CARBON FARMING IN THE KALININGRAD REGION

Research article

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Abstract

Long-term studies substantiate the possibility of using four- and five-field crop rotations with a positive balance of organic matter for the long-term binding of atmospheric carbon dioxide in the form of stable humus in the soil.

Four- and five-pillar field crop rotations with the inclusion of perennial legumes and cereals have a significant potential for accumulation of organic matter for its subsequent conservation in the form of humus. The largest positive balance of humus (+ 2,5 t/ha) was observed in crop rotation with the inclusion of fodder beans, spring barley under the cover of perennial herbs and winter triticale.

It promotes increased accumulation of organic matter in crop rotation using annual mixed legume and cereal crops when sowing in summer as precursor siderates for winter rape, barley and wheat. The mass of underground root residues during late-summer sowing in crop rotation with the inclusion of fodder beans, spring barley under the cover of perennial grasses and winter ground significantly exceeded similar absolute values at spring and mid-summer sowing by 7,7 and 1,9 t/ha, and in the above-ground part by 56,1 and 7,4 t/ha, respectively.

The ratio between the mass of aboveground organs and roots in the summer sowing period was higher by an average of 1,5 times compared to the spring. An increase in the above-ground and underground mass with active microbiota activity in the rhizosphere with a tendency to shift the soil reaction of the solution to the alkaline side in summer sowing can be used as a biological meliorant. The introduction of Sudanese grass and sorghum-Sudanese hybrids into mixed summer crops will allow the preservation of organic residues for longer preservation in the soil.

Keywords: carbon farming, 4-5 full crop rotations, perennial legumes and cereals, annual mixed crops, humus balance, biological reclamation.

УГЛЕРОДНОЕ ЗЕМЛЕДЕЛИЕ В КАЛИНИНГРАДСКОЙ ОБЛАСТИ

Научная статья

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Аннотация

Многолетними исследованиями обосновывается возможность использования четырех- и пятипольных полевых севооборотов с положительным балансом органического вещества для долгосрочного связывания атмосферного углекислого газа в виде стабильного гумуса в почве.

Четырех-и пятипольные полевые севообороты с включением многолетних бобовых и злаковых культур обладают значительным потенциалом накопления органического вещества для его последующей консервации в виде гумуса. Наибольший положительный баланс гумуса (+2,5 т/га) отмечен в севообороте с включением кормовых бобов, ярового ячменя под покров многолетних трав и озимого тритикале.

Способствует повышенному накоплению органического вещества в севообороте использование однолетних смешанных бобовых и злаковых культур при посеве летом в качестве сидератов-предшественников под озимый рапс, ячмень и пшеницу. Масса подземных корневых остатков при посевев позднелетний срок в севоооброте с включением кормовых бобов, ярового ячменя под покров многолетних трав и озимого тритикале существенно превышала аналогичные абсолютные значения при весеннем и среднелетнем сроке посева на 7,7 и 1,9 т/га, а в надземной части на 56,1 и 7,4 т/га соответственно. Соотношение между массой надземных органов и корней в летний период посева было выше в среднем в 1,5 раза в сравнении с весенним. Увеличение надземной и подземной массы с активной деятельностью микробиоты в ризосфере с тенденцией сдвига почвенной реакции раствора в щелочную сторону в летнем посеве, можно использовать как биологический мелиорант. Введение в смешанные летние посевы суданской травы и сорго-суданских гибридов позволит консервировать органические остатки для более длительной консервации в почве.

Ключевые слова: углеродное земледелие, 4-5 польные севообороты, многолетние бобовые и злаковые культуры, однолетние смешанные посевы, баланс гумуса, биологическая мелиорация.

Introduction

Initiatives to introduce a carbon price 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], [2], [3]. In this regard, the initiative of the French government, called "Four permilles" (Initiative "4 per 1000" (4 ‰ =4⁄1000= 0.4% = 0.004) voiced at an international conference held in France from June 17 to 20, 2019 in the city of Poitiers), found a positive response from politicians of leading countries. The idea is to achieve an ambitious goal: to increase the carbon level in plowed soils around the world by four ppm annually (Figure 1).

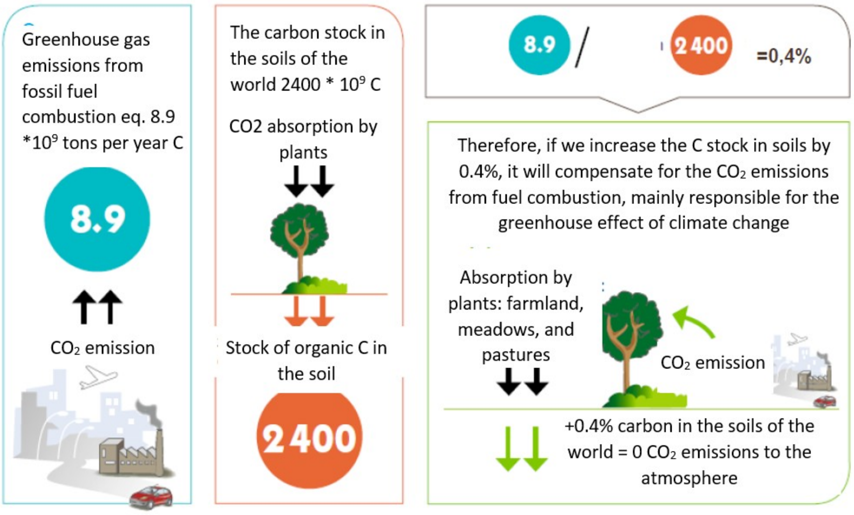

Figure 1 - Monitoring of greenhouse gas flows in natural ecosystems

Note: according to V.A. Romanenkov, 2021

Main results

Modern agriculture can become a source of technologies that ensure the removal (sequestration) of greenhouse gases from the atmosphere. Agrotechnologies aimed at capturing carbon from the atmosphere are known as carbonaceous 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 as a result of crop cultivation 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.

The EU's plans to introduce a border-correcting carbon mechanism have prompted many producers of "carbon-intensive" products exported to the EU to revise 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 new president's program explicitly provides for the introduction of a "corrective carbon levy" for countries that "do not fulfill their obligations on climate and environmental protection" [1], [4].

The first carbon tax in Africa was introduced in the Republic of South Africa (South Africa), and Singapore became a pioneer in Asia. On February 1, 2021, the national emissions trading system started operating in China. In these circumstances, agriculture, or rather biological or carbon farming can become one of the key elements of a scientifically based response to climate threats and related trade barriers.

Our research convincingly proves on specific technological agricultural practices the possibility of retaining carbon dioxide in the arable soil layer by preserving and increasing its organic part. A special role here is assigned to a stable type of organic matter – humus, since the humus content in soils directly depends on the level of organic carbon present in them (humus $= C_{org} \times 1.72$) [5], [6], [7], [8].

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

The goal is to bind as much carbon as possible with the help of traditional and original eco-friendly agricultural technologies and send it to storage 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 seeding times can act as biological meliorants, and their residues can pass into the conservative part of humus – humin and fulvic acid.

Research methods

All the studies were carried out in the experimental fields of the Kaliningrad Research Institute of Agriculture – a branch of the V.R. Williams Federal Scientific Center in the period from 2001 to 2021 in crop rotations with different saturation of legumes and cereals. A combined method of calculating the humus balance was used. The expenditure part of the balance is determined by the removal of nitrogen by the crop yield, and the input part is determined through the mass of crop and root residues. The expenditure part of the balance of organic matter was determined by the amount 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

For example, we present the calculation of the humus balance for arable sod-soft-podzolic light loamy soil using the example of four crop rotations of the Kaliningrad Research Institute of Agriculture (Table 1).

Table 1 - Balance of organic matter in crop rotations of the Kaliningrad Research Institute with sideral crops 2001-2021

Crop rotation No.	Culture	Yield, c/ha	Loss of humus from 1 ha, t	Accumulation of humus, t/ha		Humus balance
				The output of the dry mass plant matter	Plant matter humus	
1	Spring wheat	2,1	1,0	3,6	0,5	-0,5
	Perennial herbs of the 1 year of use	23,9	0,2	8,1	1,5	+1,3
	Perennial herbs of the 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 crop rotation		-	3,1	24,6	4,4	+1,5
2	Lupin for green fertilizer	227,9	0	3,2	0,7	+0,7
	Triticale	53,9	1,2	4,0	0,7	-0,5
	Feed beans	12,3	0	3,2	0,7	+0,7
	Spring wheat	22,1	1,0	3,6	0,5	-0,5
Total crop rotation		-	2,2	14,0	2,6	+0,4
3	Vika-oats for food	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
	Meadow clover for seeds, the first cut for green fertilizer	250,0	0,2	7,1	1,5	+1,3
	Winter wheat	36,1	1,5	4,8	0,9	-0,6
Total crop rotation		-	4,6	22,2	4,3	+0,2
4	Feed beans	14,0	0	3,2	0,7	+0,7
	Barley under the cover of perennial grasses	32,9	1,0	4,0	0,7	-0,3
	Perennial herbs of the 1 year of use	220,6	0,2	8,1	1,5	+1,3
	Perennial herbs of the	220,0	0,2	8,1	1,5	+1,3

	2 year of use					
	Triticale	42,2	1,2	4,0	0,7	-0,5
Total 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, a negative balance of humus has traditionally always been recorded (-0,8), but after the introduction of treatments of tuberous material 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 (+ 2,5 t/ha) is observed in the fourth crop rotation with the saturation of perennial grasses and beans.

The most significant role in the process of humification in the soil is played by soil microorganisms. Transformation and humification of organic matter carried out by soil microflora was observed in the soil of the studied crop rotations of the Kaliningrad Research Institute of Agriculture. 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, the lack of nitrogen is replenished by microorganisms due to the mineralization of humic acids, where the ratio of C:N is 10:1. The least stable humic acids serve as the most affordable source of nutrition and energy for microorganisms. The ratio of Sgc:Sfc, expressed as a percentage, indicates the degree of humification of organic matter.

In the fourth variant with the highest saturation of legumes and cereals, the share of labile humus of the total amount was 48.8%, including 22% of humic acid. In the composition of labile humus, humic acid accounted for 45%, fulvic acid accounted for 55%, 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 effect of organic matter on humification processes in crop rotations of the Kaliningrad Research Institute of Agriculture with varying degrees of saturation with cereals and legumes, 2001-2021

Crop rotation options	humus	"C" general	"C" lab.	"C"gc	"C"fc	"C"gc/ "C"fc	% "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 have found that short-day plants are adapted differently to different seeding periods during the growing season. In the spring sowing period, the plants develop directing all the energy of growth and development to the formation of generative organs, in the summer they form an enlarged root system with the build-up 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 the composition of a significant amount of organic matter in both underground and aboveground mass. Thus, the mass of underground root residues during seeding in the late summer period in the fourth variant of crop rotation significantly exceeded similar absolute values for spring and mid-summer seeding by 7.7 and 1.9 t/ha, and in the aboveground part by 56.1 and 7.4 t/ha. The ratio between the mass of aboveground organs and roots in the summer sowing period differed by an average of 1.5 times compared to 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 dates of the same mixtures of annual legumes and cereals for the development of the root system is very significant - (Table 3).

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

Crop rotation option/ Sowing period		Mass of underground residues, t/ha	Aboveground mass, 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	6,0	53,9	8,9

2	decade of July)	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

Studying the indicators of the rhizosphere index - the ratio of the content of various chemical elements and the pH of $_{KCl}$ in the rhizosphere and outside the rhizosphere of the root secretions of annual legumes in mixed crops of spring sowing, a shift in the pH of $_{KCl}$ to the acidic side was observed and vice versa, during summer sowing, the reaction of legumes in the rhizosphere zone shifted to the alkaline side. Such opposite processes occurred in the mixed sowing of legumes and cereals of summer sowing, which led to the intensive development of cereal concomitants in this mixture. So, for example, the paiza increased the mass of the root system and the aboveground part by a factor of 1.8 in comparison with the plants of spring sowing

The analysis of rhizosphere indices (RI) revealed the general orientation of soil-rhizosphere processes in legumes in the root zone and outside it in mixed crops of spring and summer terms (Fig. 2).

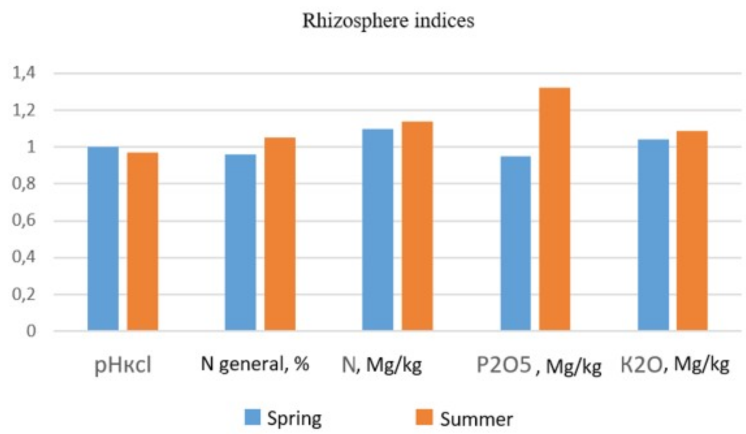

Figure 2 - Rhizosphere indices (RI) of agrochemical indicators in mixed legume and cereal crops at spring and summer sowing dates, 2019

This prompted us to the hypothesis that the combination of positive indicators in annual legume and cereal plants sown in summer, namely, a significant increase in aboveground and underground mass with active microbiota activity in the rhizosphere with a tendency to shift the soil reaction of the solution to the alkaline side, can be used as a biological meliorant (Fig. 3).

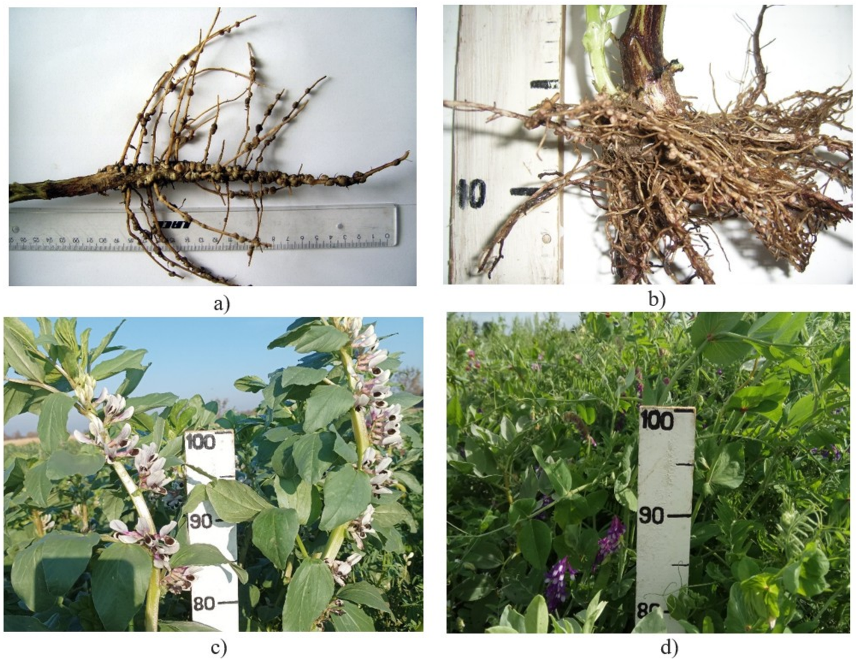

Figure 3 - The state of the underground and aboveground parts in summer mixed legume-cereal crops (sowing on 01.08.2021) in November 2021

Note: a) – November 11, 2021; b) – November 17, 2021; c) – November 19, 2021; d) – November 21, 2021

Since plants from different genera and families selected according to allelopathic compatibility are present in the mixed sowing, for additional sequestration of root carbon, we introduce such cultivated plants into the mixture that have increased natural production of suberin. Suberin is a lipophilic polyester biopolymer, also called cork, which is characterized by increased preservation in the 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 into mixed legume and cereal sowing of plants (possibly from natural ecosystems or with preliminary selection) of plants with an overwhelming effect on pathogenic organisms (lower fungi, bacteria, etc.) or a repelling effect on harmful insects could perform a protective function in crop rotations. These are search works that are in the Kaliningrad Research Institute of Agriculture, the All-Russian Williams Fodder Research Institute at the research stage.

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

It is recommended to cultivate mixed annual legume and cereal crops in carbon farming for the production of leguminous fodder, and during summer sowing – as a green feed balanced according to the main zootechnical characteristics in the late autumn period.

When plowing summer mixed crops of annual legumes and cereals, stable soil particles with a tendency to deoxidation are structured, a significantly large organic mass capable of being deposited in humus enters the soil.

As a result of the study of annual legumes and cereals in 2013 Kaliningrad Research Institute of Agriculture - a branch of the V.R. Williams Federal Research Center has received a patent of the Russian Federation for invention No. 2478301 "A method for obtaining green feed and preserving soil fertility" [9], [10]. The proposed method is based on maintaining a positive balance (depositing) 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;
- minimization of the use of mineral fertilizers and pesticides using biological preparations based on rhizospheric nitrogen-fixing microorganisms of complex action;
- the use of mixed legumes and cereals of different species composition and different sowing periods in crop rotations as precursors and green manure for the main crops;
- mixed legume and cereal crops of different species composition can perform a protective function for subsequent main crops in crop rotation against pathogenic microorganisms and invertebrate pests;
- mixed legume and cereal crops of summer sowing are the most economically and environmentally justified, and they are the suppliers of balanced zootechnical indicators of leguminous fodder and green fodder in the late autumn period;
- mixed legume and cereal crops are considered as biological meliorants and the main sources of stable humus.

Конфликт интересов

Не указан.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Conflict of Interest

None declared.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

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