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Scientific substantiation of the establishment of a carbon farm

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Abstract. The Russian Federation needs to transition to carbon standards, which are established in many foreign countries, to regulate and control the negative consequences of anthropogenic human activity. Quoting of greenhouse gas emissions at the global level pushes for the development and implementation of technologies to reduce them. One of the ways to reduce emissions in agriculture is the creation of carbon farms. At present, there is no unified methodological and statistical basis for the creation of a carbon farm in the Russian Federation. When creating it, it is necessary to understand not only the general principles of agrolandscapes functioning, but also to take into account the factors that have an impact on the carbon absorption capacity of the land located on the territory of the farm. A new approach to reducing emissions by optimising the location of agricultural land with regard to its sequestration potential on the basis of spatial modelling has been proposed. The specificity of the approach is demonstrated on the example of the farm of the All-Russian Research Institute of Reclaimed Lands (Tver region, Kalininsky district, Emmauss settlement). After additional testing, the approach can be recommended for implementation in the practice of carbon-depleting agricultural land use.

Keywords: carbon balance, carbon farms, carbon sequestration, emission allowance, spatial modeling, land use

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Научное обоснование создания карбоновой фермы

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Аннотация. В Российской Федерации в настоящее время актуальны вопросы и проблемы разработки и перехода к углеродным стандартам, которые уже установлены во многих зарубежных странах, для регулирования и контроля над негативными последствиями антропогенной деятельности человека. Квотирование выбросов парниковых газов на глобальном уровне подталкивает к разработке и внедрению технологий для их уменьшения. Одним из путей уменьшения выбросов в сельском хозяйстве является создание карбоновых ферм. В настоящее время на территории РФ отсутствует единая методологическая и статистическая база для создания карбоновой фермы. При ее создании необходимо не только понимать общие принципы функционирования агроландшафтов, но и учитывать факторы, которые имеют влияние на поглотительную способность углерода угодьями, расположенными на территории фермы. Предложен новый подход к сокращению выбросов посредством оптимизации размещения сельскохозяйственных угодий с учетом секвестрационного потенциала земель на основе пространственного моделирования. Специфика подхода продемонстрирована на примере хозяйства Всероссийского НИИ мелиорированных земель (Тверская область, Калининский район, поселок Эммаусс). После дополнительной апробации подход может быть рекомендован к внедрению в практику углерод-депонирующего сельскохозяйственного землепользования.

Ключевые слова: баланс углерода, карбоновые фермы, секвестрация углерода, квота на выбросы, пространственное моделирование, использование земель

Благодарности и финансирование. Работа выполнена в рамках реализации важнейшего инновационного проекта государственного значения «Разработка системы наземного и дистанционного мониторинга пулов углерода и потоков парниковых газов на территории Российской Федерации, обеспечение создания системы учета данных о потоках климатически активных веществ и бюджете углерода в лесах и других наземных экологических системах» (рег. № 123030300031-6).

Вклад авторов. *Коновалова А.П.* – разработка подхода, проведение эксперимента, написание статьи, подготовка иллюстраций; *Савин И.Ю.* – концептуализация, редактирование текста.

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Introduction

The problem of carbon sequestration has a transboundary character and global scale, and therefore it is most noticeable for large areas – large territories, individual countries, or natural areas [1]. Combating the problem of climate change through the exploitation of carbon farms and the creation of technologies for the absorption of greenhouse gases and their impact on the environment is a relatively new area for discussion and debate in the scientific environment both in the Russian Federation and abroad [2; 3]. Carbon farms are one of the methods to optimise carbon sequestration by introducing methods that increase the rate of CO_2 removal from the atmosphere and its accumulation in soils and plant organic matter. While conventional farming methods result in carbon emission, carbon farming in the form of carbon farming has the opposite effect [4; 5].

The article presents the results of research to scientifically substantiate a new approach to emission reduction through optimisation of agricultural land placement considering the sequestration potential of land on the basis of spatial modelling.

Object of research

The object of the research is the land of the farm of the Russian nationwide Research Research Institute of Reclaimed Lands (Kalininsky district, Tver region). The farm is located in the south of Tver region, 15 kilometres from Tver. The territory is characterised by a temperate continental climate.

The air temperature averages –8°C in winter and +20°C in summer (Figure 1 shows data on precipitation and average air temperature in Kalininsky district, where the farm is located).

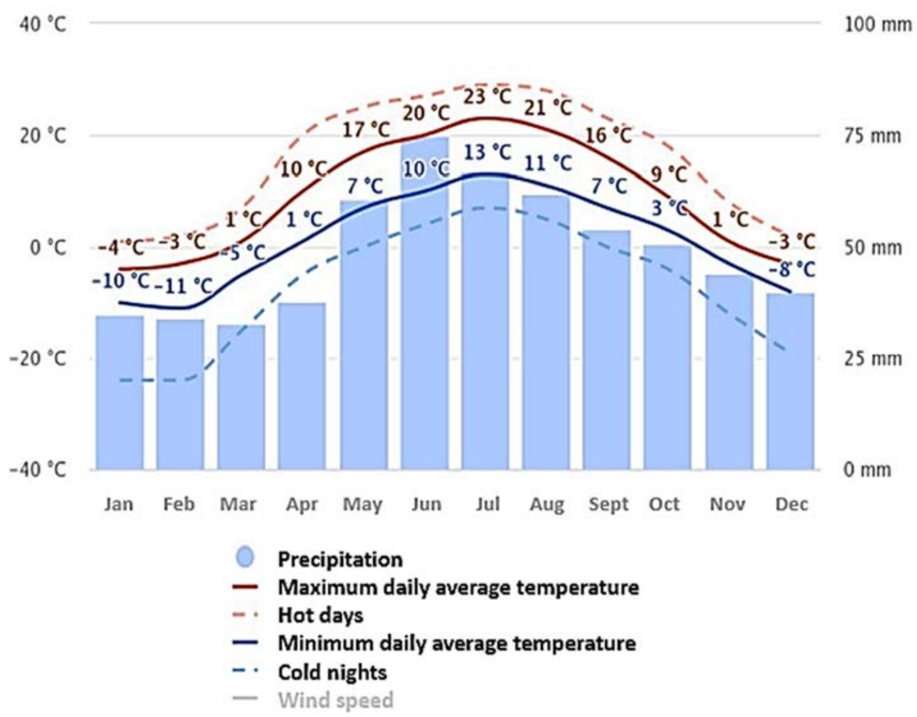

Figure 1. Average air temperature and precipitation on the territory of Kalininsky District, Tver Oblast [6].
Source: compiled by the authors.

Tver region is located in the central part of the East European Plain, with a characteristic flat relief with alternating uplands and lowlands.

Sod-mesopodzol surface-gleyic reclaimed low stony soils (29.22%) and sod-mesopodzol surface low gleyic reclaimed soils (18.71%) predominate on the farm.

Method of research

The procedure of the research is presented in Figure 2.

In the first stage, a GIS database containing data on the farm's land resources was created. The database included the following maps:

1. *Soil map*. The paper soil map of the farm at a scale of 1:10000, created by ROSGIPROZEM specialists at the end of the 80s of the last century, which was geo-referenced, vectorised and accompanied by attributive information on soil properties, was taken as a basis (Figure 3).

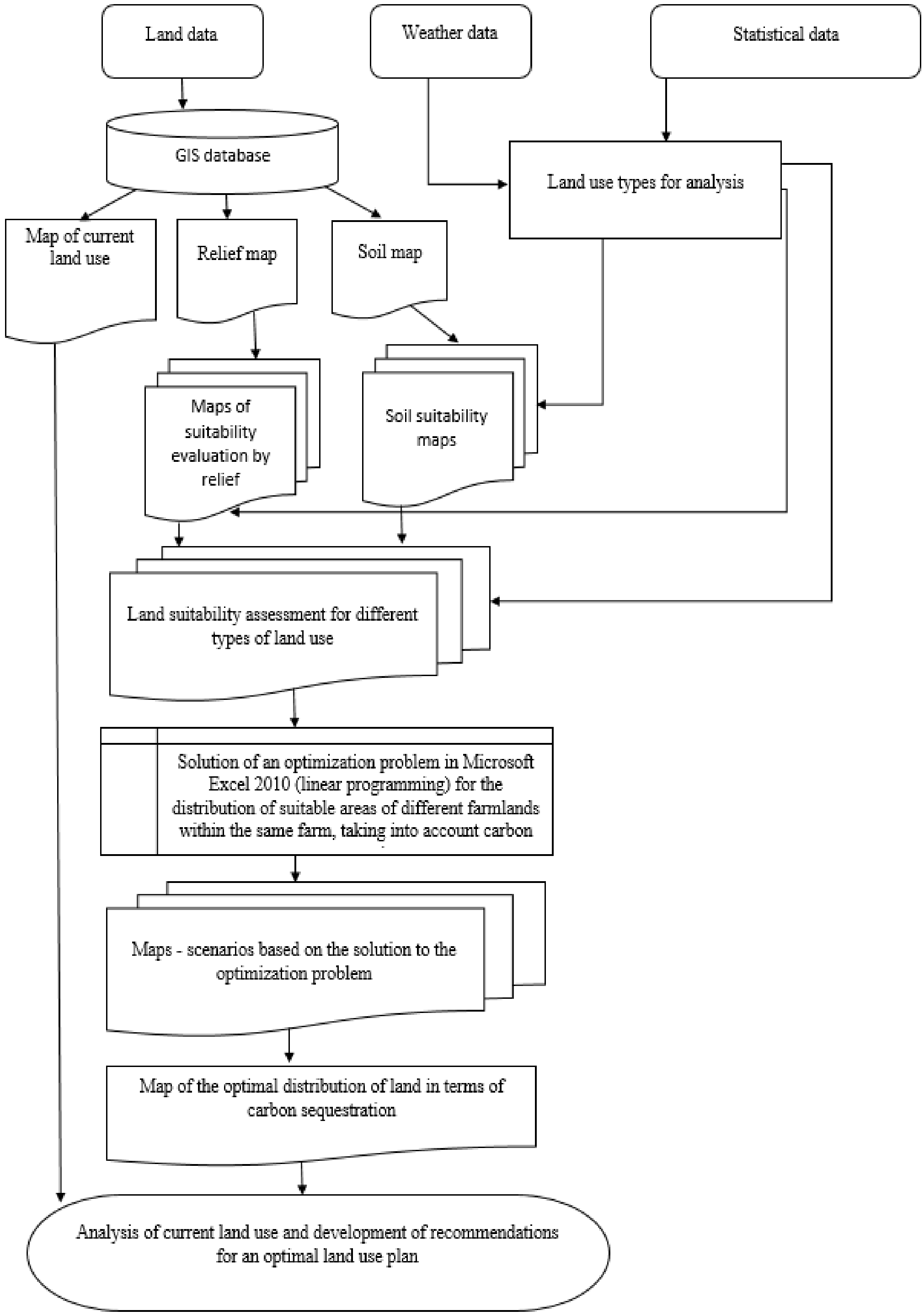

Figure 2. Scheme of sequence of works on development of an optimal scenario for the placement of farm land in terms of increasing carbon sequestration
Source: compiled by the authors.

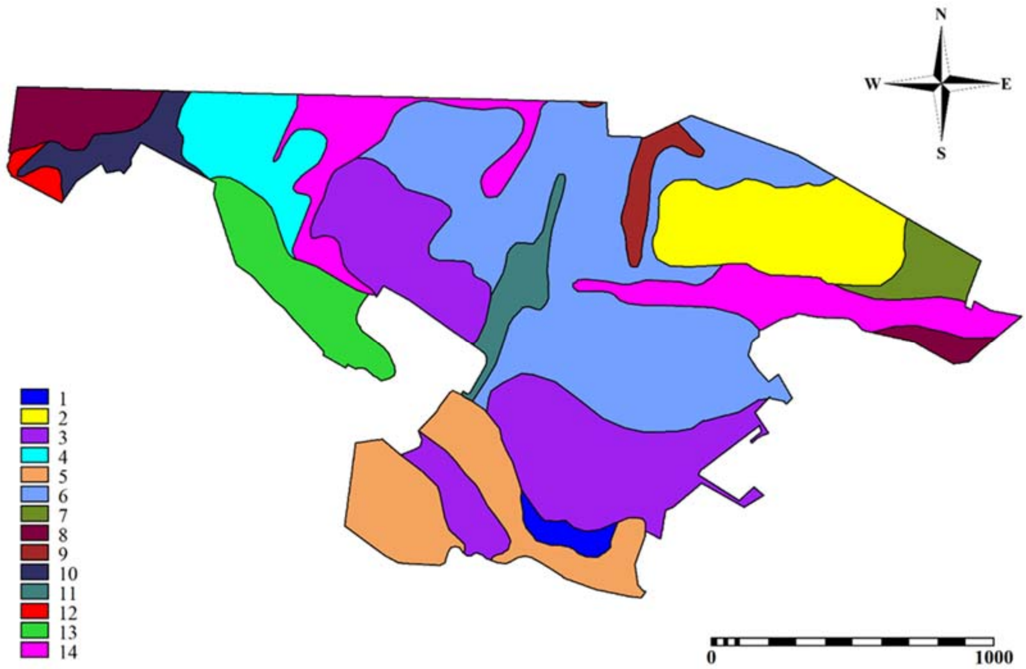

Figure 3. Soil map of the farm:
1 – sod-medium podzolic erosion-hazardous; *2* – sod-medium podzolic weakly stony drained surface-slabogleyevous; *3* – sod-medium podzolic superficially weakly gleyey drained; *4* – sod-medium podzolic psuperficially weakly gleyey; 5 – sod-medium-podzolic dried superficially gleyey; *6* – sod-medium-podzolic superficially gleyey dried slightly stony; *7* – sod-medium-podzol surface-gleyey drained weakly stony; *8* – sod-medium podzol surface-gleyey slightly stony; *9* – sod-strong-podzol profile-gleyivaty weakly stony dried; *10* – sod-strong-podzol profile-gleyey; *11* – sod-strong-podzol profile-gleyey; *11* – sod-strong-podzol profile-gleyey drained; *12* – sod-siliceous-podzolic surface-gleyey in complex up to 10% with sod-silno-podzolic profile-gleyey; *13* – over-excavated lands; *14* – sod-silno-podzolic profile-gleyey dried)
Source: compiled by the authors.

2. *Maps of terrain characteristics*. To characterise the relief, SRTM[1] terrain absolute height data were used (Figure 4). The data have a spatial resolution of 90 metres and were obtained as of the beginning of the current century. A derived terrain slope map was constructed in GIS and used in the analysis.

3. *Map of actual land use*. To assess the current land use, images of the farm territory obtained using Phantom 4 DJI FC 330 drone in 2020 and 2021 were analysed. Objects were recognised using desktop interpretation methods by visual analysis of images with spatial resolution from 10 to 50 centimetres. The farm land use map is presented in Figure 5.

[1] EarthExplorer meteoblue. Available from: https://earthexplorer.usgs.gov/ (accessed: 10.12.2023).

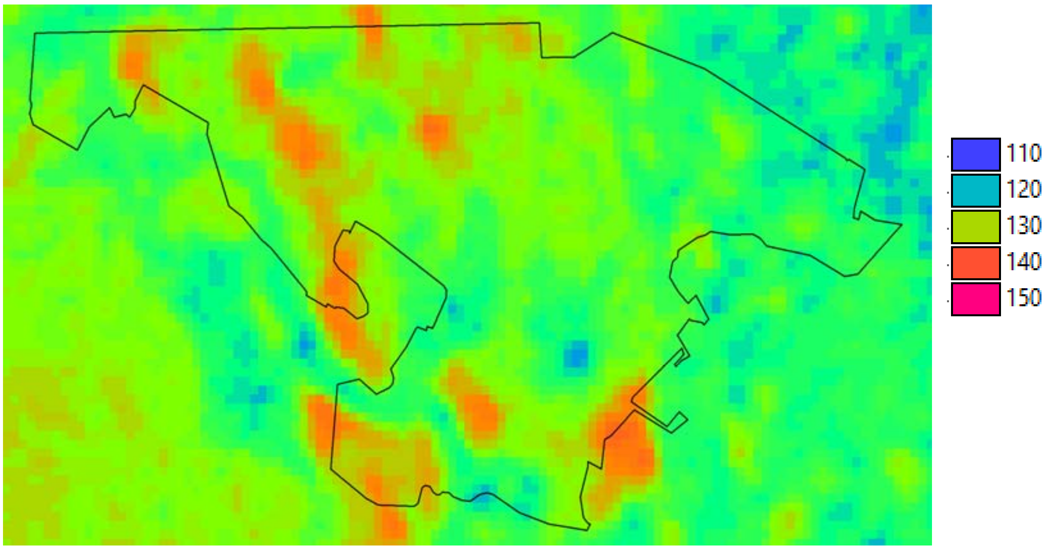

Figure 4. SRTM digital terrain model for the farm area
Source: compiled by the authors.

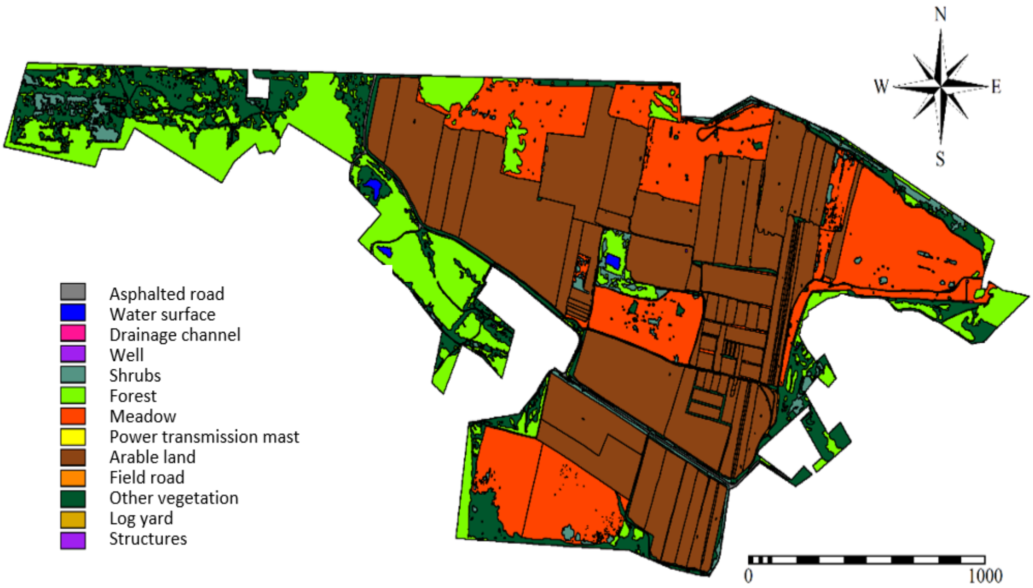

Figure 5. Map of current land use of the Emmaus settlement farms
Source: compiled by the authors.

Additionally, literature data on carbon sequestration for different land types were collected [6; 1].[2]

[2] 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, For-estry and Other Land Use. Chapter 3. Consistent Representation of Lands. Available from:

Based on the GIS database, maps of relief and soil suitability assessment for the main types of agricultural land were created. Suitability assessment was carried out based on FAO land assessment approaches adapted to Russian conditions [9].

Given the overlap between the suitability maps in the GIS, the areas of land suitable for a particular site were identified.

Having solved the problem of optimisation of areas taking into account their carbon sequestration potential by the method of linear programming, the areas of distribution of land types on the farm territory were obtained, which made it possible to create maps-scenarios for land areas taking into account carbon sequestration and select the most optimal scenario. After that, the current land use was compared with the optimal scenario in terms of carbon sequestration.

Spatial data analysis was performed using the ILWIS 3.3[3] application package. Optimisation problems were solved using Microsoft Excel 2010.[4]

Results and discussion

Land suitability assessment by topography

Using ILWIS software, suitability assessment maps were created for different types of land according to the slope of the terrain. Suitability was assessed for land such as cropland, pasture, swamp and forest using the following gradations: suitable, unsuitable and limited suitable (Table 1). Figures 6–9 show the terrain suitability assessment maps for different lands (black contour – farm boundary, green – suitable land, yellow – limited suitable, red – unsuitable).

Table 1. Criteria for assessing suitability for different types of sites

Site type	Suitable	Suitable Limited	Unsuitable
Arable land	< 2	2–5	> 5
Pasture	< 5	5–8	> 8
Forest	< 8	8–12	> 12
Marshland	< 2	–	> 2

Source: compiled by the authors.

https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_03_Ch3_Representation.pdf (accessed: 11.12.2023).

[3] ILWIS – Remote Sensing and GIS software. Available from: https://www.itc.nl/ilwis/ (accessed: 09.11.2024).

[4] Solving optimization problems in Microsoft Excel 2010: textbook / N. I. Shadrina, N. D. Berman; [ed. by E. M. Vikhtenko]. Khabarovsk: Izd-vo Tikho-Ocean. gos. un-ta; 2016. 101 p. (In Russ.); Problem formulation and solution with the help of the “Solution Search” add-in – Microsoft Support Service. Available from: https://support.microsoft.com/ru-ru/office/постановка-и-решение-задачи-с-помощью-надстройки-поиск-решения-5d1a388f-079d-43ac-a7eb-f63e45925040 (accessed: 11.11.2023) (In Russ.).

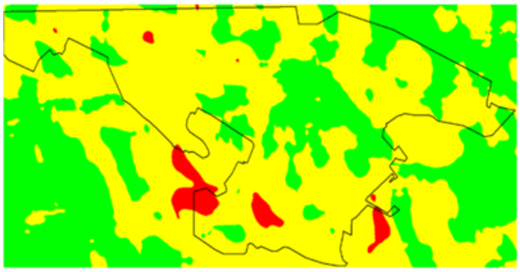

Figure 6. Map of terrain suitability for arable farming
Source: compiled by the authors.

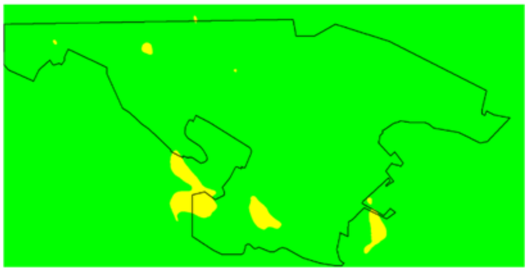

Figure 7. Map of terrain suitability for pasture
Source: compiled by the authors.

Figure 8. Map of terrain suitability for forests
Source: compiled by the authors.

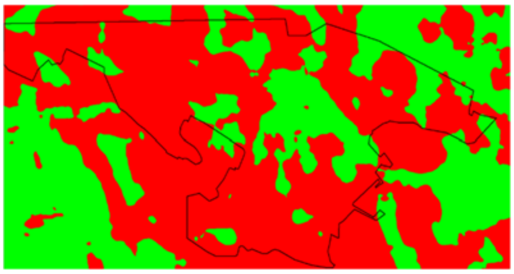

Figure 9. Map of terrain suitability for marshland
Source: compiled by the authors.

Assessment of land resources suitability by soil types

Similarly, based on the soil map, maps with soil suitability assessment for different types of land were created (Figure 10–13).

Figure 10. Map of terrain suitability for arable farming:
p – suitable; o – limited suitable; *n –* unsuitable
Source: compiled by the authors.

Figure 11. Map of terrain suitability for pasture:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

Figure 12. Map of terrain suitability for forests:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

Figure 13. Map of terrain suitability for marshland:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

Integral assessment of land suitability

To create the final land suitability maps, it was necessary to create intersections of relief and soil suitability maps for cropland, pasture, forest and swamp. The maps are presented in Figures 14–17.

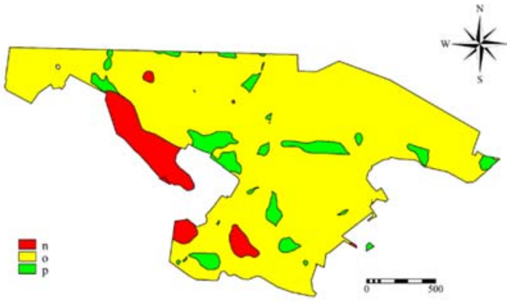

Figure 14. Map of terrain suitability for arable farming:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

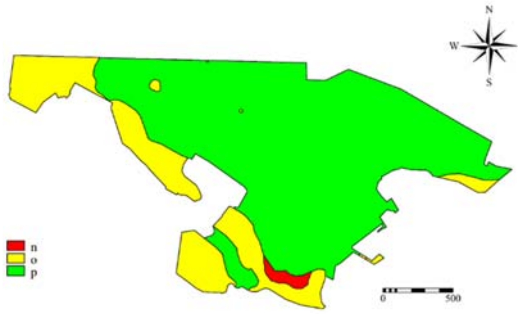

Figure 15. Map of terrain suitability for pasture:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

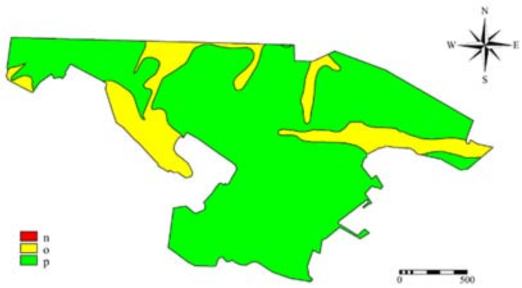

Figure 16. Map of terrain suitability for forests:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

Figure 17. Map of terrain suitability for marshland:
p – suitable; o – limited suitable; n – unsuitable
Source: compiled by the authors.

The data in Table 2, based on the literature review [6; 7], were used as the basis for optimising the location of land on the farm.[5]

Table 2. Organic C stocks in different soil types at different sites

Farmland	Soils	Stocks C_{org}, kg/m²		
		min	max	mid
Arable	Sod-podzols, sod-podzol soils	4.40	7,8	6.1
Forests	Sod-podzols, sod-podzolic soils	5.30	8.7	7
Over-watered meadow, swamp forests	Gley podzols, sod-podzol-gley soils, peat- and peat-podzol-gley soils, sod-gley soils and humus-gley soils	10.00	25	17.5
Marshland	Peat-bog	24.00	65	44.5
Meadows, meadow-shrub vegetation, abandoned arable land	Floodplains weakly acidic and neutral, meadow and grassland	21.20	36.8	29

Source: compiled by the authors.

[5] FAO, 1976. Available from: https://www.fao.org/3/x5310e/x5310e00.htm (accessed: 10.12.2023).

Using linear programming methods, a model of the optimal composition of sites on the farm was constructed using information from Table 2 and land suitability. This method was used to obtain a rational structure of land allocation with maximum carbon sequestration for each type of land. The problem was solved with the maximised optimality criterion – average carbon stock. In the end, the linear programming method allowed to calculate the areas of lands at which the maximum carbon sequestration capacity of farmlands will be achieved (Table 3).

The solution of the optimisation problem showed that lands occupied by bogs and pastures have the maximum absorption capacity in the study area. Therefore, when creating the map of optimal land distribution, the lands maximally suitable for bogs and pastures were first considered, and the remaining lands were distributed between arable land and forests. The resulting map is shown in Figure 18.

Table 3. Areas of current land use with different suitability assessments, ml

Farmland	Limited suitable	Suitable	Average carbon stock, kg/ml
Arable land	2 572 442	196 198	6.1
Pasture	627 028	2 320 629	29
Forest	518 833	2 457 809	17.5
Marshland	86 509	0	44.5
Total	2 976 642		

Source: compiled by the authors.

Table 4. Result of solving the optimization problem, ml

Farmland	Limited suitable	Suitable	Sum of suitable and limited suitable
Arable land	298	0	298
Pasture	568 908	2 320 628	2 889 536
Forest	298	0	298
Marshland	86 509	0	86 510

Source: compiled by the authors.

Comparing the map of this scenario with the map of actual land use shows that its implementation would require a fundamental change in farm specialisation. The required conversion of some lands to others is presented in Table 3.

According to the data in Table 3 and Map (Figure 18), about 67 per cent of the farm's land would need to be converted to other land. To increase carbon sequestration and transition to a fully carbon farm, it will be necessary to gradually change the farm's specialisation from crop production to livestock production, and cropland (including abandoned cropland) will need to be converted to pasture and hayfields.

It should also be noted that the results obtained are based only on the analysis of the resource potential of land and do not include an economic analysis of the consequences of the proposed land conversion, without which the practical implementation of the developed scenario is hardly advisable. However, they can be considered as a basis for the development of recommendations on the gradual optimisation of land use of the farm to make it more efficient in terms of carbon sequestration and gradual transition to a fully carbon farm.

Table 5. Comparison of land use areas and areas according to the optimal in terms of carbon sequestration on the Emmauss farm area

Current land use	Proposed land type	Suitability class	Area, m^2
Arable land	Marsh	Limited suitable	40 809.1
	Forest	Limited suitable	423.7
	Pasture	Suitable	1 254 997.8
	Pasture	Limited suitable	97 264.6
	Arable land	Limited suitable	276.3
Water surface	Pasture	Suitable	2260.0
	Pasture	Limited suitable	3904.8
Meadow	Marsh	Limited suitable	10 652.7
	Pasture	Suitable	614 018.0
	Pasture	Limited suitable	110 059.5
Drainage channel	Pasture	Suitable	1008.4
	Pasture	Limited suitable	22.9
Forest	Marsh	Limited suitable	24 469
	Pasture	Suitable	163 456
	Pasture	Limited suitable	214 832
Other vegetation	Marsh	Limited suitable	6597
	Pasture	Suitable	159 202
	Pasture	Limited suitable	130 736
Field road	Marsh	Limited suitable	958
	Pasture	Suitable	24 645
	Pasture	Limited suitable	6341
Power mast	Pasture	Suitable	1128
	Pasture	Limited suitable	19
Asphalt road	Pasture	Suitable	16 365
	Pasture	Limited suitable	1625
Structures	Pasture	Suitable	208
Shrubs	Marsh	Limited suitable	2175
	Pasture	Suitable	61 287
	Pasture	Limited suitable	5668
Log store	Marsh	Limited suitable	141
	Pasture	Suitable	747

Source: compiled by the authors.

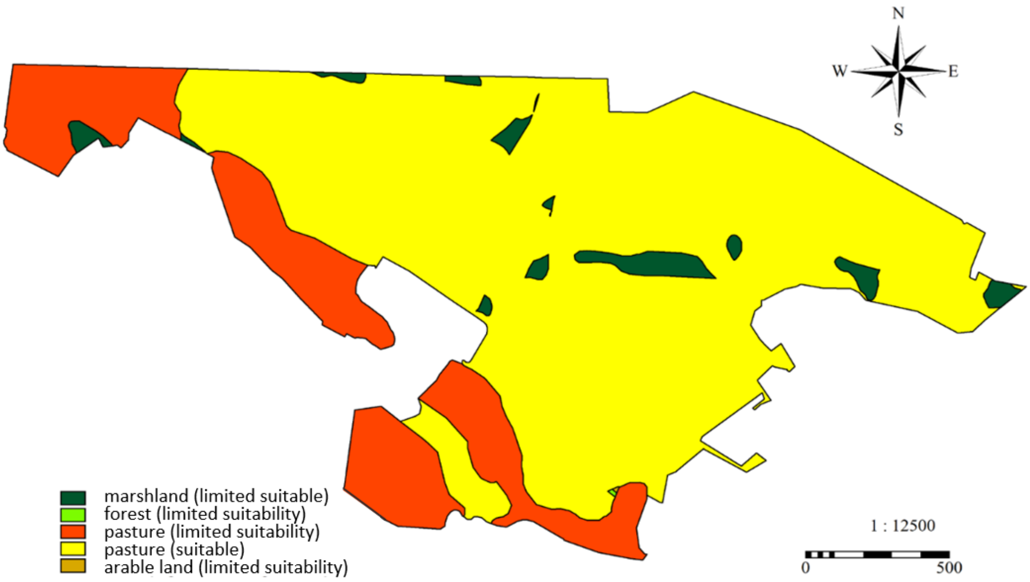

Figure 18. Map of optimal land allocation in terms of carbon sequestration
Source: compiled by the authors.

Conclusion

The study proposed a spatial scenario of optimal land allocation considering carbon sequestration on the example of the farm of the Russian nationwide Research Institute of Reclaimed Lands (Tver region, Kalininsky district, Emmauss settlement).

Such a scenario allows assessing the potential of using farm land as a carbon farm and evaluating the potential for carbon sequestration by agricultural land. The proposed approach should be considered when developing an on-farm land management plan for the planned carbon farm. It is important to note that the study was conducted only based on land resource potential. Further research on the economic efficiency of this type of land allocation should be carried out, as well as research to select potential crops to be placed within the carbon farm.

The establishment of carbon farms can serve as a mechanism to meet the COP26 greenhouse gas emission reduction targets as well as stimulate the development of a carbon trading market.

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