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Nitrogen Flows and Sustainability of Agrosystem

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Abstract*: In the experiment through sod-podzolic soil, nitrogen flows were estimated in agrocoenosis when applied under spring wheat using ^{15}N ammonium nitrate labeled with isotope and white mustard biomass as a siderate. It was established that the increase of grain yield from the use of N_{45} is 42%, the siderate – 58%, their joint introduction – 99%, from seed inoculation with the Rizoagrin biopreparation – 16%. 60 - 80% of spring wheat harvest is formed due to soil nitrogen, the share of "extra" nitrogen reaches 14%. Plants use 41% of ammonia nitrate nitrogen for crop formation, and 23% of the siderate. Seed inoculation with a biological product increases plant nitrogen intake of mineral fertilizer by 5 - 9%. 26% of ammonium nitrate nitrogen and 33% of siderate nitrogen are fixed in the soil, the biological product does not affect this process. Unaccounted losses of ^{15}N mineral fertilizer make up 32% of the applied amount and reduced by 8% when adding ammonium nitrate and inoculating seeds. The loss of labeled siderate nitrogen is 25% of the amount deposited, the use of the biological product increases the nitrogen consumption of N-fertilizers and provides a positive tendency for green manure nitrogen to fix in the soil and reduces its loss by 4%. On sod-podzolic light loamy soil, agroecosystem functions in the homeostasis mode (norm) when using green manure, in the stress mode (permissible) – when sharing green manure and mineral nitrogen fertilizer. When using only ammonium nitrate, agroecosystem operates in resistance mode. Differences in the performance of agroecosystems among variants with the inoculation of spring wheat with Rizoagrin and without it have not been established.

***Keywords*: nitrogen fertilizer, nitrogen flows in the agricultural system, siderate/green manure, spring wheat, stable nitrogen isotope, use of nitrogen by plants, yield.**

I. INTRODUCTION

The nitrogen cycle in agroecosystem is associated with mineralization and immobilization turnover in the soil. The knowledge of intra soil nitrogen cycles, attainment of mineral nitrogen accumulation synchronism's processes in the soil and its assimilation by agricultural crops helps to prevent accumulation of nitrates in environmental objects and reduces gaseous nitrogen losses [1], [2]. Agrocoenosis is considered as a controlled holistic agroecosystem of components interacting with one another (soil - microorganisms - plants - atmosphere) [3]-[5].

The evaluation of agroecosystems' functioning is carried out based on the following characterized features: humus content, plant nutrition elements, energy flows. For this, the concept of "stability" is applied [6] - the property of the system to preserve and maintain its parameters and structure in space and in time, without qualitatively changing the nature of functioning. Mineralized soil nitrogen is considered as the "entry" of a substance into the system during the growing season of agricultural crops. Net mineralized nitrogen (NM) is an "outlet", and "return" at the exit is re-immobilized nitrogen (RI), which is used to maintain the system [2], [4]. The NM indicator characterizes the nitrogen flow into the external, or autotrophic, cycle, and RI characterizes the flow (return) into the subsurface. The absence of quantitative differences among these streams indicates the closure of nitrogen cycles [4], [7], [8]. It is believed that the stability of the system is ensured by the return of 50% of the substance, in which the system approaches an ecological equilibrium state (homeostasis) [9]. An integral indicator of the functioning of agroecosystems is the ratio NM: RI, which characterizes the ratio among nitrogen flows directed to hetero- and autotrophic cycles. The NM: RI indicator, close to or equal to 1, is possible with recirculation close to 50%. Recycling can be considered as a transformation of nitrogen among components of the agroecosystem, relative to its quantity at the "inlet", i.e. return to circulation. According to the data [4], return due to the activity of biological and biochemical processes in the soil, in fact, is one of the natural homeostatic mechanisms at this level of organization. The higher the value of the ratio NM: RI, the less stable the system. At the same time, the lower the value of the RI: NM ratio (nitrogen circulation), the less stable the system.

Agroecosystems functioning is associated with changes in the anthropogenic load (fertilizer). Studies of agroecosystems stability of using the isotope indication method (^{15}N), which estimated the size and main factors of spatial differentiation of gaseous nitrogen losses of fertilizers and soil nitrogen when mineral and organic fertilizers are applied when growing crops [10] are not numerous.

Research objective: to establish the effect of biological products and fertilizers on the yield of spring wheat and intensity and direction of nitrogen flows of fertilizers in the soil using the isotope ^{15}N.

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II. METHODS AND METHODOLOGY OF THE RESEARCH

The effect of rhizosphere microorganism named Rizoagrin based on the strain belonging to the genus *Agrobakterium radiobakter* (strain 204) [11] on the yield and grain quality of spring wheat (*Triticum aestivum L.*) Zlata variety, the study of nitrogen balance and identifying the role of various nitrogen sources in the formation of yield studied in the microfield experiment in vessels without bottom using the stable ^{15}N isotope. The scheme included two backgrounds of mineral fertilizers - PK and NPK, the siderate (biomass of white mustard - BM), on which seeds inoculated with Rizoagrin were sown [12]. The experiment was carried out in the period during 2014 - 2016 on sod-podzolic light loamy soil in the Smolensk region, characterized by agrochemical parameters: humus content (according to Tyurin) - 1.98-2.04%; pH_{KCL} = 5.1-5.2; content of mobile forms of P_2O_5 and K_2O (according to Kirsanov) - 57.6-67.8 and 153.1 - 161.4 mg / kg of soil, respectively.

The study of nitrogen balance, its consumption by plants from mineral fertilizers and soil, used the stable nitrogen isotope ^{15}N as the salt $^{15}NH_4{}^{15}NO_3$ with enrichment of 54.04 at. %. Nitrogen fertilizer in a dose equivalent of N45 was applied before sowing. Double superphosphate and potassium chloride in a dose of P60K60 were used as a background. The plant mass of white mustard, containing ^{15}N with enrichment of 24.65 - 25.88 at. % was used as a siderate. The siderate was introduced into the vessels in autumn, of the year preceding the experiment. The content of total nitrogen in the biomass was 2.17-2.33%, phosphorus - 0.73-0.93%, potassium - 3.21-3.34% (on a dry matter), the ratio C: N was equal to 25:1. Repetition in the experience is of fourfold. Variants were placed by the method of randomized repetitions.

The evaluation of modes functioning of the agroecosystem in the sowing of spring wheat when using fertilizers and biological product was carried out according to the accepted method [4], [13], [14].

Statistical analysis of obtained results was carried out by a dispersion method according to the model of a three-factor field experiment using the EXCEL and STATISTICA programs. The significance of differences was assessed by *Fisher F-test*.

Meteorological conditions varied significantly over the years of research. Most of the growing season of 2014 was characterized by increased air temperature and extremely uneven distribution of precipitation with alternating periods of dry weather and heavy rainfall. The hydrothermal coefficient (SCC) was 1.33. The vegetation period of 2015 was arid in the amount of precipitation with air temperatures above the multiyear average; the SCC was 0.64. In 2016, the air temperature was 1.0 ° C higher than the climatic norm with significant precipitation, SCC = 1.63.

III. RESULTS AND DISCUSSION

The grain yield on the background of the application of RK-fertilizers was 244 g / m^2 (Table I) with variation of research years by 25-33%, which is due to the impact of meteorological conditions. Due to the improvement of plants nitrogen nutrition with the introduction of the fertilizer of the same name, the grain yield increased to 348 g / m^2, the average increase over 3 years reached 42%. The introduction of green manure contributed to the growth of grain productivity by 58%, while sharing - by 120%. When sowing with inoculated seeds, the average increase in grain yield over 3 years was 16%, with variation of seasons growing under changing weather conditions: in arid (SCC = 0.64) - 7%, over-wetted (SCC = 1.63) - 16% and optimal (SCC = 1.33) - 19%. The increase from seed inoculation of RA was less than from fertilizer application, which is associated with a low content of mineral nitrogen compounds available in plants of sod-podzolic soil [1].

When sowing inoculated seeds against NPK background, the grain increment amounted to 75% to the background of PK, 23% to the NPK variant and 51% to the version of the RK + RA. Inoculation of seeds of RA against the siderate background (BM) introduced contributed to the increase in grain yield to the background of the RK by 77%, to the variant BM - 12% and to the variant RK + RA - 54%. With the joint use of N_{45} and BM, inoculation of RA promoted the increase in grain productivity to the background of the RK by 120%, to the variant BM + N_{45} - 11% and to the variant RK + RA - 91%. Increasing effect of combined use of a biological product and fertilizers is due to the fact that plants consume nitrogen fertilizer during the initial growing season, when the activity of nitrogen-fixing bacteria is still relatively small due to insufficient heating of the soil and a small amount of root excretions, and biological nitrogen accumulated by microorganisms of associative nitrogen fixers - in the later stages of plant development, when there is no longer available fertilizer mineral in the soil [15], [16].

Table I. Effectiveness of fertilizers and Rizoagrin on spring wheat (average over 3 years)

Variant	Grain mass, g/m^2	Economic index	Content N in grain, %	Accumulated N in biomass (grain + straw), g/m^2	Nitrogen index
1. $P_{60}K_{60}$ – background (B)	244	0,37	1,94	5,7	0,74
2. B + BM	387	0,39	2,11	9,6	0,75
3. B + N_{45}	348	0,38	2,07	8,7	0,73
4. B + BM + N_{45}	487	0,40	2,20	12,4	0,76
5. B + RA	282	0,38	2,01	6,7	0,75
6. B + BM + RA	433	0,40	2,18	11,2	0,75

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7. B + N_{45}+ RA	427	0,41	2,05	10,0	0,76
8. B + BM + N_{45}+ RA	539	0,42	2,26	13,8	0,77
P, %	3,12	3,77	2,25	2,99	
HCP_{05} for main factors	16	0,03	0,05	0,5	
HCP_{05} partial differences	32	0,04	0,07	0,8	

Note: BM – biomass of siderate (white mustard), RA – Rizoagrin

Economic index (Khoz, or grain share in general biological yield) ranged from 0.37 to 0.42. Its value was largely influenced by weather conditions - with a lack of moisture, it decreased by 7–20%. When using mineral fertilizers and BM, there was a tendency to increase the share of grain in the general biological harvest when sowing inoculated seeds.

The nitrogen content in the grain of spring wheat varies from growing conditions and hereditary characteristics [17]. Because of nitrogen conditions improvement of spring wheat nutrition due to the introduction of nitrogen fertilizer, the nitrogen content in the grain increased by 0.13%, the addition of green manure to 0.17%. Significant differences in options for making green manure and ammonium nitrate on the nitrogen content in the grain is not installed. Inoculation of RA seeds on average over the years of research on the background of RK-fertilizers contributed to the increase of 0.07% in the accumulation of nitrogen in the grain, which indicates improvement in the conditions of nitrogen nutrition of wheat [15], [18].

Nitrogen consumption by plants is determined by biological characteristics of the cultivated crop (absorption of NO_3^- and NH_4^+, their assimilation, transport, distribution between organs, recycling, accumulation in reproductive organs) and soil conditions (mineralization-immobilization ratios of processes, pH_{KCL}, activity of soil enzymes and activity of microorganisms of nitrogen cycle) [1], [19]. Nitrogen accumulation in the biomass of spring wheat (grain and straw) changed in relation to the background of RK as the result of applying nitrogen fertilizer by average of 52%, application of green manure by 67%, and joint use by 118% (relative).

As the result of RA seeds inoculation, there was a further increase in accumulation of nitrogen in the harvest of spring wheat. In particular - by 18% against the background of RK, by 15% - against the background of NPK, by 18% - when making the siderate and by 11% - with the combined use of NPK and the siderate (Table I).

Activation of intrasoil nitrogen transformation cycle processes is a natural reaction of the soil to fertilizer application as a self-regulating system, tending to homeostasis and a certain dynamic equilibrium of nitrogen content [7], [20]. Species and varietal characteristics of culture cultivation affect processes of nitrogen transformation of fertilizers and soil. On the one hand, nitrogen fertilizers act as a regulator of mineralization processes - immobilization, and on the other - contribute to the additional consumption of soil nitrogen by plants [1], [21]. The use of the stable ^{15}N isotope [12] made it possible to identify nitrogen sources in the formation of the spring wheat harvest (Table II).

Table II. Nitrogen consumption by spring wheat plants when using mustard biomass, NH_4NO_3 and seed inoculation with Rizoagrin (average over 3 years)

Variant	N Removal							Associative N, г/м²	Utilization rate of N fertilizer, %	
	Fertilizers				Soils					
	BM		NH_4NO_3		Total		Additional N, g/m²			
	g/m²	%	g/m²	%	g/m²	%			BM	NH_4NO_3
1. $R_{60}K_{60}$ – (F)	–	–	–	–	5,7	100	–	–	–	–
2. F + BM	3,0	31	–	–	6,6	69	0,9	–	24	–
3. F + N_{45}	–	–	1,9	22	6,9	78	1,2*	–	–	41
4. F + BM + N_{45}	3,2	26	1,7	14	7,5	60	1,8*	–	26	37
5. F + RA	–	–	–	–	6,7	100	–	1,0	–	–
6. F + BM + RA	3,3	29	–	–	7,9	71	0,9	1,3	26	–
7. F + N_{45}+ RA	–	–	2,1	21	7,9	79	1,2*	1,0	–	47
8. F + BM + N_{45}+ RA	3,6	26	1,9	14	8,3	60	1,8*	0,8	29	42

Note: * - "extra" nitrogen, the total removal is given in Table I

The main role (70-80%) in crop formation belongs to the soil nitrogen, with introduction of nitrogen fertilizer mineralization of soil organic matter increases [21] and availability of mineralized soil nitrogen to plants increases. Against the background with nitrogen fertilizer, uptake of nitrogen by the plant increased 1.2 times compared control, while soil nitrogen share in the removal was 78%. A similar pattern was obtained when green manure was introduced, due to which mineralization of soil organic matter increased by a factor of 1.2, but soil nitrogen share in the removal was about - 70%. With the joint use of nitrogen fertilizer and siderate mineralization of soil organic matter increased by 1.3 times, and soil nitrogen share in the removal was 60%. The share of additional saline soil nitrogen when applying various fertilizers was 9-14% of the total nitrogen removal by the crop.

The maximum was obtained when applying N-fertilizer ("extra" nitrogen) (14%) and less when using green manure (9%), which indicates a decrease in mineralization of soil nitrogen when organic fertilizer is applied. With the combined use of mineral and organic fertilizers, the share of "extra" nitrogen on average was 15%.

The usage increase of soil nitrogen in the application of ammonium nitrate is explained by the fact that acid products formed during the nitrification of mineral fertilizers enhance hydrolysis of soil nitrogen and thereby increase its mobility [1]. Increased use of soil nitrogen by plants when adding green manure is associated with the entry into the soil of readily available organic compounds formed during its mineralization, which contribute to the strengthening of nitrification and denitrification [22], [23].

The usage ratio of spring wheat nitrogen fertilizer and soil nitrogen when making ammonium nitrate was an average of 0.24-0.32 : 1, and when using green manure - 0.34-0.51 : 1, with the joint application of these fertilizers - 0.68 -0.71 : 1. Higher utilization of siderate for plants to nitrogen the soil nitrogen compared to ammonium nitrate is associated with the dose of applied nitrogen. With green manure, 12.6 g / m^2 of nitrogen was added, and with ammonium nitrate, only 4.5 g / m^2. The usage of ^{15}N isotope made it possible to determine the amount of nitrogen absorbed by plants in fertilizers. In particular, spring wheat used 41% nitrogen ammonium nitrate and 24% of N siderate. When these fertilizers were used together, nitrogen utilization rate of mineral fertilizer was 37%, siderate — 26% (Table II).

The sizes of biological nitrogen fixation were established by inoculation of RA seeds. On average, over the years of research, in spring wheat crops, this plant source used 1.0 g / m^2 of air nitrogen. The diazotrophs action, as well as any microorganisms, is subject to the effects of soil temperature and humidity, therefore, fluctuations in fixation size of biological nitrogen from 0.4 in arid 2015 to 2.0 g / m^2 in 2014 are noted (wetting conditions are close to optimal).

The nitrogen fertilizer usage does not reduce the size of associative nitrogen usage, which remains at the level of RK - fertilizer application, i.e. additional N fertilization does not reduce associative nitrogen fixation. Nitrogen fertilizers, stimulating the growth of plants in the early stages of development and increasing productivity of the photosynthetic apparatus, contribute, after removing excess nitrogen mineral compounds in the soil, as a result of their consumption by plants and microorganisms, seeping into groundwater (when washing water mode) and fixing in crystal lattices soil minerals, an increase in associative nitrogen fixation at subsequent stages of plant development [13], [23]. The speed of these processes is determined by the level of biological activity of the soil.

The introduction of green manure rich in sugars and other carbohydrates, as well as easily decomposed carbon compounds, creates favorable conditions for the activation of saprophytic microflora in the soil, increases its biological activity, including nitrogen-fixing ability [24]. The presence of readily-decomposable carbon compounds, which are necessary for microorganisms, in siderorate biomass caused the increase in fixation by associative microorganisms of nitrogen in spring wheat crops, which was 1.3 g / m^2 during RA inoculation. In the variant RK + BM + N_{45} + RA, the amount of associative nitrogen decreased to 0.8 g / m^2 (less than in other variants of the experiment), which is associated with the introduction of readily available mineral forms of nitrogen and strengthening of nitrification and denitrification processes [23].

The ^{15}N isotope usage made it possible to determine the nitrogen balance items of used fertilizers (Table III). In the soil layer of 0–20 cm, 27% of N ammonium nitrate and 52% of N green manure were immobilized (stuck), and 33 and 47%, respectively, of fertilizers were used together. An essential item of nitrogen balance is unaccounted losses, which are represented mainly in gaseous form, as well as leaching into the underlying layers of the soil profile. This is the main reason for the reduction of nitrogen utilization by plants and the effectiveness of fertilizer use in all climatic zones [1], [17], [20], [21]. Unaccounted nitrogen losses from ammonium nitrate accounted for 32%, from siderate biomass - 25%. When these fertilizers were used jointly, the use of green wheat of siderate increased in spring wheat, N fixation in the soil decreased, and the use of N fertilizer from mineral fertilizers decreased slightly due to increased immobilization and reduced losses.

The microorganisms which are included in biopreparation affect the activity of nitrogen transformation subsoil cycle, including mineralization and immobilization of nitrogen in fertilizers and soil. When RA seeds were inoculated and siderate were applied, a positive trend was observed in the nitrogen usage by plants, as well as nitrogen fixation of fertilizer in the soil, which contributed to the reduction of N losses (Table III).

Table III. The nitrogen balance of fertilizers when growing spring wheat, % (average for 3 years)

Variant	Used by plants N		Fixed in the soil layer 0-20 cm		Losses	
	1	2	1	2	1	2
F + BM	23,5	–	51,6	–	24,9	–
F + N_{45}	–	41,2	–	26,5	–	32,3
F + BM + N_{45}	25,5	37,0	46,9	32,5	27,7	30,5
F + BM+ RA	26,2	–	52,8	–	21,0	–

F + N_{45}+ RA	–	46,6	–	26,9	–	26,5
F + BM + N_{45}+ RA	28,5	42,4	50,0	33,4	21,5	24,2

Note: 1 - siderate biomass, 2 – NH_4NO_3

Another pattern was observed when inoculating RA seeds and applying ammonium nitrate, where the biological product increased nitrogen usage from mineral fertilizers and did not affect immobilization processes of nitrogen in the soil (Table III). When sharing green manure and ammonium nitrate due to inoculation, plant use and immobilization of siderate nitrogen in the soil, as well as wheat use of nitrogen from nitrogen fertilizer, were increased by inoculation. And as a result - reduction of nitrogen losses of these fertilizers.

Thus, the introduction of siderate biomass into the soil in the C : N = 25 : 1 ratio enriches the soil with nitrogen as a result of its immobilization. The nitrogen usage fertilizer enriches the soil with nitrogen less, which is not enough to maintain the dynamic equilibrium of nitrogen in the soil. Inoculation of RA seeds increases the use of spring wheat, green manure nitrogen, mineral fertilizer, increases nitrogen immobilization of organic fertilizer in the soil and reduces N loss from it.

The ^{15}N isotope usage made it possible to reveal the nitrogen formation features of fertilizers and soil flows (Table IV). During the growing season, the largest amount of soil nitrogen was mineralized when using green manure (30.2 g / m^2), while the process of nitrogen re-mobilization (15.1 g / m^2) was most active, which reduced net mineralization. The maximum amount of net mineralized nitrogen in the soil was accumulated when using green manure and mineral fertilizer (16.4 g / m^2), which is associated with an increase in the consumption of soil and fertilizer nitrogen by plants, as well as increased mineralization of siderate biomass. Mineralization of soil nitrogen and nitrogen re-immobilization of ammonium nitrate is inferior to the siderate option, which is associated with a low dose of applied nitrogen from mineral fertilizer. Inoculation of RA seeds does not significantly affect the processes of mineralization and reimmobilization.

The integral evaluation calculation of spring wheat agrophytocenosis functioning revealed significant differences in the processes of nitrogen transformation in the agroecosystem. Despite the relatively similar activity of nitrogen mineralization in the agroecosystem on the background + BM and background + BM + N_{45} variants, the nitrogen flow N-M in the sod-podzolic soil when applied with organic and mineral fertilizers is marked in relative terms much more than the RI flux (59% against 41% of M). The use of only siderate led to the fact that the nitrogen flows of the radiation sources and N-M were the same. As a result, the N-M: RI ratio differed in the variants F + BM and F + BM + N_{45} (1.0 and 1.4, respectively).

Table IV. Flows of nitrogen fertilizer labeled with ^{15}N, and soil in the sowing of spring wheat during the inoculation of RA seeds (average during 2014-2016)

Indicator	F + Mustard biomass (BM)		F + N_{45}		F +BM + N_{45}	
	Non-inoculation	Inoculation	Non-inoculation	Inoculation	Non-inoculation	Inoculation
Mineralized nitrogen, g / m^2	30,2	32,0	17,7	18,3	27,8	28,4
Net mineralized nitrogen, g / m^2	15,1	15,8	13,3	13,5	16,4	16,3
Reimmobilized nitrogen, g / m^2	15,1	16,2	4,4	4,8	11,4	12,1
RI : M, %	50	51	25	25	41	43
N – M : RI	1,0	1,0	3,1	3,0	1,4	1,3

According to the scale of the integral assessment [13], [14], agroecosystem functioning when using green manure corresponded to the mode of homeostasis, and the level of impact was normal. When using green manure and ammonium nitrate, agroecosystem functioning corresponds to the stress regime, and the level of impact (load) decreased to an acceptable level. A different situation is created with the introduction of mineral nitrogen fertilizer, on average over the years of research, mineralization was significantly lower (1.7 times) compared with the use of green manure, which is associated with the dose of applied nitrogen. The functioning of the agroecosystem with the introduction of ammonium nitrate showed weak resistance to anthropogenic effects and corresponded to the resistance mode (RI : M about 30%), and the level of exposure (load) was the maximum permissible. The use of a biological preparation did not significantly affect the stability of the agroecosystem of the sod-podzolic light loamy soil, only a slight tendency of increasing its stability was noted when adding green manure due to the growth of RI.

IV. CONCLUSION

On sod-podzolic soil with an average humus content, the leading role in increasing the grain yield of spring wheat belongs to green manure and mineral fertilizers, the increase in the use of N_{45} is at least 42%, green manure - 58%, their joint application - 99%. The increase from seed inoculation with Rizoagrin biopreparation is an average of 16%.Formation of spring wheat biomass on sod-podzolic soil is mainly due to soil nitrogen, the proportion of which reaches 4/5 of the total removal of the element when using mineral fertilizers and 3/4 when applying green manure.

The share of "extra" nitrogen in the production process is limited (14% of the total removal of nitrogen fertilizer separately and in combination with the use of green manure). The additional use of nitrogen by spring wheat on sod-podzolic soil due to seed inoculation with the Rizoagrin biopreparation is 8–13 kg / ha.

Plant usage of nitrogen (^{15}N) fertilizer, established by the method of isotopic indication, on sod-podzolic light loamy soil for spring wheat is: mineral fertilizer - 41%, green manure - 23%. Seed inoculation with rhizosphere diazotrophs (Rizoagrin) enhances the consumption of nitrogenous fertilizers by plants by 5–9%, siderate — only a positive trend has been noted.

Nitrogen fertilizer and siderate are included in the cyclic mineralization and remobilization transformations in the soil. High immobilization of nitrogen fertilizers in sod-podzolic soil is a key process that determines the agroecosystem stability. The absolute size of immobilization in the balance structure of the labeled nitrogen mineral fertilizer is 26% of the applied amount and increases with the use of green manure to 33%. When using green manure, immobilization dimensions in the balance structure are 52 ± 7%. Biological inoculation of rhizosphere diazotrophs (Rizoagrin) does not affect the immobilization of nitrogen in mineral fertilizers and only a positive trend has been noted regarding the immobilization of siderate nitrogen.

The unaccounted losses of labeled nitrogen in mineral fertilizers make up 32% of the applied one and are reduced by 8% (to 24%) with the combination of organic and mineral fertilizers and seed inoculation with Rizoagrin. The loss of labeled nitrogen siderate in various meteorological conditions of the growing season is 25% of the amount applied. Seed inoculation with Rizoagrin increases nitrogen consumption of N - fertilizers and provides a positive trend in securing siderarate nitrogen in the soil and reduces its loss by 4%.

The mode of agroecosystem functioning when using nitrogen fertilizer, green manure and Rizoagrin depends on the balance of net mineralized and (re) immobilized nitrogen in the soil. On sod-podzolic light loamy soil, the agroecosystem functions in homeostasis mode (norm) when using green manure (white mustard biomass (BM), in stress mode (acceptable) - when BM and mineral nitrogen fertilizer are used together. When using ammonium nitrate, the agroecosystem is less stable: in the resistance mode (maximum permissible).

Significant differences in the agroecosystems functioning between the variants with inoculation of spring wheat with and without Rizoagrin was not been established. The use of Rizoagrin contributes to a relative increase in net mineralization (on average by 5%) and immobilization (on average by 6%) of siderate nitrogen under meteorological conditions close to the mean multiyear value.

REFERENCES

1. A.A. Zavalin, and O.A. Sokolov, "*Nitrogen flows in the agroecosystem: from the ideas of D.N. Pryanishnikov to our days*". Moscow: VNIIA, 2016.
2. V.G. Sychev, O.A. Sokolov, A.A. Zavalin, and N.Ya. Shmyreva, "*The role of nitrogen in the intensification of the crops production process. Book 2. Environmental aspects of the nitrogen role in the production process*". Moscow: VNIIA, 2012.
3. B.M. Mirkin, L.G. Naumova, and R.M. Khaziakhmetov, "Management of the agroecosystems function: the environmental aspect". *Advances in modern biology*, vol. 121(3), 2001, pp. 227-240
4. L.V. Pomazkina, "A new integral approach to the assessment of the agroecosystems functioning modes and the environmental regulation of anthropogenic pressures, including technogenic pollution of the soil". *Advances of modern biology, vol. 124*(1), 2004, pp. 66-76
5. L.V. Pomazkina, "Assessment of the influence of climatic factors and pollution of alluvial soils with heavy metals on the agroecosystems functioning of the Baikal region". *Agrochemistry, vol. 4*, 2018, pp. 78-87
6. N.Ya. Shmyreva, O.A. Sokolov, A.A. Zavalin, and V.A. Chernikov, "Nitrogen balance in growing perennial legume-cereal grasses on a slope (II rotation ^{15}N)". *Fertility, vol. 2*, 2016, pp. 43-45.
7. L.V. Pomazkina, L.G. Kotova, S.Yu. Zorina, and A.V. Rybakova, "Comparative assessment of the agroecosystems state on different soil types of the Baikal region contaminated with fluorides of aluminum production". *Soil science*, vol. 6, 2008, pp. 717-725
8. O.A. Sokolov, A.A. Zavalin, V.G. Sychev, N.Ya. Shmyreva, and L.N. Tsurikov, "*The flow of nitrogen in agrophytocenosis on eroded soils*". Moscow: VNIIA, 2015.
9. Ye. Odum, "*Ecology: in 2 books*". vol. 1. Translated from English. Moscow: Mir, 1986.
10. O.A. Sokolov, V.A. Chernikov, and I.I. Vasenev, "Agroecological assessment of nitrogen losses under the conditions of an erosive agrolandscape (based on the results of long-term studies with ^{15}N)". *AgroEcoInfo*, vol. 6, 2015.
11. I.A. Tikhonovich, A.P. Kozhemyakov, V.K. Chebotar, Yu.V. Kruglov, N.V. Kandybin, and G.Yu. Laptev, "*Biological products in agriculture. Methodology and practice of using microorganisms in crop production and feed production*". Moscow: Russian Agricultural Academy, 2005.
12. A.A. Zavalin (ed). "*Evaluation of the effectiveness of microbial drugs in agriculture*". Moscow: Rosselkhozakademiya, 2000.
13. L.V. Pomazkina, L.G. Kotova, and E.V. Lubnina, "*Biogeochemical monitoring and evaluation of the agroecosystems functioning on technologically polluted soils*". Novosibirsk: SO Science, 1999.
14. L.V. Pomazkina, L.G. Sokolova, S.Yu. Zorina, and N.N. Kovaleva, "Integral assessment of the environmental load on agroecosystems with technogenic fluoride contamination of agrozems of the Baikal natural territory". *Agrochemistry, vol. 11*, 2011, pp. 78-84
15. A.A. Zavalin, "*Biologicals, fertilizers and harvest*". Moscow: Publishing house VNIIA, 2005.
16. V.N. Kudeyarov, "The flow of nitrogen into the soil with non-symbiotic nitrogen fixation". In: "*The modern development of scientific ideas D.N. Pryanishnikov: Collection of scientific papers*". Moscow: Science, 1991, pp. 155–169.
17. G.P. Gamzikov, "*Agrochemistry of nitrogen in agrocenoses*". Novosibirsk: Rus. Acad. Agricul. Sciences, Sib. Department Novosib. State Agrarian Univ., 2013.
18. A.A. Zavalin, "*Nitrogen nutrition and productivity of spring wheat varieties*". Moscow: Agrokonsalt, 2003.
19. O.A. Sokolov, and V.M. Semenov, "Methodology for assessing nitrogen nutrition of crops. *Agrochemistry, vol. 9*, 1994, pp. 137-149.
20. A.I. Osipov, and O.A. Sokolov, "*Ecological safety and sustainable development. Book 4. The role of nitrogen in soil fertility and plant nutrition*". St. Petersburg, 2001.
21. D.A. Korenkov, "*Agri-environmental aspects of the nitrogen fertilizers usage*". Moscow: Agrokonsalt, 1999.
22. E.N. Mishustin (ed.), "Biological nitrogen in agriculture of the USSR". Moscow: "Science", 1989.
23. N.Ya. Shmyreva, O.A. Sokolov, and A.A. Zavalin, "Features of the phytomass assimilation of perennial grasses by the microorganisms in the soil of varying degrees of erodedness". *Reports of the Russian Agricultural Academy, vol. 3*, 2014, pp. 35-38.
24. V.G. Loshakov, "*Crop rotation and soil fertility*". Moscow: VNII of Agrochemistry named for D.N. Pryanishnikov, 2012.