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LARISA KUCHER*

ESTIMATION OF POTASIUM RESERVES IN ZONAL CHERNOZEMIC SOILS OF UKRAINE'S FOREST-STEPPE

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Abstract. In the soil cover of the forest-steppe zone, typical chernozems, which occupy almost 50% of the total area of arable lands that are insufficiently fertilized with organics and minerals, prevail. Our task was to investigate the potassium content in these soils in order to gain insight into its reserves and availability for agricultural plants. For this purpose, soils of this type of different granulometric texture were investigated. The content of the fine-dispersed fraction of typical chernozems, total potassium in this fraction and in the soil as a whole, is determined. Indicators on the genetic horizons were researched there. The content of hydromicaceous minerals as the most available potassium reserves of plants nutrition is shown. The reserves of potassium (after Gorbunov 1978) in one meter-deep layer of investigated soils are calculated. All investigated soils have the same specificity of the reserves distribution in the horizons due to the common genesis processes and the same parent materials. The illuvium horizon of podzolized chernozem entraps a certain part of silt and potassium that is explained by the specifics of the formation of this horizon. Near reserve of chernozem soils contains less than 50% of potassium from the general reserve that suggests the potassium depletion of chernozems.

Keywords: typical chernozem, granulometric texture, total potassium, reserves

* National University of Life and Environmental Sciences of Ukraine, Heroiv Oborony St. 15, Kyiv, Ukraine; corresponding author's e-mail: lorakucher@ukr.net

INTRODUCTION

Potassium is one of the important elements of the plant nutrition. It is involved in protein and carbohydrate metabolism, activating the synthesis of several enzymes and one of the first reactions of photosynthesis – the formation of adenosine-triphosphate (ATP) – and is necessary for the chlorophyll formation in plants, increases resistance of plants to pests and diseases (Rahman *et al.* 2014, Vozbutskaya 1964). Among many elements involved in soil-geochemical processes, potassium plays a special role (Seredyna 2013). Its behavior in the soil adequately reflects both the dynamic and statistical changes in the conditions of soil formation and direction of transformations in the soil.

Repeatedly, the researchers involved in soil potassium research pointed out that the content and forms of this element in soils are determined by the mineralogical and granulometric texture of parent rocks, zonal specificity and intensity of anthropogenic factors, including the use of fertilizers and meliorants, drainage and irrigation and development of erosion processes (Peterburgsky and Yanishevsky 1961, Darunsontaya *et al.* 2012). In general, loamy soils contain 2.0–2.5% potassium, while some sandy soils up to 0.2–0.3% (Zamyatin and Izmestyev 2013). Studying the mechanism of plants supply with potassium from the soil was a study subject of numerous researchers (Maha Mohamed El-Sayed Ali and Rasha El-Meihy 2015); they associated its moving form content with moisture available to plants (Zeng and Brown 2000, Serafim *et al.* 2012). This allows the diffusion processes in which the plants absorb this element (Titus and Pereira 2016).

Research on the soil separation into particles of different sizes helped to identify the most important for plant nutrition granulometric fractions and minerals that are their part (Vazhenyn and Karaseva 1959, Gorbunov 1978, Pivovarova 1988, Vozbutskaya 1964). The most popular studies of secondary minerals, which are part of the silt fraction, were performed by Sparks (1980, 1986).

Knowledge in different potassium fractions in soils is essential for controlling this element in the farming system (Habib *et al.* 2014, Lalitha and Dhakshinam 2013). As a rule, it is believed that our soils do not have any shortage of available potassium due to the dominance of illitic clay mineral, which provokes farmers not to bring potassium fertilizers into the soil, because potassium is mobilized from non-exchangeable forms (Gospodarenko 2013). But the increase in areas under the cultivated crops in the crop rotation system resulted in the outflow of available potassium forms from the soil, thus, increasing the sensitivity of plants to it when applying potassium fertilizers.

Ukraine's chernozems (Mollisols) represent almost 8.5% of all world reserves of this soil type. The main land fund of the forest-steppe zone is typical chernozem, which is more than 6 million hectares and subject to degradation by its agricultural use (by the farms), as after the 1990s, fertilization, especially potassic decreased dramatically, and during the period of the agriculture intensification, the areas of technical crops, that are the main consumers of potassium and are forever taken out the soil, have grown considerably (Rutkowska 2013). Therefore, one of the most discussed issues of modern research is the study of reserves of nutrient elements in soils, especially those which are subject to degradation, in order to identify this process in a timely manner and to take early actions to restore their fertility. On the other hand, insufficient regulation of doses and fertilizers proportions, non-return of the removal nutrition elements with crops, reduce the fertility, disrupt the soil processes, adversely affect the ecological conditions, that is especially actual these days.

MATERIALS AND METHODS

Guided by a soil map, we have conducted a study of zonal chernozems with different granulometric texture of the forest-steppe zone of Ukraine.

The cuts for the study of morphological characteristics and sampling on the following soils were formed: podsolized heavy loam chernozem in the forest of Monastyrsky raion of Ternopil region, typical medium loam chernozem in the forest of Fastiv raion of Kiev region, typical heavy loam chernozem in the forest of Chornukhynskyi raion of Poltava region. In the studied soils, the soil samples were taken from the horizons named according to the Ukrainian classification. In order to study the potassium reserves in these soils, total potassium was determined using the Smith method, water-soluble potassium – in a water extraction, exchangeable potassium – according to the Maslov method, and non-exchangeable – according to the Pcholkin method. Extraction of silt soil fraction was performed according to the method of measuring MMV 31-497058-003-2001 “Silt extraction by centrifugation method in the modification of National Science Centre Institute for Soil Science and Agrochemistry”, calculation of potassium reserves was carried out according to Gorbunov (1978).

RESULTS

The study of the content and the ratio of total potassium in these soils enables not only to appreciate its meaning from the agrochemical and biological point of view, but also to present its geochemical role in the processes of erosion and soil formation (Seredyna 2013). The main part of potassium in the soil is presented in the form of hardly soluble primary minerals – aluminosilicates: orthoclase and microcline, muscovite and biotite, leucite, nepheline, etc. (Luo and Jackson 1985). During intense soil ignition in its mixture with ammonium chloride and calcium carbonate, silicates are decomposed as follows:

$$2KAlSi_3O_8 + 6\ CaCO_3 + 2NH_4Cl =$$
$$6Ca\ SiO_3 + Al_2O_3 + 2KCl + 2NH_3 + 6CO_2 + H_2O$$

During the ignition process, at first, ammonium chloride decomposes to form ammonia, which disappears, and the hydrochloric acid reacts with calcium carbonate to form calcium chloride. Calcium chloride and hydrochloric acid affect aluminium silicates, dissolve them to form calcium silicate, alkali-metal chlorides and water. As a result of sintering, potassium and sodium are converted into forms of highly soluble chlorides, and silicic acid, ammonium, iron, manganese, magnesium, phosphoric acid – into an alloy that is insoluble in water. In the original Smith method, the soil in a mixture with ammonium chloride and calcium carbonate in a ratio of 1:1:4 is sintered in platinum crucibles at a temperature of 750ºC.

The total potassium reserves in the investigated soils are in the range of 74.4–104 t/ha in the upper soil root layer (Table 1). However, high reserves of potassium chloride do not mean a high supply of plants with potassic nutrition (Seredyna 2013). Two opposite processes take place in the soils simultaneously: on the one hand, under the influence of chemical and biological processes, erosion of potassium-containing minerals, which is accompanied by an increase in water-soluble and exchangeable potassium occurs and, on the other hand – there is the process of potassium fixation with soil colloids. The proportion of these processes in the soil will considerably determine the need for potassic fertilizers and their effectiveness.

The most active part of the soil, on which its agrophysical and physico-chemical properties and, as a result, fertility depend, is a silt fraction. Gorbunov notes that the mineralogical analysis of the soil can be replaced, to some extent, by chemical and mechanical ones (Gorbunov 1978). Clay minerals, such as hydrous micas, form a fraction of <0.001 mm of chernozem soils. Seredyna states that potassium, which is primarily digested by plants, is concentrated in this fraction (Seredyna 2013). The content of silt fraction in all investigated soils decreases downward the profile. The total potassium content is most correlated with this value. In typical light loamy chernozem, the correlation coefficient between these variables was 0.9, in the podzolized and medium-loamy chernozem – 0.8, in the heavy-loamy one – 0.7. We have a clear tendency to decrease the content of total potassium in this fraction downward the profile of all the studied soils. Only in the illuvial horizon of podzolized chernozem, there is a certain potassium holdup due to the genesis of this soil. Also, accumulation of total potassium in the upper genetic horizon of chernozem soils is obviously connected with its continuous biological accumulation in the accumulation horizon during the process of soil formation, as well as with higher content of humus. Equally important is the high content of hydrous micas in the humus accumulative horizon of chernozem. Hydromication of swellable minerals is a result of fixation of biogenic potassium, the annual income of which to the upper horizons of chernozem can reach 90–100 kg/ha.

Table 1. Content and reserve of total potassium (according to Smith) in chernozem soils of variable granulometric texture

Genetic horizon	Depth, sm	Content of fraction <0.001 mm	General content of total potassium in the soil		Content of total potassium in the fraction <0.001 mm	Content of hydrous mica
			%	t/ha	%	
Typical light loam chernozem in the forest						
A	0–31	22.8	2.0	74.4	2.38	39.7
AB1	32–60	21.0	1.94	65.2	2.31	38.5
AB2	61–102	18.9	1.93	95.0	2.0	33.3
C	103–130	18.7	1.93	62.5	2.0	33.3
	LSD_{05}		0.05	-	0.07	-
Podsolized heavy loam chernozem in the forest						
A	0–38	25.2	2.28	104	2.36	39.3
BC1	39–60	23.6	2.21	55.7	2.22	37.0
BC2	61–97	24.1	2.34	101	2.27	37.9
BC3	98–110	22.8	2.48	35.7	2.17	34.5
C	111–155	22.2	2.48	131	2.17	36.1
	LSD_{05}		0.09	-	0.04	-
Typical medium loam chernozem in the forest						
A	0–41	24.1	2.19	108	2.57	42.8
AB	42–70	24	2.13	68.2	2.26	37.6
CB1	71–130	23.3	2.07	150	2.26	37.6
CB2	131–203	23.7	2.07	188	2.23	37.2
C	204–220	23.4	2.02	37.8	2.18	36.3
	LSD_{05}		0.05		0.05	-
Typical heavy loam chernozem in the forest						
A	0–34	23.0	2.22	89.8	2.56	42.6
AB	35–68	21.5	2.19	86.9	2.37	39.5
CB1	69–92	20.6	2.12	58.7	2.34	39.0
CB2	93–152	19.0	2.21	159	2.28	38.0
C	153–160	19.0	2.12	20.7	2.30	38.3
	LSD_{05}		0.06		0.05	-

The carbonate forest under the podzolized chernozem contained the highest total potassium – 2.48% compared to the forests on which other soils were formed. In general, the content of total potassium according to the profile of the studied soils changed little, which is a characteristic feature of chernozem soils genesis.

The content of total potassium in the fraction of <0.001 mm closely correlates with the content of the hydrous mica in the soil (Figure 1). The correlation coefficient is 0.9. This is evidenced by research conducted by Gorbunov (1978).

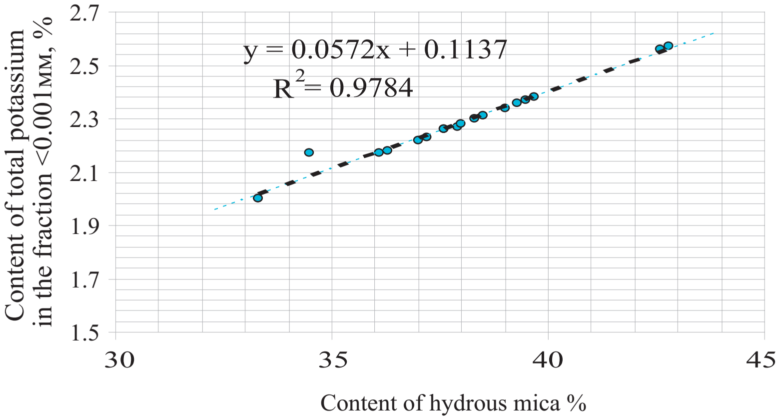

Fig. 1. Linear functional dependence between tha content of total potassium and cottent hydrous mica in the fraction 0.001 mm

In chernozems, the content of the silt fraction varies little according to the profile: in the upper profile part, hydromicaceous mineral, mixed-layer mica-smectite formations, kaolinite, chlorite, and sesquioxides – goethites and gibbsites, predominate. Also, the silt fraction of chernozem contains highly dispersed quartz. There is a slight increase downward the profile in the minerals of the montmorillonite group and the reduction of hydrous mica. This is explained by the hydromication of swellable minerals as a result of potassium fixation, as well as mica hydration.

To assess the effective and potential soil fertility, it is necessary to be aware of the reserves of soil nutrients. According to Gorbunov, the whole reserve of nutrient elements is called a general reserve. It consists of direct, proximate and potential ones, determined by bulk analysis of soils.

Using the agrochemical extracts (water and acetic ammonia) we determine the direct reserve, because it is from what the plants absorb nutrition elements. The number of elements that are in the silt soil fraction is called proximate. The selection of this reserve is explained by the fact that the plants will take ash elements from the silt part of the soil, if they are not in direct reserve. The ash elements contained in the >0.001 mm fraction are called potential reserve. The proximate reserve is calculated by multiplying the K_2O milligrams in the fraction less than 0.001mm by the amount of this fraction in the soil as a percentage and dividing by 100. The potential reserve is determined from the total, direct and proximate reserves. It should be noted that the fraction content less than 0.001 mm is approximately equal to the content of clay minerals.

To assess the availability of potassium reserves for plants, their differentiated metering according to Gorbunov (1978) was carried out (Table 2). As calculations show, in the potential reserve of the humus and accumulative horizon of investigated chernozem, 69–73% of the potassium total reserve are concentrated. This potassium is connected with particles greater than 0.001 mm in the main and acidic feldspars and coarse mica, and is a hard-to-get reserve of this element. Potassium of the potential reserve is slow-moving and is removed for a long time because the weathering in the conditions of the forest-steppe of Ukraine is rather slowly. It gradually transforms into proximate and direct reserves.

Table 2. Potassium reserves in the chernozem soils in the soil layer 0–100 sm

Soil name	Genetic horizon	Depth, sm	Potassium reserve, mg/kg			
			direct	proximate	potential	general
Typical light loam chernozem in the forest	A	0–31	189	5,420	14,390	20,000
	AB1	32–60	178	4,850	14,370	19,400
	AB2	51–100	176	3,780	15,340	19,300
Typical podsolized heavy loam chernozem in the forest	A	0–38	170	5,940	16,690	22,800
	BC1	39–60	218	5,470	16,410	22,100
	BC2	61–97	236	5,240	17,920	23,400
	BC3	98–100	189	4,940	19,670	24,800
Typical medium loam chernozem in the forest	A	0–41	162	6,200	14,540	20,900
	AB	42–70	160	5,420	14,720	20,300
	CB1	71–100	223	5,490	14,990	20,700
Typical heavy loam chernozem in the forest	A	0–34	173	5,890	16,140	22,200
	AB	35–68	177	5,100	15,920	21,200
	CB1	69–92	166	4,280	17,450	21,900
	CB2	93–100	154	4,330	17,620	22,100

The main source of replenishment of potassium available for plants is the proximate reserve, which contains 26–30% of the potassium total reserve in the upper genetic layer of chernozem soils. This reserve has potassium contained in the clay minerals of the soils.

The most important for plant nutrition is the supply of readily soluble forms of potassium in the soil – it is the so-called direct reserve, which contains a quite small amount of potassium of the general reserve – 0.8–0.9%. The most available forms were contained by the light-loamy chernozem – 189 mg/kg soil.

CONCLUSIONS

All studied soils have the same specificity of the reserves distribution on the horizons in connection with the common processes of genesis and the same parent rocks which are the forests. The illuvial horizon of podzolized chernozem holds up the certain part of silt and potassium that is explained by the specifics of the formation of this horizon. The proximate reserve of chernozem soils contains less than 50% of potassium of the total reserve, that allows to talk about the potassium depletion of chernozem, since all forms are in labile equilibrium.

Insufficient introduction of potassium mineral fertilizers will worsen the potassium state, in the first place, the typical medium loam chernozem from 162 mg/kg potassium available to plants in the upper horizons.

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