Article

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Influence of forest belts on the total content of Pb and Cd and their exchange compounds in leached chernozems

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Abstract

The creation of artificial forest belts is an effective method of land reclamation. Forest belts have a positive impact on prevention of erosion processes, formation of heat and moisture regimes, reduction of turbulent exchange in the surface air layer and reduction of carbon dioxide share in the atmosphere. An important feature of forest plantations is the prevention of soil contamination with heavy metals (HM). It occurs due to profile redistribution of HM and partial remediation of soils. The obtained data confirm this position. Reliable transformation of leached chernozems under the influence of different-age forest belts in comparison with arable soils on the territory of All-Russian Research Institute of Sugar Beet and Sugar named after A.L. Mazlumov was revealed. Forest vegetation type contributes to more sustainable ecosystems due to stabilization of humus content and its uniform distribution throughout the soil profile. Correlation analysis revealed a close relationship between content of humus, soil solution pH and the gross content, as well as the exchangeable compounds of HM. An increase in the concentration of HM in the upper layer of arable chernozem was revealed; it was caused by active emissions of exhaust gases from agricultural machinery and the application of mineral fertilizers. The design of forest belts in order to restore contaminated soils is planned in the territory of Sichuan Province (southwest China). This project needs additional research, which is planned to be carried out in the future.

Keywords: *heavy metals, lead, cadmium, gross content, exchange compounds, forest belts of different ages, arable land, leached chernozems*

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Влияние лесополос на валовое содержание Pb и Cd и их обменные соединения в черноземах выщелоченных

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Создание искусственных лесополос является эффективным методом мелиорации земель. Лесополосы положительно влияют на предотвращение эрозионных процессов, формирование тепловлажностного режима, снижение турбулентного обмена в приземном слое воздуха и снижение доли углекислого газа в атмосфере. Важной особенностью лесных насаждений является предотвращение загрязнения почвы тяжелыми металлами (ТМ). Это происходит за счет профильного перераспределения ТМ и частичной ремедиации почв. Полученные данные подтверждают это положение. Выявлена достоверная трансформация выщелоченных черноземов под влиянием разновозрастных лесополос по сравнению с пахотными почвами на территории ВНИИ сахарной свеклы и сахара им. А.Л. Мазлумова. Лесной тип растительности способствует более устойчивым экосистемам за счет стабилизации содержания гумуса и его равномерного распределения по почвенному профилю. Корреляционный анализ выявил тесную связь между содержанием гумуса, pH почвенного раствора и валовым содержанием, а также обменными соединениями ТМ. Выявлено увеличение концентрации ТМ в верхнем слое пахотного чернозема; это было вызвано активными выбросами выхлопных газов сельскохозяйственной техники и внесением минеральных удобрений. На территории провинции Сычуань (юго-запад Китая) планируется проектирование лесополос с целью восстановления загрязненных почв. Этот проект нуждается в дополнительных исследованиях, которые планируется провести в ближайшем будущем.

Ключевые слова: *тяжелые металлы, свинец, кадмий, валовое содержание, обменные соединения, разновозрастные лесополосы, пашня, выщелоченные черноземы*

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Introduction

Lead (Pb) and cadmium (Cd) in the biosphere are in a dispersed state, and also have a high degree of toxicity, which makes these HMs one of the most active pollutants in the noosphere and allows them to be classified as hazard class 1 [11, 19]. The fact of the possibility of migration of the studied HMs into various shells of our planet and active transfer along trophic chains has been experimentally proven [16]. Therefore, the creation of protective forest belts is often used to protect soils from Pb and Cd pollution [14].

The multifactorial ameliorative impact of forest belts is reliably known, scientifically substantiated for the first time by V.V. Dokuchaev. Subsequent scientific works actively studied the influence of forest phytocenoses on various properties of the soil cover [17]. Forest biogeosenosis is characterized by an increase in the intensity and productivity of the biological cycle [7, 18, 21]. This position contributed to the continuation of more in-depth scientific research, which revealed the fact of the formation of the most favorable conditions for the occurrence of active processes of humus accumulation, namely: the continuous supply of organic matter in the form of plant litter and dead roots [10, 20, 21]. An undeniable fact is the improvement in the water balance, due to the longer retention of moisture after precipitation, the intensive accumulation of snow cover and its longer melting. There is a pattern of strengthening of these processes with the age of forest plantations [14]. Scientific works reflect the positive effect of forest vegetation on the structure of microbial communities and their biomass [10]. The ability of forest belts to counteract the development of water erosion and deflation [9, 12], which has a positive effect on crop yields [3], has been established. One cannot deny the fundamental importance of green spaces in the deposition of CO_2 [5, 13, 16].

However, the issue of the influence of forest belts of different ages on the content of HMs in soils is not so widely discussed in the scientific literature. Therefore, the purpose of this work was to study the effect of forest belts of different ages on the total content and profile distribution of exchangeable forms of Pb and Cd compounds in leached chernozems.

These studies are of particular value for various projects for the restoration of soils contaminated with HMs. In the future, it is planned to establish a similar experience in the territory of Sichuan Province (southwest China).

Materials and methods

The studies were carried out on the territory of All-Russian Scientific Research Institute of Sugar Beet and Sugar them. A.L. Mazlumov (Ramonsky district of the Voronezh region). Leached medium-thick, low-humus, heavy loamy arable lands were studied (the coordinates of the section and a photograph of the section are shown in Figure 1), as well as leached medium-thick, medium-humus, heavy loamy chernozems under forest belts 50 years old (Fig. 2) and ninety years old (Fig. 3).

Full-profile sections were laid down to the depth of occurrence of parent rocks, which in this region are cover carbonate loams. Sampling for general chemical and physicochemical analyzes was carried out every 10 cm. In soil samples, the pH of the aqueous suspension was determined by the potentiometric method using an I-160MI microprocessor ionometer (Aquilon, Moscow, Russia). The gross humus content was determined according to I.V. Tyurin [8].

Figure 1. Leached medium-thick low-humus heavy loamy chernozem on mantle carbonate loams (arable land, coordinates: 51°931'094"; 9°293'506")
Source: authors' own calculations

Soil samples for analysis were weighed on an HR-100ARG electronic analytical balance. Laboratory glassware and chemical reagents for analyzes were used by Vekton (St. Petersburg, Russia). To analyze the total content and exchange compounds of Pb and Cd, mixed samples of 20 cm each were taken in the main genetic horizons (0–20; 60–80; 100–120 cm).

When conducting research on the ecological and agrochemical state of soils, it is customary to investigate mobile HM compounds. This is due to their high degree of sensitivity to changes in landscape geochemical conditions, as well as the ability to reflect the degree of availability of these chemical elements for plants [6, 22]. Therefore, mobile HM compounds were determined in the extract from ammonium acetate buffer (pH = 4.8) in the ratio of soil solution 1:10. Without data on the total content of HMs in the studied chernozems, which serve to determine both the total soil contamination and the degree of pollutant mobility [11, 15, 23]. The total content of Pb and Cd was determined as follows: soil calcined in a muffle was treated with HNO_3 (1:1) and H_2O_2 (concentrated), reagents from Vekton (St. Petersburg, Russia) and boiled. Then, the heavy metals under study were determined in the filtrate on a TA-4 voltammetric analyzer (TA-Lab, Tomsk, Russia) by stripping voltammetry.

Figure 2. Leached medium-thick medium-humus heavy loamy chernozem on mantle carbonate loams (forest belt 50 years, coordinates: 51°327'113"; 33°267'551")
Source: authors' own calculations

Figure 3. Leached medium-thick medium-humus heavy loamy chernozem on mantle carbonate loams (forest belt 90 years, coordinates: 51°930'474"; 39°292'921")
Source: authors' own calculations

Statistical processing of the obtained analytical results was performed in Microsoft Excel and STATISTICA 13.3. The standard error of the mean was used as a characteristic of the reliability of the results obtained and was calculated as the ratio of the standard deviation of a random variable to the sample size, which in our case is equal to 7.

To mathematically prove the dependence of heavy metal sorption by organic matter and express its intensity, we used the r-Pearson correlation coefficient, which is a measure of a straight-line relationship between variables, at n = 7.

Results and discussion

The investigated chernozems leached as a result of plowing are subjected to enhanced mineralization of organic matter. In this case, there is a removal with a crop of nutrients that are not fully replenished by the application of organic and mineral fertilizers. As a result, the humus content in the upper horizon of arable soils is 5.7 ± 0.10%. Chernozems, leached arable lands degrade to low humus. The distribution of organic matter along the profile of arable soils is characterized by a uniform accumulative type up to 40 cm, a regressive accumulative type from 40 to 80 cm, and a uniformly accumulative type of accumulation from 80 cm and deeper.

Chernozems leached under forest belts have a significantly higher humus content, which is 7.2 ± 0.09% for a 50-year-old forest belt, 7.8 ± 0.13% for a 90-year-old forest belt, soils are diagnosed as medium humus. The preservation of organic matter at a sufficiently high level, and to some extent its increase, is explained by the stable accumulation of plant residues on the soil surface in the form of tree litter. Then there is an intensive enrichment of the soil with minerals, proteins and carbohydrates. The profile distribution of humus up to a depth of 40 cm has a regressive-accumulative type, at a depth of 40 to 60 cm it has a progressive-accumulative type, and deeper than 60 cm it has a uniformly accumulative type of distribution.

Root secretions of woody vegetation of forest belts have an acidifying effect on the reaction of the soil solution medium. So, in the leached chernozems of arable land pHaq. is 6.8 ± 0.11 units, the reaction of the environment is characterized as neutral, and under the litter of woody vegetation it becomes slightly acidic and amounts to 6.0 ± 0.15 units. In addition, under woody vegetation there is an accumulation and retention of moisture, which penetrates into deeper soil layers. Due to this, exchangeable hydrogen of hydrolytic acidity penetrates into the deeper layers. All this leads to intensive leaching of carbonates in chernozems leached under forest belts. In the soil-forming rock, an alkaline reaction of the soil solution is noted (pH=8.3±0.15 units). The alkalinity of the soil solution is largely determined by the carbonate content of the parent rock.

Previous studies indicate that the total content of HMs and their mobile compounds are closely related to organic matter, the reaction of soil solution, and the sorption capacity of silt particles [2, 4, 16]. According to the data obtained, the accumulation of the total content of Pb (Fig. 4) and Cd (Fig. 5) is noted in the upper layer of the studied leached chernozems. Metals form strong organomineral chelate compounds with organic matter.

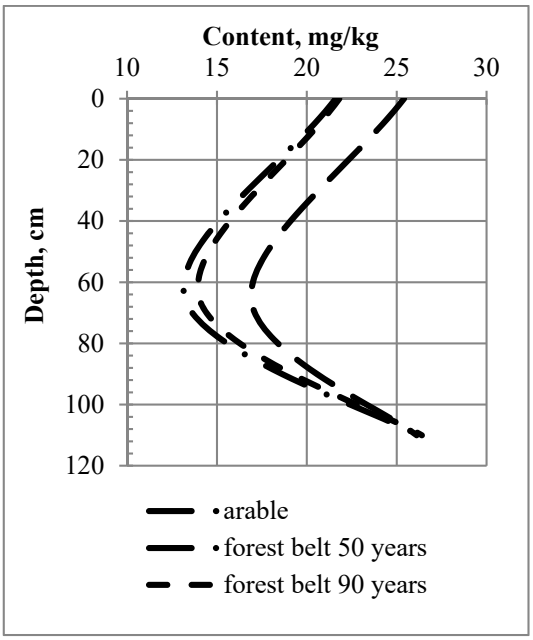

Figure 4. Distribution of the total content of Pb in the profile of leached chernozems

Source: authors' own calculations

It should be noted that in the soils of arable land, a significant accumulation of the total content of Pb and Cd is noted relative to the chernozems of the forest belts. Thus, the amount of Pb is 24.5 ± 1.05 mg/kg, Cd is 0.42 ± 0.13 mg/kg, while in the same 0-20 cm layer, the total content under a 50-year-old for-

est belt does not exceed 21 .6 and 0.35 mg/kg, 90-year-old forest belt - 21.8 and 0.37 mg/kg, respectively.

The studied metals are able to enter the surface of arable chernozems as a result of the combustion of fuel from agricultural machines, as well as as impurities of mineral fertilizers, especially phosphorus ones. Despite the noted trend, pollution of the study area does not occur, since the data obtained do not exceed the MPC accepted for soils of the chernozem series, which are 30 mg/kg for Pb and 1 mg/kg for Cd [1].

Down the soil profile of all the studied soils, a fairly uniform decrease in the total content of HMs is noted (Fig. 1, 2), following a decrease in the amount of organic matter. The results of the correlation analysis indicate a close relationship between the profile distribution of humus and the studied HMs (Table 1).

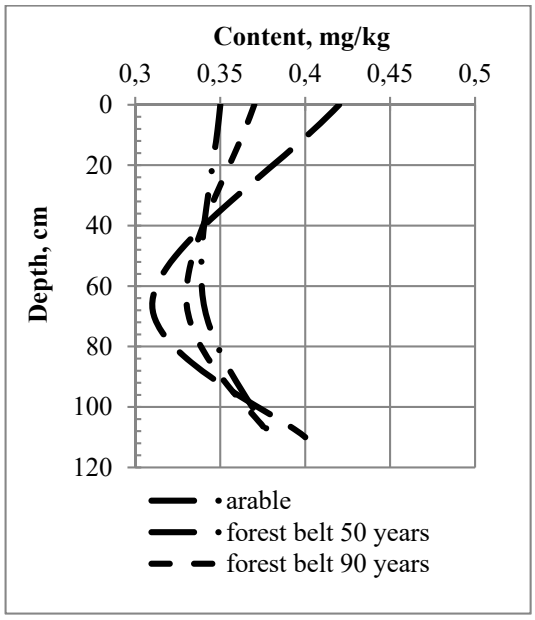

Figure 5. Distribution of the total content of Cd in the profile of leached chernozems
Source: authors' own calculations

The second peak of Pb and Cd accumulation is observed in the lower part of the soil profile, which is caused by the alkaline reaction of the soil solution and the abundance of the clay fraction, which has a high sorption capacity for HMs [2, 4, 16].

HM exchange compounds are mobile; they are able to migrate radially and laterally and enter adjacent media. Therefore, their content makes it possible to judge the ecological situation and the influence of elements on plant and living organisms [15]. The content of Pb exchangeable compounds in the upper 0-20 cm layer is 1.17±0.04 mg/kg, down the profile there is an increase in its amount to 1.24±0.01 mg/kg. The distribution curve has a regressive-eluvial type (Fig. 6).

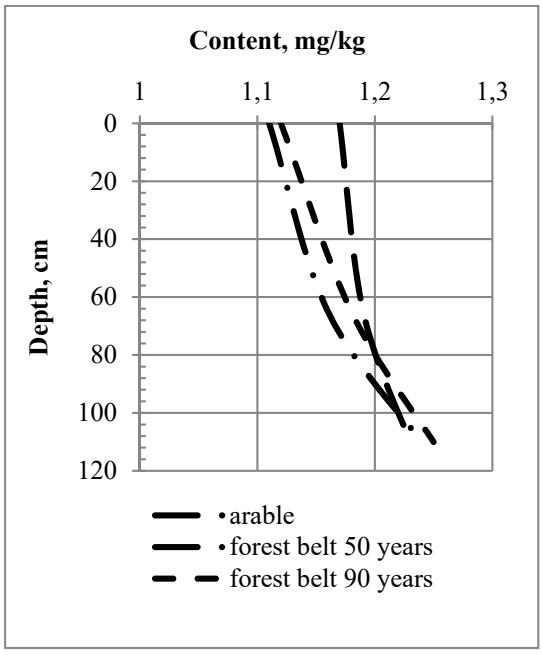

Figure 6. Distribution of exchangeable Pb compounds in the profile of leached chernozems
Source: authors' own calculations

Table 2

Correlation coefficients between the total content, exchangeable forms of Pb and Cd compounds, humus and $pH_{aq.}$ in the profile of leached chernozems under various lands

Field	Pb – humus	Pb – pH	Cd – humus	Cd – pH
Gross content				
arable	0,79	-0,71	0,80	-0,72
forest belt 50 years	0,85	-0,74	0,89	-0,74
forest belt 90 years	0,89	-0,68	0,92	-0,69
Exchange connections				
arable	-0,81	0,87	0,82	-0,73
forest belt 50 years	-0,86	0,91	0,75	-0,68
forest belt 90 years	-0,91	0,94	0,76	-0,67

Source: own calculations

There is a high negative correlation dependence between the profile distribution of exchange compounds Pb and humus, as well as a high positive dependence in the distribution of the element and pH (Table 1).

The content of Cd exchange compounds varies within narrow limits (0.03-0.05 mg/kg). The profile distribution of the element is characterized by a regressive-accumulative type in the upper part and a regressive-eluvial type in the lower part (Fig. 7).

The obtained data on the content of HM exchange compounds do not exceed the MPC used for soils of the chernozem series [1], which indicates the absence of contamination of the studied soils. Pb is characterized by a low percentage of mobility (5-9%), which indicates a low migration ability of the element and its movement into adjacent environments. The mobility coefficient Cd is higher, it ranges from 8 to 24%. This phenomenon characterizes the element as more mobile, capable of migrating to adjacent environments.

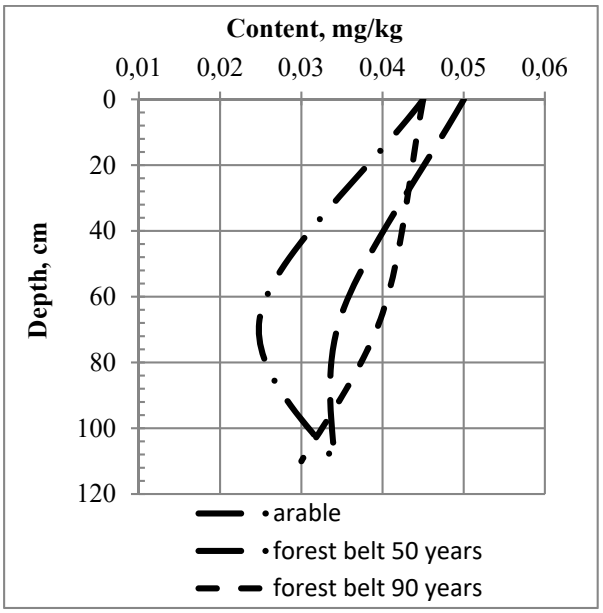

Figure 7. Distribution of Cd exchange compounds in the profile of leached chernozems
Source: authors' own calculations

Conclusion

Ecosystems of forest belts are primarily the result of anthropogenic activities, but compared to the agroecosystem, they are more resilient and stable. So, as a result of intensive plowing, increased mineralization of organic matter is noted, leading to a decrease in the percentage of humus. Leached chernozems degrade to low humus. Forest belts, on the contrary, stabilize the processes of formation and decay of organic matter, leading to a fairly stable content of humus, its fairly uniform distribution over the soil profile, and a higher percentage in the upper horizons.

Under the woody vegetation of forest belts, unique soil and climatic conditions are formed, characterized by high moisture accumulation and its long-term retention in the soil profile. This phenomenon contributes not only to a more uniform profile distribution of organic matter, but also to the reaction of the soil solution. Root secretions containing carbonic, malic, citric acids provide acidification of the soil solution. They cause the replacement of exchangeable calcium and magnesium cations with exchangeable hydrogen in the soil absorbing complex.

The noted features of soil transformation under arable land and forest belts of different ages also affect the behavior of the studied HMs. The total content of Pb and Cd in chernozems leached under various types of land is characterized by the accumulation of elements in the upper layer of the humus horizon (in which the formation of strong chelated organomineral compounds is noted) and at the depth of the parent rock, which is enriched in the clay fraction, which has an increased sorption capacity for heavy metals. Exchange compounds Pb have a regressive-eluvial type of profile distribution. The distribution of Cd exchange compounds is more complex, combining regressive accumulative and regressive eluvial types.

There is a significant increase in both the total content of HMs and their exchangeable compounds in the upper layer of arable soils. The phenomenon is explained by the intake of elements as impurities introduced with mineral fertilizers and additional components obtained as a result of the combustion of agricultural machinery fuel. Despite this, no excess of MPC was detected. Although, attention is drawn to the increase in the degree of mobility of the studied HMs in leached arable chernozems.

In order to stabilize and improve the ecological state of soils in Sichuan Province, it is planned to create forest belts in this region. This project needs additional detailed geochemical studies, which will be reflected in future publications.

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