

The Environment–Forming Role of Perennial Grasses in Agriculture of the Forest-Steppe of Western Siberia

Vasily Boiko
Department of Agriculture and
Feed Production
Omsk Agrarian Scientific
Center
Department of Agronomy,
Breeding and Seed Production
Omsk State Agrarian University
named after P. A. Stolypin
Omsk, Russia
boicko.vasily2011@yandex.ru

Natalia Voronkova
Department of Chemical
technology
Omsk State Technical
University
Department of Agriculture and
Feed Production
Omsk Agrarian Scientific
Center
Omsk, Russia
voronkova.67@bk.ru

Artem Timokhin
Department of Agriculture and
Feed Production
Omsk Agrarian Scientific
Center
Department of Agronomy,
Breeding and Seed Production
Omsk State Agrarian University
named after P. A. Stolypin
Omsk, Russia
timoxin514@mail.ru

Natalia Balabanova
Department of Agriculture and
Feed Production
Omsk Agrarian Scientific
Center
Department of Agrochemistry
and Soil Science
Omsk State Agrarian University
named after P. A. Stolypin
Omsk, Russia
natascha.balabanowa@mail.ru

Abstract—Results of field experiments in crop rotations of different specialization are presented – cereals-fallow and cereals-grasses rotations. The influence of various forecrops (fallow, Alfalfa) on individual indicators of soil fertility has been established. Negative nitrogen balance of -28 kg/ha was revealed with its intensity of 66% in a cereals-fallow rotation. The inclusion of perennial legumes, including alfalfa, provides a positive nitrogen balance in the crop rotation – 21 kg/ha without additional fertilizer with a deficiency of its intensity of 119%. Under such conditions, the content of nitrate nitrogen in soil, before sowing the wheat after plowing the bean component was high, as well as after fallowing, provides an increase in the yield of spring soft wheat by 5,0 kg/ha compared to wheat. Studies were conducted in similar conditions on irrigated meadow-chnozem soil in an eight-field stationary cereals-grasses crop rotation. The consumption of macronutrients, including nitrogen with a crop of various perennial grasses, as well as the responsiveness of alfalfa, bromus and melilot to the level of nitrogen-phosphorus nutrition, were studied. The current nitrogen mobilization under these conditions of bromus vegetation on the background without fertilizers was 76 kg/ha. When optimizing the phosphate regime of the soil, this indicator increased to 99 kg/ha. Alfalfa nitrogen removal increases on similar agricultural backgrounds due to symbiotic fixed nitrogen by 89 and 193 kg/ha, respectively, or by 2,2 and 2,9 times. In such conditions, perennial legumes (alfalfa and melilot) are highly productive without nitrogen fertilizers and respond positively to improved nutritional conditions for phosphorus. This is especially evident in alfalfa of 1-5 years of life, where harvesting of green mass and fodder units increases to 40,56 and 7,00 t/ha, respectively, or by 86% and 54%, with 82,76 GJ of exchange energy per hectare.

Keywords—soil fertility, nitrogen, phosphorus, perennial grasses, alfalfa, meadow chernozem soil.

I. INTRODUCTION

In the current agro-ecological situation of modern agriculture, increasing the biological resources use (plant residues, organic waste of various origins, grass sowing) with mineral and organic fertilizers will help to maintain them fertility level of zonal soils at an ecologically acceptable level with high agro-technical and economic efficiency of crop production [1].

Only by such methods the large difference in the balance of minerals and organic matter between natural and anthropogenic ecosystems can be offset [2-3]. In addition, it should be borne in mind that the supply and accumulation of plant biomass in the soil of agrocenoses depends on biotic factors (species, variety of crops), abiotic factors (climatic conditions of the region) and agricultural technologies (fertilizers, tillage, use of plant protection products, etc.) [4-5].

Using agro-technical techniques (introducing a fallow field into a crop rotation, early autumn tillage, early uplift of a perennial grasses layer, etc.), a significant improvement in the nitrogen regime of chernozem soils is possible [6].

When cultivating perennial legumes in crop rotation, stabilization of soil fertility is observed and crop yields increase due to the enrichment of the soil with biological nitrogen and a sufficiently large number of root and crop residues, in addition, the root system of leguminous plants has a beneficial effect on soil agro-physical parameters [7-8].

The determining role in the formation of crop productivity by a leguminous forecrop is assigned to the enrichment of the soil with a sufficiently large number of plant residues, according to the studies of E.N. Mishustina and N.I. Cherepkova [9].

II. METHODS

Field experiments were carried out in the southern forest-steppe of Western Siberia in cereals-grasses (perennial grasses (alfalfa) 1-3 years of life, spring wheat, spring wheat, oats) and cereals-fallow rotations (fallow, spring wheat, soybean, spring wheat, barley).

The soil of the experimental plot is meadow-chnozem, medium-power, medium-humus heavy loamy. The initial humus content in the arable layer is 6,4-6,6% (according to Tyurin), P_2O_5 and K_2O is 105-128 and 350-420 mg/kg of soil (according to Chirikov), respectively; exchange Ca^{2+} is 89 and Mg^{2+} is 11 mg- equiv/100 g in the absorbing complex of the soil; pH_{salt} is 6,4-6,7.

Studies were conducted in similar conditions on irrigated meadow-chnozem soil. During field irrigation, including the occupied ones, of an eight-field stationary cereals-grasses

crop rotation (planted in 1978), the nitrogen removal parameters with the harvest of perennial legumes and grasses in various soil fertilizer varieties were studied, as well as the responsiveness of alfalfa, bromus and melilot growth and productivity parameters to the level of nitrogen-phosphorus nutrition.

The soil is meadow-chnozem, heavy loamy, with a humus content in the arable layer of 6,57%, mobile phosphorus – 70-90 mg/kg (controlled) and 120-180 mg/kg in various forms with action (P_{60} before sowing the crop) and the aftereffect of phosphorus-containing fertilizers: background 0 – the average availability of phosphorus (50-100 mg/kg), background I – increased (100-150 mg/kg), background II – high (150-200 mg/kg) and background III – very high (more than 200 mg/kg).

Analysis of soil and plants was carried out by standard methods. The research results were processed by the dispersion method of statistical analysis [10].

III. RESULTS

A comparative analysis of two crop rotations (cereals-grasses and cereals-fallow) showed that in the first crop rotation in the entry item of organic matter balance, in addition to the crop residues of cereal crops, the postharvest biomass of perennial legumes accounted for a large share.

To account for the contribution of biological nitrogen from plant residues to the nitrogen regime of meadow chernozem soil, the balance of this mineral and its intensity were calculated by the method of E.N. Terpacheva [11]. By the magnitude of the balance intensity, one can estimate the level of nitrogen intake and consumption.

The nitrogen balance in the soil of cereals-fallow and cereals-grasses rotation was significantly different (Fig. 1), if in the first it was scarce (-28 kg/ha) at an intensity of 66%, then in the agrocnosis with a long-term legume crop it is surplus (+21 kg/ha) with an intensity of 119%.

The improvement of the nitrogen nutrition conditions of plants is explained, first of all, by the enrichment of the soil with leguminous plant residues. Since more than 82% in the entry of the nitrogen balance in the cereals-grasses rotation is accounted for by the plant residues of this crop [12].

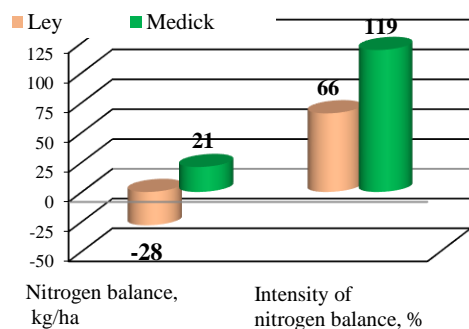


Fig. 1. Balance and intensity of nitrogen balance in crop rotation

Stable functioning of the soil cover of agricultural landscapes means an optimized combination of physicochemical and biological processes in the soil, on which the fertility and productivity of plants depends on [13-15].

Alfalfa layer, as a forecrop to cereals, including spring wheat, activates biological processes in the soil – the total number of microorganisms exceeded the fallow forecrop by 41%, on CAA – by 49%, oligonitrophils – by 48%, nitrification – by 37%. In this case, there was an increase in the activity of enzymes catalyzing hydrolytic processes, invertase and urease, by 13% and 27%, respectively. Redox processes characterized by catalase activity increased by 37% compared with the preceding fallow.

The activity of cellulose-destroying microbiota depends on the content of accessible forms of minerals in the soil and reflects, on the whole, the direction of the course of microbiological processes in the soil [16]. The decomposition rate of cellulose in meadow chernozem soil increased by 48%, under the wheat crop after alfalfa in comparison with the preceding fallow.

The soil nitrification ability, characterizing the potential of easily mineralizable nitrogen-containing organic substances after plowing alfalfa in the 3rd year of life, was 67% higher than the preceding fallow.

The release of fresh nitrogen-enriched organic matter into the soil contributed to an increase in biological activity and the accumulation of nutrients.

The content of nitrate nitrogen in the soil before sowing the wheat after plowing the legumes was high, as well as after fallowing, providing an increase in the yield of spring soft wheat by 5,0 quintal/ha in comparison with wheat by steam (Fig. 2).

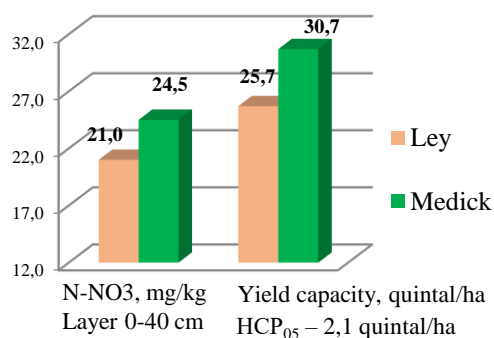


Fig. 2. Forecrop influence on nitrate nitrogen content in soil and yield of spring soft wheat

When using irrigated arable land densified over time against a natural fertility background, nitrification nitrogen was continuously used by grasses, which absorbed 76 kg/ha of nitrogen, and up to 99 kg/ha with increased phosphorus supply (Table I).

TABLE I. NITROGEN REMOVAL WITH CROP OF PERENNIAL GRASSES, KG/HA

Nitrogen application, kg/ha	Background of P ₂ O ₅ (in soil)			
	0	I	II	III
<i>Alfalfa 2-4 years of life</i>				
0	165	292	300	303
160	152	326	324	308
<i>Increase of nitrogen fertilizer removal, %</i>				
-	-8	11	8	2
<i>Bromus inermis 2-4 years of life</i>				
0	76	99	85	79
160	146	187	178	182
<i>Increase of nitrogen fertilizer removal by legumes</i>				
0	89	193	215	224
160	6	139	146	126
<i>Melilot 2 years of life</i>				
0	110	119	124	120
45	106	127	129	130
<i>Increase of nitrogen fertilizer removal, %</i>				
-	4	7	4	8

Alfalfa nitrogen removal on similar agricultural backgrounds increases due to symbiotic fixed nitrogen by 89 and 193 kg/ha, respectively, or by 2,2 and 2,9 times.

On average, alfalfa nitrogen removal in the control amounted to 265 kg/ha, which is three times more in comparison with its removal on a similar background with *Bromus inermis* – 85 kg/ha.

The removal of nitrogen by melilot of 2 years of life without the use of fertilizers (with uniaxial use) was 110 kg/ha (on average over 8 years), and against the background of optimization of phosphorus and nitrogen nutrition – 124 and 129 kg/ha, respectively.

Use of nitrogen fertilizers on legumes of previous years of sowing, judging by the removal, is ineffective and inexpedient. The increase in alfalfa nitrogen removal is 24-34 kg/ha, or 8-11%, and melilot is 5-10 kg/ha, or 4-8% of the corresponding controls.

Nitrogen removal by *Bromus inermis* under similar conditions increases by more than two times in comparison with the control. The maximum nitrogen removal by bromus is characteristic of the background with increased phosphorus supply and amounted to 187 kg/ha, which is 28% more than with the average supply of soil with mobile phosphorus and pre-sowing nitrogen fertilizers.

Perennial legumes (alfalfa and melilot) are highly productive without nitrogen fertilizers and respond positively to improved nutritional conditions for phosphorus. This is especially evident in alfalfa of 1-5 years of life, where harvesting of green mass and fodder units increases to 40,56 and 7,00 t/ha, respectively, or by 86% and 54%, with 82,76 GJ of exchange energy per hectare (Table II).

TABLE II. CROP YIELD OF PERENNIAL GRASSES DEPENDING ON GROWING TECHNIQUES

Crop	Without fertilizers	Average-fertilized background
<i>Alfalfa 1-5 years of life</i>		
Green mass, t/ha	21.80	40.56
Fodder units, t/ha	4.54	7.00
Harvest exchange energy, GJ/ha	55.44	82.76
Energy efficiency coefficient	2.92	3.76
<i>Bromus 1-5 years of life</i>		
Green mass, t/ha	13.62	32.03
Fodder units, t/ha	2.14	4.95
Harvest exchange energy, GJ/ha	29.99	68.89
Energy efficiency coefficient	1.80	2.43
<i>Melilot 2 years of life</i>		
Green mass, t/ha	22.58	30.85
Fodder units, t/ha	2.42	2.83
Harvest exchange energy, GJ/ha	37.58	44.72
Energy efficiency coefficient	2.81	2.96

Melilot of 2nd year of life is more tolerant under these conditions and is highly energy efficient – crop yield increases to 30,85 t/ha of green mass and 2,83 t/ha of fodder units at 22,58 and 2,42 t/ha, respectively, in the control. In this case, 44,72 GJ/ha of exchange energy was obtained with an energy efficiency coefficient of 2,96.

White melilot builds up a more nutritious mass in the sowing year, both in the first and second mowing when sowing it under a wide-row cover of oats than in coverless sowing and single-crop use. The second mowing is well leafy, which is also characteristic of alfalfa, since plants develop in August-early September, during lower average daily temperatures. The availability of digestible protein in fodder unit in the dry matter of white melilot in 2nd year of life reaches 200 g.

As for the yellow melilot, there are no large differences in quality in comparison with white melilot.

Melilot is well adapted to early spring sowing for a wide-row cover of annual fodder crops. The seeding rate of melilot is 6-7 million/ha. After harvesting the cover crop in July, the clarified melilot grass forms an aftergrowth, which makes up to 20-25% of the total crop weight, taking into account the cover crop. The biennial cycle of the melilot development contributes to its more intensive development in comparison with other perennial grasses and the presence of a greater share in the botanical composition when cleaning the cover crop. The single-crop use in 2nd year of life is due to the culture's biology and the need for mowing of annual fodder crops. Melilot is responsive to the application of phosphorus-containing fertilizers (P₆₀) or sowing on an agricultural background with an increased availability of phosphorus.

A long-term comparative study under similar conditions revealed a higher yield of white melilot in irrigated forage crop rotations compared to the yellow melilot.

Bromus is less effective in terms of productivity in comparison with legumes. However, the optimization of nitrogen-phosphorus nutrition against an irrigated background increases its feed and energy value to competitive values.

The formation of bromus under the wide-row cover of annual fodder crops allows the arable land to be used productively already in the first year, mainly due to the cover crop. In subsequent years, the main condition for obtaining high yields of bromus with 2-3 mowing is the application of nitrogen fertilizers in a dose of N_{60} for each mowing, which doubles yield indicators. Factors such as application of potash fertilizers (K_{60}), organic fertilizers in the reserve of 40 t/ha and foliar fertilizing with microelements (Zn and Cu) each individually can reliably increase production by at least 0,5 t/ha of dry matter. However, the maximum of bromus yield is possible with a combination of nitrogen feeding with a background of increased or high phosphorus supply. In the control (without fertilizers) experiment, bromus is the least harvested among the perennial grasses – 2,5-3,5 t/ha of dry matter.

IV. CONCLUSION

Nutrient deficiency in agrocenoses of the southern forest-steppe of Western Siberia is noted due to the low level of fertilizer use. An increase in arable land crop yield is possible due to an increase in the nitrogen cycle by agro-technical methods, expansion of perennial legumes and introduction of nitrogen fertilizers for grasses and other crops, taking into account economic and environmental restrictions.

The environment-forming role of perennial legumes and legume-grass stands on irrigated meadow-chernozem soils of the forest-steppe of Western Siberia is to maintain fertility at a high initial level.

REFERENCES

- [1] G. P. Gamzikov, O. I. Gamzikova and P. S. Wide, "Possibilities of use of nonconventional fertilizers in the siberian agriculture," *Dostizheniya nauki i tehniki APK (Achievements of science and technology of the agro-industrial complex)*, No. 3, pp. 9-12, 2012. (in russ.)
- [2] A. G. Shepelev and L. M. Samokhvalova, "Relationship between chernozem respiration and soil organic matter composition in the central forest-steppe of Western Siberia," *Vestnik Tomskogo gosudarstvennogo universiteta. Biologiya (Tomsk State University Journal of Biology)*, No. 37, pp. 6-16, 2017. (in russ.)
- [3] A. A. Titlyanova, V. I. Kiryushin, V. S. Andrievsky, N. A. Afanasev, L. V. Bykadorova, N. I. Gantimurova, I. L. Klevenskaya, V. G. Mordkovich, G. D. Mordkovich, A. V. Naumov, N. A. Tikhomirova and S. V. Shibareva, *Agrocenoses of the steppe zone*. Novosibirsk: Nauka, 1984.
- [4] P. N. Kordunyanu, *The biological cycle of nutrients of crops in intensive farming*. Chisinau: Stiintei, 1985.
- [5] V. A. Chernikov, N. Z. Milashenko and O. A. Sokolov, *Environmental safety and sustainable development. Book 3. Soil resistance to anthropogenic effects*. Pushchino: ONTI PNC RAS, 2001.
- [6] G. P. Gamzikov, "Nitrogen Agrochemistry in Siberian Meadow-Chernozemic Soils," *Pochvovedenie (Eurasian Soil Science)*, No. 1, pp. 82-91, 2004. (in russ.)
- [7] N. Ya. Shmyreva, O. A. Sokolov and L. N. Tsurikov, "The participation of nitrogen of perennial herbs in the formation of organic matter of sod-podzolic soil," *Plodorodie (Fertility)*, No. 6(69), pp. 25-27, 2012. (in russ.)
- [8] E. N. Mishustin, "The role of legumes and free-living nitrogen-fixing microorganisms in the nitrogen balance of agriculture," in *Cycle and nitrogen balance in the soil-fertilizer-water system*, E. N. Mishustin, Eds. Moscow: Nauka, 1979, pp. 9-17. (in russ.)
- [9] F. I. Levin, "The amount of plant residues in the field crops and its determination by the yield of the main products," *Agrokhimiya (Agrochemistry)*, No. 8, pp. 36-42, 1977. (in russ.)
- [10] B. A. Dospehov, *Methodology of field experience*. Moscow: Agrokhimizdat, 1985.
- [11] L. A. Lebedeva and N. L. Edemskaya, *Scientific principles of the fertilizer system with the basics of environmental agrochemistry: a training manual*. Moscow: Publishing House of Moscow State University, 2004.
- [12] N. A. Voronkova and O. F. Khamova, "Agroecological assessment of the influence of precursors on the elements of the fertility of leached chernozem and yield of spring common wheat," *Vestnik Altajskogo GAU (Bulletin of Altai State Agricultural University)*, No. 5(55), pp. 24-29, 2009. (in russ.)
- [13] B. S. Griffiths, M. Bonkowski, J. Roy and K. Ritz, "Functional stability, substrate utilisation and biological indicators of soils following environmental impacts," *Applied Soil Ecology*, Vol. 16, No. 1, pp. 49-61, 2001. [https://doi.org/10.1016/S0929-1393\(00\)00081-0](https://doi.org/10.1016/S0929-1393(00)00081-0)
- [14] G. V. Dobrovolsky and E. D. Nikitin, *Ecology of soils*. Moscow: Publishing House Moscow University, 2012.
- [15] A. V. Kozlov, A. Kh. Kulikova, O. V. Selitskaya and I. P. Uromova, "Stability of microbiological activity of the sod-podzolic soil when applying diatomite and zeolite," *Vestnik Tomskogo gosudarstvennogo universiteta. Biologiya (Tomsk State University Journal of Biology)*, No. 46, pp. 26-47, 2019. (in russ.)
- [16] N. N. Shuliko, O. F. Khamova and E. V. Tukmacheva, "Cellulolytic activity of leached chernozem in the conditions of the south of Western Siberia," *Selskohozyajstvennye nauki i agropromyshlennyy kompleks na rubezhe vekov (Agricultural sciences and agriculture at the turn of the century)*, No. 14, pp. 28-31, 2016. (in russ.)