The use of “Azofit” microbiological fertilizer to increase the productivity of the soil-plant system

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Abstract. In field experiment in conditions of the Krasnoyarsk forest-steppe, the influence of the microbiological fertilizer Azofit on the properties of chernozem and the productivity of rapeseed variety Nadezhny 92, cultivated for oilseeds, was estimated. It was shown that the treatment of rapeseed using the fertilizer with subsequent foliar treatments of vegetative plants or the use of the preparation only for vegetative plants formed a normal composition and good structure of the 0-20 cm soil layer. The use of the preparation contributed to an increase in the concentration of hard hydrolysable, easy hydrolysable and ammonium nitrogen in the soil. The maximum productivity of spring rapeseeds was formed on the variant using Azofit as a protectant in its pure form with subsequent foliar treatments of the crops (2.6 t/ha).

1. Introduction

The problem of reproduction of soil fertility, increasing the yield and quality of products while reducing the man-made load on agroecosystems is being solved at the present time through the use of biological farming technologies. The crop rotations, located on arable land, still remain a key element of modern farming systems and solve the whole range of tasks for the rational use of land, reproduction of soil fertility, its protection from erosion, for the protection of the environment and the entire agricultural landscape. Years of studies [1] have shown the important agronomic significance of rape as an ameliorative crop, which improves phosphorus nutrition and enriches the soil with organic matter. In rapeseed cultivation, technologies adapted to specific soil and climatic conditions and using various means of regulating plant growth and reducing the negative effects of abiotic and biotic stress factors, and controlling pests and weeds, as well as supplying plants with nutrients are needed [2]. Such means are traditionally plant growth regulators, pesticides and fertilizers, incl. microbiological. Of particular relevance is the use of microbiological fertilizers in the cultivation of crops. The basis of microbiological preparations is made up of live cultures of soil and rhizospheric microorganisms, which possess economically valuable properties, and the products of their metabolism [3]. Producer strains that make up biopreparations can fix atmospheric nitrogen, synthesize vitamins and phytohormones, convert some chemical compounds (for example, phosphates) into plant form that is available, colonize the roots and leaves of plants, show antimicrobial activity due to the biosynthesis of antibiotics, pigments, siderophores, etc. [4]. Unlike mineral fertilizers, microbial preparations have a number of advantages: they do not pollute the environment, are harmless to humans and animals, are not phytotoxic, and do not have mutagenic activity, because they are made on the basis of strains of natural soil microorganisms.
The purpose of the research is to evaluate the effect of the microbiological fertilizer Azofit on the properties of chernozem and the productivity of rapeseed cultivated on oilseeds under conditions of the Krasnoyarsk forest-steppe.

2. Material and research methods

Research was carried out in 2018 in field experience at the training farm “Minderlinskoe” of the Krasnoyarsk State Agrarian University in the Krasnoyarsk forest-steppe (56°N, 92°E). Research objects are a complex of leached and ordinary chernozem of heavy loamy grain-size composition, the microbiological fertilizer Azofit and rapeseed variety Nadezhny 92, following its preceding crop - par.

At the species level, the soils of the experimental plot are characterized as thin and deep with a high and very high humus content (8.6–11.1%), a neutrality (pH<200 - 6.7–6.9), a high amount of exchange bases (55-62 mg-eq/100 g). The arable layer of chernozem contains 152.0-316.0 mg/kg of P₂O₅, 178.0-288.0 mg/kg K₂O.

To study the effect of the microbiological fertilizer Azofit on soil fertility and spring rapeseed yield, field experience was conducted. The experiment scheme included the following options: 1. Control: Quickstep, ME - Galion, WS + Estok, WDG + Adueu, F - Boreas, SC - Kolosal Pro, oil concentrated feedstuff; 2. TD, VSC + Tabu Neo, SC - Quickstep, ME + Azofit - Galion, WS + Estok, WDG + Adueu, F + Azofit - Boreas, SC + Azofit - Kolosal Pro, oil concentrated feedstuff; 3. Azofit - Quickstep, ME + Azofit - Galion, WS + Estok, WDG + Adueu, F + Azofit - Boreas, SC + Azofit - Kolosal Pro, oil concentrated feedstuff.

The technology of spring rape cultivation corresponded to the farming system of the Krasnoyarsk region [5]. The dose of each of the preparations used was in accordance with the manufacturer's recommendations. Pre-sowing treatment rapeseed seeds treatment was carried out one day before sowing. Rapeseed sowing for oilseeds was carried out on May 17 using the SSFC-7 drill. 7. Sampling for agrophysical and agrochemical parameters was conducted in a layer of 0-20 cm in the phase sprouting (June), flowering (July), pod (formation August) and ripening (September) of rapeseed. Record plot is 100 m². The repetition of sampling and analytic definitions is 3-stage. In the samples were defined: the bulk density according to N.A. Kachinkiy; moisture - by thermo-weight method; structural composition - according to N.I. Savvinov [6]; nitrate, ammonium nitrogen - by the colorimetric method, easy and hard hydrolysable nitrogen - according to Cornfield [7]. Crop accounting was carried out on October 4 using the TERRION 2010 combine by a continuous method. The yield of spring rapeseed is reduced to 12% seed moisture. Statistical processing of the obtained results was carried out using the methods of dispersive, correlation analysis and descriptive statistics [8].

3. Research results

The vegetation season of 2018 was characterized as warm and arid. The beginning of the growing season was accompanied by a high average daily temperature and a small amount of precipitation. July and August were especially critical for plant growth and development. During this period, with an average air temperature close to the norm in July and exceeding the average long-term annual average figures of 3°C in August, only 15-21 mm of precipitation fell, respectively, which is 78-66% lower than the norm. Arid conditions of the rapeseed growing season were also observed during the sprouting and tillering seasons when the amount of precipitation was 66% to normal. The reserves of productive moisture accumulated in the 0–20 cm chernozem layer of heavy loamy grain-size composition indicated that the soil was satisfactorily supplied by the beginning of the growing season of rapeseed (25–26 mm). The dry conditions of June and July contributed to a significant reduction in the reserves of productive moisture during this period. In all variants of the experiment, the available moisture reserves during the period of rapeseed blooming were rated as bad (6-10 mm) (p = 0.05). It is important to note that poor moisture reserves (<20 mm) in the 0–20 cm chernozem layer remained until the end of the rapeseed vegetation, which is due to the intensive removal of productive moisture by the crop and the arid conditions of the 2018 vegetation period. Research has shown that the use of microbiological fertilizer Azofit in the complex protection of rapeseed contributed to an increase in the reserves of productive
moisture during the growing season by an average of 2 mm as compared to control. At the same time, significant differences between the variants of the experiment were recorded only in the June and July periods (p = 0.05-0.02). The revealed tendency to preserve the moisture available to plants is due to an increase in the bulk density of the root layer soil in those variants of the experiment where a microbiological preparation was used.

Observations of the state of the soil in the rapeseed crops showed that at the stage of sprouting and ripeness, there was no significant difference between the variants of the experiment in bulk density (1.01-1.04 g/cc and 0.77-0.79 g/cc, respectively) (p = 0.930). In the period of budding and fruiting, an increase in the density of the 0–20 cm layer was identified in the variants with the use of Azofit for seed treating and in tank mixtures of vegetative plants. Compared to the control variant, there is an increase in soil density by 0.15-0.28 g/cc in July and 0.14-0.17 g/cc in August (p = 0.001), which is due to a more active growth of the root system. Research has shown that the bulk density of chernozem during the growing season of 2018 varied in the control variant from 0.79 to 1.06 g/cc, which allows to consider the soil loose and well-structured (Cv = 14%). The use of complex chemical protective preparations together with the microbiological fertilizer Azofit, which is based on living nitrogen-fixing bacteria, biologically active products of their vital activity and minor nutrients, changes the dynamics of the 0-20 cm layer density. The seasonal rhythm of soil consistency to the variants of the experiment using Azofit was more visible (Cv = 18%) and characterized by an increase in soil density to 1.20-1.23 g/cc in August, which makes it possible to consider the soil tight. The seasonal density of leached chernozem in the control variant was estimated as loose (0.93 g/cc). With the use of Azofit, a normal consistency of the root layer was formed (1.00 -1.03 g/cc).

The structural composition of the soil is not a prerequisite for high crop yields. However, it affects the density of soil composition, water, air, and thermal conditions, which in turn affect the microbiological, physicochemical, and other processes occurring in the soil, ultimately providing optimal conditions for plant growth and development. The excellently structured soil of the control variant from the beginning of the growing season to fruiting was distinguished by the domination of lumpy-grainy separations of 2–1 mm (27–31%). The content of large aggregates > 10 mm was 14-27% by weight of the arable layer. Seed treatment with a microbiological preparation contributed to a significant increase in the lumpiness of the 0–20 cm chernozem layer (p = 0.005–0.000) during the period of rapeseed sprouting and budding. This caused a decrease in the content of agronomically valuable aggregates by 10–26 and 14–20% in these variants of experience as compared to control, while maintaining good soil structure. The periods of fruiting and ripening of rapeseeds were accompanied by the formation of a near-by level of the soil structure according to the variants of the experiment. The well-structured soil in August (78-83%), with an increase in humidity in September, became well-structured in all variants of the experiment (58-63%). A similar pattern of formation of large aggregates with an increase in soil moisture has been proven by studies [9].

Assessing the agrophysical characteristics of chernozem during the rapeseed growing season, it should be noted that the preparations used in complex plant protection determined the level of reserves of productive moisture close to control (15-16 mm) (table 1).

| Variant | ZPV, mm | dv, g/cc | ACF, % |
|---------|---------|----------|--------|
| M | Cv, % | M | Cv, % | M | Cv, % |
| Control - Quickstep, ME - Galion, WS + Estok, WDG + Adueu, F - Boreas, SC - Kolosal Pro, oil concentrated feedstuff | 14.6 | 59 | 0.93 | 14 | 74.7 | 16 |
| TD, VSC + Tabu Neo, SC - Quickstep, ME + Azofit - Galion, WS + Estok, WDG + Adueu, F + Azofit - | 16.4 | 45 | 1.00 | 18 | 68.2 | 15 |

Table 1. Agrophysical characteristics of chernozem when using the microbiological fertilizer Azofit for rapeseed (n = 4).
The average data indicate a change in the agrophysical state of the arable chernozem layer while retaining the optimal parameters. The use of microbiological fertilizer for rapeseed contributed to an increase in soil density compared with the control by 0.07-0.10 g/cc, a decrease in the content of agronomically valuable fractions by 7-11%. Processing of rapeseed seeds with Azofit followed by foliar treatment of vegetative plants or using the preparation only for vegetative plants created a similar level of agro-physical condition of the soil. It was estimated during the growing season of the culture by poor moisture reserves, normal composition and good structure of the 0-20 cm soil layer.

Studies [10] found that biologically active substances of preparations indirectly positively affect the soil structure, increasing the number of agronomically valuable aggregates. This happens due to the increased activity of the rhizospheric microbial flora as a result of symbiotic interaction of the root system and microorganisms, the number of which depends on the availability of waste products of plants secreted through the rhizosphere. From our perspective, the extremely arid conditions of the growing season of 2018 did not contribute to the revitalization of soil microbiological activity under the conditions of microbiological fertilizer use.

The main condition determining the productivity of agricultural crops is the soil provision with nitrogen. In the soil it is in the form of organic and inorganic substances. Mineral nitrogen compounds are nitrates, nitrites and ammonium salts, organic - proteins, amino acids, amides and other components. Mineral forms of nitrogen compounds are directly available to plants. Organic nitrogen, having sufficient stability, maintains soil fertility, determines the degree of nitrogen mobilization, accompanied by the accumulation of mineral compounds of this major nutrient element [11].

Research has shown that in the chernozem of the experimental field, the main part of nitrogen is presented in organic form (table 2). The predominant form was the fraction of hardly hydrolysable nitrogen. Its absolute amount varied during the vegetative period by the variants of the experiment from 126 to 224 mg/kg of soil (Cv = 3-12%).

**Table 2.** The content of organic and mineral forms of nitrogen in chernozem with the use of the microbiological fertilizer Azofit for rapeseed (n = 4).

| Variant | Ntg (mg/kg) | Nlg (mg/kg) | N-NH₄ (mg/kg) | N-NO₃ (mg/kg) |
|---------|------------|-------------|---------------|-------------|
| Control - Quickstep, ME + Galion, WS + Estok, WDG + Adueu, F + Boreas, SC + Kolosal Pro, oil concentrated feedstuff | 164,7 | 12 | 102,5 | 13 |
| TD, VSC + Tabu Neo, SC - Quickstep, ME + Azofit - Galion, WS + Estok, WDG + Adueu, F + Azofit - Boreas, SC + Azofit - Kolosal Pro, oil concentrated feedstuff | 203,0 | 3 | 119,0 | 6 |
| Azofit - Quickstep, ME + Azofit - Galion, WS + Estok, WDG + Adueu, F + Azofit - Boreas, SC + Azofit - Kolosal Pro, oil concentrated feedstuff | 185,7 | 12 | 102,5 | 21 |
Note: Ntg – hard hydrolysable nitrogen, Nlg - easy hydrolysable nitrogen, N-NH\(_4\) - ammonium nitrogen, N-NO\(_3\) - nitrate nitrogen.

The use of the Azofit for vegetative plants promoted an increase in the content of hard hydrolyzed nitrogen in the soil by an average of 38 mg/kg as compared with the control and ensured a steady seasonal dynamics of the indicator (Cv = 3%). Processing of rapeseed during its flowering and pods formation contributed to a significant increase in the concentration of hard hydrolysable nitrogen to 196-224 mg/kg. The dynamics of soil moisture in these variants of the experiment had a correlation with the content of hard hydrolysable nitrogen in the soil (r = -0.53 - (-0.98)).

The availability of easy hydrolysable nitrogen from chernozem varied from low to medium during the growing season (74-126 mg/kg). Research has established that the average content of easy hydrolysable nitrogen in the variants of experience with chemical protection and the use of the microbiological preparation Azofit did not significantly affect the content of hydrolysable nitrogen, but determined the nature of the dynamics of this indicator. The use of Azofit for vegetative plants in tank mixtures increases the concentration of easy hydrolysable nitrogen to 119 mg / kg and also determined the steady seasonal dynamics of the indicator (Cv = 6%). The established increase in the content of easy hydrolysable nitrogen at a time when leaves are processed with the preparation is not reliable.

In soil conditions, the role of ammonia and nitrate nitrogen in plant nutrition is far from the same. The ammonification process is extremely common in soils. It is carried out by a large number of microorganisms adapted to the most diverse environments. However, the accumulation of ammonia does not always occur, but only in those cases where, for one reason or another, there is no further conversion of ammonia into nitrates. The dynamics of ammonium nitrogen from low to medium availability was observed during the vegetative period in all variants of the experiment. The insignificant and average seasonal dynamics of the indicator (Cv = 14-21%) was accompanied by the intensification of ammonification processes against the background of the processing of rape crops with microbiological fertilizer and its use as a seed treater with subsequent vegetation treatments. The tendency of increasing the content of ammonium nitrogen in these variants of the experiment by 2-4 mg/kg on average during the vegetation period was revealed. The maximum amount of ammonium nitrogen is fixed in the case of the use of the preparation as a seed treater and for vegetative plants (21 mg/kg).

The main form of nitrogen used for plant nutrition is the nitrate form. Its amount shows the degree of plant availability with nitrogen and makes it possible to predict the need to apply nitrogenous fertilizers and determine their optimal doses for obtaining a full-fledged high yield. The low availability of chernozem with the nitrate form of nitrogen is noted in all variants during the vegetative period, which confirms the use of this form of nitrogen by plants. A decrease in the content of N-NO\(_3\) to harvesting culture was noted in the variants using the microbiological fertilizer. The average content of nitrate nitrogen is 1-2 mg/kg less compared to the control. Research has shown that an increase in soil moisture in these variants significantly reduced the concentration of nitrate nitrogen (r = -0.61 - (-0.67)).

The farming systems, their elements and the adopted agricultural methods of cultivating agricultural crops determine the levels of their productivity. The microbiological preparation “Azofit” with various methods of its use has influenced some elements of the structure of the harvest of spring rapeseed cultivated for oilseeds. The increase in the total number of pods on the variants with the use of the preparation Azofit determined an increase in the yield of rapeseed by 0.39-0.65 t/ha compared to the control. Research has established that the maximum productivity of spring rapeseed seeds was formed in the variant using the Azofit fertilizer as a protectant in its pure form with subsequent foliar treatments of crops (2.6 t/ha).

4. Conclusions
In the integrated protection of rapeseed, the microbiological fertilizer Azofit contributed to an increase in soil density compared with the control by 0.07-0.10 g/cc, a decrease in the content of agronomically valuable fractions by 7-11%, an increase in the concentration in the soil of hard hydrolysable nitrogen by 38 mg/kg, easy hydrolysable - by 17 mg/kg and ensured a steady seasonal dynamics of indicators.
(Cv = 3-6%). The enhancement of ammonification processes in the soil with the use of the microbiological fertilizer as a seed treater and for vegetative plants determined the maximum amount of ammonium nitrogen (21 mg/kg), which determined an increase in the yield of spring rapeseed by 0.39-0.65 t/ha as compared to control.

The results were obtained in conducting the research on the topic: "Creating an integrated high-tech production of vegetable oilseed raw materials and products of its processing in Siberia."

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