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Research Article

Carbon Farming in the Kaliningrad Region

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Abstract

Carbon farming in the Kaliningrad region is based on the following principles:

− Multi-field crop rotations with saturation of annual and perennial legumes and cereals;

− Minimizing the use of mineral fertilizers and pesticides using biological preparations based on rhizosphere nitrogen-fixing microorganisms of complex action;

− Use in crop rotations of mixed legume-grass crops of different species composition and different sowing dates as predecessors and green manure for the main crops;

− Mixed legume-cereal crops of different species composition can perform a protective function for subsequent main crops in the crop rotation against pathogenic microorganisms and invertebrate pests;

− Mixed legume-cereal crops of summer sowing are the most economically and ecologically justified and suppliers of leguminous fodder and green fodder balanced in terms of zootechnical indicators in the late autumn period;

− Mixed legume-cereal crops are considered as biological ameliorants and the main sources of stable humus;

Keywords: Carbon farming; Multi-field crop rotations; Legume-grass crops; Mixed crops; Humus balance; Biological melioration

Introduction

Initiatives to introduce a price on carbon - in the form of a carbon tax or an emissions trading system - are becoming more widespread in the world, today there are already about 60 of them [1]. In this regard, the initiative of the French government, called "Four ppm" (Initiative "4 per 1000" (4 ‰\u003d 4⁄1000\u003d 0.4%\u003d 0.004) announced at an international conference held in France from June 17 to 20, 2019 is significant years in the city of Poitiers), found a positive response from politicians in leading countries. The idea is to achieve an ambitious goal: to increase carbon levels in plowed soils around the world by four ppm annually (Figure 1).

Modern agriculture can become a source of technologies that ensure the removal (sequestration) of greenhouse gases from the atmosphere. Agricultural technologies aimed at capturing carbon from the atmosphere are known as carbon farming (or carbon *farming*). The essence of carbon farming is to increase soil carbon by increasing the amount of carbon and conservation in the soil, as well as reducing the rate of carbon loss due to cropping and soil erosion. One of the leading factors in reducing greenhouse gas emissions associated with agricultural production is minimizing the use of pesticides and mineral fertilizers and increasing the role of biological and innovative methods of carbon farming [2,3].

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The EU's plans to introduce a frontier carbon adjustment mechanism have prompted many producers of "carbon-intensive" products exported to the EU to review their carbon strategy. Over the past few months, it has become clear that the emergence of such a mechanism in one form or another is inevitable. Moreover, similar measures can be taken in the United States: the program of the new president directly provides for the introduction of a "corrective carbon levy" in relation to countries "not fulfilling their climate and environmental obligations" [4].

Africa's first carbon tax was introduced in the Republic of South Africa (SAR), with Singapore pioneering in Asia. On February 1, 2021, the national emissions trading system began to operate in China. In these circumstances, one of the key elements of a science-based response to climate threats and related trade barriers can be agriculture, and more specifically biological or carbon farming.

Our research convincingly proves the possibility of retaining carbon dioxide in the arable layer of the soil using specific technological agricultural practices due to the preservation and growth of its organic part. A special role here is assigned to a stable type of organic matter - humus, since the content of humus in soils directly depends on the level of presence of organic carbon in them (humus = C_{org}×1.72) [5].

Kaliningrad Research Institute of Agriculture - branch of the Federal Scientific Center. V.R. Williams has long been dealing with the problem of soil fertility by means of carbon (biological) farming by introducing perennial legume-grass grasses into a multi-field crop rotation, with the help of sideration of mixed legume-cereal crops at different sowing dates.

The goal is to capture as much carbon as possible using traditional and original sustainable agricultural technologies and store it in the form of stable humus.

Novelty - for the first time, based on long-term studies of crop rotations with varying degrees of saturation with legumes and cereals, it has been shown that their mixtures with varying composition, ratio and at different sowing dates can play the role of biological ameliorants, and their residues can pass into the conservative part of humus - humin and fulvic acids.

Research Methods

All studies were carried out on the experimental fields of the Kaliningrad Research Institute of Agriculture - a branch of the Federal Scientific Center named after V.R. Williams between 2001 and 2021. in crop rotations with different saturation of legumes and cereals. And we used a combined method for calculating the balance of humus. The expenditure part of the balance is determined by the removal of nitrogen by the crops, and the income part is determined through the mass of stubble and root residues. The expenditure part of the balance of organic matter was determined by the value of humus losses due to its mineralization. The input part of the balance of organic matter consists of newly formed organic matter due to the humification of plant residues and organic fertilizers.

Results

Let us present the calculation of the humus balance for an arable soddy weakly podzolic light loamy soil using four crop rotations of the Kaliningrad Research Institute of Agriculture as an example (Table 1).

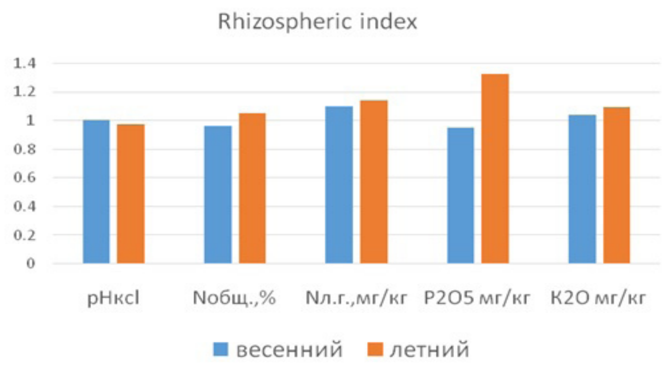

Figure 1: Monitoring of greenhouse gas flows in natural ecosystems.

Table 1: Balance of organic matter in crop rotations of the Kaliningrad Research Institute of Agriculture with green manure crops (2001-2021).

No. sowing	culture	Yield, c/ha	Humus loss from 1 ha, t	Humus accumulation, t/ha		Humus balance
				The yield of dry mass rast. leftovers	Humus from grows. leftovers	
1	Spring wheat	24.1	1.0	3.6	0.5	-0.5
	Perennial herbs 1 year of use	237.9	0.2	8.1	1.5	+1.3
	Perennial herbs 2 years of use	224.5	0.2	8.1	1.5	+1.3
	Winter wheat	33.7	1.5	4.8	0.9	-0.6
Total for crop rotation		-	3.1	24.6	4.4	+1.5
2	Lupine on green manure	227.9	0	3.2	0.7	+0.7
	Triticale	53.9	1.2	4.0	0.7	-0.5
	Fodder beans	12.3	0	3.2	0.7	+0.7
	Spring wheat	22.1	1.0	3.6	0.5	-0.5
Total for crop rotation		-	2.2	14.0	2.6	+0.4
3	Vika-oats for feed	226.4	0.7	4.2	0.8	+0.1
	Potato	201.6	1.2	2.1	0.4	-0.3
	Barley + annual grasses	35.2	1.0	4.0	0.7	-0.3
	Red clover for seeds, first cut for green manure	250.0	0.2	7.1	1.5	+1.3
	Winter wheat	36.1	1.5	4.8	0.9	-0.6
Total for crop rotation		-	4.6	22.2	4.3	+0.2
4	Fodder beans	14.0	0	3.2	0.7	+0.7
	Barley covered with perennial grasses	32.9	1.0	4.0	0.7	-0.3
	Perennial herbs 1 g.p.	220.6	0.2	8.1	1.5	+1.3
	Perennial herbs 2 g.p.	220.0	0.2	8.1	1.5	+1.3
	Triticale	42.2	1.2	4.0	0.7	-0.5
Total for crop rotation		-	2.6	27.4	5.1	+2.5

Our long-term research has established that the deficit balance of humus turned out to be the third crop rotation with potatoes. In this crop rotation with potatoes, traditionally, a negative humus balance (-0.8) was always recorded, but after the introduction of tuber material treatments and vegetation with biological preparations based on rhizosphere nitrogen-fixing microorganisms of complex action, this indicator increased to -0.3. The greatest positive balance of humus (+2.5t/ha) is noted in the fourth crop rotation with saturation of perennial grasses and beans.

Soil microorganisms play the most significant role in the process of humification in the soil. In the soil of the studied crop rotations of the field station of the Kaliningrad Research Institute of Agriculture, transformation and humification of organic matter, carried out by soil microflora, was observed. Since in the straw of grain crops C:N=98:1, in the roots 50:1, and the most favorable ratio of C:N for the development of soil microbes involved in the processes of humus formation is 25-30:1, microorganisms compensate for the lack of nitrogen due to mineralization of humic acids, C:N in which 10:1. The least stable humic acids serve as the most accessible source of nutrition and energy for microorganisms. The Cgc: Cfc ratio, expressed as a percentage, indicates the degree of organic humification.

In the fourth option with the highest saturation with legumes and cereals, the share of labile humus from the total amounted to 48.8%, including 22% of humic acid. In the composition of labile humus, 45% belonged to humic acid, 55% to fulvic acid, and the degree of humification of organic matter was 82%, which indicated an increase in soil fertility and crop yields in crop rotation (Table 2).

Table 2: The influence of organic matter on the processes of humification in crop rotations of the Kaliningrad Research Institute of Agriculture with different degrees of saturation with cereals and legumes, (2001-2021).

Crop rotation options	humus	"C" common	"C" lab.	"S" gk	"S"fk	"S" gk / "S" fk	% "C" lab.
1	2.583	1.483	0.702	0.275	0.427	0.64	47.3
2	2.569	1.475	0.716	0.313	0.403	0.78	48.5
3	2.503	1.437	0.679	0.256	0.423	0.61	47.2
4	2.674	1.535	0.749	0.338	0.411	0.82	48.8

We found that short-day plants are differently adapted to different sowing dates during the growing season. In the spring period of sowing, plants develop directing all the energy of growth and development to the formation of generative organs, in the summer period they form an enlarged root system with the growth of a significant vegetative mass, without completing the formation of the generative part. This established fact can make a significant contribution to the further development of carbon farming.

Studies have proven an increased amount of organic matter in the late summer sowing period with a significant amount of organic matter in both the underground and above ground masses. Thus, the mass of underground root residues when sown in late summer in the fourth variant of the crop rotation significantly exceeded similar absolute indicators in the spring and mid-summer sowing period by 7.7 and 1.9t/ha, and in the above-ground part by 56.1 and 7.4t/ha. The ratio between the mass of above-ground organs and roots in the summer period of sowing differed on average by 1.5 times in comparison with the spring. The formation of plants with a well-developed root system for carbon farming is due to the fact that about 20-30% of the organic matter formed during photosynthesis goes to the underground organs of plants. Of this volume, about 30% is released into the rhizosphere with root secretions (exudates), dying root cells, and as a result of root respiration. These sources are actively used by soil biota, including for the formation of organic matter and carbon sequestration. The difference between the spring and summer sowing of the same mixtures of annual legume-cereal crops in terms of the development of the root system is very significant (Table 3).

Table 3: Accumulation of raw organic matter in mixed spring-summer crops in the flowering phase (2011-2021, average values).

Rotation Option	/ Sowing Time	Weight of underground residues, t/ha	Above ground weight, t/ha	The ratio between the mass of aboveground organs and roots
1	Spring (second-third decade of April)	0.7	8.5	12.1
2		0.8	8.8	11.0
3		0.6	7.1	11.8
4		0.8	9.8	12.2
1	Mid-year, (second decade of July)	6.0	53.9	8.9
2		6.1	55.9	9.1
3		5.1	49.7	9.7
4		6.6	58.5	8.8
1	Late summer, (first decade of August)	8.0	64.4	8.0
2		8.4	63.7	7.6
3		7.8	61.2	7.8
4		8.5	65.9	7.7

Investigating the indicators of the rhizosphere index - the ratio of the content of various chemical elements and pH_{KCl}in the rhizosphere and outside the rhizosphere of root secretions of annual legumes in mixed crops of spring sowing, a shift in $pH_{KCl}$to the acid side was observed, and vice versa, during summer sowing in leguminous plants in the rhizosphere zone, a shift in the reaction to the alkaline side.

Such opposite processes occurred in the mixed sowing of leguminous-cereal crops of summer sowing, which led to the intensive development of accompanying cereals in this mixture, for example, paisa increased the mass of the root system and aerial parts by 1.8 times in comparison with spring sowing plants.

The analysis of Rhizosphere Indices (RI) made it possible to reveal the general direction of soil-rhizosphere processes in leguminous plants in the root zone and outside it in mixed crops of spring and summer periods (Figure 2).

This prompted us to hypothesize that the totality of positive indicators in annual legume-cereal plants sown in summer, namely, a significant increase in the aboveground and underground mass with the active activity of the microbiota in the rhizosphere with a tendency to shift the soil reaction of the solution to the alkaline side, can be used as biological ameliorant

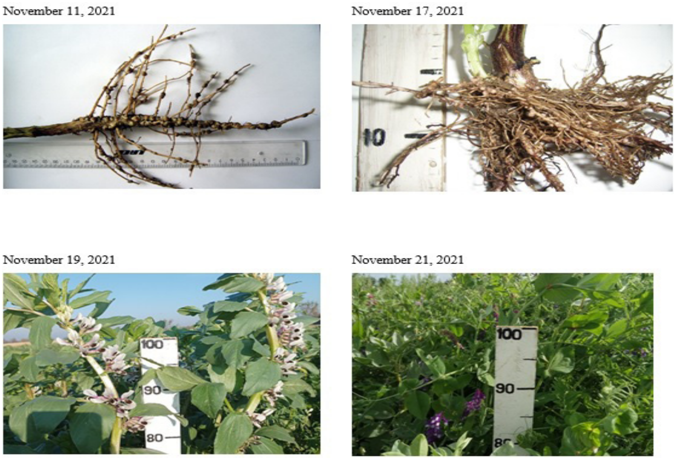

Figure 2: Rhizospheric Indices (RI) of agrochemical indicators in mixed legume-cereal crops during spring and summer sowing, 2019.
Rice 3: The state of the underground and above ground parts in summer mixed legume-cereal crops (sowing on 08/01/2021) in November 2021.

Since in the mixed crop there are plants from different genera and families selected for allelopathic compatibility, for additional sequestration of root carbon, we introduce into the mixture such cultivated plants that have an increased natural production of suberin. Suberin is a lipophilic polyester biopolymer, also called cork, that is characterized by increased retention in soil. These properties are possessed by two crops with which we are actively working in the Kaliningrad region - Sudanese grass and sorghum-Sudanese hybrids. And the introduction of plants into a mixed legume-cereal crop (possibly from natural ecosystems or with preliminary selection) of plants that have a suppressive effect on pathogenic organisms (lower fungi, bacteria, etc.) or a repellent effect on harmful insects could perform a protective function in crop rotations. These are prospecting works that are located in the Kaliningrad Research Institute of Agriculture, a branch of the FNTs VIK im. V.R. Williams is under investigation.

Mixed crops of annual legumes and cereals do not require mineral fertilization and pesticide treatment - this is another important indicator in the transition to carbon farming, since both mineral fertilizers and pesticides, when applied, have pronounced acidic pH values, which prevents the flocculation process, which is a preparatory stage formation of a stable soil particle in the process of humus formation.

Cultivating mixed annual legumes and cereals in carbon farming is recommended for the production of leguminous fodder, and during summer sowing - as a green fodder balanced in terms of the main zootechnical characteristics in the late autumn period.

When plowing summer mixed crops of annual legumes and cereals, structuring of stable soil particles occurs with a tendency to deoxidation, a significantly larger organic mass enters the soil, which can be deposited in humus.

As a result of a study of annual legumes and cereal crops in 2013, the Kaliningrad Research Institute of Agriculture, a branch of the Federal Scientific Center for All-Russian Research and Development Institute named after. V.R. Williams received a RF patent for the invention No. 2478301 "Method for obtaining green fodder and maintaining soil fertility" [6]. The proposed method is based on maintaining a positive balance (deposition) of humus for a long period of time.

Conclusion

Carbon farming in the Kaliningrad region is based on the following principles:

– Multi-field crop rotations with saturation of annual and perennial legumes and cereals [7];

– Minimizing the use of mineral fertilizers and pesticides using biological preparations based on rhizosphere nitrogen-fixing microorganisms of complex action;

– Use in crop rotations of mixed legumes and cereals of different species composition and different sowing periods as predecessors and green manure for the main crops;

– Mixed legume-cereal crops of different species composition [8] can perform a protective function for subsequent main crops in the crop rotation against pathogenic microorganisms and invertebrate pests;

– Mixed legume-cereal crops of summer sowing are the most economically and ecologically justified and suppliers of leguminous fodder and green fodder balanced in terms of zootechnical indicators in the late autumn period;

– Mixed legume-cereal crops are considered as biological ameliorants [9] and the main sources of stable humus.

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