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SYSTEMATIC STUDY OF ARID TERRITORIES

# Factors of Territorial Differentiation of the Agricultural Landscape and Prospects for the Preservation of Steppes in Belgorod Oblast

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**Abstract**—The rational organization of territories with agricultural landscapes, with consideration of the optimal spatial distribution of areas, which reduce agrogenic carbon emission, may favor a smaller carbon footprint of farming at the district level. The transition to carbon-neutral agriculture and the optimization of the agricultural landscape structure are especially urgent for such regions as Belgorod oblast, which provides 4.8% of the total value of farm products in Russia and where there are virgin areas of steppes that effectively regulate the carbon balance. Trends in the dynamics of farm lands in the structure of contemporary agricultural landscapes were revealed and compared to changes in the areas of preserved virgin steppes and lands of the nature reserve fund from an analysis of statistical parameters, cartographic and published data, reports from relevant departments and ministries, and materials of long-term terrain and experimental studies performed by the authors in Belgorod oblast at the intradistrict level in the period from 1990 to 2020. Agro-resource areas, including municipal districts with similar trends of change in areas of farm lands in the structure of agricultural landscapes, with the same farm specialization, and with identical changes in the natural, social, economic, and environmental situation have been identified: (1) an agro-resource area of industrial concentration near large cities in the western and central parts of the region; (2) an agro-resource area of conflicts between agricultural and industrial environmental management in the northern part of the region; (3) an agro-resource area of the southeastern agricultural and industrial part of the region. The key factors determining the potential of farm production and the trends in the dynamics of areas of agricultural landscapes have been identified within these areas. The percentage of specially protected natural areas that are significant for the reduction of agrogenic carbon emission is estimated, and their importance for the maintenance of carbon neutrality in modern economic development is indicated. The areas of agricultural landscapes within the specified agro-resource areas decrease to a smaller rate from the west to the northeast and southeast, but their agricultural–natural potential drops. This is explained by the enhanced effect of negative environmental factors, the insufficient introduction of an adaptive land-use system, the disproportion of investments in the agro-industrial complex, and the smaller number of working people employed in agriculture. It is shown that the conflicts between agricultural and industrial environmental management increase toward the east and northeast. The relationships between the key factors affecting agricultural use of landscapes and the dynamics of the areas of agricultural landscapes within the specified agro-resource areas are determined with the methods of mathematical statistics. The prospects of territorial protection of virgin steppe areas for solution of problems of carbon-neutral agriculture under the conditions of the revealed trends in the dynamics of areas of agricultural landscapes are analyzed. The revealed features of the transformation of the agricultural landscape of Belgorod oblast will enable the optimization of its structure to create a carbon-neutral agriculture and to increase the efficiency of the regional network of specially protected natural areas.

**Keywords:** Belgorod oblast, agricultural landscape, territorial differentiation of land use, virgin and specially protected natural areas, carbon neutrality

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## INTRODUCTION

Belgorod oblast is an long-developed agro-industrial region with economically important agricultural landscapes that provide 4.8% of the total value of farm products of Russia (*Statisticheskii...*, 2019; *Gosudarstvennyi...*, 2020). Natural, climatic, and socioeconomic factors have affected the formation of the modern territorial structure of agricultural land use in the oblast (Nekrich and Lyuri, 2019; *Doklad...*, 2020; Nekrich, 2021).

Belgorod oblast is located in a temperate, continental climate in the forest-steppe and steppe zones of the Central Russian Upland and is deeply dissected by

a valley and ravine network (*Prirodnye...*, 2007). The soil cover is represented by chernozems and gray forest soils (*Prirodnye ...*, 2007). The sum of active temperatures (>10°C) increases and precipitation drops from west to east and to southeast of the area. The moisture supply is moderate in the west and insufficient in the southeast (Strokov et al., 2019). According to open-access data from the National Oceanic and Atmospheric Administration (*Baza po osadkam i temperature...*, 2021) and scientific and applied climate reference books (*Nauchno-prikladnoi...,* 1990; *Nauchno-prikladnoi...,* 2018), the annual precipitation in the region decreased over the past 30-year period. The range comprised 56 mm in the northwestern (the Bogoroditskoe-Fenino observation point) and 116 mm in the southeastern regions (the Valuyki observation point), while there was almost no change in precipitation in the center of the oblast (the Belgorod observation point). The rise in the mean annual air temperature during this period was 0.2–0.6°C with fluctuations from year to year within 4.2–4.5°C. The increase in the sum of active temperatures ranged from 230°C in the northwest of the oblast to 250°C in the southeast. The mean duration of the frost-free period on the soil surface increased from 117 to 155 days in northwestern areas and from 103 to 160 days in the southeast (*Nauchno-prikladnoi...*, 1990, 2018). The duration of the period of active vegetation (the mean daily air temperature above 10°C) increased by 7–10 days (Petin et al., 2017; *Baza...*, 2021). About 70% of annual precipitation occurs in the growing period. The climatic conditions enable the cultivation of grain and vegetable crops in the oblast: the need for heat during the growing season for them ranges from 1200 to 2800°C (*Prirodnye...*, 2007).

Farmlands of the oblast have been gradually excluded from cultivation since the period of crisis and reforms of the 1990s. The area of agricultural lands decreased by 293 100 ha from 1990 to 2006. Despite repeated recommendations to include young steppe fallows into reserves for the expansion of the regional network of specially protected natural areas (SPNAs) (Tishkov, 2003), this process did not result in a large increase in the area of reserved lands in the region. In the next 6-year period, there was a positive dynamics in the area of agricultural land (+47 100 ha), but it began to drop in 2013 and reached 6700 ha by 2020 (Rosstat official website, 2021). This did not compensate for the long-term decrease in the area of cultivated land and, in general, did not significantly affect the territorial protection of zonal steppes in the oblast. In the period of maximal abandonment of agricultural land in the region in 2004 (*Sostoyanie...*, 2005), all types of SPNAs (mainly regional and local) occupied 47 637 ha, which comprised 1.76% of the oblast area. Almost ten years later, on the background of the rise in areas of agricultural lands, 351 territories of regional level and five protected areas of federal level were included in the regional cadastre after the certification of regional and local SPNAs in 2012 (Degtyar' and Grigor'eva, 2016). These were mainly forests (85% of the area); their portion did not exceed 1.3% of the oblast territory, and the mean area of each was only 177 ha.

Comparison of modern data on the area of regional SPNAs with statistical information on the dynamics of the area of agricultural lands in Belgorod oblast shows that the decrease in the agricultural space in the region does not affect the protection of zonal steppe ecosystems, which can effectively regulate the carbon balance in chernozem soils (Sukhoveeva et al., 2020). Only optimization of the structure of the steppe agricultural landscape in long-developed regions, in Belgorod oblast in particular, will result in the use of some inefficient arable lands for the initiation of restorative succession and will favor the solution of problems of carbon-neutral agriculture (carbon agro-industrial complex) in the region. The carbon accumulation in remediating steppes on zonal chernozems will compensate for its long-term losses from arable land (Smelansky and Tishkov, 2012; Chendev et al., 2017).

The carbon reserves in soils of Belgorod oblast vary from 1520 kg C/m$^2$ in forests on soddy-podzolic and gray forest soils to 30–50 kg C/m$^2$ in true and meadow steppes on chernozems (podzolized, leached, and typical). The specific carbon reserves in soils of the oblast are maximal in virgin steppe areas of the Belogor'e Reserve (e.g., the Yamskaya Steppe) and are noticeably lower in the agricultural landscape on arable chernozems (15–30 kg C/m$^2$). When chernozems are excluded from agriculture and their self-restoration begins, the concentration of stable forms of total carbon in them increases: the accumulation rate is to 100–300 g C/m$^2$ per year in the first 5- to 10-year period and 30 g C/m$^2$ per year on average during a 77-year succession period (Lopes de Gerenyu et al., 2009; Kurganova et al., 2010). That is, the optimal ratio between the area of arable lands and remediating steppe fallows in the agricultural landscape, combined with effective measures (the application of organic and mineral fertilizers and erosion control) and the maintenance of high farm production on intensively used lands, will contribute to the transition of the region to carbon-neutral agriculture.

The food security strategy of Belgorod oblast is based on rational management of the land resources that are already used in agriculture, not on a large increase in the area of arable land (Nekrich, 2021). Farming systems that enable the control of the development of destructive natural processes, improvement in the soil fertility, and a decrease in risks of environmental problems have improved (*Strategiya...*, 2019). However, this practice is implemented only locally and not in all municipal districts (MDs) of the oblast. Lands of intensive agricultural use are often located in the affected zone of industrial facilities, a mining complex (MC), residential areas, and transport networks.

There are conflicts between agricultural and industrial environmental management (Degtyar' et al., 2016). The areas that are not used in agriculture and industry are fragmentary. Their area is insufficient for maintenance of the ecological framework and preservation of the biological and landscape diversity under conditions of agro-industrial land use (Tishkov, 2013; Tishkov et al., 2020).

The *goal* of this work is to evaluate changes in the area of farm lands in the structure of agricultural landscapes within MDs of Belgorod oblast with respect to natural, socioeconomic, and environmental conditions, to identify factors that favored or prevented the agricultural use of landscapes in the period of 1990–2020, and to assess the prospects for territorial protection of steppes as the most carbon-intensive ecosystems in the region.

To achieve this goal, the following *tasks* were set:

(i) An analysis of the trends in the change of the areas of agricultural landscapes in Belgorod oblast for the period of 1990–2020 with land statistics and cartographic data;

(ii) The identification of areas that unite MDs with a similar change in the area of farm lands in the structure of agricultural landscapes, a similar farm specialization, and similar variations in natural, social, economic, and environmental conditions.

(iii) The determination of key factors that favor or prevent the effective use of landscapes in agriculture and the correlation between the change in these factors and the dynamics of the areas of agricultural landscapes from 1990 to 2020.

(iv) A comparison of data on the structure of the contemporary agricultural landscape and its dynamics with data on preserved virgin steppe areas in the oblast and the reserve fund to determine the prospects for the preservation of steppes as the most carbon-intensive ecosystems in the region and to use them as a basis for the formation of the ecological framework of the oblast.

The study is of great practical importance in relation to strategic documents Long-Term Forecast of Socioeconomic Development of the Russian Federation for the Period to 2030 (Agro-Industrial Complex) and Strategy of Socioeconomic Development of Belgorod Oblast for the Period to 2025, as well as to the implementation of State Programs Integrated Development of Rural Areas (2020–2025) and Effective Involvement of Agricultural Land in the Turnover and the Development of the Reclamation Complex of the Russian Federation (2021–2030). In addition, the implementation of the Ecology National Project in Russia includes a number of activities in the period to 2024 that may change the structure of the agricultural landscape in this long-developed agro-industrial region: the proportion of natural and remediating ecosystems may increase (for example, according to the article Liquidation of Landfills and Reclamation of Territories of their Location, via the remediation of unproductive fields, etc.). In 2019, Belgorod State National Research University became the base university of the Belgorod Scientific and Educational Center for Innovative Solutions in Agricultural and Industrial Complex. The research performed for this article will enable the elaboration of an optimal functioning regime of the steppe agricultural landscape of the oblast within the framework of the program for the creation of a network of carbon sites. The oblast includes a particular portion of natural steppe ecosystems that are oriented towards the respiration of greenhouse gases during remediation succession. In February 2021, the Ministry of Science and Higher Education of the Russian Federation set up a pilot project to create a network of carbon sites in Russia for the development and testing of carbon balance control technologies. The Institute of Geography of the Russian Academy of Sciences participates in these works, and the prospects of Belgorod oblast are quite great (Ministry of Education and Science..., 2021).

## MATERIALS AND METHODS

The territorial differentiation of agricultural landscapes of Belgorod oblast is studied with allowance for changes in the natural, socioeconomic, and environmental conditions according to the methodology created at the Institute of Geography of the Russian Academy of Sciences under the leadership of Runova et al. (1993). The methodology is based on the concept of resource management as a factor of the transformation of natural, environmental-geographical, and socioeconomic space (*Prirodopol'zovanie*..., 2014). It was developed in works on the creation of environmentally sustainable agricultural landscapes for optimal farming (Barsukova and Derevenets, 2016).

In this work, we used remote-sensing data to identify preserved virgin areas of steppe vegetation of Belgorod oblast (Tishkov et al., 2020). In total, more than 700 plots were identified in an area of about 39000 ha (about 2% of the oblast area), some of which were described and verified with terrain methods. The existing regional SPNAs of the oblast are too small to be shown on the map. Complex nature reserves are the greatest in number and in area among SPNAs (Table 1).

*The first task* of the study was solved with the use of a database (DB) compiled in Microsoft Excel containing information on the change in the area of agricultural lands within each MD of Belgorod oblast for the period of 1990–2020. This enabled us to determine the directions of the dynamics of areas of agricultural landscapes and to quantify the change in their areas.

The database was supplemented by the following parameters: (i) *environmental disturbances* (areas of erosion-hazardous lands, ravines, and karst lands); (ii) the *moisture supply of the territory* and the *agricultural climate productivity* (the bioclimatic potential

**Table 1.** Regional natural parks and reserves of Belgorod oblast (*Offitsial'nyi sait upravleniya...*, 2021) on August 1, 2021

| Municipal district | Natural parks | | Nature reserves | | Integrated nature reserves | |
|---|---|---|---|---|---|---|
| | amount | area, ha | amount | area, ha | amount | area, ha |
| Alekseevskii | – | – | 9 | 701.0 | – | – |
| Belgorodskii | 1 | 1556.2 | 10 | 9637.0 | 1 | 12860.0 |
| Borisovskii | 1/2 | 9077.0 | 7 | 732.3 | – | – |
| Valuiskii | 2 | 47.0 | 10 | 2192.5 | 2 | 44900.0 |
| Veidelevskii | 4 | 75.0 | 4 | 75.0 | 1 | 9932.0 |
| Volokonovskii | 1 | 57.0 | 15 | 495.9 | 2 | 18795.0 |
| Gaivoronskii | 1/2 | 1916.0 | 5 | 263.8 | – | – |
| Gubkinskii | – | – | 3 | 318.0 | 2 | 32823.0 |
| Ivnyanskii | – | – | 6 | 581.1 | – | – |
| Korochanskii | – | – | 2 | 55.0 | – | – |
| Krasnenskii | – | – | 3 | 91.0 | 1 | 12035.0 |
| Krasnogvardeiskii | – | – | 48 | 2605.1 | 2 | 4066.2 |
| Krasnoyaruzhskii | | | 2 | 44.4 | 1 | 10949.6 |
| Novooskol'skii | 1 | 575.0 | 2 | 319.0 | – | – |
| Prokhorovskii | – | – | 6 | 1074.3 | 1 | 9789.5 |
| Rakityanskii | – | – | 8 | 360.9 | – | – |
| Roven'skii | 1 | 1338.1 | 2 | 830.0 | – | – |
| Starooskol'skii | 1 | 1091.0 | 3 | 465.4 | – | – |
| Chernyanskii | – | – | 3 | 1216.4 | – | – |
| Shebekinskii | 2 | 269.2 | 20 | 894.7 | – | – |
| Yakovlevskii | – | – | 10 | 3182.3 | – | – |

(BCP) and humidity coefficient according to Sapozhnikova ($K_{hum}$), modifications of which reflect the complex impact of changes in the regional climate system on the production capabilities of agricultural landscape (Snakin and Khrisanov, 2001)); (iii) the *impact of economic activity on the natural environment* (areas that underwent technogenic contamination during the operation of industrial enterprises, MC and AIC facilities; storage areas of waste material (WM); a number of enterprises for the disposal and processing of industrial waste (IW); and the number of facilities with stationary sources of environmental pollution); (iv) the *agricultural activity* (the volume of crop yields per harvested area and the volume of mineral fertilizers applied on croplands); and (v) the *socioeconomic* parameters (the number of economically active rural population; the volume of investments into the AIC; the volume of agricultural products; and the number of profitable agricultural enterprises).

The choice of parameters is determined by a comprehensive characteristic of Belgorod oblast as a region with increasing agricultural production, dynamics of areas of farm land, conflicts of nature management, a change in the number of economically active rural population, and uneven investment in economic sectors.

At *the second stage of the study*, the database was integrated into the ArcGIS software for a combined spatial and time analysis of the impact of these parameters on the dynamics of the areas of agricultural landscapes at the intradistrict level in 1990–2020. We distinguished three areas that unite MDs that are similar in terms of the natural conditions of the formation of agricultural the type of environment disturbances, the specifics of economic development, and the environmental and socioeconomic conditions: (1) an agro-resource area of industrial concentration near large cities in the west and center of the region; (2) an agro-resource area with conflicts of agricultural and industrial environmental management in the north of the region; and (3) an agro-resource area of the southeastern agricultural and industrial part of the region. The intersector relations between MDs were taken into account. The distinguished areas reflect intraregional differences in the organization of nature management and the specificity of relations that formed as a result of the interaction of the natural environment, economy, and population.

In *the third stage of the study*, the Pearson linear correlation coefficient was calculated with the Microsoft Excel software (the CORREL function, which returns the correlation coefficient of two data massifs) in order

to identify the relationship between the change in the areas of agricultural landscapes (%) and the change in the value of each parameter in the database (%) at the intradistrict level within each distinguished area in the period of 1990–2020. The strength of the relationship was assessed with the Chaddock scale: weak ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), significant ($0.5 < r < 0.7$), great ($0.7 < r < 0.9$), and very great ($0.9 < r < 0.99$) (Koterov et al., 2019). All of the revealed dependences were described by linear functions with a coefficient of approximation confidence of $R^2 > 0.71$. The statistical significance of the correlation coefficient was checked with the Student *t*-test. The measurement frequency (*n*) for each area corresponded to the number of MDs in this area. The number of degrees of freedom (*df*) for each area was determined with the formula $df = (n_1 + n_2) - 2$. The critical value of the Student *t*-test ($t_{cr}$) for the significance level $\alpha = 0.05$ (at which the strength of relationship is significant) with allowance for the *df* was compared with the calculated one. The calculated Student *t*-test was greater than $t_{cr}$, which indicated the statistical significance of *r* (the significance level <0.05). Correlation analysis enabled us to identify the most important factors determining the dynamics of the areas of agricultural landscapes at the intradistrict level within the specified areas during the analyzed period.

In *the fourth stage of the study*, data on the structure of the contemporary agricultural landscape and its dynamics in the period from 1990 to 2020 were compared with data on preserved virgin steppe areas in Belgorod oblast and on lands under a preservation regime.

In this work, we used official data from the Federal State Statistics Service on municipal districts of the oblast (Rosstat official website, 2021) and Belgorod Statistic Survey (*Itogi*..., 2018; *Statisticheskii*..., 2019); reports of the Russian State Register (*Doklad*..., 2015, 2020, 2021), of the Department of Agro-Industrial Complex and Environmental Reproduction of Belgorod oblast (Degtyar' et al., 2016; *Gosudarstvennyi*..., 2020) and from the Department of Economic Development of Belgorod Oblast (*Strategiya*..., 2019); cartographic materials of the Belgorod Agrochemical Service Center (*Prirodnye*..., 2021) and the Belgorod State Research University; reports from the Ministry of Agriculture of the Russian Federation (Gordeev et al., 2006); climate reference books (*Nauchno-prikladnoi*..., 1990; *Nauchno-prikladnoi*..., 2018); and databases from the National Oceanic and Atmospheric Administration Research (Climate Data Online..., 2021).

It is taken into account that the Resolution of the Government of Belgorod oblast of August 15, 2016 (no. 299-pp) approves the list of SPNAs of regional importance (300 in total), which are dominated by forest areas (Resolution..., 2016) on lands of the forest fund and settlements. Steppe SPNAs in the agricultural landscape (on farm lands) only include the territories of some regional nature reserves, e.g., a plot of virgin steppe near the village of Kovalevo (380 ha), Melovaya Mountain near the village of Belomestnoe (30 ha), etc., which intentionally preserve steppe ecosystems.

From our point of view, there is a unique phenomenon in Belgorod oblast: fragments of secondary forests and forest plantations, including those on the lands of settlements (not areas of preserved zonal vegetation (meadow and true steppes)), become the objects of territorial nature protection. This fact and differences in interests of the forestry and agricultural departments may explain the fact that steppe areas on abandoned plowed lands rarely become objects of territorial protection.

Data of the Management of Forests of Belgorod oblast testify that there are 314 SPNA with a total area of 301 106.9 ha (Forest Department..., 2021). According to the report on the status and use of lands in Belgorod oblast for 2020 (*Doklad o sostoyanii*..., 2021), the lands of protected areas still occupy 2800 ha, or 0.1% of the total area of the oblast (on January 1, 2021). They include the lands of the Belogor'e Nature Reserve and its plots: Forest on Vorskla in Borisovskii district, Yamskaya Steppe and Lysye Mountains in Gubkinskii district, and Stenki Izgor'ya in Novooskol'skii district. It is important that these are data on nature protection lands, while regional SPNAs are mainly allocated to forest and agricultural lands and lands of settlement and are assigned to other statistical categories. As a result, regional nature reserves, natural parks, and natural monuments on farm lands (within agricultural landscape) are not accounted for, although objects corresponding to this status (preserved areas of steppe vegetation, old fallows, degraded steppe pastures, etc.) are present in their structure.

## RESULTS AND DISCUSSION

The areas of agricultural landscapes in Belgorod oblast decreased by 167 500 ha from 1990 to 2020. The dynamics of the areas comprised: −44 500 ha for arable land, −48 700 ha for pastures, +17 000 ha for hay lands, and +6700 ha for permanent crops in farms of all categories (Rosstat official website..., 2021). The areas of abandoned agricultural land gradually decreased during the 30-year period, and steppe fallows were plowed or transformed into lands of industry and settlements. The chance to create steppe SPNAs on old fallows was missed (Kitov et al., 2016). The area of fallows amounted to 12 500 ha in 2016, which was the smallest area in the Central Federal okrug according to the data of the All-Russia Agricultural Inventory (*Itogi*..., 2018) and did not exceed 100 ha by 2020 (*Doklad*..., 2020). The area of croplands decreased by 161 000 ha from 1990 to 2020. Arable lands that were not excluded from agricultural rotation, were not transformed into other types of farm lands or into

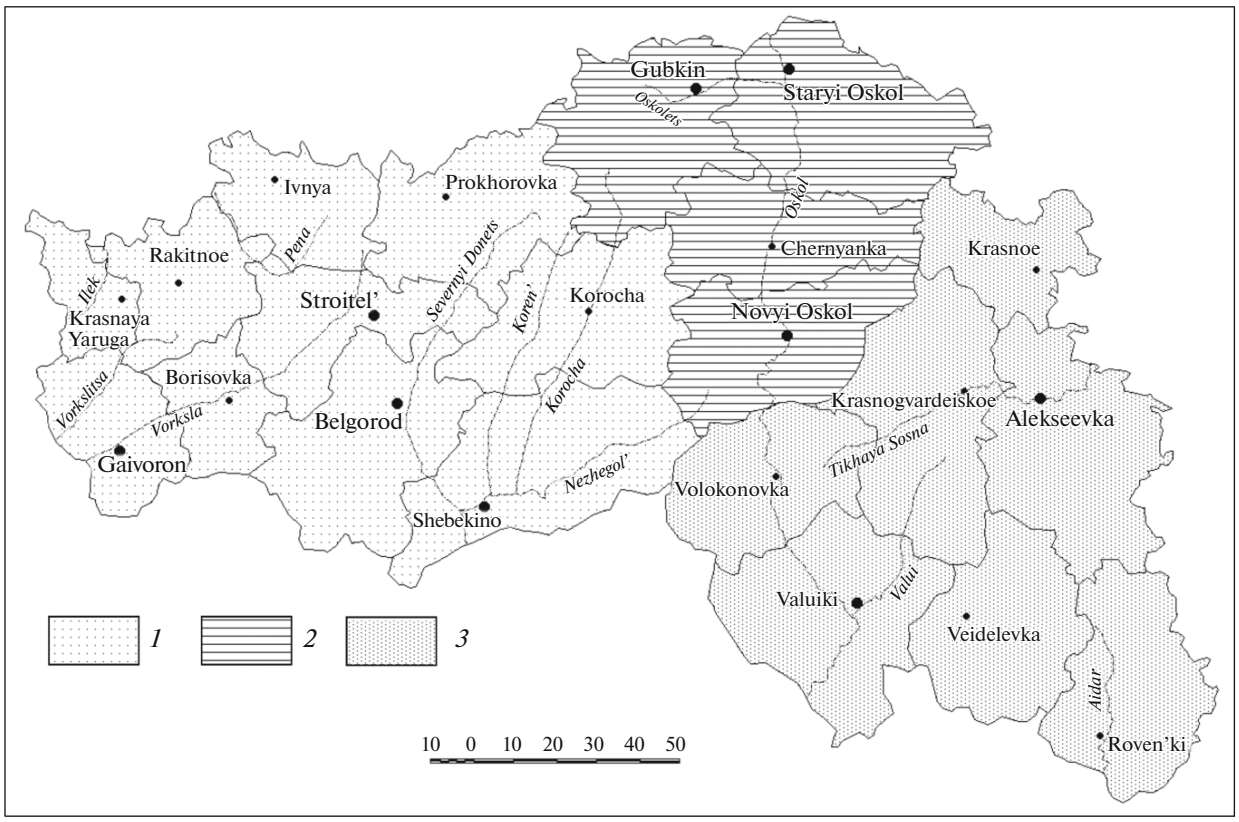


**Fig. 1.** Territorial differentiation of agricultural landscapes in Belgorod oblast. Designations: *1*—agro-resource area of industry concentration near large cities in the west and center of the oblast, *2*—agro-resource area of conflicts between agricultural and industrial nature management in the north of the oblast, and *3*—agro-resource area of the southeastern agricultural and industrial part of the oblast.

another category, and were not used for crops were occupied by perennial grasses (*Prirodnye...*, 2007).

There have been positive trends in the dynamics of croplands in some MDs of Belgorod oblast since 2014 (+4.9% in Belgorodskii, +0.5% in Krasnoyaruzhskii, and +6.4% in Novooskol'skii MDs) (*Doklad...*, 2015, 2020, 2021) on the background of a decrease in the area of agricultural lands (by 11.2% for the oblast). Although the increase in the cropland area have not reached the 1990 values since 2014, the crop production in actual prices increased by 70% with a rise in the yield from 2.0 to 4.6 t/ha of harvested area (*Statisticheskii...*, 2019). This may be explained by application of the adaptive land-use approach in agriculture, the introduction of precision farming systems, the use of agrotechnologies in accordance with the landscape and environmental features of the region, fertilizer application, and investments (their largest amount was spent in agriculture) (*Strategiya...*, 2019). In 2020, the mean yield of grain crops was 2.89 t/ha in Russia (Medvedeva, 2021) and reached 5.53 t/ha in Belgorod oblast, which compensated for the decrease in the agricultural space there.

Areas that unite MDs that are similar in the change in the area of farm lands in the structure of agricultural landscapes, the farming specialization, and the changes in the natural, social, economic, and environmental conditions in the period of 1990–2020 are distinguished in Belgorod oblast (Fig. 1).

(1) *Agro-resource area of industrial concentration near large cities in the west and center of the oblast* (Fig. 1, area 1). This area is located in the forest-steppe zone. It formed in the place of cereal and forbs steppes and steppe meadows on slightly and medium eroded typical chernozems, leached chernozems, and dark-gray forest soils. The main natural factors limiting the development of agriculture include karst (the number of open karst elements of topography increased by 10% during the period of 1990–2020 and ranges from 10 to 25 elements per 100 km$^2$) and the dense valley–ravine network (its density varies from 0.6 to 0.8 km/km$^2$) (*Prirodnye...*, 2021). The applied adaptive land-use system of agriculture, in combination with erosion control measures, favors lesser growth of eroded areas (*Doklad...*, 2020), the proportion of which among farm lands reaches 65% (Strokov et al., 2019).

The agriculture is specialized in poultry and dairy farming in combination with vegetable growing (*Prirodnye...,* 2021). In 1990–2020, there was a 7% increase in the portion of arable land and a 5% increase in hay-

fields (Rosstat official website, 2021), but the area of agricultural landscapes decreased by 4% due to the transformation of farm lands into industrial lands and lands of settlements (*Doklad...*, 2015, 2020, 2021). The area of crops decreased by 65 722 ha, or by 9.9% (Offitsial'nyi sait Rosstata, 2021). According to the data of the All-Russia Agricultural Inventory, the area of fallows decreased by 6337.5 ha (in 2016–2020). The agricultural landscapes are located on lands of increased anthropogenic load: near suburbs, district centers, industrial zones, and highways (Degtyar' et al., 2016). The air, surface water, and soil pollution is moderate (*Strategiya...*, 2019).

The area of agricultural lands decreases upon an increase in the number of facilities of industry and AIC with stationary pollution sources (production complexes, landfills of household waste, poultry farms, dairy farms, pig breeding complexes, etc.; $r = -0.49$, the strength of relationship is moderate), and it decreases in parallel with the number of enterprises for the disposal and processing of industrial waste ($r = 0.50$, the strength of relationship is moderate). It was found that the area of agricultural land decreases in parallel with the number of the working rural population ($r = 0.56$, the strength of relationship is significant). Despite the rise in the BCP (+2.2%), the areas of agricultural landscapes have not increased, which may be explained by smaller moisture supply of the area (the change in the Sapozhnikova humidity coefficient ($K_{hum}$) is –7.5%). The crop yields rose (by 52%) and agricultural production increased despite a decrease in the area of farm land ($r = -0.60$, the strength of relationship is significant, Table 2).

(2) *Agro-resource area of conflicts of agricultural and industrial nature management in the north of the oblast* (Fig. 1, area 2). The area is allocated to cereal and forb–steppes and steppe—meadows that formed on medium and strongly eroded chernozems (typical, calcareous, and leached) and on gray and dark-gray forest soils. During the period of 1990–2020, the area of eroded soils within the area increased by 30%. The number of karst elements increased by 15% and reached 30 elements per 100 km$^2$. The rise in the areas occupied by ravines was 15%. The density of the valley–ravine network reached 1.2 km/km$^2$. About 60% of the farm land area underwent soil degradation (Strokov et al., 2019).

The areas of agricultural landscapes decreased by 1.5% during the period of 1990–2020 due to the transformation of farm lands into lands of industry and settlements (*Doklad...*, 2019). There was a 10% increase in the area of arable land and a 4% increase in permanent crops in the structure of agricultural lands of the oblast. The area of fallows decreased by 2962.9 ha (in 2016–2020). The area of crops decreased by 30452 ha, or by 8.9% (Rosstat official website, 2021). However, their decrease was not constant: there was a rise of 18827 ha, or by 6.5%, since 2014. Agriculture (dairy farming and crop production) is often allocated to the affected zone of the open-pit mining of the Kursk magnetic anomaly and mining enterprises (*Prirodnye...*, 2021).

The deterioration of the environmental conditions due to pollution of the atmospheric air, surface waters, and soils by industrial enterprises is strong (*Strategiya...*, 2019). The development of deposits is often not accompanied by land reclamation. The negative technogenic impact on the natural environment affects the status of the soil and plant cover: a 2- to 10-fold excess of iron content as compared to the background was detected in the arable horizon of typical chernozems at a distance to 20 km from the MC (*Prirodnye...*, 2007; *Doklad...*, 2020, 2021).

It was found (Table 2) that the change in the area of landscapes useful for agriculture correlates with the variation in areas undergoing technogenic pollution from MC and AIC and in the storage areas of WM ($r = -0.92$, the strength of relationship is strong; and $r = -0.40$, the strength of relationship is moderate, respectively). The area of agricultural landscapes also decreases upon an increase in the number of objects with stationary sources of environmental pollution ($r = -0.83$, the strength of relationship is high). The larger the area of erosion-hazardous and karst lands is, the smaller is the area of agricultural landscapes undisturbed by these processes ($r = -0.82$, the strength of relationship is high; $r = -0.61$, the strength of relationship is significant, respectively). Smaller investments in the AIC have caused a decrease in the area of agricultural landscapes ($r = 0.91$, the strength of relationship is great). The relationship between the change in the number of rural population and in the area of agricultural landscapes is weak (Table 2).

(3) *Agro-resource area of the southeastern agricultural and industrial part of the region* (Fig. 1, area 3). It was formed in place of steppes with *Festúca valesiáca* and *Stipa* spp. on medium and strongly eroded, calcareous-cretaceous, typical and ordinary chernozems. Over the period of 1990–2020, the area of eroded soils increased by 5%, and the portion of eroded agricultural land reaches 85% (Strokov et al., 2019). The density of the valley–ravine network does not exceed 1 km/km$^2$. The number of karst elements of the topography increased by 4% and is now five elements per 100 km$^2$. Deflation affects 20% of agricultural land (*Prirodnye...,* 2021). The BCP increased during the study period (+5.5%). However, a rise in the total active temperatures and the duration of the growing season did not compensate for the decrease in the area humidification (the change in the Sapozhnikova humidification coefficient reached –6.5%). This did not favor the productive capacity of agricultural landscapes (Gordeev et al., 2006; Petin et al., 2017).

Dairy farming, pig breeding, poultry farming, grain farming, and vegetable growing are developed within the area (*Prirodnye...*, 2021). There was almost no

**Table 2.** Correlation between factors (affecting the use of landscapes in agriculture) and the dynamics of areas of agricultural landscapes in Belgorod oblast at the regional level in 1990–2020

| Change in the areas of agricultural landscapes (%) within agro-resource areas | Key factors affecting the use of landscapes in agriculture, change in parameters, %* | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | natural | | | | | economic | | | | | | socioeconomic | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | correlation coefficient ($r$) | | | | | | | | | | | | | | |
| Concentration of industry near large cities in the west and center of the oblast (ten municipal districts) | –0.41 | –0.23 | –0.31 | –0.32 | – | –0.31 | –0.50 | 0.50 | –0.49 | –0.60 | –0.30 | 0.56 | – | –0.60 | –0.28 |
| Conflicts between agricultural and industrial nature management in the north of the oblast (four municipal districts) | –0.82 | –0.42 | –0.61 | – | – | –0.92 | –0.40 | – | –0.83 | – | – | 0.21 | 0.91 | –0.81 | 0.81 |
| Conflicts between agricultural and industrial nature management in the southeastern agricultural and industrial part of the oblast (seven municipal districts) | –0.53 | –0.31 | –0.21 | – | 0.36 | 0.81 | –0.40 | –0.20 | –0.60 | –0.80 | – | 0.53 | – | –0.25 | 0.59 |

* Parameters: 1—areas of erosion-hazardous lands (ha), 2—areas of ravines (ha), 3—areas of karst lands (ha), 4—bioclimatic potential; 5—Sapozhnikova humidification coefficient ($K_{hum}$), 6—areas that underwent technogenic pollution during the operation of industrial enterprises, MC, and AIC (ha), 7—areas of storage of industrial waste (ha), 8—the number of enterprises for the disposal and processing of industrial waste (unit), 9—the number of objects with stationary sources of environmental pollution (unit), 10—crop productivity per harvested area (centner per hectare), 11—application of mineral fertilizers (recalculated per 100% of nutrients) for crops (centner), 12—the number of economically active rural population (people), 13—the volume of investments into the agro-industrial complex (ruble), 14—the volume of agricultural production (ruble), 15—the number of profitable agricultural organizations (unit).

change in the areas of agricultural landscapes during the period of 1990–2020, but the portion of pastures in the structure of agricultural lands increased by 9%. The decrease in the area of crops reached 61 803 ha, or 11% (Rosstat official website, 2021). According to data from the All-Russia Agricultural Inventory, the area of fallows decreased by 31 564 ha (2016–2020). The impact of the AIC on the components of natural environment is moderate (*Gosudarstvennyi...*, 2020) and does not exert a negative effect on nature and population (*Strategiya...*, 2019).

It was found (Table 2) that an increase in the area of soil erosion is accompanied by a drop in arable land ($r = –0.53$, the strength of relationship is significant). With a rise in the number of objects with stationary sources of pollution, the area of noncontaminated arable land decreases ($r = –0.60$, the strength of relationship is significant). The stabilization of areas of agricultural landscapes is accompanied by a rise in crop yields per harvested area ($r = –0.80$, the strength of relationship is high, Table 2) and in the number of profitable agricultural organizations ($r = 0.59$, the strength of relationship is significant, Table 2). There is a moderate relationship between the dynamics of areas of agricultural landscapes and the change in the moisture supply of the area ($r = 0.36$) and a weak rela-

tionship between the change in the BCP and in the area of agricultural landscapes. The drop in the working rural population resulted in a decrease in cropland area ($r = 0.53$, the strength of relationship is significant; Table 2).

**Prospects for the preservation of steppes in Belgorod oblast under new trends in the dynamics of the structure of the agricultural landscape.** The total area of SPNAs of all categories and management levels in Belgorod oblast is 47600 ha, which is only 1.8% of the oblast area. This is one of the lowest values among the subjects of the Russian Federation (according to the recommendations of the Sustainable Development Goals, it is 17%). The regional network of protected areas here is mainly formed by plots of secondary forests and areas unsuitable for agriculture. There are almost no steppes (Smelyansky and Tishkov, 2012; Smelyanskii and Titova, 2018). The proportion of forests in SPNA reaches 80–85% with a mean area of 100–150 ha, which makes it impossible to use a preservation regime, because they may undergo the effect of neighboring areas under economic use.

Different trends in the status of the agricultural landscape revealed in areas 1–3 make it possible to assess their focus on territorial nature protection and the development of a regional network of SPNAs. *Area 1* (meadow-steppe) has a pronounced tendency toward a reduction of the area of agricultural landscapes and includes districts with the maximal proportion of SPNAs (Borisovskii (17.1%), Belgorodskii (15.1%), and Gaivoronskii (6.6%)) and their minimal proportion (Korochanskii (0.02%), Shebekinskii (0.6%), and Ivnyanskii (0.6%)).

Within *area 2*, there are no districts with the maximal proportion of regional SPNA. In general, their area comprises from 2.1% (Gubkinskii district) to 0.4% (Novooskol'skii district) and is 1.0% in the Starooskol'skii and Chernyanskii districts.

*Area 3*, the steppe southeastern area, is characterized by less contrasting proportions of regional SPNAs: the maximal ones are in the Veidelevskii (8.3%) and Volokonovskii (6.6%) districts and the minimal ones are in Alekseevskii (0.4%), Krasnogvardeiskii (1.1%), and Roven'skii (1.2%) districts.

Due to specific features of carbon sequestration in the steppe ecosystems of Belgorod oblast, their carbon intensity, and the long-term storage and sequestration of carbon in chernozems, which occupy about 75% of the area here, it may be concluded that the increase in the area of steppe SPNAs will significantly reduce agrogenic carbon emission and increase its fixation and accumulation. The long-term carbon losses as a result of the plowing of meadow and real steppes in the oblast amount to 20–30% of its initial content (*Prirodnaya...*, 1989; Smelansky and Tishkov, 2012). The removal of steppe ecosystems from plowing and their assignment to SPNAs allows carbon fixation from the atmosphere during the secondary succession at a rate of 1.0 to 2.0 t/ha per year and its long-term (for thousands of years) sequestration (to 700 and more t/ha). During the period of abandonment of agricultural land in steppe regions, the rate of carbon sequestration at the start of secondary succession on fallows of the steppe zone of the Russian Plain is to 2.5 kg/ha per year during the first 15-year remediation period, depending on the type of chernozem and on the fallow age. In the next 15-year period, the accumulation rate may decrease by half, to 0.9 kg/ha per year (Kurganova et al., 2010). If we take into account that the remediation period of steppe ecosystems on fallow is from 30 to 60 years (Tishkov, 2012), then the formation of a sustainable carbon neutrality core within the agricultural landscape of Belgorod oblast is obvious.

## CONCLUSIONS

Areas uniting MDs that are similar in terms of the trends in the change of areas of farm lands in the structure of agricultural landscapes, the agriculture specialization, and changes in the natural, social, economic, and environmental conditions that formed in Belgorod oblast during the period of 1990–2020: (1) *agro-resource area of industry concentration near large cities in the west and center of the oblast*; (2) *agro-resource area of conflicts between agricultural and industrial environmental management in the north of the region*; and (3) *agro-resource area of the southeastern agricultural and industrial part of the region*. A comprehensive analysis of the natural conditions and economic and socioeconomic relations between MDs within each area may favor the solution of problems of the creation of an optimal spatial organization of branch-specific agriculture in Belgorod oblast and the development of mechanisms to reduce carbon footprint at the intra-district level.

The agricultural landscapes within the specified agro-resource areas are characterized by a small decrease in the areas from the west to the northeast and southeast, but their agro-natural potential drops significantly. This is explained by the increased effect of negative environmental factors, the insufficient implementation of the adaptive land-use system in agriculture, the disproportion in investments in the AIC (more than 300 billion rubles were invested in the agro-industrial complex over the past 15 years, and more than a half of this sum was spent for industrial poultry and pig farming, while improvement of the farming system itself was not sufficiently supported (Gritskov, 2020)), and a reduction in the working population employed in agriculture. The conflicts between agricultural and industrial environmental management increase to the east and northeast.

In *area (1)*, the decrease in the areas of agricultural landscapes during the study period is caused by: an increase in the storage areas of WP, a decrease in the amount of enterprises for the disposal and processing of IW, and smaller number of economically active

rural population. In *area (2),* the areas of agricultural landscapes decreased due to an increase in the areas of erosion-hazardous and karst lands, the areas undergoing man-made pollution during the operation of enterprises of the MC and the AIC, and the number of facilities with stationary sources of environmental pollution and due to a decrease in investments in the AIC. In *area (3)*, the dynamics of the areas of agricultural landscapes is affected by a smaller moisture supply, an increase in the amount of profitable agricultural organizations and of objects with stationary sources of pollution, and a decrease in the number of economically active rural population.

A highly efficient agriculture in Belgorod oblast can be maintained by a rational, territorial organization of the agricultural landscape that takes into account the existing natural, economic, environmental, and social factors, as well as the optimization of its structure due to greater portion and area of steppe SPNAs, where carbon will accumulate at the rate of 1.0–2.0(2.5) t/ha per year at the beginning of restoration processes in chernozems until the restoration of its zonal pool (700 t/ha and higher). The carbon losses in agriculture may be compensated for as a result of the optimal proportion of steppe SPNAs in the agricultural landscape (apparently, at least 10–15%), which is calculated as the difference between the mean rates of soil emission and $CO_2$ fixation. This optimization of the agricultural landscape in Belgorod oblast will enable the formation of carbon-neutral agriculture and carbon AIC in the future.

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## COMPLIANCE WITH ETHICAL STANDARDS

*Conflict of interests*. The authors declare that they have no conflicts of interest.

*Statement on the welfare of humans or animals*. This article does not contain any studies involving humans or animals performed by any of the authors.

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