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Improving Biological Sustainability of Agrophytocenosis Of Winter Wheat and Potatoes by Applying Silicon-Containing Ores and Growth Promoting Factor Of "Krezacin" In the Context of Nizhny Novgorod Region.

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ABSTRACT

The work considers the changes in the biological productivity of winter wheat of the Moskovskaya 39 variety and potato of the Red Scarlett variety, as well as the structure of the crops yield obtained in the micro-field experiments laid down in the conditions of derno-podzolic light loamy soils in the Bor District of the Nizhny Novgorod Region. In the experiments we studied the capabilities of improving sustainability of agricultural crops agrophytocenosis by joint effect of the synthetic growth promoting factor of Krezacin and different doses of high-silicon-containing ores such as diatomite, zeolite and bentonite clay applied into the soil along with the NPK-compound. With regard to winter wheat, it is established that at the background of application of NPK-compound and plant treatment with Krezacin, the most effective is double and triple doses (6 and 12 t/ha) of diatomite and bentonite clay, as well as a double dose (6 t/ha) of zeolite. Here, the greatest increment in the context of the total biomass of winter wheat was found to be 24% when applying diatomite and 20% when applying bentonite. In the context of crop grain, these figures were 16 and 32%, respectively. With regard to potatoes, it is established that at the background of NPK-compound and plant treatment with Krezacin, the most effective is double dose (6 t/ha) for diatomite, as well as double and triple doses (6 and 12 t/ha) for bentonite clay. Here, the largest increments were 13% for diatomite and 21% for bentonite in the context of the total biomass of potatoes, as well as 16 and 27%, respectively, with respect to the crop tubers.

Keywords: winter wheat, sustainability of agrophytocenosis, crop bioproductivity, yield structure, diatomite, zeolite, bentonite clay, Krezacin.

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INTRODUCTION

Currently, the issue of improving the sustainability of agrophytocenoses is among priority objectives to ensure food security of the country. In this perspective, one of the most relevant aspects of the applied agroecology, as a part of agronomy of any agricultural production, is to find environmentally and economically acceptable ways of enhancing the efficiency of agricultural crops through the use of innovative sources of mineral nutrition [1, 2, 3, 4]. These generally include substances that are not industrially produced mineral fertilizers, but actively used in local agriculture as milled natural ores or processed fertilizing substances [5, 6, 7, 8, 9, 10].

The increasing interest in the agronomic study of silicate ores, despite universal recognition of the importance of silicon and its compounds in plant and animals life [11], often encounters the scientific stereotype of the biochemical inertness of silicon contained substances.

This leads to a lack of awareness among agricultural producers about the possibility of improving agronomic properties of soils [12, 13, 14, 15, 16] and increasing productivity of cultivated plants [17, 18, 19, 20, 21, 22, 23, 24, 25] through soil application of such natural substances as diatomite [26, 27, 28], zeolite [29, 30] and bentonite clays [31, 32].

However, these substances are essentially aluminosilicate ores of organogenic sedimentary and volcanogenic-sedimentary genesis, which include up to 80% of SiO_2, presented in half by an amorphous form which, in turn, is most susceptible to degradation within the soil and migration of silicon into the soil solution in the form of a silicate anion [33, 34]. Such movable silicon compounds can exert an effect on the soil acidity [35], its microbial and biochemical activity, the mobility of soil phosphates and silicates, as well as the productivity of crops and their resistance to unfavorable factors during the vegetation period such as a deficit of available moisture [36, 37, 38, 39], crop infestation with pathogenic microorganisms and pests [40, 41], as well as the overall low level of fertility of arable soils [42, 43], or their pollution with toxicants [44, 45]. Reducing the negative effects of the above factors leads to increased sustainability of agrophytocenosis and, consequently, to increase of its biological productivity. Besides, in the domestic literature, there is a lot of information about the comprehensive positive impact of the composite silicate and other silicon-containing substances [46, 47, 48, 49] on the components of agrophytocenosis. At that, their active ingredient is represented by the nanoparticles. Previously [6, 33, 42], in terms of micro-field experiments, it was found that diatomite, zeolite and bentonite clay in different doses are capable of effectively adjusting a positive impact on bioproductivity of cereals and tilled crops while increasing the gluten content in grain and fiber content in straw (tops) and optimizing the condition of the soil biota. In the framework of the present research the goal was set to study the biological productivity change of winter wheat and potatoes in the context of the micro-field experiments, as well as their yield structure, exposed to integrated impact of diatomite, zeolite and bentonite clay, whose different doses were used at the background of NPK-compound and treatment of plants with synthetic growth promoting factor of Krezacin.

MATERIALS AND RESEARCH METHODS

Micro-field experiment No.1 with winter wheat of the variety *Moskovskaya 39* was laid during the season of 2014, while the experiment No. 2 with the potatoes of the variety *Red Scarlett* was laid during the season of 2015, both based on potato-growing enterprise “Elitkhoz” JSC situated in the Bor District of the Nizhny Novgorod Region. The experiments were conducted to investigate the combined effect of Krezacin , NPK-compound and different doses of silicon-containing agronomical ore, namely diatomite, zeolite and bentonite clay.

The scheme of both experiments was similar. It included using the Krezacin and NPK-compound as a background (variant 1), as well as three variants of combined application of mineral fertilizers, three doses of diatomite (variants 2, 3 and 4), zeolite (variants 5, 6 and 7), and bentonite clay (variants 8, 9 and 10). At that, growth promoting factor Krezacin was applied in each of the variants. Agronomical ores were applied into the arable layer of soil once in summer period of 2014 when carrying out plots breakdown and laying the experiments in doses at the rate of 3, 6 and 12 t/ha for each ore. The NPK-compound was applied by soil application of nitrogen-phosphorus-potassium fertilizer (azophoska) and ammonium nitrate along with silicon agronomical ore in an amount of $N_{80}P_{80}K_{80}$ kg/ha of active substance in the experiment with wheat, and in an amount of $N_{100}P_{80}K_{80}$ kg/ha of active substance in the experiment with potatoes. The doses of Krezacin for soil treatment of winter wheat and potatoes were taken in accordance with the manufacturer's recommendations. Treatment with the agent was conducted three times, including treatment of wheat seeds and potato tubers by soaking them in the drug solution before planting, treatment of the crops in the spring of 2015 at the beginning of growth (tillering phase for wheat, and the third leaf phase stage for potato), as well as treatment in summer period of 2015 during the active growing season (beginning of flowering phase for wheat, and budding phase for potatoes).

Krezacin (active ingredient is tris (2-hydroxyethyl) ammonium o-tolyloxy-acetate) is a growth promoting factor, which in the physiological sense is a broad-spectrum adaptogen of plants and animals. This drug increases the body's resistance to prolonged exposure to adverse factors such as low and high temperatures, low content of nutrients in the soil, drought and many others.

In plants the drug promotes increased biosynthesis of proteins and nucleic acids, increases the activity of enzymes. Krezacin helps enhancing the resistance of organisms against diseases that results in increased natural productivity, i.e. increase in crop yield and product quality.

Micro-field experiment was laid out at the same site with derno-podzolic light loamy soils, which is characterized by low content of humus (1.2%), medium acid soil reaction (4.8 pH_{KCl}) as well as average provision with the mobile forms of phosphorus (86 mg/kg) and potassium (110 mg/kg). Winter wheat was harvested at the phase of complete ripeness of grain (August 2015), while potatoes – at the phase of foliage drying (September 2015). The area of the plot was 1 m^2 at randomized arrangement of plots and fourfold biological replication.

The diatomite under study was from Inzensky diatomaceous earth deposit (the Ulyanovsk Region), zeolite – from Hotynetsky field (the Oryol Region), and bentonite clay – from Zyryansky deposit (the Kurgan Region). Amounts of the plant nutrients, containing in these ores are presented in Table 1.

Table 1: Chemical composition of the investigated high-silica ores

Ore	The element in the oxide form (% on absolutely dry basis)					
	SiO (general)	SiO_2 (amorphous)	K_2O	P_2O_5	CaO	MgO
Diatomite	83.1	42.1	1.25	0.05	0.52	0.48
Zeolite	56.6	26.7	1.25	0.23	13.3	1.90
Bentonite	52.3	33.4	0.92	0.12	5.49	3.03

Mathematical processing of the research results was performed based on variance analysis according to B.A. Dospekhov [50] using the Microsoft Office Excel 2007 software.

RESEARCH RESULTS AND DISCUSSION

In the experiment we determined the effect of application of silicon agronomical ores in various doses in combination with superimposed effect of NPK-compound and growth promoting factor of Krezacin on the biological productivity of winter wheat and potatoes, as well as the structure of the obtained crop yield. Total biomass, grain and straw yield, as well as herbage and tubers were measured by weigh method, calculating then their ratio.

Thus, the conducted experiments revealed positive effect of the studied ores on total bioproductivity of winter wheat and potatoes (Table 2).

In the variants of combined use of Krezacin (KC) and the minimum doses of silicon-containing agronomical ores, applied to soils along with NPK-compound, there was a tendency to an increase in total biomass of winter crops. Here, minimum increment was noted in the variant with zeolite (5%), while maximum increment was obtained in the variant with bentonite clay (15%). The variants with the combined application of Krezacin and minimal doses of silicon-containing agronomical ores also showed a tendency towards increasing the total biomass of potatoes. In this case, the minimum increase was observed in the variant with zeolite (2%), while maximum increase was achieved in the variant with bentonite clay (12%).

Application of double and triple doses of diatomite (variants 3 and 4) and bentonite (variants 9 and 10) revealed a significant increase in total productivity of winter wheat. However, in the study of application doses of diatomite and zeolite, the maximum increment in the total biomass of wheat was noted only at double dose (24% for diatomite and 15% for zeolite). In case of a double dose of diatomite (variant 3), as well as in the variants with double and triple doses of bentonite (variants 9 and 10), a significant increase was observed in the overall productivity of the potatoes. Here, the maximum gain from the combined use of Krezacin and full NPK-compound with diatomite amounted to 13%, while the same effect with bentonite clay amounted to 21% in relation to the background.

Table 2: Table 2. The effect of silicon-containing agronomical ores, NPK-compound and Krezacin (KC) on the gross productivity of winter wheat and potatoes

No.	Variant	The total biomass of winter wheat, g/plot				The total biomass of potatoes, kg/plot			
		Ava-rage	± to the background		«G : S»	Ava-rage	± to the background		«T : H»
			g/plot	%			kg/plot	%	
1	NPK + KC	526	–	–	1 : 1.19	4.06	–	–	1 : 0.43
2	NPK + KC + D_1	580	54	10	1 : 1.30	4.37	0.31	8	1 : 0.42
3	NPK + KC + D_2	651	125	24	1 : 1.34	4.57	0.51	13	1 : 0.39
4	NPK + KC + D_3	640	114	22	1 : 1.37	4.47	0.41	10	1 : 0.38
5	NPK + KC + Z_1	553	27	5	1 : 1.24	4.15	0.09	2	1 : 0.41
6	NPK + KC + Z_2	605	79	15	1 : 1.29	4.55	0.49	12	1 : 0.41
7	NPK + KC + Z_3	597	71	13	1 : 1.28	4.44	0.38	9	1 : 0.40
8	NPK + KC + B_1	603	77	15	1 : 1.21	4.54	0.48	12	1 : 0.39
9	NPK + KC + B_2	630	104	20	1 : 1.19	4.76	0.70	17	1 : 0.37
10	NPK + KC + B_3	691	165	31	1 : 1.18	4.90	0.84	21	1 : 0.36
HCP_{05}			79	13	–		0.51	11	–

With regard to winter wheat, in the variants with the combined application of Krezacin and bentonite clay, the maximum gain of 31% was noted when applying the triple dose of agronomical ore. Here, it was observed also a 15% significant gain due to a fourfold increase in the dose of bentonite.

In terms of the grain to straw ratio (G : S) in the total biomass of winter wheat, it should be noted that in all variants of combined application of Krezacin, NPK-compound and silicon-containing agronomical ores, the proportion of straw in the gross mass of the harvest was always increased. Only in the variant 10, when applying growth promoting factor and highest dose of bentonite clay, the proportion of grain was higher than that in the background. When increasing the dose of silicon-containing ores, the proportion of straw was increased as following: in the variants with application of diatomite – up to a triple dose, in the variants with zeolite – to double dose. When applying bentonite, the proportion of the straw in the crop steadily decreased.

In the context of tubers to herbage ratio (T : H) in the total biomass of potato, in all variants of combined application of growth promoting factor and silicon-containing agronomical ores, the proportion of herbage in the total mass of the harvest was always reduced in relation to the background. At that, with increasing the dose of any considered siliceous ores, the proportion of potato herbage has steadily decreased. At that, the greatest effect was obtained when applying the diatomaceous agronomical ore.

Table 3 shows mass change in the grain and straw of winter wheat for the investigated variants.

With respect to winter wheat, it should be noted that in the variants with minimum doses of silicon-containing ores applied at the background of NPK-compound and Krezacin, there were certain gains in weight. Minimum gain was noted for zeolite (3%), medium – for diatomite (5%) and the highest one – for bentonite clay (14%), which proved furthermore to be statistically significant.

In the variants with application of diatomite and zeolite, the greatest amount of grain was noted at applications of their double doses. However, this 16% increase was significant only when applying to soil double dose of diatomite. The variants with application of zeolite showed just a trend.

In all variants of the bentonite clay application in combination with NPK-compound and Krezacin, a significant increase in grain yield of wheat relative to the background was noted. The largest increase of 32% was observed at application of a triple dose of agronomical ore. Also, it should be noted that this variant was characterized by a significant gain due to a fourfold increase in the dose of bentonite, which amounted to 16% in relation to the variant with a single dose.

The productivity of the straw component of the winter crop also was positive against the background, when applying jointly Krezacin, NPK-compound and silicon-containing agronomical ores. Here, the largest gain in weight was noted in the variants with a double dose of diatomite (30%) and zeolite (19%). With respect to the bentonite clay, the highest yield of straw, equal to 31%, was observed when applying the triple dose.

Table 3: The effect of silicon-containing agronomical ores, NPK-compound and Krezacin (KC) on yield of winter wheat grain and straw

No.	Variant	Grain, g/plot			Straw, g/plot		
		average	± to background		average	± to background	
			g/plot	%		g/plot	%
1	NPK + KC (background)	240	–	–	286	–	–
2	NPK + KC + $Diatomite_1$	252	12	5	328	42	15
3	NPK + KC + $Diatomite_2$	278	38	16	373	87	30
4	NPK + KC + $Diatomite_3$	270	30	13	370	84	29
5	NPK + KC + $Zeolite_1$	247	7	3	306	20	7
6	NPK + KC + $Zeolite_2$	264	24	10	341	55	19
7	NPK + KC + $Zeolite_3$	262	22	9	335	49	17
8	NPK + KC + $Bentonite_1$	273	33	14	330	44	15
9	NPK + KC + $Bentonite_2$	288	48	20	342	56	20
10	NPK + KC + $Bentonite_3$	317	77	32	374	88	31
HCP_{05}			27	10		41	12

When doubling the dose of diatomite, the weight of straw was increased by 14% as compared to its weight, obtained when applying a single dose. In addition to the above, increasing the dose of diatomite and bentonite clay fourfold also led to equivalent increments of weight by 13% relative to that for the variants with single doses of siliceous ores.

Table 4 shows changes in the weight of potato tubers and herbage, observed in the investigated variants.

Table 4: The effect of silicon-containing agronomical ores, NPK-compound and Krezacin (KC) on the yields of potato tubers and herbage

No	Variant	Grain, kg/plot			Straw, kg/plot		
		average	± to background		average	± to background	
			kg/plot	%		kg/plot	%
1	NPK + KC (background)	2.84	–	–	1.22	–	–
2	NPK + KC + $Diatomite_1$	3.08	0.24	8	1.29	0.07	6
3	NPK + KC + $Diatomite_2$	3.29	0.45	16	1.28	0.06	5
4	NPK + KC + $Diatomite_3$	3.24	0.40	14	1.23	0.01	1
5	NPK + KC + $Zeolite_1$	2.94	0.10	4	1.21	-0.01	-1
6	NPK + KC + $Zeolite_2$	3.23	0.39	14	1.32	0.10	8
7	NPK + KC + $Zeolite_3$	3.17	0.33	12	1.27	0.05	4
8	NPK + KC + $Bentonite_1$	3.27	0.43	15	1.27	0.05	4
9	NPK + KC + $Bentonite_2$	3.48	0.64	23	1.28	0.06	5
10	NPK + KC + $Bentonite_3$	3.61	0.77	27	1.29	0.07	6
HCP_{05}			0.40	12		0.11	9

With regard to the crops tubers weight, it should be noted that in the variants with minimum doses of silicon-containing ores, applied along with Krezacin and NPK-compound as a background, the increments in weight were as follows: minimum – for zeolite (4%), medium – for diatomite (8%), and the highest – for bentonite clay (15%), which also proved to be statistically significant.

In the variants with application of diatomite and zeolite, the highest yield of potato tubers was recorded at application of their double doses. However, just at application of diatomite in double dose, noted increment of 16% was significant. The variants with zeolite have shown just a trend.

All variants with the bentonite clay application in combination with the fertilizers as a background revealed significant increments in yield of potato tubers relative to the background. At that, the largest increment of 27% was observed when applying the triple dose of agronomical ore.

The productivity of potato herbage was positive with respect to the background in almost all experiments except of variant 5 with a minimum dose of zeolite. However, all the changes in the herbage mass of the crop did not obey any particular patterns.

CONCLUSIONS

The results of micro-field experiments have shown the joint effect of the silicon-containing ores, NPK-compound, and synthetic growth promoting factor of Krezacin on biological productivity of winter wheat of the variety *Moskovskaya 39* and potatoes of the variety *Red Scarlett*, as well as on the yield structure of the crops.

Concerning grain crops, it was revealed that in the conditions of derno-podzolic light loamy soils in the Bor District of the Nizhny Novgorod Region, the most effective are double and triple doses (6 and 12 t/ha) of diatomite and bentonite clay, and a double dose (6 t/ha) of zeolite as compared to the background of Krezacin and NPK-compound. Here, the greatest increments amount to 24% for diatomite and 20% for bentonite with regard to the total biomass of winter wheat, as well as 16 and 32%, respectively, with regard to the wheat grain.

Concerning potatoes, it was revealed that the most effective is double dose (6 t/ha) for diatomite, as well as double and triple doses (6 and 12 t/ha) for bentonite clay as compared to the background of Krezacin and NPK-compound. Here, the maximum increments amount to 13% for diatomite and 21% for bentonite in terms of the total biomass of potatoes, as well as 16 and 27%, respectively, in terms of the weight of weight crops tubers.

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REFERENCES

[1] Bocharnikova, E.A., Matychenkov, V.V., and A.G. Pogorelov, 2011, Sravnitel'naya harakteristika nekotoryh kremnievyh udobrenij [Comparative characteristics of some silicon fertilizers] [Text]. Agrochemistry, 11, pp. 25-30.

[2] Kulikova, A.Kh., 2013, Kremnij i vysokokremnistye porody v sisteme udobreniya sel'skohozyajstvennyh kul'tur [Silicon and high-silicon-containing ores as crops fertilizers] [Text]. Ulyanovsk, Publishing House of the Ulyanovsk State Agricultural Academy named after P.A. Stolypin, 176 p.

[3] Uromova, I.P., 2008, Biologizirovannaya sistema zashchity kartofelya ot boleznej [Biologized system of potato protection against diseases] [Text]. Agrochemical Bulletin, 6. pp. 38-40.

[4] Epstein, E., 2009, Silicon: its manifold roles in plants. Ann. Appl. Biol., pp. 155-160.

[5] Bocharnikova, E.A., Matichenkov, V.V., and Matichenkov, I.V., 2011, Biologizirovannaya sistema zashchity kartofelya ot boleznej [Silicon fertilizers and ameliorants: history of research, application of theory and practice] [Text]. Agrochemistry, 7, pp. 84-96.

[6] Kozlov, A.V., Kulikov, A. K., and Yashin, E.A., 2015, Rol' i znachenie kremniya i kremnijsoderzhashchih veshchestv v agroehkosistemah [The role and importance of silicon and silicon-containing substances in agro-ecosystems] [Text]. Bulletin of Minin University, 2(10), pp. 23.

[7] Kulikova, A.Kh., 2010, Vliyanie vysokokremnistyh porod kak udobrenij sel'skohozyajstvennyh kul'tur na urozhajnost' i kachestvo produkcii [The effect of high-silicon-containing ores as fertilizers for agricultural crops on products yield and quality] [Text]. Agrochemistry, 7, pp. 18-25.

[8] Matychenkov, V.V., 2008, Rol' podvizhnyh soedinenij kremniya v rasteniyah i v sisteme pochva-rastenie [The role of mobile silicon compounds in plants and in the soil-plant system] [Text]. Higher Doctorate Thesis in Biology, Pushchino, 34 p.

[9] Heather, A.C., Carole, C.P., 2007, Silica in plants: biological, biochemical and chemical studies. Ann. Bot. 100(7), pp. 1383-1389.

[10] Ma, J.F., Yamaji, N., 2006, Silicon uptake and accumulation in higher plants. Trends Plant Sci., 11(8), pp. 392-397.

[11] Ammosova, Ya.M., Balabko, P.N. , Matichenkov, V.V., and Avetyan N.A., 1990, Kremnezem v sisteme pochva – rastenie [Silica in the soil – plant system] [Text]. Agrochemistry, 10, pp. 103-108.

[12] Vodyanitsky, Yu. N., 1984, Deficit kremniya v nekotoryh pochvah i puti ego ustraneniya [Lack of silicon in some soils and ways of its elimination] [Text]. Agrochemistry, 8, pp. 127-132.

[13] Matychenkov, V.V., Ammosova, Y.M., 1994, Vliyanie amorfnogo kremnezema na nekotorye svojstva dernovo-podzolistoj pochvy [Effect of amorphous silica on some properties of derno-podzolic soil][Text]. Soil Science, 7, pp. 52-61.

[14] Samsonova, N.E., 2005, Rol' kremniya v formirovanii fosfatnogo rezhima dernovo-podzolistyh pochv [The role of silicon in formation of the phosphate regime of derno-podzolic soils] [Text]. Agrochemistry, 8, pp. 11-18.

[15] Ma J.F., Takahashi, E., 2002, Soil, fertilizer, and plant silicon research in Japan. The Netherlands, Elsevier, 281 p.

[16] Samsonova, N., 2004, Silicon role in formation of phosphate conditions in soddy-podzolic soils. Proceedings of the Environmental Int. Conference and Exhibition, Pushchino, Institute of Basic Biological Problems, 29 p.

[17] Loboda, B.P., Bagdasarov, V.R., and Fitsuro, D.D., 2014, Vliyanie udobreniya na osnove ceolitsoderzhashchih trepelov Hotyneckogo mestorozhdeniya na urozhajnost' i kachestvo kartofelya [Effect of fertilizer based on zeolite-containing rottenstones of Hotynetsky deposits on potatoes yield and quality] [Text]. Agrochemistry, 3, pp. 28-35.

[18] Kulikova, A.H., Yashin, E.A., Danilova, E.V., Yudina, I.A., Granina, O.S., and Nikiforov, S.A., 2007, Vliyanie udobreniya na osnove ceolitsoderzhashchih trepelov Hotyneckogo mestorozhdeniya na urozhajnost' i kachestvo kartofelya [Effect of diatomite and mineral fertilizers on yield and quality of sugar beet] [Text]. Agrochemistry, 6, pp. 27-31.

[19] Kulikova, A.Kh., Nikiforov, A.E., Elagin V.P., and Yashin, E.A., 2004, Vliyanie diatomita na urozhajnost' i kachestvo ovoshchnoj produkcii [Effect of diatomite on vegetable products yield and quality] [Text]. Agrochemistry, 2, pp. 52-58.
[20] Matychenkov, V.V., Bocharnikova, E.A., and Ammosova, Y.M., 2002, Vliyanie kremnievyh udobrenij na rasteniya i pochvu [Effect of silicon fertilizers on plants and soil] [Text]. Agrochemistry, 2, pp. 86-93.
[21] Nikitin, S.N., 2015, EHffektivnost' primeneniya udobrenij, biopreparatov i diatomita v lesostepi Srednego Povolzh'ya [Efficiency of application of fertilizers, biologics and diatomite in the forest-steppe of the Middle Volga Region] [Text]. Higher doctorate thesis in agricultural sciences, Saransk, 40 p.
[22] Ryabov E.A., 2016, Produktivnost' ozimoj pshenicy v zavisimosti ot primeneniya diatomita i udobrenij [Productivity of winter wheat depending on application of diatomite and fertilizers] [Text]. Proceedings of the Scientific and Practical Conference devoted to the 65th Anniversary of the Department of General Agriculture and Reallocation of Land, and the Day of Russian Science "Energy-Saving Technologies in the Landscape Specific Agriculture", pp. 218-221.
[23] Slastya, I.V., 2012, Vliyanie obrabotki soedineniyami kremniya semyan i vegetiruyushchih rastenij na produktivnost' sortov yarovogo yachmenya [The effect of seeds and vegetating plants treatment with silicon compounds on the productivity of spring barley varieties] [Text]. Agrochemistry, 10, pp. 51-59.
[24] Chekaev, A.E., 2014, Soderzhanie saharov v uzlah kushcheniya ozimoj pshenicy v zavisimosti ot primeneniya diatomita i udobrenij [The content of sugars in the tillering nodes of winter wheat depending on the application of diatomite and fertilizers] [Text]. Proceedings of the X Int. Scientific and Practical Conf. "Agroindustrial complex: state, problems, and prospects", pp. 137-142.
[25] Uromova, I.P., Shtyrlina, O.V. Koposova, N.N. Kozlov, A.V., and Shtyrlin, D.A., 2014, Brassinosteroids in breeding technologies healthcare potato. American Journal of Agricultural and Biological Sciences, 9(3), pp. 445-449.
[26] Kapranov, V.N., 2010, EHffektivnost' kremnijsoderzhashchego veshchestva diatomita na dernovo-podzolistoj pochve [The efficiency of silicon-containing substance of diatomite on derno-podzolic soil] [Text]. Problems of Agrochemistry and Ecology, 2, pp. 10-14.
[27] Kulikova, A. Kh., Yashin, E.A., 2015, Rol' kremniya i vysokokremnistyh porod v zashchite posevov sel'skohozyajstvennyh kul'tur [The role of silicon and high-silicon-containing ores in the protection of agricultural crops] [Text]. Bulletin of the Ulyanovsk State Agricultural Academy, 4 (32), pp. 30-35.
[28] Chekaev, A.E., 2015, Vozmozhnosti ispol'zovaniya diatomitov Korzhevskogo mestorozhdeniya Penzenskoj oblasti [The possibility of using diatomite of Korzhevsky deposit of the Penza Region] [Text]. Proceedings of 3rd all-Russian Scientific and Practical Conf. "Innovative Technologies in Agribusiness: Theory and Practice", pp. 139-145.
[29] Iskandarov, I. Sh., 1979, Ispol'zovanie prirodnyh ceolitov [Use of natural zeolites] [Text]. Soil Science, 10, pp. 426-429.
[30] Loboda, B.P., 2000, Primenenie ceolitsoderzhashchego mineral'nogo syr'ya v rastenievodstve [Application of a zeolite-containing mineral raw materials in crop research] [Text]. Agrochemistry, 6, pp. 78-91.
[31] Agafonov, E.V., Khovansky, M.V., 2014, Vliyanie bentonita na povyshenie plodorodiya chernozema obyknovennogo [The effect of bentonite on the improvement of fertility of ordinary chernozem] [Text]. Soil Science, 5, pp. 597-601.
[32] Yapparov, A.H., L.M.H. Bikinina, Yapparov, I.A., Aliyev, Sh.A., et al., 2015, Izmenenie svojstv i produktivnosti chernozema vyshchelochennogo i seroj lesnoj pochvy pod vliyaniem meliorantov [Changing properties and productivity of leached chernozem and grey forest soil under the effect of ameliorants] [Text]. Soil Science, 10, pp. 1267-1272.
[33] Kozlov, A.V., and Kulikova, A.H., 2016, Vliyanie vysokokremnistyh porod na strukturu, chislennost' i fermentativnuyu aktivnost' cellyulozosaprotrofnogo mikrobnogo pula dernovo-podzolistoj pochvy v usloviyah vyrashchivaniya ozimoj pshenicy i kartofelya [The influence of high-silicon-containing ores on the structure, abundance, and enzymatic activity of the cellulose-containing microbial pool of derno-podzolic soils at the cultivation of winter wheat and potatoes] [Text]. Bulletin of the Ulyanovsk State Agricultural Academy, 1(33), pp. 56-65.
[34] Bocharnikova, E.A., and Matichenkov, V.V., 1994, Silicon soil state and biogeochemical balance in forest and grass ecosystems. Sustainable Development: the View from the Less Industrialized Countries. San Jose, Costa Rica, UNED, pp. 453-466.

[35] Pashkevich, E.B., Kiryushin, E.P., 2008, Rol' kremniya v pitanii rastenij i v zashchite sel'skohozyajstvennyh kul'tur ot fitopatogenov [The role of silicon in plant nutrition and protection of the agricultural crops against plant pathogens] [Text]. Problems of Agricultural Chemistry and Ecology, 2, pp. 52-57.

[36] Samsonova, N.E., Zaitsev, Z.F. Kapustina, M.V., and Antonova, N.A., 2014, Vliyanie soedinenij kremniya i slozhnogo NPK-udobreniya na vodnyj rezhim list'ev i urozhajnost' yarovoj pshenicy [The influence of silicon compounds and NPK-compound on the water regime of leaves and yield of spring wheat] [Text]. Agrochemistry, 9, pp. 58-66.

[37] Slastya, I.V., Lozhnikova, V.N., Kondratyeva, V.V., Nilovskaya, N.T., 2013, Dejstvie vodnogo stressa i soedinenij kremniya na soderzhanie ehndogennyh fitogormonov i rost yarovogo yachmenya [The effect of water stress and silicon compounds on the content of endogenous phytohormones and growth of spring barley] [Text]. Agrochemistry, 8, pp. 38-48.

[38] Agus Suyono, E., Nopitasari, S.M., Zusron, P., Khoirunnisa, D., Ayu, C., Buana Prabeswara, 2016, Effect of silica on carbohydrate content of mixed culture *Phaeodactylum* sp. and *Chlorella.* Biosciences Biotechnology Research Asia, 13(1), pp. 109-114.

[39] Wang, X., Ou-yang, C., Fan, Z., 2010, Effects of exogenous silicon on seed germination and antioxidant enzyme activities of *Monordiacharantia* under salt stress. Journal of Animal & Plant Sciences, 6, pp. 700-708.

[40] Belanger, R.R., 2005, The role of silicon in plant-pathogen interaction: toward universal model. Proceedings of the 3rd Conference on Silicon in Agriculture, Umberlandia, Universodate Federal de Uberlandia, pp. 34-40.

[41] Neumann, D., 2003, Silicon in plants. Silicon biomineralization. Progress in Molecular and Subcellular Biology, Ed. Muller W.E.G., 3, pp. 149-160.

[42] Kozlov, A.V., Uromova, I.P., Kulikova, A.Kh., 2016, Vliyanie kremnijsoderzhashchih stimulyatorov rosta na biologicheskuyu produktivnost' i pokazateli kachestva ozimoj pshenicy i kartofelya [The effect of silicon-containing growth promoters on the biological productivity and quality indicators of winter wheat and potato] [Text]. Bulletin of Minin University, (1-1,13), pp. 31.

[43] Samsonova, N.E., Kapustina, M.V., and Zaitsev, Z.F., 2013, Vliyanie soedinenij kremniya i mineral'nyh udobrenij na urozhajnost' yarovyh zernovyh kul'tur i soderzhanie v nih antioksidantnyh fermentov [The influence of silicon compounds and mineral fertilizers on the yield of spring grain crops and content of antioxidant enzymes] [Text]. Agrochemistry, 10, pp. 66-74.

[44] Belousov, V.S., 2005, Primenenie ceolitsoderzhashchej porody kak sorbenta ammiaka i pesticidov iz vodnyh sred [Application of the zeolite-containing ore as sorbent of ammonia and pesticides from aqueous media] [Text]. Agrochemistry, 8, pp. 65-69.

[45] Yoshida, S., 1975, The physiology of silicon in rice. Food Fert. Tech. Centr. Tech. Bull. Taipei. Taiwan, 4, pp. 35-42.

[46] Ezhkov, V.O., Bikinin, L.M.H., and Polivanov, M.A., 2013, Vliyanie nanostrukturnoj vodno-ceolitovoj suspenzii na produktivnost' grechihi [The effect of nanostructured water-zeolite suspension on productivity of buckwheat] [Text]. Bulletin of Kazan Technological University, 16(19), pp. 241-245.

[47] Panova, G.G., Semenov, K.N., Shilova, O.A., Khomyakov, Yu.V., et al., 2015, Vodorastvorimye proizvodnye fullerenov i kremnezol'nye nanokompozicii kak perspektivnye nanomaterialy dlya ispol'zovaniya v rastenievodstve [Water-soluble derivatives of fullerenes and sol-silicate nanocompounds as promising nanomaterials for use in crop research] [Text]. Agrophysics, 4, pp. 37-48.

[48] Panova, G.G., Anikina, L.M. Shilova, O.A., Kanash, E.V. Sinyavina, N.G., Hamova, T.V., Khomyakov, Yu.V., and Yakushev, V.V., 2015, Kremnijsoderzhashchie biologicheski aktivnye kompozicii s kompleksom poleznyh funkcij dlya ispol'zovaniya v rastenievodstve [Silicon-containing biologically active compounds with a set of useful functions for use in crop science] [Text]. Abstracts of the International Symposium "Chemistry for Biology, Medicine, Ecology and Agriculture", pp. 18-20.

[49] Fedorenko, V.F., Baklagin, D.S., Golubev, I.G., Nemenushchaya, L.A., 2015, Rossijskih nanopreparatov dlya obrabotki sel'skohozyajstvennyh kul'tur [A survey of Russian nano-preparations for treatment of agricultural crops] [Text]. Russian Nanotechnology, 10(3-4), pp. 126-131.

[50] Dospekhov, B.A., 2011, Rossijskih nanopreparatov dlya obrabotki sel'skohozyajstvennyh kul'tur [Methodology of field experiment (with fundamentals of statistical processing of research results)] [Text]. Moscow, Alliance Publishing House, 352 p.