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ENERGY-ECONOMIC ASSESSMENT OF IMPROVED FODDER CROP ROTATIONS IN THE NOVGOROD REGION

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Abstract

Specially for sod-podzolic soils of the Novgorod region, improved short-rotation fodder crop rotations with the use of biological sources of organic matter: straw of grain crops, green manure and stubble-root residues, were developed. The saturation of soil with annual and perennial legumes amounted to 25-50% in crop rotations. The lowest specific energy intensity in the production of a ton of fodder units was obtained from perennial grasses: meadow clover of the first year of use and clover-and-timothy grass mixture of two years of use. Then in an ascending order - the energy intensity of winter rye grains; barley grains; oat grains. Increased productivity per rotation was obtained in crop rotations with lupine, clover and clover-and-timothy grass mixture of two-year use. The highest yields were obtained in the clover-and-timothy grass mixture of the first and second year of use, then in a descending order: the yields of winter rye, barley and oats. The use of green manure and straw as organic fertilizers and the introduction of moderate doses of mineral fertilizers allowed to obtain a low specific energy intensity of production of a ton of fodder units per rotation in all crop rotations. In addition, the balance of humus in the soil of short-rotation crop rotations per rotation in all studied crop rotations was positive.

Keywords: Energy intensity, energy potential of soil, green manure, profitability, straw.

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1. Introduction

Currently, the biological aspects of agriculture are paid an increasing attention to. By greening agricultural production, it is possible to achieve greater stability, reducing energy and resource costs in agriculture. One of the promising solutions to these problems is the widespread introduction of environmentally-friendly farming systems based on crop rotations using alternative sources of organic matter (Gamzaeva, 2015).

In the conditions of acute energy crisis, the only available way of intensification of agriculture is the introduction of biological methods of reproduction of soil fertility. Legumes, especially legume perennial grasses, not only enrich the soil with nitrogen, the effect of which is manifested within 2-3 years, but also improve the structure of the soil and create a favorable sanitary regime (Kokorina, 2001).

One of the promising solutions to these problems is the widespread introduction of environmentally-friendly farming systems based on crop rotations with promising crops (Vorobiev & Chetvertnia, 1987).

In modern conditions, the system of crop rotation should be flexible, with due consideration of market conditions and avoiding the violation of the environmental safety of the landscape. One of the most important conditions for improving crop rotations is their optimal saturation with legumes, allowing to reliably solve the problem of increasing soil fertility and productivity of arable land alongside with saving costs. It should be noted that multi-field crop rotations are less flexible than those with short rotation. It is expedient to use crop rotations with short rotation (4-5 years), they are most suitable for small farms and peasant farms, and can be mastered in production during the period of 2-3 years.

To increase the agricultural productivity on sod-podzolic soils, which in the Novgorod region occupy more than 64% of the total soil cover, it is necessary to introduce and develop biologized crop rotations of short and medium rotation. Over 50 % of sod-podzolic soils have poor cultivation. Increasing soil fertility and crop yields should be based on the maximum use of local soil and climatic conditions and means of biologization of agriculture. However, the use of traditional types of organic fertilizers (peat, manure, compost) is associated with high energy costs. In addition, in the context of a sharp reduction in the number of livestock, there is an acute shortage of organic fertilizers. In recent years, the use of organic fertilizers in the Novgorod region has decreased significantly.

In this regard, it is necessary to attract alternative sources to replenish the organic matter of the soil and, first of all, the green manure and straw of cereals.

Green manure plays an important role in biological agriculture. Winter rye, mustard, rape plant and other crops, except legumes and grain legumes, are used as green manure (green fertilizers).

Straw, green manure and plant residues can fully meet the needs for restoration and replenishment of organic matter in sod-podzolic soil. In the conditions of sharp reduction of animal husbandry, the importance of various types of organic fertilizers, including green, increases (Vorobiev & Chetvertnya, 1987).

A significant amount of nutrients, so necessary for plants, enters the soil with 1 ton of straw or 5-6 tons of biomass: nitrogen - 3.7-5.5 kg, phosphorus - 0.8-1.0 kg, potassium - 5.5-11.0 kg, calcium - 2.2-9.2 kg (Eremina, Mashchenko, Chuian, Fedorchenko, & Ermakova, 2005).

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The rational combination of perennial legumes in the adaptive-landscape systems of agriculture (40-50% in the structure of crop rotation), the introduction of scientifically reasonable norms of mineral fertilizers, the use of stubble-root residues, straw and green manure serves as a basis for increasing the fertility of sod-podzolic soils and productivity of agricultural crops (Esedullaev, 2016).

2. Problem Statement

The research is aimed at obtaining high crop yields in improved forage crop rotations in the climatic conditions of the Novgorod region with low energy consumption of production units and high profitability of production with maximum use of biological factors.

3. Research Questions

The research focused on the following issues:

3.1. To determine the biological factors that allow to achieve the lowest specific energy intensity in the production of 1 ton of fodder units on sod-podzolic soils of the Novgorod region in improved short-rotation forage crop rotations.

3.2. To identify the effect of alternative organic fertilizers (green manure, straw of grain crops, stubble-root residues) and moderate doses of mineral fertilizers on crop yields and the increase in the energy potential of the soil.

4. Purpose of the Study

The assessment of energy and economic efficiency of crop cultivation technologies in improved short-rotation forage crop rotations in the study of alternative sources of organic matter (green manure, straw of grain crops) and moderate doses of mineral fertilizers on sod-podzolic soil in the Novgorod region.

5. Research Methods

In a stationary field experiment, studies on sod-podzolic, light loamy, clay, soil of medium degree of cultivation, with a capacity of the arable layer of 0-20 cm, were conducted.

Five models of improved short-rotation fodder crop rotations were developed for the climatic conditions of the Novgorod region on sod-podzolic soil (which cover 83% of the arable land in the region).

Models of fodder crop rotations:

1. Lupine*, winter rye**, barley * * + winter rye**, oats**;

2. Lupine (biomass), winter rye**, barley * * + winter rye***, oats * * + winter rape plant***;

3. Oats + clover, clover of the first year of use*, winter rye**, barley**;

4. Oats + clover, clover of the first year of use for biomass, winter rye**, barley** + winter rape plant***;

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5. Barley + clover + timothy, clover + timothy of the first year of use for biomass, clover + timothy of the second year of use for biomass, first mowing (second mowing*), oats**.

Note: when straw was ploughed for fertilizer, 10 kg of nitrogen was added to each ton of straw due to the high C:N = 80-90: 1 ratio. When ploughing straw with stubble green fertilizer, nitrogen fertilizers were not used.

* crop is used for green manure;

** - straw for organic fertilizer;

*** - winter rape plant, winter rye, as intermediate crops were sown in the spring along with the main crop for green manure.

Mineral fertilizers were applied to each cultivated crop: lupines, clover of the first year of use, clover-and-timothy grass mixture of the first year of use − N0P60K60; clover-and-timothy grass mixture of the second year of use − N30-60 of % clover in the stand of grass − P60K60; winter rye − N30P30K30; barley, oats − N60P60K60.

The area of experimental plots is 50 m2, the repetition is fourfold, the placement of plots is randomized.

Replenishment of soil organic matter was carried out by means of green manure of steam fields and intermediate crops (winter rye, winter rape plant, which were sown in the spring with spring barley), straw of grains and stubble-root residues of cultivated crops (Loshakov, 1987).

Ammonium nitrate with a nitrogen content of 34.6 % GOST 2-85 (granules), azofoska N – 16 %; P2O5 – 16 %; K2O – 16 % TU 113-03-466-91 (granules), potassium chloride – 60 % K2O, GOST 4568-95 (powder), double superphosphate – 43 % P2O5 TU 82-176-00209438-00 were used in the experiment.

Agricultural crops were cultivated according to the technologies developed for the conditions of the Novgorod region. Sowing was held with the seed planter SN-16: lupines of Nemchinov-97 variety for green forage and green manure 1.2 million of viable seeds per hectare; barley of BIOS 1 variety – 4.5 million viable seeds per hectare; the oats of the Borrus variety − 4 million of viable seeds per hectare with complimentary seeding of clover of the Sedum variety – 13 million of viable seeds per hectare; barley and complimentary seeding of clover − 6 million of viable seeds per hectare and meadow timothy of Leningrad-204 variety − 7 million of viable seeds per hectare; winter rye of the Volkhova variety – 6 million of viable seeds per hectare. Depth of seeding the grains was 5-6 cm, lupine - 2-3 cm, meadow clover and timothy - 1-2 cm.

Lupine in the phase of formation of "brilliant beans", clover of the first year of use in the phase of flowering and the second mowing of the clover-and-timothy grass mixture of the second year were used for green manure. Green manure was crushed by a heavy disc harrow BDT-3 and ploughed to a depth of 15-20 cm. Nitrogen fertilizers were not applied to green manure.

Biomass harvesting of the clover of the first year of use and the clover-and-timothy grass mixture of the first and second year of use was carried out in the phase of budding. Silage harvesting of narrow-leaved lupine was carried out in the phase of brilliant beans. Layer disking of clover of the first year of use, perennial grasses of the second year of use was carried out by heavy disc harrows in two tracks (MTZ-82+HDH-3), ploughing was performed in the second decade of July, cultivation and mineral fertiliser application, sowing of winter rye were carried out in optimum time.

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In crop rotations No. 1, 2, 4, where intermediate crops were cultivated together with spring crops, the biomass and straw of grains were cultivated with a heavy disk harrow (BDT-3) at the end of August, under-winter ploughing was carried out in October.

6. Findings

The yield of cultivated crops in crop rotations is presented in Table 01.

Table 01. Crop yields and productivity per 1 rotation in crop rotations, tons of fodder units per hectare

№ Crop Rotation	Crop Yield				Crop Productivity per Rotation
	1-st crop	2-d crop	3-d crop	4-th crop	
1	9.7*	6.6	5.4	3.8	4.0
2	9.3	5.4	5.0	3.7	5.9
3	3.9	10.7*	7.3	6.5	4.4
4	3.5	8.6	6.3	5.1	5.9
5	4.8	11.2	10.9	4.5	7.9
LSD05	0.7	0.6	0.7	0.6	0.5

*- the crop was used as green manure
LSD05 – the least significant difference with a probability of 0.95 (Dospekhov, 1985).

An indicator characterizing the effectiveness of biologization techniques, in addition to crop yields, is the productivity of crop rotations (in fodder units). Increased productivity per rotation − 5.9: 5.9 and 7.9 tons of fodder units/ha and the digestible protein 0.62; 0.58 and 0.8 t/ha was obtained in the crop rotations with double crops of lupine, clover and clover-and-timothy grass mixture of two-year use. Assessment of the level of productivity was carried out according to the generally accepted data of long-term experiments of the geonet (Guidelines for research in long-term experiments with fertilizers: Part 2, 1983).

The highest productivity of 10.9 and 11.2 t. u. / ha (1.2-1.4 t / ha of digestible protein) was obtained during the harvesting of the clover-and-timothy grass mixture of the first and second year of use; then in a descending order: winter rye - from 5.4 to 7.3 t. u. / ha, barley - 5.0-6.3 t. u. / ha and oats - 3.7-4.5 t. u. / ha.

Green fertilizer is a powerful means of increasing soil fertility, promoting the accumulation of humus and nitrogen. Accompanied by green manure (lupine, meadow clover) the soil received 180; 368 kg / ha of nitrogen, including symbiotic 144 and 294 kg/ha; 41 and 84 kg/ha of P_2O_5; 160 and 410 kg / ha of K_2O.

Using the guidelines (Guidelines for determining the nutrients balance of nitrogen, phosphorus, potassium, humus, calcium, 2000) the balance of humus was calculated. The humus balance in the soil of short-rotation crop rotations per rotation (Table 02) in all studied crop rotations is positive. High increase of humus per rotation was obtained in all rotations No. 1-5 – 2.24-3.65 t/ha. The soil fertility increased by +75; +70; +84; +52; +55 kJ/ha, respectively.

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Table 02. Humus balance in soil of crop rotations per 1 rotation

№ Crop Rotation	Humification of stubble-root residues, t/ha	Humification of organic fertilizers, t/ha	Mineralization of humus, t/ha	Humus Balance, +,-, t/ha
1	2.87	3.20	2.83	+3.24
2	2.70	2.92	2.58	+3.04
3	3.60	2.70	2.65	+3.65
4	3.00	1.89	2.65	+2.24
5	4.30	0.85	2.22	2.48

Calculation of energy and economic assessment of cultivation technologies of agricultural crops in short-rotation crop rotations (Table 03) showed that the lowest specific energy intensity of production of a ton of fodder units was obtained in perennial grasses − clover of the first year of use and clover-and-timothy grass mixture of the second year of use – 0.9-1.0 kJ. Then in an ascending order – the grains of winter rye – 1.6-1.8 kJ; barley – 2.0-2.6 kJ; oats – 3.3-4.0 kJ (Tiranova & Tiranov, 2005; Kirkorova, Lipnitsky, Tiranova, & Tiranov, 2019).

Table 03. Energy and economic assessment of cultivation technologies in short-rotation crop rotations

Indicator	Unit of measurement	Crop			
		lupine	**winter rye**	**barley**	**oat**
Crop rotation № 1					
Crop yield	t k units / ha	9.7*	6.6	5.4	3.8
Specific Energy Intensity	$\frac{kJ}{t\ к.unit.}$	2.2	1.8	2.2	3.9
Profitability	%	-	81.0	35.0	58.0
Energy efficiency coefficient	units	-	8.6	4.4	5.4
Crop rotation № 2					
Crop yield	t k units / ha	9.3	5.4	5.0	3.7
Specific Energy Intensity	$\frac{kJ}{t\ к.unit.}$	2.6	1.71	24.0	4.0
Profitability	%	11.0	61.0	21.0	46.0
Energy efficiency coefficient	units	6.6	7.9	3.9	5.0
		Crop			
		oat + clover	clover of the 1st year of use	winter rye	barley
Crop rotation № 3					
Crop yield	t k units / ha	3.9	10.7*	7.3	6.5
Specific Energy Intensity	$\frac{kJ}{t\ к.unit.}$	3.2	0.9	1.6	2.0
Profitability	%	52.0	-	98.0	93.0
Energy efficiency coefficient	units	6.0	-	9.4	7.1
Crop rotation № 4					
Crop yield	t k units / ha	3.5	8.6	6.3	5.1
Specific Energy Intensity	$\frac{kJ}{t\ к.unit.}$	3.7	1.0	1.8	2.6
Profitability	%	35.0	68.0	71.0	53.0

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Energy efficiency coefficient	units	5.3	18.0	8.4	5.6
		Crop			
		barley + perennial grasses	perennial grasses of the first year of use	perennial grasses of the second year of use on s/ m, 2 mowing for green manure	oat
Crop rotation № 5					
Crop yield	t k units / ha	4.8	11.2	10.9	4.5
Specific Energy Intensity	$\frac{\text{kJ}}{t\ \text{к.}unit.}$	2.2	1.0	1.0	3.3
Profitability	%	41.0	61.0	95.0	73.8
Energy efficiency coefficient	units	6.0	19.2	17.9	6.0

*- the crop on green manure

Low specific energy intensity of production of a ton of fodder units per rotation − 2.2; 2.7; 2.0; 2.3; 1.9 kJ respectively was obtained in all crop rotations. High energy efficiency ratio of production per rotation − 9.3 and 12.3 units was noted in the rotation with double crops of clover and clover-and-timothy grass mixture м.

7. Conclusion

The use of moderate doses of mineral fertilizers, green manure and straw as organic fertilizers on sod-podzolic soil in the conditions of Novgorod region and the saturation of forage crop of short rotations with legumes 25-50 % provided high productivity - from 4.0 to 7.9 tons of fodder units per hectare, profitability with production of 44-68 %, low specific energy intensity of production of less than 2.7 kJ per a ton of fodder units and a high energy efficiency coefficient - more than 5 units.

In the Novgorod region, the cultivation of perennial legumes (meadow clover) provides high crop yields of 9 to 11 tons of fodder units per hectare with a high energy efficiency coefficient of production of more than 18 units and a low specific energy intensity of production which equals to 1 kJ with a profitability above 61%.

The use of biological sources of organic matter (straw and green manure) in short-rotation crop rotations allowed to increase the energy potential of the soil per rotation by 52-84 kJ / ha.

In the conditions of the Novgorod region, it is necessary to include double crops with annual and perennial legumes in fodder crop rotations. This will allow to obtain high productivity per rotation of more than 5.9 tons of fodder units per hectare, digestible protein of more than 0.6 tons per hectare, to preserve and improve soil fertility by using straw of cultivated crops and intermediate green manure as organic fertilizer.

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