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Optimization of the Productivity of Agricultural Crops at Application of Natural Minerals as Ameliorants and Mineral Fertilizers on Sod-Podzolic Soils

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Abstract
The paper concerns the results of altering the biological productivity of winter wheat of the Moskovskaya 39 variety, barley of the Veles variety and pea of the Chishminsky 95 sowing variety obtained in a three-year microfield experiment carried out in 2015 to 2017 on the sod-podzolic lightly argillaceous soils of the Borsky District of the Nizhny Novgorod Region. The experiments concerned the combined use of various dosages of highly siliceous minerals (3, 6 t/ha and 12 t/ha), diatomite, zeolite and bentonite clay introduced in the soil together with full mineral fertilizer. It was established with respect to winter wheat that vs. the NPK background the most effective method was to introduce a minimal dosage of 3 t/ha, under which conditions the addition in grain weight was 24% with respect to diatomite, 12% with respect to zeolite and 25% with respect to bentonite clay. It was established with respect to barley and pea that vs. the NPK background the most effective was the third dosage (12 t/ha), where the grain addition was 22% and 22% with respect to diatomite, 13% and 14% with respect to zeolite, 28% and 30% with respect to bentonite. As a whole, with respect to the study years, the alleviation in the effect of silicon-containing materials on the productivity of the crops was traced in the zeolite variants. In the variants with diatomite rocks and bentonite clay, this effect was about the same in the third year as the parameters of the first year, and it was increased under the high dosage conditions.
Keywords: winter wheat, barley, pea, crop bioproductivity, diatomite, zeolite, bentonite clay, mineral fertilizers.

1. Introduction

In the modern agroecological practice, the study of the effect of highly siliceous materials on the productivity of agricultural crops and the fertility state of the soil under conditions of various soil and climatic territories of Russia remains an important issue [1-5]. In particular, it is known that plants absorb silicon from the soil solution in the form of ions (SiO_3^{2-}) and (SiO_4^{4-}), and also in the form of monosilicic acids themselves (H_2SiO_3 and H_4SiO_4), which are then transformed in the cellular liquid into silica gel $SiO_2 \times nH_2O$. Then its biochemical binding with cellular polymers (proteins, carbohydrates) and accumulation on the surface of the cell walls take place in cover tissues (upper layers of the leave and root epidermis, crust) or in various types of phytoliths (organo-mineral formations, globules, that form coating and mechanical tissues of the plants). The skeletal formation of the coating and conducting tissues of the plant is essentially accompanied by the formation of a double cuticle layer which is a silicon-cellulose membrane. Due to this, the optimization of silicon nutrition of the plants leads to an increase in the biomass of the roots, their volume, total and operational adsorbing surface. Moreover, the use of silicon-containing fertilizers improves root nutrition, increases plant resistance to nematodes, hyphae of phytopathogenic fungi and other root pests [2, 6-8].

Despite the obviousness of the positive effect of such natural rocks as diatomites, gaizes, berg-meals, zeolites and various clays on plant yield, the parameters of plant quality and the agronomically valuable parameters of the plough horizon fertility, many issues of the compound behavior in the soils remain undisclosed.

Earlier, we have already established the effect of one of the natural silicon-containing materials, diatomite of the Inza basin and full mineral fertilizer on the yield of two agricultural crops under the conditions of vegetation experiments, which were started on the light-grey lightly argillaceous soil from the Bogorodsky District of the Nizhny Novgorod Region [6]. The aim of the studies is to study the effect of high (ameliorative) dosages of three rocks, diatomite, zeolite and bentonite clay, on the productivity of the main agricultural crops under the conditions of microfield experiment started on the sod-podzolic lightly argillaceous soil of the Nizhny Novgorod Region.

2. Methods and Materials

The studies were carried out in the microfield experiment basing on the potato enterprise "Elitkhoz" LLC of the Borsky District of the Nizhny Novgorod Region in 2015 to 2017. The microfield experiment comprised the control variant (NPK background) and 9 variants with introduction into the plough layer of the high (ameliorative) dosages of diatomite from Inza (Ulyanovsk Region), zeolite from Khotynets (Orel Region) and bentonite clay from Zyirian (Kurgan Region) basins with respect to the fertilizer background: NPK-background – full mineral fertilizing of the crop without introduction of highly siliceous rocks, NPK+diatomite basing on 3 tons per hectare, NPK+diatomite – 6 t/ha, NPK+diatomite – 12 t/ha, NPK+ zeolite – 3 t/ha, NPK+zeolite – 6 t/ha, NPK+ zeolite – 12 t/ha, NPK+bentonite – 3 t/ha, NPK+ bentonite – 6 t/ha, NPK+ bentonite – 12 t/ha. The rocks were introduced in the soils manually in August 2014 at preparation of the site and its separation into plots together with mineral fertilizers by spreading the material weights on the soil surface and digging of the plough horizon with the compounds.

The full mineral fertilizing of the crops was carried out by introducing into the soil the mixtures of azophoska (16:16:16), phosphorite meal (P_{20}) and ammonia saltpeter (N_{34} based on the $N_{80}P_{80}K_{80}$ kg/ha of the active substance in the experiment with winter wheat, $N_{80}P_{80}K_{60}$ kg/ha of the active substance in the experiment with barley and $N_{30}P_{40}K_{60}$ kg/ha of the active substance in the experiment with pea. In the first year of growing winter wheat, the mineral fertilizers were introduced together with the silicon-containing rocks in the year of starting the experiment (August 2014) and in the second and third year – divisionally in the autumn and spring periods (September, May).

The dosages of mineral fertilizers were taken in accordance with the generally accepted recommendations for using the mineral fertilizers in agriculture of the Nizhny Novgorod Region [9]; the dosages of silicon-containing rocks were determined by the importance of the modern study of high (ameliorative) norms for introducing such materials, which was mentioned in the papers of known scholars [4-5, 8]. There are a number of opinions that the potential effect of natural highly siliceous rocks on the state of SAC and SBC of the soils can be fully disclosed only if these are used in high dosages.

The generalized chemical contents of the studied materials are outlined in Table 1.

Table 1. Chemical contents of the natural silicon-containing materials

Rock	Element in the oxide form (% based on absolutely dry compound)					
	SiO_2 (total)	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

The soil of the experimental field is the sod-podzolic averagely soddy not deeply podzolic non-gleyed lightly argillaceous soil that is characterized as averagely acidic (exchange acidity is 4.8 pH_{KCl}), low-humus (humus content is 1.21%) with average occurrence of mobile phosphorus and potassium compounds (according to Kirsanov, it is 86 and 110 mg/kg soil, correspondingly) and also with the average deficiency level in the actual and potential silicon balance (according to Matychenkov, it is 16 and 23 mg/kg correspondingly).

In 2015, winter wheat (*Triticum L.*) of the *Moskovskaya 39* variety was grown; in 2016, barley (*Hordeum sativum Jessen.*) of the *Veles* variety was cultivated; in 2017, field pea (*Pisum L.*) of the *Chishminsky 95* variety was grown. The crop varieties are regionalized according to the Volgo-Vyatka Region.

Winter wheat (2015) and barley (2016) were harvested in August, in the grain full ripeness phase; pea was harvested in the top drying starting phase (August 2017). The experiments were carried out with strict adherence to the methodical requirements for microfield experiments and all works were performed manually. The accounting area of the plot was 1 m^2 and it was determined by the starting record of the hypothesis for carrying out the studies. The plot locations were randomized; the repetition was four-fold.

The weather conditions in 2015 were characterized by insignificant amount of precipitation, and the year itself was as a whole hotter compared to the average climatic norms of the region. The meteorological conditions of 2016, on the contrary, were not characterized by precipitation deficiency and the air temperature oscillated within the normal parameters with slight exceeding of it in August. The conditions of 2017 were characterized by abundant amount of precipitation in spring and in the first half of summer, the air temperature did not differ from the year-average norms during the entire summer.

The mathematical processing of the study results was carried out according to Dospekhov [10] using the dispersion analysis method with LSD calculation at the statistical significance level of $p<0.05$ using Microsoft Office Excel 2007 software.

3. Results

In the experiments, the degree of the effect of silicon rocks' dosages vs. the effect of full mineral fertilizer on the biological productivity of winter wheat, barley and pea was determined. The total biomass and also yield of grains and straw was measured by the weighing method directly under field conditions.

Thus, a positive combined effect of the studied rocks and NPK fertilizers on the bioproductivity of winter wheat was established in the experiment (Figure 1).

First of all, a high level of the NPK fertilizer background effect on the dosage of one or another rock should be noted. Thus, already at the 3 t/ha diatomite dosage, the effect of NPK background was 24% with respect to grains and 33% with respect to straw, and at the analogous dosage of zeolite rock, it was 12% and 23%, and at the bentonite dosage, it was 25% and 33%, correspondingly.

However, at higher dosages of silicon-containing materials, the effect of mineral fertilizer background appeared to be not quite significant already and varied approximately at the same level irrespective of the dosage itself. In particular, the minimally effective were the variants with zeolite (9% to 10% with respect to grains and 19% with respect to straw), averagely effective were the variants with diatomite (20 % to 21% and 26% to 25%) and the most effective were the variants with bentonite clay (22% to 23% and 28% to 29%) correspondingly with respect to the second and third rock dosages.

The straw part of the wheat yield was stably better responsive to the background effect on the dosage of all highly siliceous rocks in contrast to the grain part. It also should be noted that in the first year of the effect of the studied materials on crop productivity, no positive effect of the frequency of the dosage increase of one or another rock was noted.

The productivity of barley grown in the second year of the exposure to highly siliceous rocks and mineral fertilizers is shown in Figure 2.

With respect to grains and straw of this crop, the effect of the background on the rock dosage stably increased. Here, the additions in the yield of the grain and straw part of the yield were correspondingly from 6% to 22% and from 4% to 11% at exposure to diatomite, from 1% to 13% and from 4% to 8% at exposure to zeolite, from 16% to 28% and from 9% to 12% at exposure to bentonite.

Also, a statistically reliable positive effect of the frequency in dosage of each rock was noted in the second year, which was mostly manifested with respect to crop grain. In particular, the minimal effect was with the bentonite clay (5% to 10% depending on the dosage), the average effect was with zeolite (9% to 12%) and the best effect was with diatomite rocks (8% to 15%).

The data of Figure 3 reflect the degree of effect of silicon-containing materials and mineral fertilizers on the productivity of field pea.

It should be said that in the third year of effect of the studied substances, the degree of the background effect on the dosage increased in all study variants except the variants with zeolite with respect to pea straw, which apparently depends not just on the biological features of the crop but also on the prolongation of the effect of interaction of natural materials with the soil.

The effect of the frequency of the dosage increase of each of the rocks remained approximately at the same level compared to the past year. In particular, at the two- and four-fold diatomite dosage increase, the grain yield has increased correspondingly by 5% to 6% and that of straw - by 4% to 7%, the zeolite dosage increase has increased these by 4% to 7% and 2% to 5%, and the bentonite clay dosage increase has increased these by 5% to 8% and 3% to 5%.

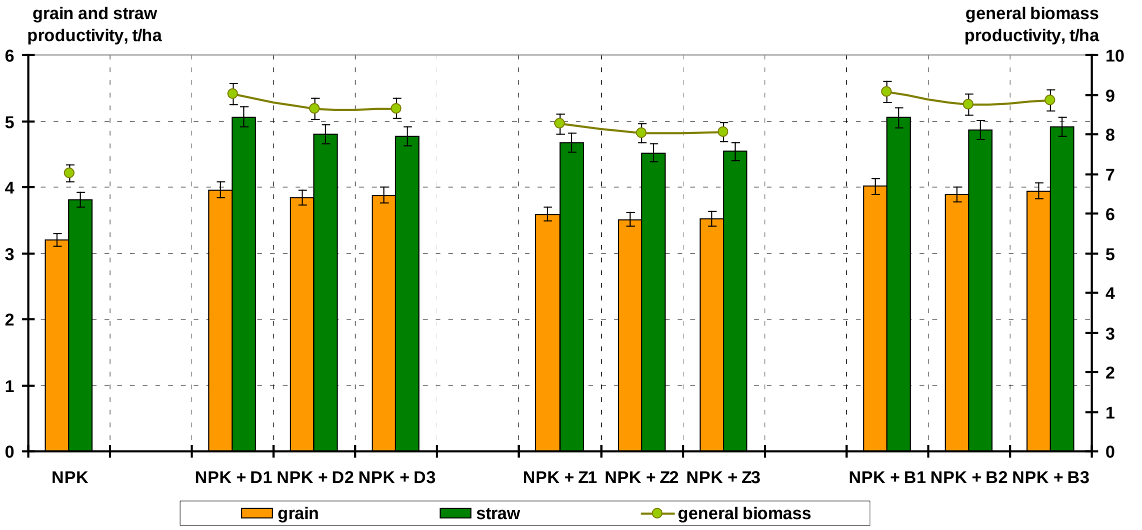

Figure 1. Effect of silicon-containing materials and mineral fertilizers on the productivity of winter wheat (2015)

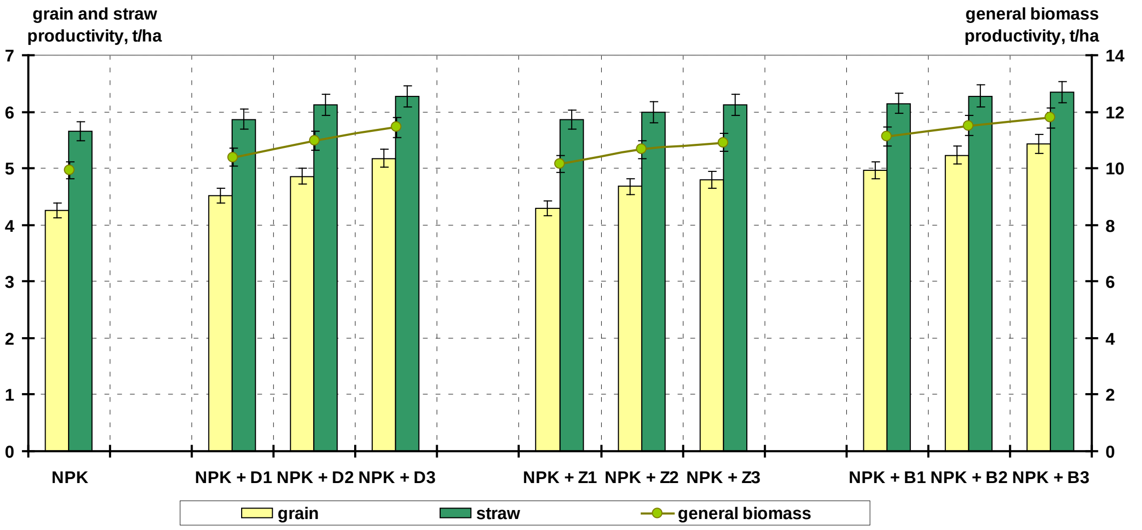

Figure 2. Effect of silicon-containing materials and mineral fertilizers on the productivity of barley (2016)

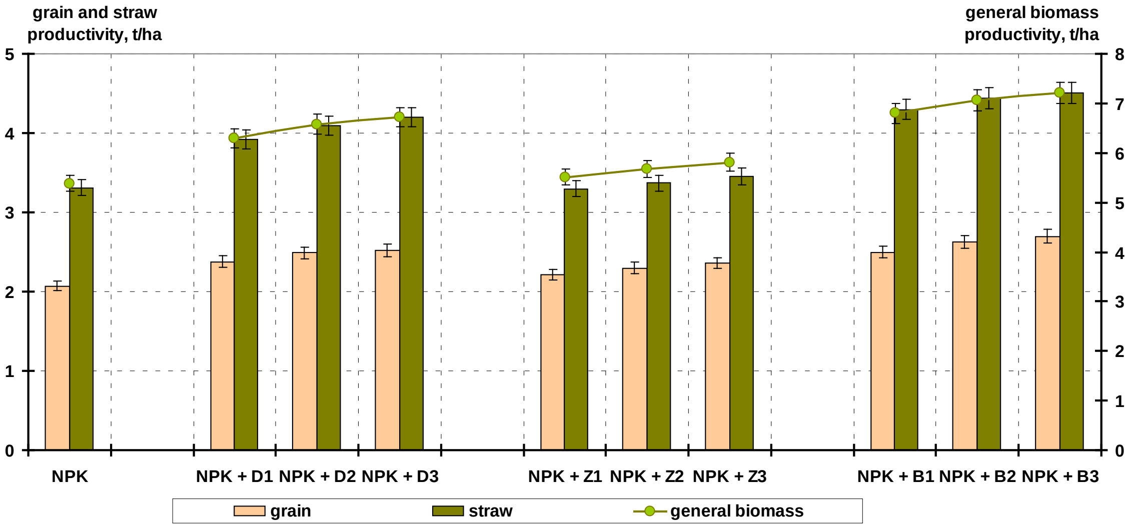

Figure 3. Effect of silicon-containing materials and mineral fertilizers on the productivity of pea (2017)

4. Discussion

It should be noted that as a whole over the study years the significant alleviation of the effect of silicon-containing materials on crop productivity was traced in zeolite variants. In the variants with diatomite rock and bentonite clay, this effect by the third year remained approximately at the same level with the parameters of the first year, and it increased under the high dosage conditions.

In particular, in the variant with the diatomite dosage of 12 t/ha, the addition to the background in the first year was 23% and it was 25% in the third year. In the variants with the bentonite dosage of 6 t/ha and 12 t/ha, the addition to background in the first year was 25% and 26% and in the third year it was 31% and 34%, correspondingly.

It is obvious that apart from the biological features of the crops (in particular, the degree of uptake of the mobile silicon compounds from the rock compounds and response to alterations in SAC) which would determine the annual variability of productivity on the yield there is a prolongation of interaction of silicon-containing rocks with soil.

5. Conclusion

The results of the three-year microfield experiment have shown the combined effect of various dosages of silicon-containing rocks and full mineral fertilizer on the biological productivity of winter wheat of the *Moskovskaya 39* variety, barley of the *Veles* variety and field pea of the *Chishminsky 95* variety under the conditions of sod-podzolic lightly argillaceous soils of the Borsky District of the Nizhny Novgorod Region. It was established with respect to winter wheat that vs. the NPK background the most effective was to introduce a minimal dosage of 3 t/ha, under which conditions the additions in the grain weight were 24% with diatomite, 12% with zeolite and 25% with bentonite clay. It was established with respect to barley and pea that vs. the NPK background the most effective was the third dosage (12 t/ha) wherein the additions in the grain weight were 22% and 22% with diatomite, 13% and 14% with zeolite, 28% and 30% with bentonite.

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