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Modern adaptive intensification and diversification of the cultivation of leguminous crops in the conditions of the Central Precaucasus

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Abstract
Over a long period from 1995 to 2018, scientists of the Gorsky State Agrarian University have monitored the biological potential of leguminous plants adapted to the climatic conditions of the piedmont and mountain landscape zones of the Central Precaucasus.
The purpose of the study is to develop a concept, theoretical and practical rationale for the use of adaptive resource and energy saving technologies that provide resuscitation of soil fertility and the formation of highly productive crops of various species of leguminous plants.
The purpose was achieved by performing the following *tasks*: studying the monitoring of the content of microelements and the dynamics of their changes in soils and leguminous plants, taking into account their synergism and antagonism with microelements in soils and plants; the influence of the use of natural mineral waters on the bioresource potential of leguminous plants; the use of foliar fertilizing and presowing seed treatment and their impact on the yield and the quality of leguminous species.
One of the priority areas of our scientific activity was to obtain products with environmentally friendly parameters and to study the biological, chemical and agronomic effects of leguminous plants on the content of the microcomponent composition of the studied soils.
The studies were conducted for four types of soils of the piedmont zone of the Republic of North Ossetia-Alania: ordinary chernozem, podzolized and leached chernozems and alluvial-meadow soils of the Pravoberezhny and Prigorodny Districts of the Republic of North Ossetia-Alania. The objects of our study were perspective varieties of leguminous plants of Kuban selection, as well as those selected by scientists and plant selection breeders of the Republic of North Ossetia-Alania. In the scientific process, the developed method of presowing treatment of leguminous plants' seeds *(Patent No. 2188531)* was used. Liming of soils was carried out with dolomite flour of North Ossetian origin.
The results, obtained in this segmental study, reflected the influence of boron on the yield increase and improvement of the morphometric parameters of certain species of leguminous plants in different soil environments and changing weather conditions, by optimizing the metabolic processes and activation of their symbiotic apparatus, due to the synergistic effect between boron-containing microfertilizers and mobile forms of boron soils.
Keywords: boron-containing microfertilizers, leguminous crops, natural mineral water, inoculation.

INTRODUCTION

Modern innovative agricultural production is characterized by the high dynamics of scientific search for the use of non-traditional methods of plant nutrition with biogenic microcomponents and the search for adaptive low-cost, energy-saving, environment-friendly agricultural methods for the purpose of reproduction of soil fertility and transmutation of the existing paradigms [1-3].

This strategic direction is due to the abundance of problems arising during the introduction of traditional technogenic and chemical intensification, which led to serious environmental consequences that violated the natural balance of the biosphere, and, to a large extent, reduced food safety [4-5].

It has been scientifically approved that climatic conditions, the composition of bedrock soil with a certain mineral structure and the degree of its dispersion, which involves complex biological, physical, chemical and thermodynamic exo- and endogenous processes, are closely interrelated and respond differently to external influences. At the same time, the biological cycle and water migration of elements, with their synergistic and antagonistic effect on the three-phase heterogeneous system of soils having a complex stoichiometric composition, form its chemical basis and properties. In this context, modern methods allow creating favorable conditions for the activation of biochemical and physiological processes that occur under the influence of enzymes that stabilize the metabolism of the cellular level and are resistant to the risks of changing climatic conditions [2, 6-8].

The soil solution in composition and concentration is determined by the interaction of soil, water and organisms and, as a rule, is formed as a result of dissolution of mineral and organic substances, and also, during peptization, coagulation and exchange among solutions' ions with soil colloids [6-9].

It is historically well known and confirmed by numerous experiments, studied by the scientists from all over the world, that leguminous plants are an excellent environmental resource affecting the conservation and reproduction of soil fertility, performing unique bioecological functions and providing high profitability [1, 6, 10-14].

Understanding that bioecosystems are very complex and are the result of not only abiotic, biotic, but anthropogenic factors, we have purposefully neutralized and compensated for unfavorable effects of weather and climate conditions and impacts through the use of resource and energy saving technologies [2].

Our studies are focused on improving the quality and productivity of leguminous plants when cultivating them in the piedmont zone of the Republic of North Ossetia-Alania using non-traditional fertilizers, bioresources and natural raw materials that provide resuscitation of soil fertility and high yield due to the formation of highly productive crops of various types of legumes with improved morphological characteristics.

OBJECT, CONDITIONS AND METHODS OF STUDY

The studies were carried out on the soils of the piedmont zone of the Republic of North Ossetia-Alania: ordinary chernozem, podzolized and leached chernozems and alluvial-meadow soils of the Pravoberezhny and Prigorodny Districts with altitude above sea level of 600-800 m.

The objects of our study were perspective varieties of leguminous plants of Kuban selection and those selected by scientists and plant selection breeders of the Republic of North Ossetia-Alania: cow clover (*Trifolium pratense* L.), eastern galega (*Galega orientalis* Lam.), variable alfalfa (*Medicago sativa L.*), which were sown with a wide-row method, with a row spacing of 45 cm.

Based on the previously developed method of presowing treatment of leguminous plants' seeds (Patent No. 2188531), the inoculation of seeds before sowing was carried out with the crushed roots of the same species of leguminous plants of the 2nd and 3rd years of life, differing in a significant number of nodules that provided the presence of biological nitrogen in root layer. The crushed roots were moistened with Zamankul mineral water at a rate of 1.5-2.0 l/ha and mixed with a hectare rate of seeds – 12 ... 15 kg/ha [15].

The rationale for the parameters of the mineral water used is explained by the amount of moisture required for the activity of the nodule bacteria, since its higher dosage strongly moistens the sowing mixture, lowering the flowability of the seed material at the time of the SZT-3.6 seeder operation. The irrigation of leguminous plants seeds was carried out according to the periods of development.

To study the responsiveness of legumes to the application of microfertilizers for root nutrition and foliar fertilizing of plants, 0.03% of a weakly concentrated sodium tetraborate salt solution $Na_2B_4O_7 \cdot 10\ H_2O$ containing 11.5% boron was added.

We rejected the use of boric acid for several reasons: firstly, the mass fraction of boron in orthoboric acid (H_3BO_3) was 17.7%, which was an order of magnitude higher than in sodium tetraborate; secondly, irrigation of crops of perennial leguminous plants was planned to be carried out with natural Zamankul mineral water with high mineralization and the content of active forms of metaboric acid HBO_2; thirdly, presowing inoculation of seeds was accompanied by treatment with the same mineral water that activated the functionality of nodule bacteria; therefore, the exceeded concentration threshold of boron-containing compounds could negatively affect the results of the study.

Liming of weakly subacid soils with dolomite flour of North Ossetian origin was carried out at the rate of 4 tons/ha.

In the course of the study, we twice visually determined the nitrogen fixing capacity of the nodule of leguminous plants and their number. In the first year of the life of perennial grasses, in mid-August we dug out the plants at a depth of 15 cm. The study was repeated in the spring of the following year, two weeks after the growth of the plants.

RESULTS

Along with the study of the biological potential of small-seeded species of leguminous plants grown on four subtypes of the piedmont zones' soils: alluvial-meadow soils, ordinary chernozem, podzolized and leached chernozems, when exposed to boron-containing micronutrient fertilizers and carrying out presowing seed inoculation, sowing of perennial grasses was carried out in the spring in the first ten days of April. In the process, we tracked the phases of their development: germination, sprouting, branching, stooling, budding, flowering and seed ripening.

The study of the range of boron concentrations in vegetative and reproductive organs of small-seed plants of legumes, before and after liming of three soil subtypes with dolomite flour of North Ossetian origin – $CaCO_3 \cdot MgCO_3$, allowed establishing their migration sensitivity to the missing element.

The obtained indicators of boron content in nodules, leaves and seeds of leguminous plants indicated that its highest concentration prevailed in the leaves of plants, the lowest concentration threshold was found in the seeds (Table 1).

It can be seen from the table that before liming, the content of boron in nodules, leaves and seeds of leguminous plants prevailed over the content after liming. This fact indicates that the content of mobile forms of boron-containing compounds in soils after liming has decreased, which is reflected in transactional activity and migration of this element to the vegetative and reproductive organs of plants. Minimal indicators were noted on the soil of ordinary chernozem.

Our data are consistent with the results of studies performed by well-known scientists Kabat-Pendias and others.

Natural Zamankul mineral water contributed to the moistening of the soil, initiating the process of softening and decomposition of the root remains of the previous year, thereby increasing the content of humus and the number of nodule bacteria in the upper layers of the arable horizon. Nodule bacteria due to virulence – a specific ability to penetrate the roots of legumes, largely activated the process of fixing gaseous nitrogen from the air, transferring it into forms available for plant nutrition, and also for feeding and maintaining the vital activity of the nodule bacteria themselves.

Table 1. The content of boron in nodules, leaves and seeds of leguminous plants, in mg/kg of dry weight, grown on three subtypes of soils of the Pravoberezhny District

No.	The content of boron in legumes in mg/kg dry weight before and after liming	The content of boron in legumes in mg/kg dry weight before and after liming soil					
		cow clover		eastern galega		variable alfalfa	
		without liming soil	with liming soil	without liming	with liming soil	without liming	with liming soil
		Ordinary chernozem (pH = 7.4-8.1), p. Zamankul					
1	In the nodules of leguminous plants	11.4	9.5	14.7	11.3	12.4	10.9
2	In the leaves of leguminous plants	17.7	15.2	18.3	16.9	19.8	18.1
3	In the seeds of leguminous plants	10.3	8.1	12.7	10.5	14.2	11.4
		Podzolized chernozems (pH = 5.1-6.4), p. Zamankul					
1	In the nodules of leguminous plants	14.6	11.8	17.3	16.1	18.4	16.7
2	In the leaves of leguminous plants	23.1	20.6	24.3	22.8	24.7	21.2
3	In the seeds of leguminous plants	13.7	11.3	16.5	15.4	17.3	15.1
		Alluvial-meadow (pH = 5.3 – 6.5), p. Zamankul					
1	In the nodules of leguminous plants	14.1	11.3	16.9	15.7	17.8	16.3
2	In the leaves of leguminous plants	22.4	19.6	24.7	21.8	23.3	21.4
3	In the seeds of leguminous plants	14.4	10.8	16.1	14.2	15.9	13.6
		Leached chernozem (pH = 4.8-5.6), OPH "Mikhailovskoe"					
1	In the nodules of leguminous plants	16.4	12.3	19.8	18.4	21.4	14.1
2	In the leaves of leguminous plants	24.8	21.6	27.3	23.2	25.3	22.9
3	In the seeds of leguminous plants	15.1	10.7	18.1	17.1	17.2	13.6

The boron-containing micronutrients used in the irrigation and presowing inoculation of seeds of leguminous plants provided additional mineral nutrition for the plants, catalyzing nitrogen-fixing microorganisms free-living in the soil, and nodule bacteria, followed by the formation of nitrogen-fixing nodules involved in the biological fixation of chemically inert molecular nitrogen of air.

Nitrogen-fixing nodules participating in biochemical processes and activated by enzymes turned nitrogen of air into ammonia, which was easily assimilated by plants. This process of plant nutrition with an organogenic and nutrient element – nitrogen - is the most cost-effective and environmentally safe, since it does not require the use of increased pressure and temperature indicators, as in the case of the production of mineral fertilizers produced by the fertilizer industry.

In turn, fresh nodule bacteria, during the renewal of their development, increased the activity of the symbiotic apparatus, especially in the second year of plant life, improving biometric indicators: the number, size and quality of nodules in the process of their formation; acceleration of growth and development of plants; an increase in the above-ground mass and seeds, as well as the yield and quality of legumes, increasing resistance to a sharp change in temperature gradients and humidity, as well as to various diseases, with a significant reduction in energy and resource costs (Fig. 1, Table 2).

The use of natural resources of the Republic of North Ossetia – Zamankul mineral water with high boron content and dolomite flour to reduce the acidity of alluvial-meadow soils, podzolized and leached chernozems, provided an increase in the yield of the green cow clover from 11.2 t/ha on podzolized chernozem to 13, 4 t/ha on ordinary chernozem; eastern galega – from 13.7 t/ha on alluvial meadow soils to 16.1 t/ha on ordinary chernozem; variable alfalfa – from 13.0 t/ha on alluvial meadow soils to 16.5 t/ha on ordinary chernozem.

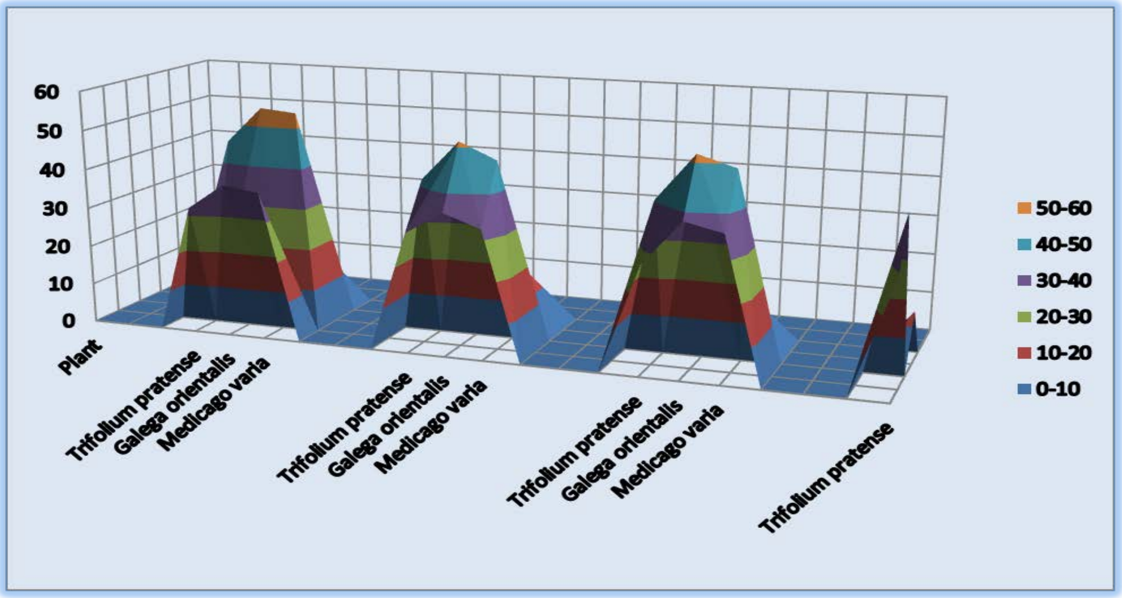

Figure 1. Influence of boron-containing microfertilizers on the yield increment of small-seed leguminous crops, in t/ha, grown on four subtypes of soils of the piedmont zone of the Republic of North Ossetia-Alania

Table 2. Influence of boron-containing microfertilizers on the biometric parameters of leguminous crops grown on four subtypes of soils of the piedmont zone of the Republic of North Ossetia-Alania

No.	Plant	Fresh yield (t/ha)			Number of nodules (pcs. per plant)		Height of the plant,(cm)		Weight of 1000 seeds, (g)	
		without boron	with boron	increase	1st year	2nd year	1st year	2nd year	1st year	2nd year
		Ordinary chernozem (pH = 7.4-8.1), p. Zamankul								
1.	Cow clover	32.2	45.6	13.4	89	108	59	67	1.8	2.4
2.	Eastern galega	38.6	54.7	16.1	85	99	88	97	4.6	5.4
3.	Variable alfalfa	37.4	53.9	16.5	97	121	61	65	1.9	2.6
		Podzolized chernozems (pH = 5.1-6.4), p. Zamankul								
1.	Cow clover	30.2	41.4	11.2	83	118	56	67	1.9	2.5
2.	Eastern galega	35.9	51.3	15.4	79	97	89	98	4.7	5.6
3.	Variable alfalfa	32.6	47.3	14.7	99	126	65	71	1.9	2.5
		Alluvial-meadow (pH = 5.3 – 6.5), p. Zamankul								
1.	Cow clover	27.1	40.4	13.3	79	105	58	63	1.7	2.3
2.	Eastern galega	38.2	51.9	13.7	81	95	85	96	4.5	5.6
3.	Variable alfalfa	36.1	49.1	13.0	95	119	61	69	1.9	2.3
		Leached chernozem (pH = 4.8-5.6), OPH "Mikhailovskoe"								
1.	Cow clover	28.6	41.8	13.2	86	109	58	64	1.6	2.5
2.	Eastern galega	37.7	52.4	14.7	77	96	83	95	4.4	5.2
3.	Variable alfalfa	31.8	48.2	16.4	94	121	62	68	1.7	2.4

Of the 20 plants considered, on the area of 25-30 m^2, of all the studied soils, the maximum number of nodules, on average per plant, was found on alfalfa variable, which varied in the range of 99-126 pcs. on soils of podzolized chernozem. In the plants of the first year, this indicator was 8.59% higher than that for eastern galega and 8.99% more than for cow clover on the ordinary chernozem. In the plants of the second year, this indicator for alfalfa variable exceeded that for eastern galega by 7.86% on the ordinary chernozem and by 9.37% for cow clover on the podzolized chernozem, respectively.

The parameters of the plant height and the weight of 1000 pieces of seeds of eastern galega on the plots fertilized with boron exceeded those of alfalfa variable and cow clover and varied in the ranges of 85-98 cm and 4.5-5.6 g, respectively.

The obtained results illustrate the influence of boron on the possibility of optimizing the metabolism in leguminous plants, increasing the yield and the number of nodules on plant roots, indicating the activation of their symbiotic apparatus due to the synergistic effect between boron-containing microfertilizers and mobile forms of boron soils.

CONCLUSION

1. The performed studies on the characteristics of small-seed leguminous plants grown on four subtypes of soils of the piedmont zone of the Republic of North Ossetia-Alania allowed revealing their ability to self-regulate the complex biochemical processes activated by presowing inoculation of seeds and natural Zamankul mineral water.

2. The results of the study showed that the highest increase in the fresh yield of the studied small-seeded leguminous crops was on the soil of ordinary chernozem, while the maximum indicator was determined for alfalfa variable, which was 16.5 t/ha, which was 8.1% more than for cow clover and 9.8% more than for eastern galega.

3.The obtained indicators on the content of boron in the vegetative and reproductive organs of perennial leguminous plants indicated that its content in leaves prevailed over the content in nodules and in seeds, the lowest concentration threshold was found in seeds.

4.The use of foliar fertilizing of leguminous plants gave a distinct advantage and resonated after presowing seed treatment.

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