high-humus soil according to the empirical equation:

$$\ln (y_2) = -0.089 - 0.17 \times t, \qquad (2)$$

where t is conditional time (number of washings). Empirical equation (2) is significant by the F-test at a very high level of significance P-value $(F) = 0.009$ with the coefficient of determination $R^2 = 0.7$. The average decay rate for the logarithmic data over the entire observation interval: $v_2 = -0.17$ lg(mg). The graph of equation (2), function $y_2(t) = \exp(-0.089 - 0.17 \times t)$ is shown in the Figure 2.

The maximum amount of Sr (1.5 mg) leached from the limed soil with a low-humus content occurred in the 1st washing. It by 1.25 times exceeded the amount of Sr leached from the high-humus soil in the 1st washing. Further, throughout the entire period of the experiment, the decrease in the Sr content in the leachates was of a stepwise nature. Thus, the amount of removed Sr in the filtrates from the 2nd to 4th washings varied from 1.1 to 0.8 mg. In the eluates of the 6th to 8th washings, the amount of Sr decreased and was at the level of 0.3 mg. A comparative analysis of the data on Sr content in the eluates of individual washings of the two treatments showed that in all cases the amount of Sr leached in the treatment with low-humus soil was greater than that from

the soil with a high-humus content. The exception was the 7th washing, where the amount of leached Sr in both treatments was the same.

The total loss of Sr over the entire period of the experiment from the low-humus soil was 6.1 mg (39.3% of the amount applied with chalk minus the share of the soil Sr). This is 1.6 times more than from the soil with a high-humus content. Complete removal of Sr applied with chalk did not occur over the 8 experimental years. None of the eluates was found to exceed the model predictive control (MPC) for Sr for drinking water.

The paired linear regression after logarithm of the experimental data of leaching of Sr from the limed low-humus meadow soil according to the empirical equation:

$$\ln (y_3) = 0.66 - 0.24 \times t, \qquad (3),$$

where t is conditional time (number of washings). Empirical equation (3) is significant by the F-test at a very high level of significance P-value $(F) = 0.0017$ with the coefficient of determination $R^2 = 0.83$. The average decay rate for the logarithmic data over the entire observation interval: $v_3 = -0.24$ lg(mg). The graph of equation (3), function $y_3(t) = \exp(0.66 - 0.24 \times t)$ is shown in Figure 2.

Empirical equations (2) and (3), built for the logarithmic data, have a very high level of significance according to F-test. The average decay rate for the logarithmic data over the entire observation interval for empirical equation (3) is higher than for empirical equation (2). Comparison of the decay rates for empirical equations (2), (3) and (1) is difficult, since the leaching volumes differ greatly and the process of leaching for non-limed low-humus soil No. 2 (forest) begins only from the 4th washing. The main difference between the treatments of the experiment is that the volumes of leaching for the treatment 2 and 3 (limed soils) are an order of magnitude larger than for the treatment with non-limed soil.

Strontium is an active water migrant (Claval et al., 2002; Dubchak, 2018) and highly reactive alkaline metal (Srivastava, Ilyas, 2020). It migrates especially vigorously in humid landscapes with Sr ahead of Ca in terms of the intensity of runoff into the ocean. On the contrary, in our earlier studies carried out in column experiment (Litvinovitch et al., 2015), the intensity of Ca migration exceeded the mobility of Sr. Humates and fulvates contribute to the fixation of Sr in soils. In the study of Лаврищев and Литвинович (2019), up to 50% of the total Sr in *Albic Retisol* was associated with humic acids. Sharma (2020) suggests that Sr is strongly fixed by organic substances, clay minerals and oxides in soil environment. In addition, low molecular weight organic substances released by the root system promote the binding of Sr in the composition of organomineral complexes and, as a result, its migration ability decreases (Лаврищев, Литвинович, 2019). So, organic complexation significantly reduces the mobility of Sr in soils. However, the binding of Sr in the organomineral complexes cannot prevent its losses from the soil due to vertical migration, since soil Sr can migrate as a part of organomineral complexes. Similarly, Dubchak (2018) also found that in the soil poor in humus and nutrients the mobility of Sr increased significantly, which in turn increased migration rate of ^{90}Sr in plants.

In a column experiment carried out on *Albic Retisol* light loamy soil limed with dolomite particles of various sizes containing 160 mg kg^{-1} Sr, the composition of organomineral complexes precipitated was studied (Pavlova et al., 2018). It was found that the content of Sr in the organomineral complexes varied from 0.67 to 3.1 g kg^{-1} of sediment. In the experiment with CC used for reclamation at a dose of 2.5 Hy, 5 years after liming the Sr content migrating in the organomineral complexes was also 3.1 g kg^{-1} (Pavlova et al., 2018). In addition, Frei et al. (2020) found that Sr derived from lime products is efficiently retained near the surface in agricultural farmland in Denmark. Nevertheless, it is eventually released into surface waters and thus significantly alters the isotopic signature of the naturally occurring bioavailable Sr. In addition, in our study, 99.8% of the chalk used was

composed by particles with a size of <0.25 mm (Table 3). This predetermines its high reactivity and rapid dissolution, since the finer the lime particle is the greater the reactive surface area of soils (Heinrich et al., 2020).

A number of studies have shown that the factors that most affect the migration ability of Sr in soil are moisture (Arapis et al., 1997; Dubchak, 2018; Zhang et al., 2019; Cai et al., 2020; Mikhailovskaya, Pozolotina, 2020) due to high mass flow of Sr in the liquid phase; soil humus content (Guillén, 2018; Burger, Lichtscheidl, 2019) due to its ability to fix Sr compounds; soil acidity (Kashparov et al., 2013; Burger, Lichtscheidl, 2019) and content of exchangeable Ca (Labunska et al., 2021). These parameters are important variables influencing migration ability of Sr in the soil, which can prevent its downward migration. Although soil organic complexes have the ability to retain Sr applied with lime, Oeser and Blanckenburg (2020) found that the loss of Sr from solid organic matter contributes to the establishment of the isotopic ratio of dissolved or bioavailable Sr.

Therefore, organic matter is a significant export route for Sr-reducing elements. In addition, surface soil layer containing higher amount of organic matter are prone to water erosion. This poses a risk of secondary contamination driven by horizontal migration contributing to the spread of Sr through the agricultural catchment area (Claval et al., 2002).

Conclusion

1. The rates of leaching of strontium (Sr) from native low-humus soil were −0.2 mg and from native high-humus soil −0.16 mg over the entire observation period implying a possibility of migration of certain compounds of stable Sr from native soil.

2. The total amount of Sr leached from the soil with a low-humus content was 1.25 times higher than that leached from the soil with a high-humus content.

3. Liming of soils with conversion chalk (CC) containing 1.5% Sr led to an increase in the volume of Sr leaching from the soil. Eluvial losses from the low-humus and high-humus soils corresponded to 39.3% and 24.3% of the amount applied with CC, respectively.

4. Systematic liming of with CC may lead to the accumulation of Sr in the soils and, as a result, contamination of crop production. To prevent the ingress of an excess amount of Sr into the human body with crop products grown on soil limed with CC, systematic monitoring of the content of Sr in food chains is required.

Acknowledgments

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Stroncio (Sr) išplovimas iš dirvožemio, kalkinto stroncio turinčiomis pramonės atliekomis

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Santrauka

Siekiant ištirti stabilaus stroncio (Sr) migracijos intensyvumą iš lengvos granuliometrinės sudėties *Albic Retisol* dirvožemio su skirtingu kiekiu humuso, buvo atliktas kolonėlių eksperimentas. Kaip Sr šaltinis naudota jo turinti konvertuojamoji kreida, kuri yra azoto trąšų gamybos šalutinis produktas (90 % CaCO$_3$ ir 1,5 % Sr). Eksperimentą sudarė 8 plovimai, kurių metu tirtas Sr kiekis, išplautas iš lengvos granuliometrinės sudėties pievos ir miško *Albic Retisol* dirvožemio. Visiškas judriojo Sr pašalinimas iš didelio humusingumo dirvožemio buvo pasiektas per 3-iąjį plovimą. Mažai humusingame dirvožemyje Sr išplovimas prasidėjo tik po 3-iojo plovimo ir nesibaigė net po 8-ojo. Suminis Sr kiekis, išplautas iš mažai humusingo dirvožemio, 1,3 karto viršijo Sr kiekį, pašalintą iš daug humuso turinčio dirvožemio, ir sudarė atitinkamai 0,21 bei 0,16 mg. Dirvožemį kalkinant konvertuojamosios kreidos atliekomis, iš mažai humusingo dirvožemio išplauta 6,1 mg, iš didelio humusingumo dirvožemio – 3,8 mg daugiau Sr. Iš kalkintų dirvožemių išplauto Sr dalis sudarė 24,3 % (didelio humusingumo dirvožemio) ir 39,2 % (mažo humusingumo dirvožemio) nuo su kreida įterpto kiekio. Sudarytos empirinės lygtys atskleidė Sr išplovimo iš natūralių ir kalkintų dirvožemių procesą. Esant modeliuojamiems kritulimams, Sr išplovimo vidutinis intensyvumas buvo: iš natūralaus mažai humusingo dirvožemio −0,29 lg(mg) per metus, iš karbonatingo mažai humusingo dirvožemio −0,24 lg(mg) per metus, iš karbonatingo didelio humusingumo dirvožemio −0,17 lg(mg) per metus.

Žemės ūkio sistemose, kuriose dirvožemiai ilgą laiką sistemingai kalkinami Sr turinčiais meliorantais (dirvožemio gerinimo medžiagomis), siekiant išvengti per didelio Sr kiekio patekimo į žmogaus organizmą, būtina nuolat stebėti Sr kiekį maisto grandinėje.

Reikšminiai žodžiai: *Albic Retisol*, empirinės lygtys, kalkinimas, migracija, stabilusis stroncis.