A paradigm shift in the agricultural system in the Arctic zone of the Russian Federation

Andrey Ingiri[1,*], *Polina* Ageeva[2], *Natalia* Ikko[3], *Anna* Yashkina[4]

[1]Junior researcher, Laboratory of the medical and Biological Technology, FRC KSC RAS, 184209, Apatity, Russian Federation
[2]Head of the scientific direction of lupin narrow-leaved breeding, All-Russian Lupine Research Institute, a branch of the FWRC FPA, 241524, Bryansk, Russian Federation
[3]Ph.D. of Biological Sciences, docent, Department of Natural Sciences, MASU, 183038, Murmansk, Russian Federation
[4]Senior lecturer, Department of Technosphere Safety, MSTU, 183010, Murmansk, Russian Federation

Abstract. The article presents an overview of the environmental and economic consequences of chemicalization in crop production of the Murmansk region. Proposed is a way to overcome the current situation in the industry through alternative biological sources of increasing soil fertility. Three original varieties of lupines inoculated with a highly effective strain of nodule bacteria Rhizobium lupini were studied in a production experiment. The fodder value of green mass was calculated. Microbiological and agrochemical analyzes of soil in areas with alternative and traditional agricultural technologies were carried out.

1 Introduction

The first steps in the direction of agricultural development of Russia's Polar territories date back to the 1920s. And, in a fairly short time on a historical scale, the ambitious goal set by the young Soviet state was achieved. Already in 1930, the first state farm was organized on the Kola Peninsula, which made it possible to test experimental work in production conditions [1, 2]. Later on, especially in the post-war years, the agriculture of the Arctic only developed. This became possible with the full support and interest of the state in the development of the Northern territories of the country, as well as the mobilization of modern achievements of science and technology [3].

The unpreparedness of the agro-industrial complex of the Murmansk region to the change of political and economic paradigm in the 1990s in the country led to bankruptcy and liquidation of a large number of agricultural enterprises, which caused a number of negative social and economic consequences and threatened the food security of the region. The reduction in the production of local products inevitably led to an increase in the share of food imports from other regions and abroad.

To date, a comprehensive analysis of the economic and socio-economic integral indicators of the industry characterizes it as unstable. The economic efficiency of agricultural enterprises is at an unacceptably low level; most farms are unprofitable even taking into account subsidies. The provision of the local population with locally produced food is also insufficient. All this suggests the need to revise the agrarian policy of the Murmansk region [4].

Pioneers in the direction of agricultural development of the northern territories had to overcome the difficulties associated with the agro-environmental and climatic features of the region. Insufficient heat supply of short vegetation period, poor soil microflora and other factors significantly slow down the processes of mineralization of plant nutrition elements occurring in the soil. In this regard, application of increased doses of mineral fertilizers has become a determinant condition for increasing productivity of arable land.

E.E. Kislykh points out that the average NPK fertilizer system in the region should be at least 260-320 kg/ha of active substance (a.s.) or N120-180P60-80K60-80 in mineral fertilizers and 50-100 t/ha of organic [5].

According to the data of the Murmansk agrochemical service station, the highest yield of forage grasses in the region was achieved in 1986-1990 when NPK was applied with mineral fertilizers in doses of 323 kg/ha a.s., and 400 kg/ha a.s. with organics. With this amount of ameliorants applied, the yield of perennial grasses averaged 126 h/ha in the region, and annual grasses reached 171 h/ha. Harvested areas amounted to more than 17 thousand hectares. Since 1990, there has been a sharp decline in the use of organic and mineral fertilizers. This led to an imbalance of basic nutrients in soils, which negatively affected the yield of annual and perennial forage crops. In 2016, application doses were already 117 kg/ha a.s. of organic and 52 kg/ha a.s. of NPK mineral fertilizers, and the yield of annual grasses decreased to 90 h/ha and perennial to 51 h/ha [6]. For 2020, the average yield of annual grasses is 65 h/ha, perennial grasses - 45 h/ha, with the application of fertilizers of 111 kg/ha of a.s. NPK organic and 4 kg/ha in a.s. NPK mineral.

* Corresponding author: dr.varuly@inbox.ru

Thus, we can conclude that the regulation of the productivity of artificial agrophytocenoses in the Murmansk region is ineffective. The inability to replenish soil reserves of nutrients used by plants for crop formation leads to a violation of the environmental balance and, ultimately soil degradation.

The solutions proposed today have three main directions: a return to the intensive model by increasing funding, restoration and modernization of technologies serving the industry; the use of foreign experience in the development of agriculture in similar agro-climatic conditions; the extensive model implying emphasis on traditional trades such as reindeer husbandry, fishing and gathering wild plants [7, 8]. Such strategies are not able to solve the complex of accumulated socio-economic problems, to ensure environmental and food security of the Arctic territories.

The preservation and restoration of soil fertility by traditional means for Polar agriculture, with the help of chemicals and organic fertilizers, is associated with significant material investments and environmental risks. The use of mineral and organic fertilizers, plant protection chemical products in crop production puts agriculture on a par with industry, transport and energy in terms of the level of negative impact on the environment. The delayed course of biochemical reactions in the Arctic ecosystems, associated with the predominance of low temperatures and other factors, significantly affects their ability to self-purification and recovery rate, therefore, the search for environmentally safe technologies in all spheres of economic activity is most relevant for the region in conditions of high industrial and anthropogenic load.

Crop production in the Murmansk region is mainly focused on the production of green and preserved non-transportable feed for dairy farming. The species composition of crops used in fodder production is not very diverse. Annual fodder grasses, such as oats, in pure form or grass mixtures with vetch and rapeseed are uses as green fodder and for silage preparation. Perennial grasses, such as meadow fescue, red fescue, sown 20 or more years ago, are used for green fodder, hay, haylage and preparation of silage.

The most effective and universal solution may be the use of symbiotic nitrogen fixation by legume crops. Narrow-leaved lupine (Lupinus angustifolius) is considered as the most promising crop for introduction due to its biological and environmental characteristics (deeply penetrating root system, ability to grow in a wide range of soil conditions, high productivity of green mass). In addition to its excellent fodder qualities, which are ensured by high content of high-grade protein, vegetable fat, small amount of anti-nutrients, etc., this plant is known for its environmental and health-improving properties [9].

Earlier studies of the effectiveness of the introduction of annual and perennial legume components into the structure of crop production have shown that inoculation of seeds is a mandatory technique, because there are no species-specific microsymbionts in the soils of the Murmansk region. Pre-sowing treatment of seeds with a biological preparation containing bacteria of the genus Rhizobium provided a significant increase in yield and, more than doubled the accumulations of crude protein, compared with non-inoculated samples [10].

The purpose of this work was to study the agrobiological and feed potential of three varieties of narrow-leaved lupines with inoculation of the seed material by Rhizobium lupini in the Murmansk region without applying of mineral and organic fertilizers. The tasks of the study included: calculation of the energy nutritional value of the aboveground mass of L. angustifolius varieties; determination of the number of diazotrophs in soils, as well as microorganisms assimilating mineral forms of nitrogen; determination of agrochemical indicators in the areas under L. angustifolius and under Avena sativa after harvesting.

2 Materials and methods

The objects of research were three original varieties of seeds of the second reproduction of Lupinus angustifolius obtained at the All-Russian Research Institute of Lupine - a branch of the V.R. Williams Federal Research Center, Bryansk: Vityaz, Belorozovy 144 and Bryanskiy kormovoy, in the amount of 72 kg (24 kg of each variety). To inoculate the seed material with species-specific symbiotic nitrogen-fixing bacteria, the biological preparation "Rhizotorphin brand A" produced by the ECOS Biopreparations Company, St. Petersburg was used.

To test the varieties of narrow-leaved lupines under production conditions, an area of 0.4 hectares on the land of a farm in the Kola district of the Murmansk region was determined. According to archival materials of field soil survey conducted by Murmansk prospecting expedition of the Sevzapgiprozem institute in 1981, the soil at the site is sandy sod-weakly podzolic illuvial-ferruginous.

According to the comprehensive agrochemical survey conducted in 2020, the soil at the site has the following agrochemical characteristics (Table 1).

Table 1. Agrochemical characteristics of the soil before laying the production experiment.

pH_{KCl}	P_2O_5, mg/100g	K_2O, mg/100g	Org. matter, %
6.3	362.5	19.6	5.21

Soil samplings were carried out by a soil drill according to GOST R 58595-2019.

Laboratory tests of soils were carried out according to standard methods: determination of pH in salt extract (KCl) by the CSRIAS method, GOST 26483-85; determination of mobile compounds of phosphorus and potassium by the Kirsanov method in modification of the CSRIAS, GOST R 54650-2011; determination of soil organic matter by the Tyurin method in the modification of the CSRIAS, GOST 26213-91.

The soil at the site has a high content of mobile phosphorus, very low content of exchangeable potassium, high content of organic matter and neutral acidity of the soil solution (gradations according to the M.g. for conducting ...) [11].

Laboratory tests of the aboveground mass of lupines were carried out in the Lupine Research Institute, Bryansk. The following indicators were studied: crude protein (GOST 13496.4-2019); crude fiber (GOST 31675-2012); crude fat (GOST 13496.15-2016); crude ash (GOST 32933-2014).

To study the microbiological activity of soils, we used elective nutrient media: Ashby, Bean agar, and Starch-Ammonia agar.

After harvesting, the following agrochemical parameters were determined: alkaline hydrolyzable nitrogen by the Cornfield method: M.g., 1985, and exchange phosphorus by the Kirsanov method, GOST 26207-91.

Seeding was carried out on 06.29.20. seeding rate was determined according to the standard methodology based on the seeding qualities of the seeds.

Before sowing, the soil was mechanically tillaged twice with disc harrows to remove weeds and improve the air regime. seeds immediately before sowing were treated with the preparation "Rhizotorphin brand A". Mineral and organic fertilizers were not applied.

3 Results

Harvesting was carried out on 08.09.20. The vegetation period was 70 days (Table 2).

Table 2. Characteristics of the yield of L. angustifolius.

Variety	Yield of green mass, t/ha	Height of herbage, cm	Vegetation phase
Vityaz	18	84	End of flowering, beginning of beans formation
Belorozovy 144	31	108	End of flowering, beginning of beans formation
Bryanskiy kormovoy	24	84	End of flowering, beginning of beans formation

At the time of harvesting, the plants reached the bean tying phase (the length of the beans is 3-5 cm), but flowering was still present in the upper tier. The formation of large nodules of light pink color was located on the roots.

To compose a balanced ration for feeding livestock, it is necessary to know the biochemical composition of the harvested feed (Table 3).

Table 3. Results of laboratory studies of varieties L. angustifolius

Variety	Mass fraction, % on a.d.m.*			
	Protein	Fat	Cellulose	Ash
Vityaz	19.3	1.50	21.1	11.75
Belorozovy 144	16.5	1.75	20.4	9.90
Bryanskiy kormovoy	21.2	1.91	19.0	10.48

* on absolutely dry matter.

Based on the data obtained, calculations of the energy value of feed for cattle were made (Table 4).

The regression equation developed at the L. K. Ernst Institute of Animal Husbandry was used to calculate the exchange energy in coarse fodder from raw nutrients for cattle:

$$EEC = 0.012 * P + 0.020486 * F + 0.00159 * C + 0.0105 * NFES, \quad (1)$$

where EEC – exchange energy for cattle in MJ per 1 kg of feed (hay, hay cutting, haylage, straw, silage up to 50% moisture and other coarse feed); P, F, C, NFES – protein, fat, cellulose, nitrogen-free extractives in grams per 1 kg of feed.

The content of nitrogen - free extractives is calculated by the formula:

$$NFES = 1000 – (P + F + C + A), \quad (2)$$

Energy Feed Unit (EFU = 10 MJ): EFU = EE (MJ)/10

Table 4. Assessment of energy nutritional value of coarse L. angustifolius fodder for cattle

Variety	g/kg, on a.d.m.					EEC, MJ	EFU
	P	F	C	A	NFES		
Vityaz	193	150	211	117	329	9.17	0.92
Belorozovy 144	165	175	204	99	357	9.62	0.96
Bryanskiy kormovoy	212	191	190	105	302	9.92	0.99

The "Methodical guidance for assessment of quality and nutritional value of feed raw materials", adopted by the Ministry of Agriculture of the Russian Federation on 20.06.2002, proposed formulas for calculation of EE and FU (feed unit) in forages based on mass fraction of crude cellulose content in dry matter and constant coefficients [12] (Table 5).

For grass artificially dried forages (grass flour, cutting, briquettes, pellets) prepared from annual and perennial legumes and cereals rich in protein, the formula for calculating energy nutrition is as follows:

$$EE = 13.71 - 16 * C; FU = EE2 * 0.0081, \quad (3)$$

where EE is the amount of exchange energy (for cattle) in 1 kg d.m. (dry matter), MJ; FU is the amount of forage units in 1 kg d.m., kg; C is the mass fraction of crude cellulose in 1 kg of d.m., kg.

Table 5. Assessment of the energy nutritional value of lupinus angustifolius varieties, according to the "Methodical guidance for assessment of quality and nutritional value of feed raw materials".

Variety	EE, MJ/kg	FU, kg
Vityaz	13.37	1.45
Belorozovy 144	13.38	1.45
Bryanskiy kormovoy	13.41	1.46

The data of laboratory tests and calculated indicators of energy nutritionness make it possible to classify all studied samples under study to the first quality class according to the regulatory requirements for artificially dried forages (M.g. for assessing…).

For microbiological sowing, mixed soil samples were selected from a plot under lupine, as well as, for comparison, from a plot under oats, traditionally cultivated in the Murmansk region for fodder. The plots are located on the same array, in close proximity, and have similar agrochemical characteristics and area. Sampling was carried out after harvesting. Elective media (bean agar and Ashby medium) and starch-ammonia agar (SAA) for cultivating microorganisms using mineral forms of nitrogen were used for cultivation of aerobic diazotrophs. Microbial counts were performed using the Koch's cup method. The results of the study are presented in Table 6.

Table 6. The number of the main physiological groups of microorganisms under crops L. angustifilius and Avena sativa

Plot	Number CFU per 1 g of absolutely dry soil		
	Ashby	**Bean agar**	**SAA**
under lupines	3465±308	2502±316	7728±2818
under oats	575±201	3367±30	3137±557
t	7.8	4.3	1.6
p	< 0.05	> 0.05	> 0.05

We can note a marked increase in the number of nitrogen fixers in the plot under the lupine. The increase in the number of this group of microorganisms in relation to the control (the plot under oats) was about 4 thousand CFU/1 g of soil. At the same time, the number of other physiological groups of microorganisms did not change significantly. From the results obtained, we can conclude that the use of symbiotic strain of microorganisms for pre-sowing inoculation of L. angustifilius seeds affected the direction of microbiological processes in the soil. Narrow-leaved lupine, covering its own needs in nitrogen nutrition through symbiosis, returns to the soil from 30 kg/ha of nitrogen with crop residues, thereby providing a nutrient substrate for soil microbiota for further transformation of biogenic elements. It should also be noted that the reaction of the soil solution in the plots is neutral, close to alkaline, pH 7.2, 7.5, under oats and lupine, respectively. This is the most favorable environment for the life activity of soil microorganisms.

Mixed soil samples were taken after harvest to determine alkaline hydrolyzable nitrogen and exchangeable phosphorus (Figure 1).

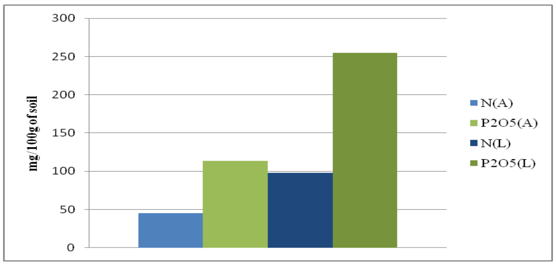

Figure. 1. Nitrogen and phosphorus content in experimental plots after harvesting.

Legend: N, P2O5(A) – the content of nitrogen, phosphorus in the area under Avena sativa; N, P2O5(L) – under L. angustifolius.

The content of nitrogen and phosphorus compounds potentially available for plant nutrition is at a very low level, but in the area under the narrow-leaved lupine, the indicators are more than twice as high (N(A) – 45.5; N(L) – 98; P2O5(A) – 113.6; P2O5(L) – 254.5 mg /100g). This may indicate lower costs of soil resources for the formation of a crop of narrow-leaved lupine in comparison with oats.

4 Discussion

Narrow-leaved lupine is a promising fodder crop for cultivation in the agro-climatic conditions of the Arctic. The inclusion of narrow-leaved lupine in crop rotations will reduce fodder consumption in the farms of the region, improve the quality and quantity of livestock products, significantly reduce the need for the use of chemical meliorants. Introduction of legume components, with mandatory inoculation of seed material with species-specific highly effective strains of microsymbionts, into the crop production of the Arctic, will allow without significant financial costs to approach the problem of conservation and reproduction of soil fertility, stop soil degradation, increase the stability of artificial agrocenoses at the northern limit of agriculture.

The problem of the development of the agro-industrial complex of the Murmansk region is complex and requires a similar approach to its solution. It is necessary, first of all, to revise the system of agriculture, to restructure it in accordance with modern achievements of fundamental and applied science, increase the knowledge intensity of the industry through the integration of precision farming technologies, remote monitoring, etc. It is necessary to work on the development of local varieties of annual and perennial legumes, sidereal and fodder directions, which are able to ensure their growth at the expense of biologically fixed atmospheric nitrogen.

This approach is consistent with the "State program for the development of agriculture and regulation of agricultural products, raw materials and food markets" (approved by the Decree of the Government of the Russian Federation from July 14, 2012 No. 717), one of the goals of which is to reproduce and increase the efficiency of agricultural use of land and other natural resources of the Russian Federation. Realization of the natural potential of legume-rhizobial symbiosis in the agro climatic conditions of the Arctic territories will contribute to the environmentalization of production and will solve a number of problems related to ensuring food security of the Murmansk region.

The introduction of environmentally oriented natural technologies in production cycles should contribute to the speedy progressive development of a "green economy" in the Russian Federation.

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