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Impact of Multiple Forms and Application Methods of Natural Zeolite on Potato Yield Increase

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Abstract— **The article shows the results of researches of the natural zeolites influence on potato yield increase. It was found that the treated seed tubers and plants during the growing season with activated zeolite separately and in combination contributed to an increase in crop yield of 3.0-3.6%, when treated with an ultrafine analogue-by 4.3-12. 8% to the background. The marketability of potatoes in the variants where activated zeolite was used varied from 90.9 to 92.9%. When using ultrafine zeolite yield of commercial tubers was 92.9-97.1%. Ultrafine zeolite of particle sizes 80.0-350.0 nm was produced by ultrasonic action on activated zeolite (0.25-40.0 microns) at a frequency of 15.0 Hz (±10%). It was found that high biological activity of ultradispersed zeolite in comparison with actvated analog is caused by highly developed surface. In the process of dispersion of agglomerates and aggregates (associations of primary particles and crystallites) of actvated zeolite, a more developed specific surface of ultrafine zeolite is formed, which increases the number of active sites. Consequently, the processes of interaction between particles, including with a biological object, increase.**

Keywords—zeolite, activated, ultrafine, fertilizer, potatoes, yield, marketability.

I. INTRODUCTION

The most important problem of modern potato growing is the non-conformity between the potential yield and the actual one. In light of this, the overriding concern of the agro-industrial complex is to improve the existing technologies of potato cultivation.

Using high standards of mineral fertilizers and pesticides in conditions of intensive agriculture leads to a decrease in the earnings dilution of production, soil contamination and the environment with toxic substances as well as to product quality disruption.

Intensification of agriculture creates prerequisites for studying the ways of the best use of nutrients by plants. This requires the search for new methods and approaches to improve the efficiency of mineral fertilizers, increase the duration of their action and reduce the load on the biosphere. In this context, it is a good practice for agriculture to involve alternative sources of mineral raw materials in production activities.

Among mineral products the long-range agricultural raw materials are zeolite-containing rocks. Their useful qualities are connected with high absorption and ion exchange capacity.

A wide range of technological tests of zeolite-containing rocks in a number of areas (industry, environmental protection, agriculture) showed the practicability of using them in agriculture [1].

Tatar-Shatrashan zeolites deposit concentrates more than 13.0% of the reserves of this raw material in Russia. The development of the field is engaged in the Volga Region Zeolites JSC.The production capacity of finished products is 320 thousand tons per year. Proven reserves of raw materials are about 88 million tons [2].

On the basis of multi-year fundamental and applied researches, agricultural scientists have developed technologies for the use of zeolite-containing rocks in various fields of agriculture. The efficiency of zeolites application as ameliorants and substrate in greenhouse economy for increase of crop yield and production of ecologically clean products is proved [3].

Long-term field researches concerning zeolites influence on action and carry-over effects on leached chernozem showed a marked improvement in the agrochemical properties of the soil. Firstly, the use of zeolites led to a decrease in soil acidity. A shift in salt ph. was 0.4 units. Mobilization of soil phosphates into available forms was noted, the sum of fractions of the first and second groups (Ca–P_1 and Ca–P_1) has increased by 5.5 and 6.0 mg / 100 g of soil, respectively. Zeolites application in 10 and 15 t / ha doses contributed to an increase in the soil content of exchange potassium - by 24.0 and 33.0 mg / kg of soil, an increase in the rhizosphere activity of microflora - by 1.4 and 2.7 mg / 100 g and the growth of microbial biomass - by 4.7 and 15.5 mg/100 g per hour, respectively [4].

The soil fertility indicator is the plants themselves. K. A. Timiryazev (1948) believed that all the tasks of agriculture are boiled down to the definition of " ...and possibly strict implementation of the conditions of plant nutrition." As for fertilizers, they should be applied in such a way and in such a place that they are most positionally accessible to plants [5].

The objectives of improving the bioavailability of macro - and microelements of mineral raw materials through the use of innovative methods of their processing are of particular relevance in modern times. Domestic and foreign scientists have proved the importance of nanotechnology in various fields of science and technology. Nanoindustry achievements should be directed to the solution of actual problems of an agroindustrial complex of the country: resource saving, advancement in manufacturing technology, raw material processing, and recovery of ecologically safe goods of crop growing and animal production.

In the literature, descriptions of the properties of nanomaterials and their impact on the plant organism are increasingly common. Some authors report that Pennisetum glaucum seeds treated with nanosilver showed better germination. The infection degree of plants grown from treated seeds decreased by more than three times. According to A. Parveen and S. Rao (2015), silver nanoparticles selectively numbed harmful fungi and bacteria and did not have a negative impact on the plant itself [6, 7].

A number of authors, studying the productivity potential of corn when using nanostructured water-phosphorus suspension (NWPS) for pre-sowing seed treatment, noted an increase in green mass-by 29.0-41.0%. Such treatments of tomato and cucumber seeds provided an increase in fruit yield – by 19.0 and 22.0% [8]. In case of non-root treatment of NWPS, the yield of tomatos and cucumbers increase per square meter was 22.0 and 24.0%, respectively [9].

The nanostructured phosphates and zeolites efficiency was studied on buckwheat. Pre-sowing seed treatments contributed to an increase in grain yield – by 13.8-27.6 and 25.0-30.0%, respectively. The authors noted that there were not any deviations in the development of the studied cultures [10, 11].

In favor of limiting of the excessive fertilizers use, the results of studies using wood wastes as a nano-fertilizer are presented. The present research reports on the sustainable impact of nanocarbons on overcoming the shortage of stored nutrients which are placed inside the seeds [12].

A. M. Yezhkova (2016) points out the usefulness of crop and livestock products when using agrominerals in the "soil-plant-animal" system. Researches conducted with natural bentonites and phosphorites allowed to develop technologies for producing environmentally safe agricultural products on technogenic contaminated soils. The author concludes that in the toxicological safety research held on white mice, natural agrominerals are low-risk when used in the form of effective biogenic and readily available mineral feed additives and drugs [13].

Thus, the advantages of using ultrafine substances in terms of reducing the cost of agricultural production are pointed out.

The aim of the research is to identify effective ways of using ultrafine zeolite in potato cultivation.

II. Materials and methods

The researches were carried out in a small-scale field experiment in 2013-2015. The initial agrochemical indexes of the gray forest medium loamy soil of the experimental site were: the content of organic matter-2.7%; the pH of the salt extract-6.7; hydrolytic acidity and the sum of absorbed bases-0.9 and 23.6 mg-EQ/100 g of soil; labile phosphorus and exchangeable potassium – 145.0 and 118.0 mg/kg, respectively.

Experimental studies were carried out with the use of activated zeolite from Tatar-Shatrashan deposit of the Republic of Tatarstan (TU 2163-001-27860096-2016) and its ultrafine analogue.

According to the mineral composition the zeolite-containing rocks are characterized by the following composition: zeolite-21.0%, calcite-18.0%, SiO2 act. (opal-cristobalite) - 27.0%, clay -34.0%, including montmorillonite component -7.0%. The chemical composition of this rock is: CaO – 14.43%, Fe_2O_3 gen.– 1.9%, MgO – 1.86%, Na_2O – 0.20%, K_2O – 1.1%, P_2O_5 –0.08%, Mn – 0.01%, Cu– 0.0001%, Zn– 0.003%, Co – 0.001%, Ni– 0.004%, Pb– 0.0044%. Cation-exchange capacity is 82.0 mg-EQ./ 100 g of soil [14].

Activated zeolite was produced by mechanical activation using jaw and rotary breakers. The next stage was thermal activation in a drying cylinder with a diameter of 2.5 and a total length of 18.0 m at a temperature of 11000C. Heating was carried out by burning natural gas by burner with a capacity of 3.5 MW.

Готовая продукция активированного цеолита по гранулометрическому составу классифицируется по размерам: 0.2-1.25 мм, 1.25-2.5 мм, 2.5-5.0 мм, 5.0-10.0 мм, 5.0-20.0 мм. Доступная фракция цеолита наиболее тонкого помола составила 0.25-40.0 мкм.

Ultradisperse zeolite was produced in the research innovative and applied center "Nanomaterials and nanotechnology" in Kazan. For this purpose, the activated zeolite mixed with deionised water was subjected to ultrasonic dispersion in UZV-28/200 MP RELTEK, Russia (output power was 100 W at a frequency of 15.0 kHz (±10%) for 20 minutes.

The surface topography of activated zeolite and its ultrafine analogue was studied by atomic force microscopy (AFM) on the scanning probe microscope MultiModeV (Veeco, USA) [8]].

Scheme experience consisted of options: 1). Control; 2). Mineral fertilizers N80P80K90-background; 3). Background + pre-sowing treatment of potatoes with activated zeolite, 1.25 kg / t; 4). Background + pre-sowing treatment of potatoes with ultrafine zeolite, 1.25 kg / t; 5). Background + non-root treatment with activated zeolite, 0.1%; 6). Background + foliar treatment with ultradispersed zeolite, 0.1% 7). Background + complex treatment with activated zeolite (pre-sowing treatment of 1.25 kg/t and non-root 0.1%); 8). Background + complex treatment with ultrafine zeolite (pre-sowing treatment of tubers 1.25 kg/t and non-root 0.1%).

Seed tubers treatment by soaking in aqueous suspensions of activated zeolite and its ultrafine analogue was carried out on the day of planting potatoes. Non-root treatment - spraying of plants during the growing season (the phase of budding and flowering) was carried out twice.

The registered area of the plot was 100 m2. The repeatability of the experience is fourfold, the arrangement of options is randomized.

Ultrafine zeolite doses for pre-sowing treatment of tubers and root treatment of plants during the growing season were established on the basis of laboratory and vegetation experiments. Increased doses of ultrafine zeolite had no significant effect on germination and morphometric parameters of seedlings, as well as on yield and potatoes quality, and reduced doses had less efficiency.

The total discharge per hectare of area, both activated zeolite and ultrafine analog, at presowing treatments of potato tubers was 6.0-8.0 kg, and at non-root spraying of vegetating plants-2.0 l.

Biological testing of ultrafine zeolite was carried out in accordance with Guidelines 1.2.2968-11 "Biological assessment order of nanomaterials on plants by morphological characteristics", in laboratory conditions on Petri dishes by processing seeds of test crops (wheat, rye, barley, corn, buckwheat). The analysis showed that the seeds gave even sprouts, the plants had a healthy appearance, well-developed roots and seedlings without visible development deviations.

In order to create an optimal level of soil nutrition, mineral fertilizers were applied annually in the calculation of ($N_{80}P_{80}K_{90}$) on the potatoes yield 170 kg / ha.

The research object is potato of Rosara variety. Culture refers to short-duration crop varieties with a pronounced purple color and yellow tuber pulp. Tubers weighing 60.0-80.0 g were planted, the planting depth was 10-12 cm.

Potato harvesting was carried out manually during the period of tops withering, determined the yield and products quality. In tubers, the vitamin C content (according to Murri), starch (antron method), dry matter (weight method) was determined.

The tests were carried out using instruments: pH meter by MP – 220 («MettlerToledoGmbn», Switzerland) laboratory, spectrophotometer 5400 UF («Shanghai Mapada InstrumentsCo, Ltd»), flame photometer FP-640 («LE KIinstruments», Finland), automatic installation for decomposition across Kjeldahl TURBOTERM-TT 100 (C. Gerhardt, Germany).

III. RESULTS AND DISCUSSIONS

Analysis of the AFM image of the activated zeolite surface allows us to conclude that its structure is represented by conglomerates of different shapes with a large dispersion of particle sizes in the micrometer range (figure 1).

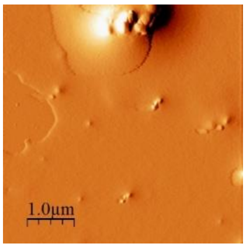

Fig. 1. AFM image of the surface of the activated zeolite, the particle size of 0.25-40.0 µm.

Ultrasonic dispersion of activated zeolite contributed to decomposition and splitting of large conglomerate fractions to form ultrafine zeolite particles of nanometer range (figure 2).

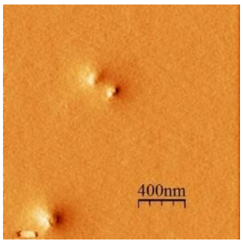

Fig. 2. AFM image of the surface of the activated zeolite, the particle size of 80.0-350.0 µm.

Phenological observations showed that the growth and development of potato plants in the control and experimental versions corresponded to the generally accepted terms. Germination of tubers occurred on 16-20 days (days) after planting. There were no significant differences in germination in plants obtained from treated seeds with activated zeolite and its ultrafine analogue.

The initial blossom phase was noted on 18-20 days after sprouting. In plants in variants with the use of ultrafine zeolite it was 1-2 days earlier. Full blossom of potatoes was noted on 32 days after sprouting.

The overground part development of the studied culture depended on varietal characteristics. It means that shoots branching occurred more in the upper tier, which is typical for short-season varieties.

Potato treatments with activated zeolite and its ultrafine analogue, according to the scheme of the experiment, contributed to an increase in plant height-by 0.05-0.20 m to the background (table 1).

The tallest bushes (0.65-0.70 m) were noted in the variant with complex treatment with ultrafine zeolite, relative to the background of the plant were higher-by 0.15-0.25 m.

TABLE I. MORPHOMETRIC PARAMETERS AND POTATO YIELD

Variant	Plant height, m	The number of stems, pieces on 1 plant	Yield for 3 years, C / ha
Control	0.40-0.45	3.8	102.0
$N_{80}P_{80}K_{90}$– background	0.45-0.50	4.3	164.0
Background+t/t[a] AZ[d] 1.25 kg/t	0.50-0.55	4.3	170.0
Background+t/t[a] UZ[e] 1.25 kg/t	0.55-0.65	4.5	176.0
Background+n/t[b] AZ[d] 0.1%	0.50-0.55	4.3	169.0
Background+n/t[b] UZ[e] 0.1%	0.55-0.60	4.3	171.0
Background+c/t[c] AZ[d] (1.25 kg/t + 0.1%)	0.55-0.60	4.3	170.0
Background+c/t[c] UZ[e] (1.25 kg/t + 0.1%)	0.65-0.70	4.5	185.0
$HCP_{0.5}$	0.03	0.05	3.6

a. t/t – tubers treatment,
b. n/t – nonroot treatment,
c. c/t – complex treatment,
d. AZ – activated zeolite,
e. UZ – ultrafine zeolite.

In variants with presowing and nonroot treatments, the height of the tops increased by 0.05-0.20 m and 0.05-0.15 m respectively to the background. However, nonroot treatment with ultrafine zeolite in comparison with pre-sowing restrained the growth of plants. The height of the bushes in these variants was shorter by 0.05 m.

Complex treatments with activated zeolite stimulated elongation of elevated potato stems by 0.05-0.15 m, and separate treatments by 0.05-0.10 m to the background. Thus, the effect of activated zeolite use was observed to a lesser extent.

High bushiness was noted in variants with presowing and complex treatment with ultrafine zeolite, the increase was 0.2 pieces to the background.

The reduction of potato yield in the phases of budding and flowering under the influence of ultrafine zeolite is explained by the improvement of phosphorus nutrition of culture due to the active participation of phosphorus in the biochemical processes of plant life. The period of growth and development of potatoes, from the beginning of blossoming to the complete cessation of the amount of tops growth in duration was 20-25 days. At this time, there was an increased formation of the main crop. The process of stopping of the amount of tops before its natural wilting lasted for 8-10 days. Potato harvesting was carried out on 80 days after sprooting.

The ultrafine zeolite use contributed to obtaining the greatest yield increases. Treatment of seed tubers caused an increase in potato yield by 7.3%, nonroot by 4.3%, complex treatment by 12.8% to the background. A significant reserve of potato yield was noted during complex treatment, compared with separate treatments, the tubers yield increased by 5.1 and 8.2% respectively.

Additional increases in potato yield during treatment with activated zeolite amounted to 3.6; 3.0 and 3.6% respectively to the third, fifth and seventh variants of the experimental background. The indicators were low in comparison with similar treatments with ultrafine zeolite by 3.5, 1.2 and 5.1% respectively.

During the intensive growth period of the tops, potatoes are particularly in need of nutrients (table 2).

TABLE I. POTATO QUALITY INDICATORS DEPENDING ON THE APPLICATION OF ACTIVATED ZEOLITE AND ITS ULTRAFINE ANALOGUE

Variant	Vitamin C, mg / 100 g	Starch,%	Nitrates, mg / kg	Dry substance, %	Marketability%
Control	10.88	11.0	157.0	19.3	86.9
$N_{80}P_{80}K_{90}$– background	11.47	12.7	168.0	19.4	91.6
Background+t/t* AZ 1.25 kg/t	11.49	12.8	167.0	20.7	92.9
Background+t/t UZ 1.25 kg/t	12.12	13.0	164.0	20.2	94.6
Background+n/t AZ 0.1%	11.48	12.6	170.0	20.6	90.9
Background+n/t UZ0.1%	12.23	12.8	162.0	20.7	92.9
Background+c/t AZ (1.25 kg/t + 0.1%)	11.49	12.8	167.0	19.6	91.6
Background+c/t UZ (1.25 kg/t + 0.1%)	12.24	13.1	156.0	21.1	97.1
$HCP_{0.5}$	0.13	0.08	1.34	0.12	0.30

The biological value of potatoes depends on the mineral nutrition and is characterized by the content of the tubers of the most useful substances. The assessment of culture quality was characterized by the content of vitamin C, starch, nitrates and dry substance [15].

Potatoes are one of the most important sources of ascorbic acid (vitamin C). Its daily requirement for humans is 60.0-100.0 mg, which is equivalent to 600.0 g of potatoes per day.

The ascorbic acid accumulation in tubers depended on potato growing conditions.The use of ultrafine zeolite contributed to an increase in its content: pre-sowing treatment by 5.7%, nonroot treatment by 6.7%, complex treatment by 6.6% to the background. Activated zeolite was less effective, the amount of vitamin C increased by 0.17; 0.1 and 0.2% to the background respectively.

Starch is an important indicator of the potatoes quality, as it is a source of spare nutrients and the main component of the potatoes.

Increased starchiness of potatoes was noted in variants where ultrafine zeolite was used: for pre-sowing treatment by 0.3%, nonroot treatment by 0.1% and complex treatment by 0.4% to the background. The effect of activated zeolite on the increase in starch content in tubers was noted in variants with pre-sowing and nonroot treatments by 0.01% to the background respectively.

The potatoes quality is determined by the nitrate content. As a natural plant component, nitrates in limited quantities are necessary for potatoes. Moreover, nitrogen is vital, because without it, plants do not form amino acids and proteins.

In all variants, the nitrate content in potatoes was below the maximum permissible concentration (MPC of potatoes is 250 mg / kg). A noticeable decrease in nitrate nitrogen was observed in potato products obtained by complex treatment with ultrafine zeolite by 7.1% to the background.

One of the important indicators of potato quality is the solution of dry substance. The use of both activated zeolite and ultrafine analog was accompanied by its increase. The maximum amount of dry substance was formed during complex treatment with ultrafine zeolite, relative to the background increased by 1.7% to the background. In variants with pre-sowing and nonroot treatments, the increase was 0.8 and 1.3%. The accumulation of dry substance was noted in variants with separate treatments with activated zeolite, at 1.3 and 1.2% to the background.

The zeolite use contributed to an increase in the number of marketable potatoes. The higher one was noted in the complex treatment with ultrafine zeolite - 5.5% to the background. Pre-sowing and nonroot treatment contributed to an increase in potato tubers marketability by 3.0 and 1.3% to the background respectively.

IV. CONCLUSION

The research results showed that theultrafine zeolite use for separate pre-sowing and nonroot treatments of potatoes, as well as for complex treatment, contributed to an increase in crop yield by 7.3%, 4.3% and 12.8% to the background respectively. Similar treatments with activated zeolite provided crop growth by 3.6%, 3.0% and 3.6% to the background respectively.

The mechanism of biological activity of ultrafine zeolite is explained by the increase in the number of contacts between particles, including in the case of heterogeneous interlocking.

The researches are exploratory in nature. The obtained results indicate the prospect of application in agriculture of fertilizers in ultrafine state. At the same time, a necessary condition of the fertilizer system is its environmental and resource-saving components, which exert a minimum load on the biosphere. Fertilizer control of concentrations in the ideal range will allow to make a significant contribution to improvment of efficiency of agricultural production.

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