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Research Article

Formation of the Symbiotic Apparatus and Yield of Soy Varieties Depending On the Level of Fertilization

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ABSTRACT

Due to the rapid development of the livestock sector in the Belgorod Region during the last decade, soybean areas increased more than 30 times. The increase in the soy yield is based on the intensification of its cultivation technology, the most effective of which are fertilizer and variety. Thus, the aim of the research was to analyse the influence of various types of fertilizers (straw-litter compost (20 t / ha), ammonium nitrate (30 kg / ha), Azosol 36 Extra (2 x 2 l / ha)) and their combinations on the formation of a symbiotic apparatus and the yield of soybean varieties of different ripening groups (early-ripening - Lancet and medium-ripening - Belgorod 48). Symbiotic activity in soybean crops did not depend on the variety of plants, but was entirely determined by the option of fertilizing the crops. The introduction of fertilizers contributed to a significant increase in the number of nodules in 1,8-4,2 times. The maximum effect was achieved with the use of a full three-component fertilizer (12.9 pcs / plant). Compost and ammonium nitrate, when used together, significantly increased the effect of each other - by 1.5-2.1 times. The yield of soybean seeds depended on the variety, on fertilizers, and on the year conditions. In 2014 and 2015, the early Lancet variety had an advantage of 0.12-0.18 t / ha (3-7%), whereas in 2016 Belgorod 48 exceeded by 0.57 t / ha (32%). Regardless of the variety, the maximum yield of soybean seeds was due to the option of using the full fertilizer Compost + Ammonia Nitrate + Azosol - 3.01-3.04 t / ha, which is 18-22% more than the control level. Thus, the use of a complex organic-mineral fertilizer contributes to the formation of a balanced nutrient regime of the soil, to the enhancement of symbiotic nitrogen fixation, to an increase in soybean yield and to the preservation of soil fertility. The combination of varieties of different ripeness groups stabilizes the production of seeds in the southwest of the Central Black Earth Economic Region.

Key words: soybean, symbiosis, variety, nitrogen fixation, nodules, yielding capacity, organic and mineral fertilizers.

1. INTRODUCTION

In connection with the rapid development of the livestock sector in the Belgorod region during the last decade, soybean areas increased more than 30 times, reaching 190,000 hectares (http://www.bel.ru/news/region/2015/08/31/909 286 .html (circulation date 4.08.17)). Soybean is of economic interest as a grain fodder crop, its seeds being extremely rich in protein and fat, and also as a source of environmentally safe biological nitrogen for increasing soil fertility (Agafonov et al., 2005). According to the protein content in the soybean grain, there is no equal among the other leguminous plants (Aksenov, Voloshin, 2005). The use of soy in the production of high-protein feed is an urgent task, and its solution will serve the successful development of livestock in the Central Black Earth Region in general and in the Belgorod Region in particular. Obtaining high and stable yields of soybean seeds is based on the study of the varietal features of its production, the ways of its regulation, including by optimizing the nutritional regime (Kotlyarova et al., 2012; Titovskaya, Golovkov, 2012). All researchers point to the great need of soybean plants in nitrogen, which is explained, first of all, by high protein content. Numerous studies indicate the significant nitrogen-fixing ability of soybeans, which to a certain extent satisfies the increased requirements for nitrogen. Under favorable

conditions, soybean fixes 50 to 77% of the necessary nitrogen from the air, accumulating 30-50 kg / ha of it in the soil (Patyka et al., 1992; Kashukoev, 1997; Penchukov et al., 2004; Gubanov et al. 2007). World experience in soybean grain production shows that with a well-functioning symbiosis without the use of nitrogen fertilizers, a yield of 3.0 t / ha is generated (Weiss, 2000). Nevertheless, there are a number of works where high efficiency of nitrogen fertilizers on soybeans was noted (Gukova, Korenjo, 1982; Purcell L.C., 1996; Abdykarimova, Sultangazieva, 2015; Syromyatnikov, 2011). The question of the effect of mineral fertilizers on the symbiotic nitrogen fixation of soy is very problematic. According to a number of studies, nitrogen fertilizers are depressing, yet phosphorus and potassium fertilizers stimulate the processes of formation and vital activity of nodules (Smolin, 1996; Kotlyarova, Laktionov, 2010; Zverev, 2004). The results of a number of studies (Wiersma, 1992, Tolkachev, 1997, Zaveryukhin, 1983, Vavilov, Posypanov, 2003) show that nitrogen fertilizers reduced the formation of nodules, their number and mass, nitrogenase activity with an increase in the dose of nitrogen applied, whereas its moderate doses did not inhibit nodule bacteria. Taking into account the analysis of studies on the effect of fertilization on soybeans symbiotic activity of, it can be stated that the application of mineral nitrogen at a dose not exceeding 30-40 kg / ha has a more positive effect on the nitrogen-fixing capacity of the crops (Persikova, Kurulenko, 2006; Donchenko et al., 1990; Krugova, 1995; Starchenkov, 1996). Several studies (Myakushko, Baranov, 1982; Neunylov, Slabko, 2008) showed that the fractional application of mineral fertilizers in top dressing does not cause a noticeable inhibition of nodule bacteria. Deep application (20 cm) of nitrogen fertilizer (granulated urea) in contrast to conventional surface does not reduce nitrogen fixation.

The studied micro- and complex mineral fertilizers had a positive effect on the yield of seeds, the protein content in them, and the collection of protein and oil (Tishkov et al., 2007; Schegolkov, 2015, Vorontsov et al., 2013). It is generally believed that the most important trace elements for soy are molybdenum, boron, cobalt, zinc, copper, manganese (Sheugen, 2006). Nowadays in this country and abroad various fertilizers for foliar top dressing of agricultural crops are created. One of them is Azosol 36 Extra (ADOB, Poland). In addition to nitrogen (36.6%), this complex contains chelate forms of microelements (Mg, Mn, Cu, Fe, B, Zn, Mo), which have high digestion efficiency and make it possible to fully realize the genetic potential of crop yields. The development of modern fertilizer systems assumes the fullest satisfaction of the needs of soy in food elements, the enhancement of symbiotic nitrogen fixation, the involvement of this deficient plant nutrient in the biological cycle. At the same time, the most important theoretical and applied task is to increase the productivity of the crop with the mandatory preservation of soil fertility. There is no doubt that organic fertilizers have a positive effect on soil, including on the basis of bird droppings. There is also evidence of the positive effect of such fertilizers on soy productivity of (Titova et al., 2009; Barsukov, Barsukov, 2005). In addition, large-scale development of animal husbandry in the region calls for the recycling of organic waste from poultry farming complexes, on the one hand, and their more economically efficient use against the backdrop of rising mineral fertilizers, on the other. However, in specialized literature there is no data on the comparative study of the effect of separate and combined usage of organic and mineral fertilizers on the formation of the soybeans symbiotic apparatus. Consequently, the study of the reaction of soybean varieties of different ripeness groups to changes in the background of organic and mineral nutrition, taking into account their adaptability, plasticity, stability is important for increasing the symbiotic activity and productivity of seeds, which is the purpose of this work.

2. MATERIALS AND METHODS

The research area is located in the southern part of the forest-steppe zone of Russia, characterized by a temperate continental climate with an average annual temperature of 6.2 ° C, a

sum of average daily temperatures above 10 ° about 2900 °, an average annual precipitation amount of 475 mm. The annual hydrothermal coefficient is about 1 and indicates a region of unstable moistening. The probability of wet years is 25-40%, semi-arid and arid 30-50%. The main crops are winter wheat, sugar beet, corn, sunflower, soybean, barley and others.

Field research was carried out in Educational and Scientific Innovation Center 'Agrotechnopark' of Gorin Belgorod State Agricultural University in 2014-2016 on the basis of the grain rotation: soybean - winter wheat - buckwheat - millet. The soil of the experimental site is typical heavy loam black earth. The humus content is 5.1%; pH sol. = 6.0; the content of mobile phosphorus and potassium (according to Chirikov), respectively, 125-167 and 128-133 mg / kg. The soil was analyzed for the content of organic matter, phosphorus, potassium and pHKCl in accordance with the recommended methods (State Standards: GOST 26213-91, GOST 26204-84 and GOST 26483-85) in the research laboratory of the Gorin Belgorod State Agricultural University. In the experiment the full scheme of fertilizers, including eight variants (factor A), was studied: 1. Control - without application of fertilizers; 2. Compost (here and further on compost is litter-straw); 3. Compost + Ammonium nitrate; 4. Compost + Ammonium nitrate + Azosol; 5. Compost + Azosol; 6. Azosol; 7. Ammonium nitrate + Azosol; 8. Ammonium nitrate. 20 t/ha were introduced in the autumn under the main treatment with a disc harrow BDT-5.4 to a depth of 10-12 cm. Ammonium nitrate at a dose of 30 kg a.i./ha was applied in spring under pre-sowing cultivation. Treatment with microfertilizer Azosol 36 Extra at a dose of 2 l/ha was carried out 2 times during vegetation in the phases of the third triple leaf and budding. The investigated soybean varieties (early-ripening Lancet and medium-ripening Belgorod 48) originate from Belgorod SAU. The total area of the plots was 37 m^2, the registration area was 25 m^2, the repetition was three-fold, the plots were regularly placed by organized repetition. Care of crops included: the first chemical treatment in the phase of the formation of the first triple leaf with: Quickstep 0.8 l/ha + Harmony 6 g/ha + Trend 90 + Vantex 60 ml/ha; the second chemical treatment was carried out in the phase 3-4 of the triple leaf with Fusilat Forte 1 l/ha. Determination of the number of nodules and their masses was carried out 30 days after emergence, during the full flowering period and the formation of beans. Critical period of active build-up of leaf-weights and the beginning of flowering for soy in the Belgorod region is the end of June and the beginning of July. In 2014 and 2015, the hydrothermal conditions of this time of year were more favorable for the crop - in conditions of a comfortable air temperature for soybean plants, the amount of precipitation was at or slightly above the annual norm. In 2016, during this period, hot weather was observed with a significant lack of moisture (Table 1).

Years	Decade of the month	June				July			
		Average daily air temperature, °C		Precipitation sum, mm		Average daily air temperature, °C		Precipitation sum, mm	
		During the year of study	Deviations from the average,%	During the yea of study	Deviations from the average, %	During the year of study	Deviations from the average, %	uring the yea of study	Deviations from the average, %
2014	1	21,0	3,7	23,1	122	20,2	1,1	6,1	25
	2	15,7	-1,9	2,5	12	23,0	2,5	13,4	58
	3	15,7	-3,2	101	439	22,4	2,4	4,6	21
	Total	17,5	-0,4	126,6	201	21,9	2,0	24,1	35
2015	1	21,6	4,3	0,0	0	23,2	4,1	3,7	15
	2	21,5	3,9	22,5	107	18,4	-2,1	19,2	83
	3	20,9	2,0	27,0	117	23,2	3,2	44,2	201
	Total	21,3	3,4	49,5	79	21,6	1,7	67,1	97
2016	1	15,1	-2,2	17,0	89	21,4	2,3	–	–
	2	20,9	3,3	18,4	88	25,7	5,2	15,3	67
	3	24,3	5,4	2,0	9	21,2	1,2	58,2	265
	Total	20,1	2,2	37,4	59	22,8	2,9	73,5	107

Table 1. Meteorological conditions during the active growth of soybean leaf-weights and the beginning of flowering (Smurov et al., 2017)

3. RESULTS AND DISCUSSIONS

3.1. Dynamics of the formation of the main indicators of the symbiotic apparatus development

The high protein content in the vegetative mass and in the soybean grain determines its greater demand for nitrogen, which is largely satisfied by its nitrogen fixation from the atmosphere.

Molecular nitrogen of air is attached as a result of plants symbiosis with a specific group of nodule bacteria - Rhizobium japonicum. Infection of the root system of soybean occurs through the root hairs or damaged cells of the epidermis. The cells infected with nodule bacteria, as well as neighboring uninfected cells of the root cortex begin to actively divide, which leads to the formation of swelling – a nodule. The number of nodules on a soybean plant can vary significantly - from single to several hundred.

Highly efficient for increasing the symbiotic activity of soybeans is the method of seed inoculation with nodule bacteria, yet only when their soil populations are few or completely absent (Vasilchikov, 2013.) Otherwise, with prolonged soybean cultivation and the presence in the soil of a spontaneous race of nodule bacteria, pre-sowing inoculation is not effective. This is confirmed by a comparative analysis of the symbiotic soybean apparatus parameters in two experiments conducted simultaneously on a single landscape massif – the authors' (without inoculation) and of Smurov (Smurov et al., 2017) (with inoculation).

The dimensions of the symbiotic apparatus of legumes can be judged, first of all, by the number and weight of the nodules. In this case, the most interesting are active nodules, that is, containing legoglobin. The active symbiotic potential and, ultimately, the size of nitrogen fixation depend on their quantity and mass.

Analysis of the number of active nodules on the plants roots in different phases of soybean development revealed that this indicator was independent of the variety of plants, but was entirely determined by the option of fertilizing the crops. Without the application of fertilizers, a small number of them were noted: in the branching phase 1.2 pieces/plant, in the flowering phase 2.4 and in the bean filling phase 3.1 pieces. The increase in their number when introducing only compost was unreliable, while all other fertilizer variants significantly increased this index by 1.8-4.2 times.

Of the three types of fertilizers with their independent application, the most effective was foliar top dressing with Azosol which provided 8.7 pieces/plant in the bean filling phase. The effect of Azosol increased with its combined use with ammonium nitrate (11.2 pcs/plant) and, finally, the maximum effect was achieved with the use of mineral fertilizers against the compost background (12.9 pcs/plant). It should be noted that compost and ammonium nitrate, when used together, significantly increased the effect of each other - by 1.5-2.1 times. Moreover, these variants of the factor under consideration also had higher rates of increase in the number of nodules in the process of crop growing, by 40-60% compared to the control levels.

The mass of active nodules was directly dependent on their number. In all phases of vegetation a positive effect of various types of fertilizers and their combinations on this indicator was noted, except for compost used separately. The distribution of the effect of fertilization options for soybean on the weight of nodules is similar, as in the analysis of their number. Strengthened influence occurs in the following sequence: 'Ammonium nitrate', 'Compost + Azosol', 'Azosol', 'Compost + Ammonium nitrate', 'Ammonium nitrate + Azosol', 'Compost + Ammonium nitrate + Azosol', i.e. with saturation of the fertilization background, the weight of the nodules is increased by 1.7-3.4 times. It should be noted that the rate of this indicator increase with foliar top dressing usage is 1.5 times higher than in the other variants.

The total number of nodules per area unit depends both on their number on one plant, and on the crops density. Considering that soy variety has no influence on the crops density and the similar effect of fertilizers on this indicator, the fertilizer options affect the total number of nodules to the same extent as their number on a single plant. The greatest positive effect was exerted when using a full three-component

fertilizer - 6.2-6.5 million pieces/ha, then followed joint application variants based on ammonium nitrate - 4.3-5.4 million pieces/ha.

Thus, the prevailing view that fertilizers inhibit symbiotic activity has not been confirmed by our studies. Moreover, taking into account that in the year when there was no formation of nodules with nitrogen-fixing bacteria on the roots of soybean plants (2014), the yield level was quite high (Table 2) and sometimes exceeded the one formed with their participation, it can be concluded that soy is an 'altruistic' crop, taking certain 'care' of the soil fertility and of future harvest.

The fertilizers used largely contribute to an increase in soy symbiotic activity. Given that the formation of nodules is due to the outflow of carbohydrates from the aerial part to the roots, that is, some 'energy costs' for soy, it becomes necessary to "start the generator" in the initial period of plant growth, which is apparently associated with the positive effect of the integrated application of all fertilizers in a balanced distribution in space and time of the growing season of the crop. The better conditions are created for the development of soybean plants, the more effectively the symbiotic apparatus is formed.

Yield of soybean seeds of different ripening groups depending on the fertilizers used

Crop yields are an integral indicator of the effectiveness of a particular method of cultivation, plant nutrition systems included. The results of the present study showed that the yield depended on all the three factors: the variety, fertilizers, and the conditions of the year (Table 2).

On average, the early-ripening Lancet was superior to the medium-ripening Belgorod 48 in producing seeds, irrespective of the fertilizers used during 2014 and 2015, while in 2016, the situation changed to the opposite. In 2014, the difference was 0.18 t ha or 7%, in 2015, respectively, 0.12 t / ha or 3%, in 2016, 0.57 t / ha or 32% in favor of Belgorod 48.

Fertilizer (factor B)	Variety (factor A)								Average for factor B
	Lancet			Average in 3 years	Belgorod 48			Average in 3 years	
	2014	2015	2016		2014	2015	2016		
Control (no fertilizer)	2,43	3,56	1,40	2,46	2,41	3,50	1,84	2,58	2,52
Compost	2,90	3,68	2,06	2,88	2,64	3,54	2,41	2,86	2,87
Compost + Naa	3,00	3,84	1,60	2,81	2,61	3,64	2,53	2,93	2,87
Compost + Naa + Azosol	3,04	4,19	1,80	3,01	2,47	3,90	2,76	3,04	3,03
Compost + Azosol	2,65	3,85	1,86	2,79	2,62	3,88	2,53	3,01	2,90
Naa + Azosol	2,54	4,01	1,98	2,84	2,50	3,77	2,43	2,90	2,87
Azosol	2,65	3,96	1,52	2,71	2,54	3,87	2,01	2,81	2,76
Naa	2,62	3,84	1,92	2,79	2,58	3,82	2,19	2,86	2,83
Average for factor A	2,72	3,86	1,77	2,79	2,54	3,74	2,34	2,88	-
HCP_{05} A	0,18	0,11	0,21	0,16					
HCP_{05} B and AB	0,37	0,22	0,42	0,33	-	-	-		-

Table 2. Yield of soybean seeds of different ripening groups depending on fertilizers used, t / ha

The highest yield of Lancet in 2014 and in 2015 was obtained with the combined use of compost, ammonium nitrate and Azosol foliar top dressing: in 2014, the increase in comparison with the control was 0.61 t/ha, in 2015 - 0, 63 t/ha. In addition, a significant excess of the productivity of Lancet in comparison with Belgorod 48 in the first two years of research was noted when compost and compost with ammonium nitrate were used, and in 2015 also with the use of Azosol foliar top dressing. In 2016, due to all variants of factor B (fertilizer), Belgorod 48 had a significant advantage compared to Lancet, including in control. It is obvious that hot weather in the critical phases of Lancet development adversely affected the crop formation.

The effect of fertilizers on this indicator also depended on the year conditions. In 2014, the yield of Belgorod 48 did not depend on the fertilization level, while the yield of Lancet was significantly increased on compost-based fertilizers.

In 2015, there is a similar effect of fertilizers on the yield of both varieties: the maximum was with the use of a three-component fertilizer - 3.9 t/ha (Belgorod 48) and 4.2 t/ha (Lancet). In other variants, the yield was aligned with the tendency of increase when fertilizers were used (Lancet). The difference in the yield level when using compost and compost+ammonium nitrate (Belgorod 48) was within the error of experience.

In 2016, all fertilizer options, apart from the joint use of mineral fertilizers, led to a significant increase in the yield of Belgorod 48. The yield of Lancet was significantly increased only with independent use of organic and mineral fertilizers.

Thus, the research showed that the behavior of varieties belonging to different ripening groups is unstable and largely determined by the weather conditions of the year. The period of research included years in which Lancet (2014-2015) and Belgorod 48 (2016) ad significant yield advantages. This led to the lack of a reliable difference between these varieties on average over three years. Only the variant with joint application of compost and Azosol foliar top dressing led to the yield increase (5% level of significance) of Belgorod 48 compared to Lancet and amounted to 0.22 t/ha.

The instability of the annual weather conditions (south-western part of the Central Black Earth Region) which largely define the behavior of varieties of different ripening groups, giving advantage for early maturing or medium-sized varieties, determines the need for soybean varieties of different maturation periods. This will stabilize the production of soybean seeds, regardless of the weather factors.

Weather conditions also influence the effectiveness of various types of fertilizers. Nevertheless, on an average level for three years the yield of Belgorod48 was significantly increased with the help of two- and three-component fertilizers on the basis of litter by 0.35-0.46 t/ha/ and of Lancet with the help of all fertilizer options, except for the separate use of Azosol foliar top dressing - by 0.33-0.55 t/ha. Regardless of the variety, the maximum yield of soy was due to the full fertilizer Compost + Ammonia Nitrate + Azosol - 3.01-3.04 t/ha, which is 18-22% more than the control levels.

Considering that the preservation of soil fertility is a prerequisite for modern agricultural production, a systematic approach to assessing the economic effectiveness of various fertilizer options is necessary, taking into account the subsequent costs of its restoration as a result of the apparent decompensated removal of food elements when using mineral fertilizers, especially Azosol.

To stabilize the production of soybean seeds in the region (south-western part of the Central Black Earth Region) with unstable weather conditions and increase the fertility of the soil, it is recommended to use a combination of varieties of ripeness (early and mid-ripening) and to apply mineral fertilizers: ammonium nitrate (30 kg a.i./ha) and Azosol (2l/ha - 2 times) against the background of litter-straw compost to create a balanced diet during the whole period of vegetation and soil fertility preservation.

CONCLUSION

The results are obtained that broaden the knowledge of the effect of organic, mineral fertilizers and their combinations on the symbiotic activity and productivity of soybean varieties of different ripeness groups in the south-west of the Central Black Earth zone. The positive effect of joint use of litter-straw compost (20 t / ha), ammonium nitrate (30 kg ai / ha) and foliar top dressing (Azosol 36 Extra (2 times 2 l / ha)) on nitrogen fixing capacity and soy yield due to the formation of a balanced nutrient regime of the soil is proved.

The increase in the number of nodules on compost was unreliable, while all other fertilizer variants significantly increased this index by 1.8-4.2 times. The maximum effect was achieved with a full three-component fertilizer (12.9 pcs/plant). Compost and ammonium nitrate, when used together, significantly increased the effect of each other - by 1.5-2.1 times. Moreover, these options also had a higher rate of increase in the number of nodules - by 40-60% compared with the control levels. The mass of active nodules was directly dependent

on their number and (as the fertilizing saturation rose) increased by 1.7-3.4 times. It should be noted that the increase of this indicator when using foliar top dressing is 1.5 times higher than in the other variants. Thus, the prevailing view that fertilizers inhibit symbiotic activity has not been confirmed by our studies. The better conditions are created for the development of soybean plants, the more effectively the symbiotic apparatus is formed.

On average (for three years), the yield of soy of Belgorod48 significantly increased due to the two- and three-component fertilizers based on litter at 0.35-0.46 t ha, and of Lancet due to the joint use of compost and ammonium nitrate, as well as the separate use of compost and Azosol foliar top dressing - by 0.35-0.55 t/ha (at HCP_{05} = 0.33 t/ha). The maximum yield was (regardless of the variety) due to the full fertilizer "compost + ammonium nitrate + Azosol" - 3.01-3.04 t/ha, which was 18-22% more than the control levels.

The instability of weather conditions in the region of research (south-western part of the Central Black Earth Region), which in many respects define the behavior of varieties of different ripening groups, giving priority to early ripening ones (Lancet in 2014-2015), and then to medium-ripening ones (Belgorod 48 in 2016 g.), determines the farming needs for soy varieties of different maturation periods. This will stabilize the production of soybean seeds, regardless of the weather factors.

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