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Fertility Improvements Methods of Frozen Soil in Central Yakutia of Russian Federation

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Authors' contributions

The work was done in collaboration between all authors. Author MHI designed the program and led the study, wrote the manuscript, author NVS spent observations of experiments, analysis of experimental data, author PEI conducted research in microbiology, at agrophysical, agrochemical properties of soils, author LVN conducted research on resource-saving tillage and performed technical and economic analysis. All authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

The paper presents the results of field studies on methods of increasing the fertility of soils in permafrost conditions of Cryolithozone.
It was established the effectiveness of the use of gypsum, green manure, as well as resource-saving tillage technology in the conditions of the permafrost zone, which increases the fertility of permafrost saline soils, which are poor in nitrogen and a low power humus layer. Adding gypsum at a dose of 4 t, 8 t, 12 t on saline soils contributes desolonetzization of soil in layer 0-40 cm, gypsum deposit options at a dose of 8-12 t/ha on a background of green manure and manure, soil alkalinity decreases from 8.56 to 7.54. At resource saving tillage technology observed preservation of productive moisture in frozen soils at 20-25% more than the recommended zonal tillage technology, reduced soil density from 1,23 g / m to 1.18 g / m³.

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1. INTRODUCTION

Specific conditions of Central Yakutia are a short growing season, cold and poor soil (in the winter for eight months the soil is frozen, cease all biological, biochemical processes of life) non-flushing nature of soil determines the formation of low biological activity and fertility of soils on frozen ground, which requires new ways of increasing the biological activity and soil fertility in the conditions of the permafrost zone. In Central Yakutia, almost 40% of arable lands are in varying degrees of salinity. Dominate sulfate-chloride and soda salinization. This is caused by a high content of exchangeable sodium in the composition of absorbed cations and high alkalinity of the soil environment.

The process of decomposition and accumulation of soil organic matter in the soil is limited by the frozen state of the soil for a long time and with intensive evaporation of soil moisture during the growing season.

The entire territory of the republic is in the zone of continuous permafrost. Power of permafrost in Central Yakutia is 200-500 m [1].

The action of permafrost on the process of soil formation is associated with the restriction of moisture circulation of the soil active layer and prevents the formation of groundwater. Soil processes providing the growth and development of vegetation have seasonal character and develop in thawing thicker soil during the summer, which is the active layer of permafrost landscapes. Low temperatures of the active layer interfere with the normal development of microbiological and biochemical processes in the soil, slow the transformation of organic residues and reduces the rate of the biological cycle of matter and energy. In the conditions of weak heat supply of the northern territories in the active layer of soil acts permanent antagonism of heat and moisture, which in combination with other factors leads to the formation low productive, extremely resistant to changes in exogenous conditions of ecosystems [2].

In the conditions of Yakutia salt and hydrologic cycle are limited by seasonally thawing layer in the 2.0-2.2 m. The presence of waterproof layer of permafrost precludes completion of salts due to the underlying rocks. Horizon of permafrost also makes it difficult to wash. Salt accumulation is shown in seasonally thawing horizon, i.e. there is the high content of exchangeable sodium in the absorbed cations and high alkalinity of the soil environment. Exchangeable sodium content is 3-20% of the absorption capacity, which significantly affects the physical and mechanical properties of the soil, in these conditions the lack of moisture and a high concentration of soil solutions the forage crop drastically reduced [3].

With an increase in the sodium content increases the amount of magnesium and calcium content is reduced, which determines the alkalinity of soils. Alkalinity of soil cover is one of the most complex objects of agricultural use.

In the natural state these lands are unproductive. On the land without cultivation crop can be obtained only in wet years, in dry years - the plants are oppressed and burn. Therefore, applying chemical reclamation (gypsum) in the alkaline horizon can be replaced the excess of absorbed sodium by other cations causes irreversible coagulation of silt and colloid nanoparticles. If to the factors of gypsum and fertilizer added the factor of green manure crops and irrigation, we can expect a high effect on the reclamation of these techniques [4].

In the application of chemical reclamation ($CaSO_4$) absorbed Na replaced by Ca. Formed by a chemical reaction of sodium sulfate (Na_2SO_4) is readily soluble in irrigation, has a neutral reaction, easily washed out by precipitation. This method is most effective in Cryolithozone [5].

In the context of the presence of permafrost in Central Yakutia agrotechnological reception of soil tillage with a turnover of reservoir and spring-field activities carried out in 4-5 receptions particularly degraded soil structure, reduce fertility, increase moisture loss and reduce yield, mean:

- The low power of the humus layer of the soil (5 – 20 cm);
- Arid climate, low relative humidity in the summer (30-70%) contributing to intense evaporation of soil moisture and the drying of the upper soil layers;
- The weakest supply of moisture in the month of June, when the need of plants for it is great (period of sowing, sprouting, tillering);

- Particularly hard soil drought appears on crop yields after dry autumn, when the most important period of growth and development of plants (3rd decade of May, June, 1st decade of July) few precipitation or within the permafrost.

Resource saving tillage technology using multifunctional tillage machines and agricultural biologization increases the yield of forage crops through better moister conservation, improves soil structure, prevents deformation and compaction of the subsoil horizons, and enriches permafrost soils with organic matter.

The aim of research is to study the technological foundations of rational use of permafrost saline lands in Central Yakutia.

Objectives: to study the effect of different doses of gypsum and combined application of gypsum with organic and green manures, as well as resource saving technologies of permafrost soils on soil fertility and increasing the yield of green mass of forage crops.

2. MATERIALS AND METHODS

The territory of the Republic of Sakha (Yakutia) extends between 7700' and 5540' north latitude and 10530' and 16240' east longitude. The area of the largest subject of Russia is 3103.2 m^2, which amounts 2/3 of Western Europe [6].

Climate of Prilensky agrolandscape of Central Yakutia characterized by greater supply of heat and aridity. The amplitude of the average monthly temperature of the coldest and warmest months (January and July) ranges from 50ºC to 60ºC, the date of average daily temperature transition through 10ºC (spring) occurs at the end of May. The sum of temperatures above 10ºC is 1565ºC, frost-free period on the surface of the soil - on the average of 88 days. During the summer this heat supply of area is sufficient to thawing of frozen sandy soils to 2.0-2.5 m [7].

Field experiments on methods of rational use of permafrost saline lands based on irrigation, gypsuming, organic and green manure were carried out in 2005-2008 on the site "Moydookh" of Khangalassky district, and resource saving tillage in the period 2009-2014 on the site "Mundulaakh" of Megino-Kangalassky district, located on the second terrace above the floodplain of river Lena (Prilensky agrolandscape).

Analyses on agrophysical, agrochemical properties of soils conducted in the laboratory of Biochemistry (Yakut Scientific Research Institute of Agriculture) on the infrared analyzer "Infranid 61" based on the calibration. Statistical analysis of the experimental data was conducted on software package Snedecor and Microsoft Office Excel 2003. The observations and surveys were carried out according to the procedure of field experience [8]. Agrotechnics tillage performed according to the recommendations Yakut Scientific Research Institute of Agriculture [9].

Soil of experimental site "Moydookh" is meadow black earth, weakly saline. Type of salinization is chloride-sulfate with a ratio Cl_2SO_4 of soil: 0 – 40 cm - 0.76; 40-60 cm - 0.71; 60-80 cm - 0.67; 80 – 100 cm - 1.15 mg - eq/100 g of soil. Salinization of soil determined by the gradation of L.G. Elovskaya [10].

The reaction of medium is alkaline, aqueous pH - 7.6 -8.4, humus content in the upper horizon is 3.14%, the content of mobile forms of nitrogen $N_{nitr.}$ - 0.38, mobile forms of phosphorus P_2O_5 - 13.4, potassium K_2O - 22.1 mg/100 g.

After treatment arable layer is friable – 1.09-1.23 g/cm^3, gradually compacted and reaches the density of 1.25-1.27 g/cm^3. In over permafrost horizons density decreases slightly, which is typical of permafrost soils in the area.

The following options are studied the effect of different doses of gypsum on the yield of vetch-oat mixture and on fertility of saline soils:

1) control - without introduction of gypsum and fertilizer; 2) introduction of gypsum at a dose of 4 t/ha; 3) introduction of gypsum at a dose of 8 t/ha; 5) introduction of gypsum at a dose of 12 t/ha; 6) organic fertilizer - manure 30 t/ha; 7) manure 30 t/ha + gypsum 4 t/ha; 8) manure 30 t/ha + gypsum 8 t/ha; 9) manure 30 t/ha + gypsum at a dose of 12 t/ha; 10) green manure - oats in the tillering phase of 40 t/ha; 11) green manure + gypsum 4 t/ha; 12) green manure + gypsum 8 t/ha; 13) green manure + gypsum 12 t/ha.

Introduction of gypsum and organic fertilizer manure at a dose of 30 t/ha for autumn tillage and green manure (legume-grass mixture of 40 t/ha) with the sealing held in July 1 time in 4 years. Sowing of vetch-oats mixture held on the 1st decade of June at a depth of 4-5 cm. with oat seeding rate of 120 kg/ha and vetch 70 kg/ha.

Soil of experimental site "Mundulaakh": the reaction of the medium is alkaline, aqueous pH - 8.1 -8.2, the humus content in the upper horizon - 2.92%, the content of mobile forms of nitrogen $N_{nitr.}$ - 0.17%, mobile forms of phosphorus P_2O_5 - 16.4, K_2O - 29.7 mg/100 g.

Variants of experience in resource saving technology of permafrost taiga fawn soils processing:

1. Traditional tillage;
2. Resource saving tillage.

In an embodiment of resource saving technology the autumn tillage conducted by a complex machine APC-5.7; pre-sowing treatment and sowing of oats at a rate of 200 kg/ha, introduction of mineral fertilizer at a dose of $N_{60}P_{60}K_{60}$ was held by multifunctional tillage machine Ob-4-3T.

3. RESULTS

Years of research were different by weather conditions. In 2005-2007 the weather conditions were favorable. Hydrothermal coefficient was 1.08 - 1.73. The vegetation period of 2008 was dry (hydrothermal coefficient - 0.77).

The experimental results show that at gypsuming the amount of cations (exchaneable Na, Ca, Mg) in the soil has changed (Table 1).

Cations of exchangeable Na significantly decreased, the content of exchangeable Ca increased by 14-48%, the content of the exchangeable Mg decreased. The content of the absorbed Na from absorption capacity shows that the degree of alkalinity of meadow black soils decreased from weakly alkalinity (6.73-8.38%) to non-alkalinity (4.99-2.06%). Percentage of Na reduction of the total amount of the variants is from 37.6 to 71.2. Percentage of overset Na is from 28.8 to 62.3. After agrotechnical methods and chemical melioration the baseline salinity (1.69-2.92) has changed to the definition of slightly saline (0.42-0.83).

Introduction of the gypsum at a dose 4 t, 8 t, 12 t on saline soils promotes alkaline absorption of soil layer 0-40 cm, percent of overset Na from its total amount is 28.8-65.5. On gypsum adding options at a dose of 8-12 t/ha with the joint application of organic and green manures analyses of aqueous extract shows non-salinity of the soil - 7.54. Soil pH decreased from 8.56 to 7.54.

Studied methods of increasing the fertility of saline soils contributed to the optimal conditions of plant nutrition, high yields of green mass of vetch-oats mixture - 200 - 330 kg/ha. Introduction of different doses of gypsum on the background of organic and green manure provides an increase of green mass from 31 to 64 quintals per 1 ha.

Experimental studies on the impact of resource saving technology on fertility of permafrost taiga-fawn soils were carried out in 2009-2013 years.

Resource saving tillage included the following farming practices:

- Plowing by heavy harrow BDT-3.0 of oat green mass or legume-grass mixtures in the tillering phase (July) of oats to a depth of 18-20 cm;
- Autumn tillage (September) by multifunctional tillage machine APK - 5.7; or harrow BDP -3 x 4 (loosening the soil to a depth of 16 cm);
- Closing of moisture (May) by multifunctional tillage machine APK - 5.7 at a depth of 8-10 cm;
- Seedbed preparation, fertilizing and seeding of forage crops (June) by multifunctional tillage machine Ob-4-3T (loosening the soil to a depth of 5-7 cm, application of mineral fertilizers at a dose of (NPK) 30, seeding and packing).

Studies have shown that the amount of total water use per harvest unit during resource saving tillage is 105.5 mm (in the processing at the zonal technology – 91 mm). Yield of green mass in this version was up to 147 kg/ha, increase of green mass of oats - 7 t/ha. Green manure contributes to the humus content increase of 0.28% (humus content percent in the embodiment of the traditional tillage - 2.89%, on resource-saving technology - 3.17%). At resource saving technologies observed saving of productive moisture in frozen soils at 20-25% more than the recommended zonal tillage. There is an improvement in agrophysical properties by reducing the density (bulk density of soil by recommended zonal tillage is 1,23 g/m³, with resource saving treatment - 1.18 g/m³) and increased by 2 times the number of microorganisms in the soil layer 0-20 cm from 120.8 million in 1 g on the soil at the zonal processing technology, to 232.0 million in 1 g of soil.

Table 1. The effect of gypsum on the exchangeable content of Na in the soil (0-40 cm)

Option	Exchangeable bases, mmol/100 g			Amount of absorption mmol/g	% of absorbed Na content by the absorption capacity	% of decrease in the Na content	% of overset Na
	Ca	Mg	Na				
Control	7.38	6.87	2.08	15.29	6.73	-	-
Gypsum 4 t/ha	11.50	4.62	1.48	24.25	3.12	71.2	28.8
Gypsum 8 t/ha	9.37	2.50	1.24	12.50	4.99	59.6	40.4
Gypsum 12 t/ha	9.62	3.87	1.00	14.00	3.56	48.0	52.0
Manure 30 t/ha	12.25	3.75	1.37	16.68	4.09	65.9	34.1
Manure 30 t/ha + gypsum 4 t/ha	10.00	4.62	0.93	15.10	3.09	44.7	55.3
Manure 30 t/ha + gypsum 8 t/ha	15.00	4.75	0.84	20.17	2,06	40.4	59.6
Manure 30 t/ha + gypsum 12 t/ha	9.12	4.12	1.21	13.86	4.38	58.2	41.8
Green manure (control)	11.34	5.50	1.54	18.38	8.38	-	-
Green manure + gypsum 4 t/ha	14.88	2.25	0.58	17.71	3.27	37.66	62.3
Green manure + gypsum 8 t/ha	10.75	3.63	0.85	15.23	5.58	55.19	44.8
Green manure + gypsum 12 t/ha	10.65	3.63	0.75	15.03	4.99	48.70	51.3

Comparison of the effectiveness of technologies held by two indicators - fuel consumption for processing and sowing of 1 ha of field by reducing the number of passes of technical means and saving wages by reducing the number of workers employed in the processing and planting of 1 ha of field. The use of technical means for resource saving technology for the main and pre-seeding tillage under fodder crops in the conditions of Yakutia from experimental data reduces costs for fuel consumption at 3.39 times, saving the wages of workers in the primary production at 2.49 times.

4. CONCLUSION

Adding gypsum, green manure and organic fertilizers, the use of resource saving tillage in the conditions of Cryolithozone can increase the fertility of permafrost saline soils. The use of multifunctional technical units reduces power consumption at 1.5 - 2.0 times compared to conventional technology and increases productivity by 1.5 - 1.8 times.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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