ҐРУНТОЗНАВСТВО ТА АГРОХІМІЯ

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SOLUBLE SILICON COMPOUNDS IN SOILS OF DIFFERENT GRANULOMETRIC COMPOSITION OF THE WESTERN REGION OF UKRAINE

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Abstract. *One of the most common elements in the earth's crust is silicon. In soils, its content varies widely. One hundred years ago, to the role of silicon in agriculture and human nutrition was not paid attention. But with the intensification of agricultural production in addition to the basic elements, nitrogen, phosphorus, potassium, the importance of which for crop yields is recognized, much attention was paid to secondary and trace elements, in particular, silicon.*

The aim of the research was to determine the content of soluble silicon compounds in the arable layer of chernozem-type soils depending on their particle size distribution. The research was conducted on arable lands of Novoushitsky district of Khmelnytsky region. In soil samples were determined: particle size distribution and content of fractions of different sizes according to SSTU 4730:2007; pH of salt extract according to SSTU ISO 10390:2001; humus content according to SSTU 4289:2004; the content of exchangeable compounds of calcium and magnesium by extraction with 1.0 M KCl solution. Silicon compounds in soils were determined by the method of Mullen and Riley with extraction of silicon by the method of V.V.Matichenkov.

Studies that were conducted on agricultural soils of Khmelnytsky region have shown that the content of silicon compounds in soils is related to the particle size distribution of

the soil, the values of exchangeable acidity, humus content, as well as the composition and content of exchangeable cations. The average values of readily-available silicon compounds in the studied soils of agricultural lands of Novoushitsky district of Khmelnytsky region range from 87 to 120 ppm SiO2, and hard-soluble - 520-854 ppm SiO2. To assess the content of silicon compounds in the soils of Ukraine and the need for the use of silicon fertilizers, we propose to use the ratio of the content of readily-available (active) and hard-soluble (potential) silicon. Optimal values should be 3-4 for the ratio of exchangeable calcium to fixed silicon, and 5-6 for the ratio of hard-soluble to readily-available silica. The studied soils of Novoushitsky district of Khmelnytsky region have low-deficient and non-deficient balance of silicon, both of readily-available and hard-soluble forms. Since the yield of winter wheat was closely related to the content of readily-available silicon compounds (r = 0.74 ± 0.09), it is important to continue research on the use of silicon fertilizers.

Key words: *readily-available silica, hard-soluble silica compounds, reaction of soil medium, exchangeable cations, particle size distribution of soil.*

Actuality.

The intensification of agricultural production leads to an increase in the number of elements that are involved in the biological cycle. Including meso- and microelements, which are in the soil, become part of crops during their cultivation and are removed from the crop. Silicon is a micronutrient of ash type and is an integral part of any plant organism. The silicon content in the ash of cultivated plants ranges on average from 0.16 to 8.4%. The largest amount of Si is contained in cereals - up to 8-16%, and in the rice plant - up to 15-20% SiO_2 (Органічний кремній, 2016). The aim was to study the content of silicon compounds of different mobility in soils and its relationship with soil physicochemical parameters, yield of winter wheat.

Аналіз останніх досліджень та публікацій.

Large-scale studies of the effect of silicon on crop yields have begun relatively recently. The results of many studies confirm that silicon compounds can promote better plant development, alleviate the effects of negative biotic and abiotic factors, and increase yields in both stressful and non-stressful conditions (Ma J. F., 2004). The ability of the root system to absorb silicon distinguishes monocotyledonous plants, which include cereals, as those that effectively use silicon from the soil, and dicotyledons, which include legumes, most vegetable crops, as those in which is the low ability to absorb silicon compounds from soil. The largest consumers of silicon among cultivated plants are sugar cane and rice (Jian F. M., Tamai K., Yamaji N., et al., 2006; Casey W. H. At all., 2004; Mitani N., Ma J. F., 2005) Typical plants that like silica are sunflower, table and sugar beet, cereals (especially rice, wheat and barley), and some berry crops, such as strawberries. The use of silicon fertilizers had a positive effect on crops from the families of cereals, legumes, nightshade, pumpkin, quince, root, grape and others (Органічний кремній, 2016).

According to M.P.Kolesnikov, plants absorb silicon from the soil solution in the form of ions (SiO_3^{2-}) and (SiO_4^{4-}), as well as in the form of mono-silicic acids (H_2SiO_3 and H_4SiO_4), which in cell

juice are converted into silicon gel $SiO_2 \times nH_2O$. Then there is its biochemical binding with cell polymers (proteins and carbohydrates) and accumulation on the surface of cell walls, in integumentary tissues (surface layers of the epidermis of leaves and roots, bark), or in various types of phytoliths (organomineral formations - globules that make up mechanical plant tissue). The formation of integumentary and conductive tissues of the plant, in fact, is accompanied by the formation of a double cuticular layer in the intercellular spaces inside the cells, which is a silicon-cellulose membrane (Органічний кремній, 2016).

The availability of silicon for plants from silicon-containing fertilizers depends on the acidity. Acidic soils are considered more depleted, and therefore respond better to silicon fertilizers. When conducting research on acidic, neutral and alkaline soils, there was an increase in crop yields on all these soils (Ohyama N., 1985). It is noted that there is a positive correlation between the supply of silicon and phosphorus in plants. This situation is explained both in terms of the direct effect of silicon on the availability of phosphorus (Mitani N., Ma J. F., 2005), and indirect - silicon reduces the supply of manganese and iron to plants, and these elements are phosphorus antagonists. Accordingly, the supply of phosphorus in plants increases. Relevantly, the conditions under which a large number of mobile compounds of iron and manganese are observed in soils that are formed in acidic soils and in soils that have wet conditions.

Studies (Ma J. F., 2004; Matychenkov V. V., Ammosova Y. M., 1996) show that the use of silicon reduces salt stress in plants in arid conditions. Because this element helps to increase the ability of the root system to absorb water, root activity increases and transpiration reduces. Also, silicon is involved in regulating the activity of enzymes, which increase the ability to absorb potassium by plant cells and reduce the absorption of sodium.

Some authors in studying the effect of silicon compounds on crop yields in vegetation and field experiments with unregulated moisture supply found that the effectiveness of silicon is higher in adverse weather conditions of the growing season (drought and high temperatures). The effectiveness of the use of silicon-containing compounds to improve drought resistance and productivity of plants is mostly determined by species and varietal characteristics of cultivated crops (Mitani N., Ma J. F., 2005; Титова В.И., Дабахова Е.В., Дабахов М.В., 20011; Tonkha O.L. ; Dzyazko, Y.S., 2014; Tonkha O.L. at all, 2018; Піковська О.В., Вітвіцька О.І., 2016).

The aim of the research was to evaluate the dependence of the content of silicon compounds of different mobility on the physicochemical parameters of soils of heavy texture of Novoushitsky district of Khmelnytsky region.

Research methodology.

The research was conducted on arable lands of Novoushitsky district of Khmelnytsky region. Crops grown on these arable lands: corn, sunflower, winter wheat, soybeans. Soils of the territory - chernozems podzolized heavy loam and light clay on loess, have erosion of different intensity. The humus content in the upper layer is up to 2.5-2.9 %. Availability of mobile phosphorus compounds - from low to high, mobile potassium - from high to very high. Soil samples were taken from a depth of 0-25 cm in the amount of 44 soil samples by randomization according to ISO 10381-2. Preparation for chemical analysis was carried out in accordance with SSTU ISO 11464-2001.

In soil samples were determined: particle size distribution and content of fractions of particles of different size according to SSTU 4730:2007; pH of salt extract according to SSTU ISO 10390: 2001; humus content according to SSTU 4289:2004; the content of exchangeable compounds of calcium and magnesium by extraction with 1.0 M KCl solution. Silicon compounds in soils were determined by the method of Mullen and Riley with extraction of silicon by the method of V.V. Matichenkov. This method allows to determine the content of monosilicic acids in the soil. Silicon compounds were determined in 2 types of extractants: readily-available (actual) silicon was determined by extraction with 0.01 M $CaCl_2$ solution, hard-soluble (potential) silicon was determined by extraction with 0.1 M HCl, in the ratio soil:solution 1:10, time of interaction of soils with extraction solutions was 1 hour.

Research results

Organic silicon is multifunctional and has two types of impact on crop yields: direct impact on plants and indirect - through soil or soil fertility. Today, studies aimed at assessing the content of silicon compounds, their relationship with other elements in soils for agricultural use are becoming widespread. In our opinion, it is important to quantify the content of silicon compounds in soils of different texture, as well as to find the relationship between the dynamics of silicon compounds and physical-chemical properties and the composition of exchangeable cations.

The analyzed samples of the arable layer of soils were grouped by the content of the fraction of physical clay, particle size less than 0.01 mm, in the following groups: 40.1-45.0%, 45.1-50.0% (heavy loam soils), 50, 1-55.0%, 55.1-60.0% (clay soils). For each group of samples, the mean values of the studied indicators are derived, as well as the calculated standard deviations, which are presented in relative percentages. We assume that if the standard deviation of individual values from the mean is less than 30%, it is possible to draw conclusions with high reliability about the patterns and relationships between indicators. The exchangeable acidity of the studied soils averaged 4.4-4.7 pH units, dependence on the studied soil textures is not observed. This reaction belongs mainly to the medium acid, i.e. soils are unsaturated by bases. The average values of humus content tend to increase from heavy loam to light clay texture, and varies from 1.8 to 2.4% on average. The amount of exchangeable cations of calcium and magnesium increases with increasing of physical clay content in soils, on average from 10.0 to 16.4 mmol/100 g of soil (table 1, Fig. 1).

The content of exchangeable cations in the soil of Novoushitsky district is represented mainly by calcium. From this position, the content exchangeable calcium and magnesium compounds was studied in the soils of different texture and relationship with soluble silicon compounds. The average values of exchangeable calcium content in the studied soils are 1750-2790 ppm, exchangeable magnesium -183-302 ppm (Table 2).

According to the removal of silicon, all plants are divided into two groups: plants with low removal (usually dicotyledons - potatoes, buckwheat, clover, etc.) and plants with high removal (mostly monocotyledonous families, such as cereals). It is also noted that all plants remove silicon slightly more than other macronutrients. For example, for potatoes, the amount of SiO_2 removal varies from 50 to 70 kg / ha, for cereals - from 100 to 300 kg / ha.

1. Granulometric composition and some physical and chemical properties of the investigated soils of the Khmelnytsky region, Novoushitsky district, mean values and standard deviations

Groups by physical clay particles (<0,01 mm) content in soil	Amount of soil samples analyzed	Content of granulomentric particles of different sizes						pH, salt extraction		Humus content, %	
		<0,01 mm, %		<0,005 mm, %		<0,001 mm, %					
		average	deviation, % relative	average	deviation, % relative	average	deviation, % relative	average	deviation, % relative	average	deviation, % relative
40,1-45,0%	10	43,0	3	33,8	6	21,5	20	4,4	11	1,8	17
45,1-50,0%	15	47,2	4	36,4	12	25,0	10	4,7	9	2,2	14
50,1-55,0%	13	51,6	2	42,3	4	30,0	8	4,6	7	2,4	13
55,1-60,0%	6	56,2	1	44,4	10	32,3	19	4,5	11	2,3	22

The minimum (critical) for most plants concentration of monosilicic acids in the soil solution is 20 ppm (Casey W. H. At all., 2016). Higher content increases the germination of cereal seeds, ripening of corn cobs, increases the accumulation of starch in potato tubers. Organic silicon is involved in the processes of phosphorylation of carbohydrates. This enhances the synthesis of simple sugars and increases the starch content of cereals, sugar content of beets, citrus and berry crops. Average values of readily-available (actual) silicon at the level of 21-40 ppm SiO_2 and 301-600 ppm SiO_2 hard-soluble (potential) silicon according to this gradation refer to low-deficit silicon balance, and values higher than 40 ppm SiO_2 readily available and higher than 600 ppm of hard-soluble SiO_2 - to non-deficit balance.

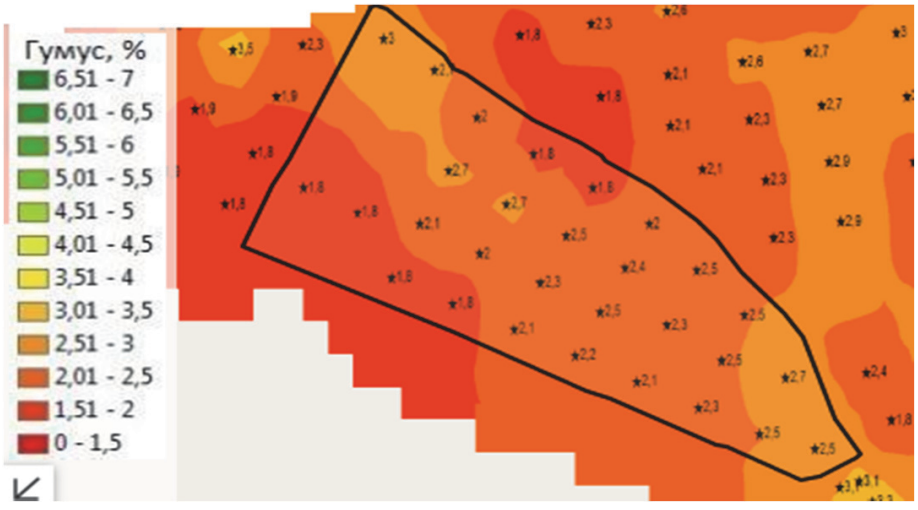

Fig. 1. Cartogram of the humus content of the field with the content of physical clay 45-50%

2. Exchangeable calcium and magnesium compounds in soils of the Khmelnytsky region, Novoushitsky district, mean values and standard deviations

Groups by physical clay particles (<0,01 mm) content in soil	Amount of soil samples analyzed	Exchangeable calcium content, Ca, ppm		Exchangeable magnesium content, Mg, ppm		Content of sum of exchangeable bases Ca+Mg, mmol/100 g soil	
		average	deviation, % relative	average	deviation, % relative	average	deviation, % relative
40,1-45,0%	10	1750	19	183	37	10,0	17
45,1-50,0%	15	2060	12	248	34	12,4	15
50,1-55,0%	13	2520	9	302	24	15,1	9
55,1-60,0%	6	2790	19	295	25	16,4	20

The content of readily-available silicon compounds in the studied soils averages 87-120 ppm. At the same time significant (31-59%) relative deviations of individual values from averages are observed in heavy textured soils. The average values of hard-soluble silicon compounds in the studied soils are 520-854 ppm, the standard deviation of individual values from the averages is 17-31%. That is, the content of these silicon compounds in soils is 3.3-4.0 times lower than the content of exchangeable calcium. In the soils of Novoushitsky district there is slight relationship between the change in the ratio of Ca/SiO_2 and an increase in the content of physical clay in soil. The largest values of this ratio are observed when the content of physical clay in the soil is 45.1-55.0%, decreasing at both lower and higher content of physical clay in the soil.

In the soils of Novoushitsky district there is a tendency to increase the content of hard-soluble silicon compounds with an increase from of the fraction of physical clay 40 to 60% (table 3).

For conclusions on the assessment of the content of silicon compounds in the soils of Ukraine and the need for the use of silicon fertilizers, we propose to use the ratio between the content of

3. Content of silicon compounds of different fractions in soils of Khmelnytsky region, Novoushitsky district, mean values and standard deviations

Groups by physical clay particles (<0,01 mm) content in soil	Amount of soil samples analyzed	Readily-available silicon content, SiO_2, ppm		Hard-soluble silicon content, SiO_2, ppm		Ratio Ca exchangeable/ SiO2 hard-soluble., based on averages	Ratio SiO2 hard-soluble/ SiO2 readily-available, based on averages
		average	deviation, % relative	average	deviation, % relative		
40,1-45,0%	10	101	59	520	31	5,1	3,4
45,1-50,0%	15	87	51	514	31	5,9	4,0
50,1-55,0%	13	112	52	671	17	6,0	3,8
55,1-60,0%	6	120	31	854	27	7,1	3,3

readily-available (active) and hard-soluble (potential) silicon. Optimal values are observed as 3-4 for the ratio of exchangeable calcium to hard-soluble silicon, and 5-6 for the ratio of hard-soluble (potential) to readily-available (active) silicon. The studied soils of Novoushitsky district of Khmelnytsky region have low-deficient and non-deficient balance of silicon, both easily-accessible and hard-soluble forms. The yield of winter wheat is closely related to the content of readily available silicon compounds and the correlation coefficient is $R = 0.74 \pm 0.09$, it is important to continue research to establish the norms of silicon fertilizers.

Conclusions.

The average values of easily-available silicon compounds in the studied soils of agricultural lands of Novoushitsky district of Khmelnytsky region range from 87 to 120 ppm SiO_2, and the average content of hard-soluble compounds is 520-854 ppm SiO_2. Studies show that the content of silicon compounds in soils is associated with the particle size distribution of the soil, the values of exchangeable acidity, humus content, as well as the composition and content of exchangeable cations. To assess the content of silicon compounds in the soils of Ukraine and the need for the use of silicon fertilizers, we recommend to use the ratio between the content of readily- available (active) and hard-soluble (potential) silicon. The studied soils of Novoushitsky district of Khmelnytsky region have low-deficient and non-deficient balance of silicon, both easily-available and hard-soluble forms. The correlation coefficient between the yield of winter wheat and the content of readily-available silicon is $R = 0.74 \pm 0.09$.

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О. Є. Бикова, О. Л. Тонха, О. В. Піковська, О. В. Пак (2020). РОЗЧИННІ СПОЛУКИ КРЕМНІЮ У ГРУНТАХ РІЗНОГО ГРАНУЛОМЕТРИЧНОГО СКЛАДУ ЗАХІДНОГО РЕГІОНУ УКРАЇНИ. *PLANT AND SOIL SCIENCE, 11(2): 22–29. https://doi.org/10.31548/agr2020.02.022*

Анотація. *Одним із найпоширеніших елементів земної кори є кремній. У ґрунтах його вміст суттєво варіюється. Сто років тому на роль кремнію в сільському господарстві та харчуванні людини не звертали уваги. Але з інтенсифікацією сільськогосподарського виробництва, окрім основних елементів: азоту, фосфору, калію, важливість яких визнається для врожаю сільськогосподарських культур, велика увага приділяється вторинним та мікроелементам, зокрема кремнію. Метою дослідження було визначення вмісту розчинних сполук кремнію в орному шарі ґрунтів чорноземного типу залежно від їхнього розподілу за розмірами частинок. Дослідження проводилися на ріллі Новоушицького району Хмельницької області. У ґрунтових зразках визначали: розподіл частинок за розміром та вміст фракцій різних розмірів згідно з ДСТУ 4730: 2007; pH сольового екстракту згідно з ДСТУ ISO 10390 : 2001; вміст гумусу згідно з ДСТУ 4289: 2004; вміст обмінних сполук кальцію та магнію через екстракцію 1,0 М розчином KCl. Сполуки кремнію в ґрунтах визначали методом Маллена та Райлі з вилученням кремнію методом В. В. Матиченкова. Дослідження, проведені у ґрунтах Хмельницької області, показали, що вміст сполук кремнію в ґрунтах пов'язаний із розподілом ґрунту за розмірами частинок, значеннями обмінної кислотності, вмістом гумусу, а також зі складом та вмістом обмінних катіонів. Середні значення легкодоступних сполук кремнію на досліджуваних ґрунтах сільськогосподарських угідь Новоушицького району Хмельницької області становлять від 87 до 120 проміле SiO2, а важкорозчинні - 520-854 проміле SiO2. Для оцінки вмісту сполук кремнію в ґрунтах України та необхідності використання кремнієвих добрив пропонуємо використовувати співвідношення вмісту легкодоступного (активного) та важкорозчинного (потенційного) кремнію. Оптимальні значення повинні бути 3-4 для відношення обмінного кальцію до нерухомого кремнію та 5-6 для відношення твердорозчинного до легкодоступного кремнезему. Досліджені ґрунти Новоушицького району Хмельницької області мають низькодефіцитний та недефіцитний баланс кремнію, як легкодоступних, так і важкорозчинних форм. Оскільки урожай озимої пшениці був тісно пов'язаний із вмістом легкодоступних сполук кремнію (r = 0,74 ± 0,09), важливо продовжити дослідження щодо використання кремнієвих добрив.*

Ключові слова: *легкодоступний діоксид кремнію, важкорозчинні сполуки кремнезему, реакція ґрунтового середовища, обмінні катіони, розподіл ґрунту за розмірами частинок.*