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[1]The balance of elements in the system "Luvic Chernozems – agricultural plants" on the Plavsk upland (Tula region of Russia)

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Abstract: To assess the transfer of macro (K, P, S, Mg, Ca, as well as Si, Na, Fe, Al, Mn and Ti) and microelements (Zn, Ba, Cu, Sr, Mo, as well as As, Zr, Pb, Co, Ni, V and Cr) from Luvic Chernozems (Aric, Loamic, Pachic) into

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agricultural plants, we studied the inventories of chemical elements in three agrocenoses (wheat, soybean, *Galega orientalis* Lam. and *Bromopsis inermis* Leyss grass mixtures) from the Plavsk upland (Tula Region). This territory is subjected to intensive industrial and agricultural impacts: it is 40 km away from the town of Shchekino with a nitrogen fertilizer plant and a thermal power plant, 60 km away from Tula with large metallurgical enterprises, 70 km away from the town of Novomoskovsk with several chemical enterprises and state district power plant. In soils, the total content of elements was determined by the X-ray fluorescence spectrometry. The elemental composition of plants after autoclave decomposition with a mixture of concentrated nitric acid and hydrogen peroxide and the content of the bioavailable fraction (extracted by an ammonium acetate buffer with pH 4.8) of elements in soil were estimated by the atomic emission spectrometry with inductively coupled plasma. In topsoil (a 10-cm layer), maximal inventories are typical of total Si (40 ± 4 kg/m^2), Al (7.0 ± 0.8 kg/m^2) and Fe (3.4 ± 0.3 kg/m^2) and of bioavailable Ca (570 ± 48 g/m^2), Mg (43 ± 4 g/m^2), K (22 ± 6 g/m^2). In plants, the main inventories (g/m^2) of K, P, S, Mg, Si, Mn, Zn, Ba, Cu, Mo occur in the above ground phytomass. The most effectively plants assimilate bioavailable fractions of K, P, Ti, Mo, As, Zr, V. Based on the resource method for soil quality assessment, the studied Chernozems are characterized by a low level of Ni contamination, a moderate supply of bioavailable K with a lack of bioavailable P.

Keywords: biogeochemistry, soil pollution, potentially toxic elements, heavy metals and metalloids, quality of agricultural products, biological absorption, Central Russian Upland.

INTRODUCTION

A resource-based approach to assessing soil quality is focused on a differentiated estimation of the inventories of polluting and potentially useful substances in soils (Smagin et al., 2008). Pollutants enter into arable soils as part of air deposition, and also due to the direct introduction of agrochemicals and ameliorants. Under the conditions of increasing anthropogenic pressure, it is necessary to know the biogeochemical specialization of various crops clearly to reduce the risk of obtaining the poor-quality agricultural products (Ilyin, 1973). The intensity of chemical elements (CEs) absorption by plants from soils is determined by many factors: concentration and forms of CEs occurrence in the soil, pH, Eh, total organic carbon content (TOC), biogenic competing CEs and nutrients (P, N, K), etc. (Bargaly, 2005).

The Tula region remains an important producer of industrial and agricultural products in Central Russia, which determines the supply of various pollutants due to the high concentration of chemical and metallurgical industries and the use of mineral fertilizers and herbicides (Arlyapov et al., 2015). The content of heavy metals in crops grown in contaminated areas has been the subject of many studies (Wang et al., 2020; Zhang et al., 2019; Liu et al., 2014). Studies of the inventories of elements in soils and plants (Suleimanov, Nizamov, 2015; Ramazanova, Akhmedova, 2010; Overesch et al., 2007) are much less common and have not yet been carried out in the Tula region.

The aim of our work is to assess the intensity of geochemical fluxes of CE from Chernozems to agricultural plants grown at the highest part of the Central Russian Upland – the Plavsk upland.

MATERIALS AND METHODS

In the Plavsk upland (southern part of the Tula region), to study the total annual consumption and redistribution of CEs in the organs of plants of the *Poaceae* and *Fabaceae* families, we chose three sites with Luvic Chernozems (Aric, Loamic, Pachic) under agrocenoses of wheat (*Tríticum Aestívum* L.), soy (*Glycine Max* L.) and galega-bromes (*Galega Orientalis* Lam. and *Bromopsis Inermis* Leyss) grass mixture (Fig. 1). There were taken 16 samples of above-ground phytomass (shoots and seeds) and 4 of underground (roots) phytomass. Bulk-core soil samples (together with the underground phytomass) were selected using an annular sampler from an area of 300 cm^2 in layers with the step of 10 cm to the depth of 30 cm in triplicate (27 samples in total). The aboveground vegetation was collected by the method of continuous mowing within an area of 2 500 cm^2 in triplicate, above the place of soil sampling, leaves with stems and grain were analyzed separately. Plants were washed from soil under running water until the wash water was completely clarified on a sieve system with 1 and 0.5 mm diameter cells. The quality of root washing was monitored using optical microscopy at 10x magnification. Plants were dried at room temperature and grinded up for further chemical analyses.

Fig. 1. Sampling Area.

In the soils the pH of the aqueous extract was determined potentiometrically (Ekspert-01 device, Russia), C_{org} – titrimetrically according to I.V. Tyurin with phenylanthranilic acid (Arinushkina, 1970), the particle size distribution was measured by laser diffractometry (Fritsch Analysette 22 MicroTec Plus device, Germany), the elemental composition was determined by X-ray fluorescence spectrometry (Spectroscan Max-GV device, Russia) and the content of bioavailable forms of CE was determined in the extraction of an acetate-ammonium buffer (NH_4AAc) with a pH of 4.8 by the AES-ICP (iCAP-6500 devices from Thermo Scientific and X-7 - Thermo Elemental, USA). The elemental composition of the plants was also analyzed by the AES-ICP after autoclave decomposition of plants with a mixture of concentrated HNO_3 and H_2O_2.

Data processing included determination of CEs inventories in the 30 cm topsoil (total concentration / bioavailable concentration × soil density × square × layer thickness) and in plant organs (concentration in the organ × inventory of phytomass), calculation of the OSOR coefficient (relative content in a plant organ, $\frac{\text{concentration of CE in organ}}{\text{concentration in roots}}$) (Kovalevsky, 1969) and the coefficient of use of the element by plants from the soil (Ci; $\frac{\text{inventory of CE in plant}}{\text{bioavailable inventory in soil}}$) (Radov et al., 1971). The fraction of alienation of CEs from the soil was also calculated ($\frac{\text{inventory of CE in upland part of plant}}{\text{total inventory of CE in plant}}$) (Ramazanova, Akhmedova, 2010). The Mann – Whitney test was performed to assess the differences in the mean of independent variables using STATISTICA 10 package.

RESULTS AND DISCUSSION

Physico-chemical properties of soils. All the studied sites in the agrocenoses have the similar conditions of (trans)-autonomous landscapes and differ insignificantly in the physical and chemical properties of soils (Shopina et al., 2020): pH of the upper horizons is 6.3 ± 0.4 (n = 14), TOC content 4.6 ± 0.8% (n = 27), silt particles (with a diameter 0.001–0.05 mm) prevail in the granulometric composition: coarse (44 ± 4%, n = 27), fine (25 ± 4%) and medium (15 ± 3%) with a subordinate role of sand (4 ± 4%) and clay (6 ± 3%) fractions.

Total inventories of CEs in soils. The elemental composition of the topsoil studied differs insignificantly. The highest values of inventories in the topsoil are typical of Si (40 ± 4 kg/m^2, for the 10 cm layer), followed by Al and Fe with 7.0 ± 0.8 and 3.4 ± 0.3 kg/m^2, respectively. The high contents of these CEs are associated with their constitutional role in the soil matrix. The inventories of biogenic K, P, Mg, and Ca in the studied Chernozems are also considerable. Minimum inventories are typical of the trace elements – As, Pb, Co, Ni (Table 1).

Standards for total CE inventories developed by Smagin et al. (Smagin et al., 2008) based on the values of permissible concentrations for Pb, Zn, Cu, As are not exceeded in studied soils. And the Ni reserves (> 90 g/m^2 in the 1 meter layer) correspond to a weak degree of soil contamination, probable reasons for the increased content of Ni in soils may be the following: input with applied fertilizers and aerogenic input – sediments resulting from industry and transport emissions.

Table 1. Total and bioavailable inventories of chemical elements in Chernozem topsoils (cm) studied on 3 sampling areas at the Plavsk upland

CE	Wheat			Soybean			Grass mix		
	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
K*	2.3/25	2.6/33	2.5/26	2.3/17	2.5/24	2.4/25	1.8/22	2.3/16	2.1/13
P*	0.12/2.2	0.14/2.5	0.13/2.4	0.09/1.7	0.11/1.8	0.1/2	0.09/2.2	0.1/1.3	0.1/1.6
S*	-/1.4	-/1.6	-/1.3	-/1.2	-/1.1	-/1.4	-/1.3	-/1	-/0.9
Mg*	0.56/42	0.64/50	0.61/44	0.58/39	0.65/45	0.65/43	0.49/45	0.62/42	0.58/36
Ca*	1.1/495	1.2/583	1.2/517	1.1/564	1.2/630	1.3/590	1.1/529	1.3/632	1.2/595
Si*	41/6.0	46/6.7	44/6.0	39/10	44/13	41/12	32/9.2	40/11	38/10
Na*	-/2.3	-/3.1	-/2.1	-/2.9	-/3.4	-/3.5	-/2.6	-/3.1	-/1.7
Fe*	3.4/1.2	3.9/1.5	3.7/1.6	3.5/0.87	4/0.41	3.6/0.46	2.8/0.27	3.4/0.45	3.3/0.49
Al*	7.1/9.1	8/11	7.8/10	7.3/5.6	8.4/3.5	7.8/3.8	5.7/2.2	7.3/3.6	7/4.1
Mn	91/10	104/12	99/11	85/7.6	97/5.2	90/6.1	73/9.0	84/6.7	84/6.5
Zn	9.9/0.34	11/0.31	11/0.26	11/0.26	13/0.25	10/0.31	7.9/0.09	9.2/0.05	9.1/0.17
Ba	-/5.4	-/6.3	-/5.69	-/5.0	-/5.2	-/5.1	-/3.9	-/5.1	-/4.9
Cu	7.1/0.01	7.7/0.01	7.7/0.01	7.8/0.01	9.2/0.01	7.5/0.01	5.7/0.01	7.1/0.01	7/0.01
Sr	19/3.3	21/3.8	20/3.4	17/2.8	19/2.5	18/2.4	15/2.3	17/2.5	17/2.8
Ti	632/ 0.06	715/ <0.05	689/ <0.05	657/ <0.05	752/ <0.05	669/ <0.05	520/ <0.05	636/ <0.05	614/ <0.05
As	0.80/ <0.1	0.88/ <0.1	0.85/ <0.1	0.89/ <0.1	1.11/ <0.1	0.81/ <0.1	0.66/ <0.1	0.73/ <0.1	0.68/ <0.1
Pb	2/<0.01	1.9/<0.01	1.8/<0.01	2.6/<0.01	3.3/<0.01	1.9/<0.01	1.5/<0.01	1.3/<0.01	1.4/<0.01
Co	3.6/0.03	4/0.03	4/0.03	3.8/0.02	4.4/0.03	3.9/0.02	2.8/0.01	3.6/<0.01	3.6/<0.01
Ni	8.2/0.09	8.8/0.1	8.8/0.1	8.2/0.07	9.3/0.07	8.6/0.06	6.8/0.04	8.0/0.06	8.0/0.06
V	14/<0.01	15/<0.01	15/<0.01	14/<0.01	16/<0.01	15/<0.01	11/<0.01	14/<0.01	13/<0.01
Cr	12/0.03	13/0.04	13/0.06	12/0.05	13/0.04	13/0.04	9/0.02	12/0.03	11/0.02

Note. The numerator is the total inventories; the denominator is the inventories of bioavailable forms. ***** – in kg/m^2 for total inventories; dash – not determined.

Inventories of bioavailable forms of CEs in soils. According to the content of bioavailable forms of CEs, the soils of the three sites also differ insignificantly.

Inventories of bioavailable forms of CEs form the series: Ca (570 ± 48 g/m^2) >> Mg (43 ± 4)> K (22 ± 6) >> Zn (0.2 ± 0.1), Ni, (0.07 ± 0.02) > Cr (0.04 ± 0.01), Co (0.02 ± 0.01) > Cu (0.01 ± 0.003) and Pb (0.01 ± 0.001) (see Table. 1).

Compared to the stocks of elements in the arable layer of typical chernozems of the Orenburg region the 20-cm layer of soils of the Plavsk upland had the comparable total inventories of P, higher inventories of K, Zn, Ni, Cr, and lower inventories of Cu (Ryakhovsky, 2006). The inventories of bioavailable K exceeded the data for the 25-cm layer of arable gray forest soils of Tatarstan (Suleimanov, Nizamov, 2015), but the reserves of mobile P were 10 times less in the chernozems of the Plavk upland. Compared to the alluvial soils of the Elbe Valley, which are also under the pressure of a high anthropogenic load (Overesch et al., 2007), the reserves of mobile Cu and Ni were lower in the studied soils, Cr – higher, and Zn and Pb – comparable.

According to the soil quality requirements (Smagin et al., 2008), the studied Chernozems are characterized by a lack of bioavailable P (< 160 g/m^2 in the upper 1 meter layer) and have a moderate K content (> 200 g/m^2, but < 600 g/m^2).

CEs inventories in plants. In the aboveground parts of all the studied plants, the contents of biogenic $P_{1.5\text{-}5}$, $K_{2\text{-}3}$, $Zn_{2\text{-}4}$, and $Mg_{1.5\text{-}3}$ are maximum (subscript index – OSOR values). In the roots, there is recorded a greater accumulation of non-biophilic CEs – $Fe_{0.1\text{-}0.7}$, $Al_{0.1\text{-}0.5}$, $As_{0.1}$, $V_{0.1}$, $Cr_{0.1}$, $Co_{0.1\text{-}0.4}$, $Na_{0.3\text{-}0.6}$, $Zr_{0.02\text{-}0.1}$. In the underground and aboveground organs the contents of $Cu_{0.9\text{-}1.3}$ and $Ba_{1\text{-}1.5}$ are similar. In the aboveground parts of *Fabaceae* species, in addition to the CEs mentioned above, Ca_4, $Ni_{2\text{-}8}$, $S_{2\text{-}3}$, and $Mn_{3\text{-}4}$ as nutrients are accumulated according to the barrier-free type (Kabata-Pendias, Szteke, 2015). In the aboveground organs of *Poaceae* species the content of $Si_{2\text{-}7}$, which performs a skeletal function, is increased (Kolesnikov, 2001).

In all the studied agrocenoses of cultivated plants, the aboveground fraction prevails in the phytomass structure, with the maximum phytomass inventories being typical of wheat grains and soybeans (Table 2). Compared to other organs, the inventories of biogenic P, Mg, S and essential Zn, Mn, Co, Cu, and Si are maximal in grain and beans.

Table 2. Phytomass and inventories of chemical elements in plants (mg/m^2)

CE	***Poaceae***					***Fabaceae***				
	Wheat			**Bromes**		**Soybean**			**Galega**	
	Grain	**Shoots**	**Roots**	**Shoots**	**Roots**	**Beans**	**Shoots**	**Roots**	**Shoots**	**Roots**
Phytomass *	*1816*	1270	40	*270*	121	*1724*	738	83	*290*	227
K*	4.9	*6.8*	0.045	*3.4*	0.20	*2.4*	14	0.48	*2.3*	0.55
P*	*4.9*	2.1	0.021	*0.6*	0.1	*6.9*	2.2	0.1	*0.9*	0.5
S*	*2.2*	1.3	0.027	*0.23*	0. 11	*3.7*	1.2	0.07	*0.29*	0.12
Mg*	*0.16*	0.96	0.02	*0.26*	0.07	*4.7*	2.9	0.13	*1.2*	0.32
Ca*	0.72	*1.7*	0.14	0.73	*0.74*	*7.1*	8.7	0.3	*4.1*	0.95
Si	203	*218*	3.0	*52*	3.3	*224*	15	34	8.6	*18.8*
Na	180	*535*	8.8	11	*18*	43	*78*	28	45	*64*
Fe	105	*149*	25	16	*35*	*97*	62	9.4	30	*34*
Al	78	*135*	32	11	*37*	38	*49*	11.7	24	*36*
Mn	*69*	48	1.36	*11*	4.1	*33*	21	0.50	*16*	3.6
Zn	*40*	20	0.33	*3.8*	2.2	*47*	14	0.58	*4.8*	2.3
Ba	8.5	*28*	0.56	*1.7*	1.6	5.9	*8.9*	0.91	*3.4*	1.79
Cu	*4.4*	2.3	0.10	*1.0*	0.91	*6.4*	2.2	0.20	*2.1*	1.18
Sr	4.0	*9.14*	0.76	2.7	*3.5*	17	*23*	2.0	*14*	6.1
Ti	2.2	*5.3*	0.68	<0.1	*1.0*	<0.1	*3.1*	0.37	*1.1*	0.25
Mo	*0.33*	0.15	0.003	*0.15*	0.04	*0.88*	0.15	0.04	0.07	*0.08*
As	*0.24*	<0.01	0.007	<0.01	*0.004*	<0.01	<0.01	*0.004*	<0.01	*0.007*
Zr	0.09	*0.10*	0.02	0.03	*0.05*	*0.07*	0.05	0.04	0.02	*0.03*
Pb	0.07	*0.17*	0.02	0.02	*0.02*	<0.01	*0.08*	0.01	*0.04*	0.02
Co	*0.04*	<0.01	0.01	<0.01	*0.02*	*0.03*	0.02	0.007	*0.01*	0.007
Ni	<0.01	<0.01	*0.07*	<0.01	*0.19*	*12*	2.2	0.07	*0.31*	0.09
V	<0.01	<0.01	*0.08*	<0.01	*0.21*	<0.01	<0.01	*0.03*	<0.01	*0.07*
Cr	<0.01	<0.01	*0.08*	<0.01	*0.05*	<0.01	<0.01	*0.02*	<0.01	*0.15*

Note. Maximum values in the plant are in *Italic*. * – in g/m^2.

The wheat grains, in addition to the mentioned CEs, are rich in As, and the soybeans are characterized by quite large values of Fe, K, Ni, as well as Sr, Mo, and Zr.

In all plants studied, toxic V and Cr are localized mainly in the roots. In the aboveground phytomass of *Fabaceae* species, in contrast to the *Poaceae* species, the content of Co and Ni involved in the synthesis of specific proteins is higher than in the underground one. An increased accumulation of Ni in soybeans grown on anthropogenically contaminated soils was also revealed in studies carried out in China and Argentina (Zhang, 2019; Lavado, 2006).

Of all the plants studied, the bromes have the largest number of CEs with the maximum values of inventories in roots (Ti, Fe, Al, and Co, As, V, Cr, as well as Ni, Sr, Na, and Zr), which is explained by the more developed biological barrier between the roots and the aerial part of the *Poaceae* species, and, in general, the greater absolute and relative biomass of the roots of the bromes compared to wheat.

Soybean and galega, as representatives of *Fabaceae* plants differ from *Poaceae* species by the distribution of inventories of Si, which is concentrated mainly in roots. This is due to the fact that in *Poaceae* species, Si plays a greater role in physiological processes than in *Fabaceae* species (Kolesnikov, 2001).

In general, in the given research the *Fabaceae* species have more CEs inventories in the aboveground phytomass than the *Poaceae* species: P > K > Zn > Mg are the most transferred from roots to aboveground parts, while Fe > Na > Al > Co > Zr > As, V, Cr are concentrated in roots and weakly pass into aboveground parts. The largest reserve of most CEs is the aboveground parts of the studied plants, which is especially high in wheat and soybean. Only bromes is characterized by comparable concentrations of CEs in the phytomass both in roots and aboveground plant parts.

It is noticed that compared to wheat grown on the Kastanozems at Dagestan (Russia), all organs of wheat from the Plavsk upland contain less Mo, while inventories of K and P are higher in roots, and more than 100 times higher in aboveground plant parts (Ramazanova, Akhmedova, 2010). In all the studied plants removal of P and K with aboveground phytomass exceeds the removal of these nutrients by sunflower (Suleimanov, Nizamov, 2015).

During the process of wheat growing, almost all Ni, V, and Cr absorbed by the plants annually return to the soil with mineralized root residues (the removed fraction is ~ 0%), 80% of Co and 93% of Al are removed from the soil with the yeild, as well as 90–98% Ca, Fe, Sr, Ti, As, Zr, Pb. The depletion of K, P, S, Mg, as well as Si, Na, Mg, Zn, Ba, and Cu exceeds 99%. In soybean agrocenosis, total amounts of As, V, and Cr remain in the soil within plant roots (~ 0% removal), 75–89% of Si, Na, Al, Ti, Zr, Pb, Co, as well as about 95% of Fe and Ba are carried out with aboveground part. In addition to the listed CEs, Ni (99.5%) is characterized by a high rate of removal in soybean agrocenosis. The grass mix is characterized by the highest return of CEs to the soil. The depletion rates of most CEs vary from 27 to 90%, whereas the ones of As, V, and Cr are close to 0%.

CE uptake by plants. According to the results of calculation of Ci (an element utilization index), plants assimilate the bioavailable forms of K, P, Ti, as well as Mo, As, Zr, and V in the most active way. The main (K, P) CEs are biogenic (Kabata-Pendias, 2011), while the rest are contained in plants, but their bioavailable forms are not found in soils (Table 3). Extremely low Ci values are characteristic of Sr and Ca, due to the high content of bioavailable forms in soils, and for Co and Cr, because they are phytotoxic. All plants, except for bromes, actively absorb S. Galega is characterized by the highest value of Cu utilization. Soybean absorbs Ni more actively than other plants, which is probably due to its participation in the formation of special enzymes in *Fabaceae* species – urease, dehydrogenase, etc. (Boer et al., 2014).

The values of Ci for K and P obtained on the Plavsk upland for wheat and soybean are several times higher than the average ones found in published scientific literature. This may be explained by more favourable soil, biological and climatic conditions of the territory studied and the mineral composition of soil-forming rocks. The values of Ci for the bromes are generally correspond well to the literature data (Ryzhikh, Lipatnikov, 2018). The values of Ci for P in all plants are ten times higher than the maximum value for sunflower (Suleymanov, Nizamov, 2015).

Pretty the same values were obtained for Ni when studying the natural meadow vegetation of the Elbe floodplain, however, mobile Cu and Zn are absorbed from soils by meadow vegetation more intensively, probably due to higher concentrations of these elements in floodplain soils (Overesch et al., 2007).

Table 3. Coefficients of use of elements from soils by plants

CE	Wheat	Soybean	Bromes	Galega
K	0.48	*2.3*	0.02	0.02
P	*3.3*	*5.4*	*1.6*	*1.3*
S	*2.4*	*4.2*	0.59	*1.1*
Mg	0.06	0.20	0.01	0.01
Ca	0.01	0.03	0.001	0.003
Si	0.07	0.03	0.16	0.55
Na	0.32	0.05	0.02	0.01
Fe	0.23	0.19	0.11	0.40
Al	0.03	0.02	0.02	0.03
Mn	0.01	0.01	0.01	0.01
Zn	0.18	0.23	0.18	0.23
Ba	0.01	0.003	0.002	0.002
Cu	0.97	0.85	0.84	*1.31*
Sr	0.004	0.02	0.001	0.001
Ti	*>1*	*>1*	*>1*	*>1*
Mo	*>1*	*>1*	*>1*	*>1*
As	*>1*	*>1*	*>1*	*>1*
Zr	*>1*	*>1*	*>1*	*>1*
Pb	0.004	*>1*	*>1*	*>1*
Co	0.002	0.003	0.001	0.001
Ni	0.001	0.219	0.0043	0.0089
V	*>1*	*>1*	*>1*	*>1*
Cr	0.003	0.0004	0.0024	0.0071

Note. Elements with Ci > 1 are shown in italics.

CONCLUSIONS

The maximum removal of CEs from studied soils occurs during the cultivation of wheat and soybean: K (total rate of removal with plant parts is 25 ± 19 kg/m^2) > P (8 ± 1.4), Ca (9 ± 6) > Mg (5 ± 3), S (4 ± 1) > Fe (223 ± 83 g/m^2) > Mn (86 ± 43) and Zn (60 ± 0.8). The same elements, but to a lesser extent, are carried out when mowing grass mixture of galega and bromes. For the components of the grass mix, the percentage of CEs removal with the yield is also minimal compared to other agrocenoses. Only for studied plants of *Fabaceae* species, the proportion of Ni carried out with the aboveground phytomass exceeds the fraction remaining in roots.

Plants assimilate bioavailable forms of K, P, Ti, as well as Mo, As, Zr, and V the most actively. Extremely low values of Ci are characteristic of Sr, Ca, Co, and Cr.

The Chernozems of Plavsk upland have a low level of pollution with Cu and Ni, and are characterized by moderate supply of bioavailable forms of K and a lack of bioavailable P, based on the resource method of soil quality assessement.

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