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Assessing the Impact of Land Degradation on Agricultural Output Using a Stochastic Frontier Production Function [1]

Abstract. Land degradation is a widely discussed and pressing global issue, as highlighted in the UN Sustainable Development Goals (SDGs). Understanding the extent of land degradation and its impact on agriculture requires precise research and an interdisciplinary approach due to the complexity of factors and indicators that characterize the issue. This paper focuses on one of Russia's key agricultural regions, Samara Oblast, to examine how land degradation of agricultural soils affects crop production at the farm level. The dataset used in the study includes farm inputs (costs, land, and labour) and land quality variables, such as organic content (humus), levels of land degradation and soil erosion, as well as climate indicators, at the municipal level. To analyse the relationship between land degradation and agricultural output, the stochastic frontier analysis (SFA) was employed. This method not only estimates the parameters of a classic production function but also accounts for errors in the model by evaluating parameters related to risk and technical inefficiency. The results indicate that the proportion of degraded land in a district of the given region moderately reduces the maximum potential for crop production. In contrast, most inputs—such as production costs, cropland area, and labour—contribute positively to output. The study suggests that both the method and the estimates could be refined if data on land degradation, alongside other economic and environmental indicators, were collected and published annually.

Keywords: land degradation, soil erosion, production functions in agriculture, stochastic frontier analysis

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ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ

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Анализ влияния деградации земель на производство сельскохозяйственной продукции с помощью производственной функции со стохастической границей

Аннотация. Деградация земель – важная проблема современного общества, которая нашла своё отражение в Целях устойчивого развития ООН (ЦУР). Масштаб деградации земель и её влияние на сельскохозяйственную деятельность приводят к необходимости подробного исследования и применения междисциплинарного подхода с учетом специфических черт и индикаторов, характеризующих данное явление. В настоящей представлен анализ влияния деградации земель сельскохозяйственного назначения на выпуск продукции растениеводства на уровне ферм в одном из ключевых агропромышленных регионов России — Самарской области. В качестве данных использованы показатели, характеризующие средства сельскохозяйственного производства (затраты, площадь возделываемых земель, трудовые ресурсы), а также показатели качества почв, такие как содержание органических веществ (гумуса), доля деградированных земель, эрозия почв. Для выявления взаимосвязи между деградацией земель и выпуском сельскохозяйственной продукции использован метод производственной функции со стохастической границей, поскольку он не только позволяет оценить параметры классической производственной функции, но и учитывает ошибки модели в части рисков и технической неэффективности. Результаты исследования показали, что доля деградированных земель в конкретном регионе умеренно влияет на потенциал растениеводческой продукции. В то же время большая часть факторов производства, таких как затраты на производство, площадь посевов, трудовые ресурсы, напротив, позволяют увеличить производство. Используемый метод и полученные оценки могут быть улучшены, если появится возможность ежегодного сбора и публикации данных о деградации земель и других экономических и экологических индикаторах.

Ключевые слова: деградация земель, эрозия почв, производственные функции в сельском хозяйстве, метод стохастической границы

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Introduction

Land degradation is a pressing global challenge, featured in the United Nations Sustainable Development Goals (SDGs) for 2030, particularly in Goals 12 (Sustainable Consumption and Production) and 15 (Life on Land). Goal 12 states that "land degradation, declining soil fertility, unsustainable water use … are all lessening the ability of the natural resource base to supply food"[1]. One of the targets of Goal 15 is to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world"[2].

Land degradation as a research problem requires a comprehensive and consistent approach, as recent studies reveal significant variations in estimates. Nkonya et al. (2016) found that differences in methodology, scale, and the inclusion of ecosystem service values result in

[1] See "Facts and figures" for Goal 12 at this link — URL: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/ (date of access 1 December 2023).

[2] See "Goal 15 targets" at this link — URL: https://www.un.org/sustainabledevelopment/biodiversity/ (date of access 31 October 2024).

global cost estimates ranging from $21 billion to $9,400 billion (in 2007 USD). Soil erosion, a key indicator of land degradation, represents the loss of soil from a specific area, typically measured in tons of soil or organic matter per hectare. The FAO's Global Soil Partnership reports that annual soil loss from arable land can reach up to 75 billion tons, leading to financial losses of nearly $400 billion each year[1]. Borrelli et al. (2017) critique previous estimates of soil erosion and propose a new methodology that highlights the effects of land use changes—such as deforestation and the conversion of natural land to cropland—and rainfall on soil erosion. Their findings indicate that current global soil losses amount to 36 billion tons per year, with an average global erosion rate of 2.8 tons per hectare annually, which is nearly half of the FAO's earlier estimate. The latter was developed into modern spatially explicit tool named Global Soil Erosion map[2] with estimates for every country of the world for years 2001 and 2012.

Among countries with extensive cropland areas, Russia stands out for having one of the lowest soil erosion rates (Sartori et al., 2019). In contrast, countries like Brazil, the USA, India, Australia, and China have soil erosion rates at least 3–4 times higher than Russia's. This disparity is primarily due to significant land use changes, such as deforestation and the conversion of natural lands into cropland, as well as greater climate vulnerability (Sartori et al., 2019; Borrelli et al., 2017). In Russia, much of the current research on soil erosion focuses on comparing present rates to those of the Soviet era, typically the 1980s. These studies often highlight a reduction in cropland areas and corresponding declines in soil erosion rates, particularly in the European part of Russia (Golosov et al., 2018; Litvin et al., 2017; Ivanov, 2018). For example, Litvin et al. (2017) analysed average soil erosion rates from 2012–2014 compared to 1980 for several regions in this area. In Samara Oblast, erosion rates decreased by 13.8 % in the forest-steppe zone and by 11.7 % in the steppe zone. According to the Global Soil Erosion map, the average soil erosion rate in Samara Oblast in 2012 was 0.28 tons per hectare, slightly lower than the 2001 level of 0.29 tons per hectare per year (Borrelli et al., 2017). These rates are significantly lower than earlier estimates for cropland erosion in Samara, which reached 2.2 tons per hectare annually in 1995 (Litvin, 2002). This raises the question: where does the truth lie, and what are the implications for farmers' practices?

To estimate the impact of land degradation on farm output (focused solely on crop production), we use farm-level data from the 2013–2016 period, as no more recent data (post-2020) is currently accessible. While this may seem outdated, there are several reasons why an analysis of this past period remains relevant and valuable for readers.

Over the last 11 years (2014–2024), the Russian economy has faced two distinct waves of international sanctions. The "second wave" of sanctions, starting in 2022, continues to impact current growth rates (Simachev et al., 2023). However, there has been little in-depth analysis of farm-level factor productivity during the "first wave" of sanctions in the 2014–2016 period. Previous research indicates that, at the macro level, Russian agriculture maintained steady growth despite the 2014 sanctions (Uzun, Shagaida, & Lerman, 2019) and even in 2022 (Shagaida & Ternovskiy, 2023). This resilience was supported by factors such as high growth rates in labour, feed production, livestock numbers (Seitov, 2023), and innovation (Orlova & Nikolaev, 2022). These factors have laid a solid foundation for continued production growth for a period until 2030 (Ushachev, Kharina, & Chekalin, 2022). Understanding the contributions of both on-farm factors (e.g., production inputs) and off-farm influences (e.g., land degradation and climate) offers valuable insights from a microeconomic perspective. Our integrated model, which combines these factors, contributes to interdisciplinary discussions on soil erosion and land degradation. Literature reviews show that environmental and economic factors are often studied separately, especially in Russia, where research mainly focuses on land degradation (Zhidkin, Komissarov, Shamshurina, & Mishchenko, 2022; Kust, Andreeva, Lobkovskiy, & Annagylyjova, 2023). Although models integrating economic and ecological factors exist, they are typically based on state-level data (Agheli, 2023). This leaves significant gaps in understanding of micro-level impacts, for example, how land quality affects crop and food production. Similar analyses are more common in international studies (e.g., Fentahun,

[1] See article "Global Soil Partnership Endorses Guidelines on Sustainable Soil Management". URL: http://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/416516 / (date of access 31 October 2024).

[2] See https://esdac.jrc.ec.europa.eu/content/global-soil-erosion#tabs-0-description=0 (accessed multiple times between 2021 and 2022, with the most recent access on October 31, 2024). We contacted the authors of this database to obtain the data for Russia, which we then disaggregated to the regional level (1st administrative level, or "oblast") and municipal level (2nd administrative level) to estimate soil erosion rates.

Amsalu, & Berhanie, 2023; Patault et al., 2021; Kucher, 2019). Our research seeks to address this gap by exploring farm-level effects and the consequences of natural resource degradation, offering a more comprehensive view of the interplay between environmental and economic factors.

In the next section (Description of the Focus Region) we analyse the level of land degradation and crop yields in the districts of Samara Oblast. Next comes Materials and Methods part, where the theoretical issues of using land quality or land degradation concepts in economic literature are given, and analysis of empirical methods for such type of economic research is revealed. For our case we choose a production frontier analysis approach with estimation of production function along with error (risk) function, and technical inefficiency function. In the Results section we analyse regression results. In the Discussion section we explain the accuracy of our methods, and how they are related with previous research on this problem. Finally, in Conclusions we describe our recommendation for the Russian Government for better agricultural bookkeeping and organizing proper data collection for land degradation quantity and particularly soil erosion data.

Samara Oblast: Regional Profile

Russia is one of the world's largest breadbaskets, and Samara Oblast, with over 1 million hectares of cultivated cropland along the Volga River, is particularly notable in this regard. Samara Oblast is a relatively low productivity region where some of the districts are located in the dry steppe area (Litvin, 2002; Litvin et al, 2017) and might suffer from land degradation (particularly soil erosion), and climate vulnerability (Pavlova and Varcheva, 2017). Recent research provides data on current levels of nutrient content in the soil in different districts of Samara Oblast (Gnedenko and Obushenko, 2013; Chekmarev and Obushenko, 2016), but does not offer recent estimates of soil erosion rates or other land degradation indicators. These data are not publicly available from regional Agrochemistry services, the main source of soil data in Russia (Lukin, 2016). Figure 1 illustrates the share of degraded land among agricultural areas in the district based on earlier research (Stolbovoy et al., 1999). The colours indicate the level of degradation: light blue — less than 10 %, pink — 11–20 %, orange — 21–40 %, grey — 41–50 %, and brown — 51–76 %.

Figure 1 shows that most of the degraded districts are concentrated in the eastern part of the region, which has a steppe climate (mostly dry with low average precipitation). Figure 2 illustrates the distribution of average crop yields across municipal districts, showing a decline in yields from the western part of the region to the eastern and south-eastern districts. A comparison of Figures 1 and 2 reveals a pattern—though not in all districts—that higher-yielding areas tend to be located on the left bank of the Volga River or in the northern part of the region, where the amount of degraded land is relatively low (10–20 % of the municipal agricultural area).

The eastern and south-eastern parts of the region have larger areas of degradation, with more than 40 % of the land affected, and in some districts degradation exceeds 50 %. In these areas, average crop yields are 15–30 % lower than those in districts near the Volga River. This observation led to the following hypothesis: land degradation, particularly the extent of degraded land, negatively impacts crop production and yields in these districts. Unfortunately, no open-access data on the most recent land degradation estimates for Samara Oblast is available. While several studies discuss soil erosion issues, they lack spatially explicit data (Ibragimova and Kazantsev, 2013; Tsarev, 2018). Therefore, the Global Soil Erosion Map estimates (Borrelli et al., 2017) were used to obtain the most up-to-date soil erosion data for the districts of Samara Oblast. These data were then reorganized (upscaled) to the municipal level, as shown in Table 1.

Table 1 shows that the soil erosion rate in Samara Oblast ranges from 0.02 to 0.77 tons of depleted soil per hectare per year, which is significantly lower than the global average of 2.8 tons per hectare, as reported by Borrelli et al. (2017). My analysis of district data reveals little change in soil erosion rates across most districts. According to Borrelli et al. (2017), this is mainly due to minimal land use changes in the region, unlike in Brazil, where erosion rates are much higher. The only districts with noticeable changes are Alekseevskiy (in the south-eastern part of the region) and Bezenchukskiy (on the right bank of the Volga River), where soil erosion rates decreased between 2001 and 2012.

Materials and Methods

Land quality has been a central topic in economic literature since the late 1700s. Malthus (1798) assumed land to be homogeneous with constant crop yields, leading to predictions of extensive land expansion and a finite amount of food production—insufficient to meet the nutritional needs of a growing population. In contrast, Ricardo (1817) recognized the heterogeneity of land

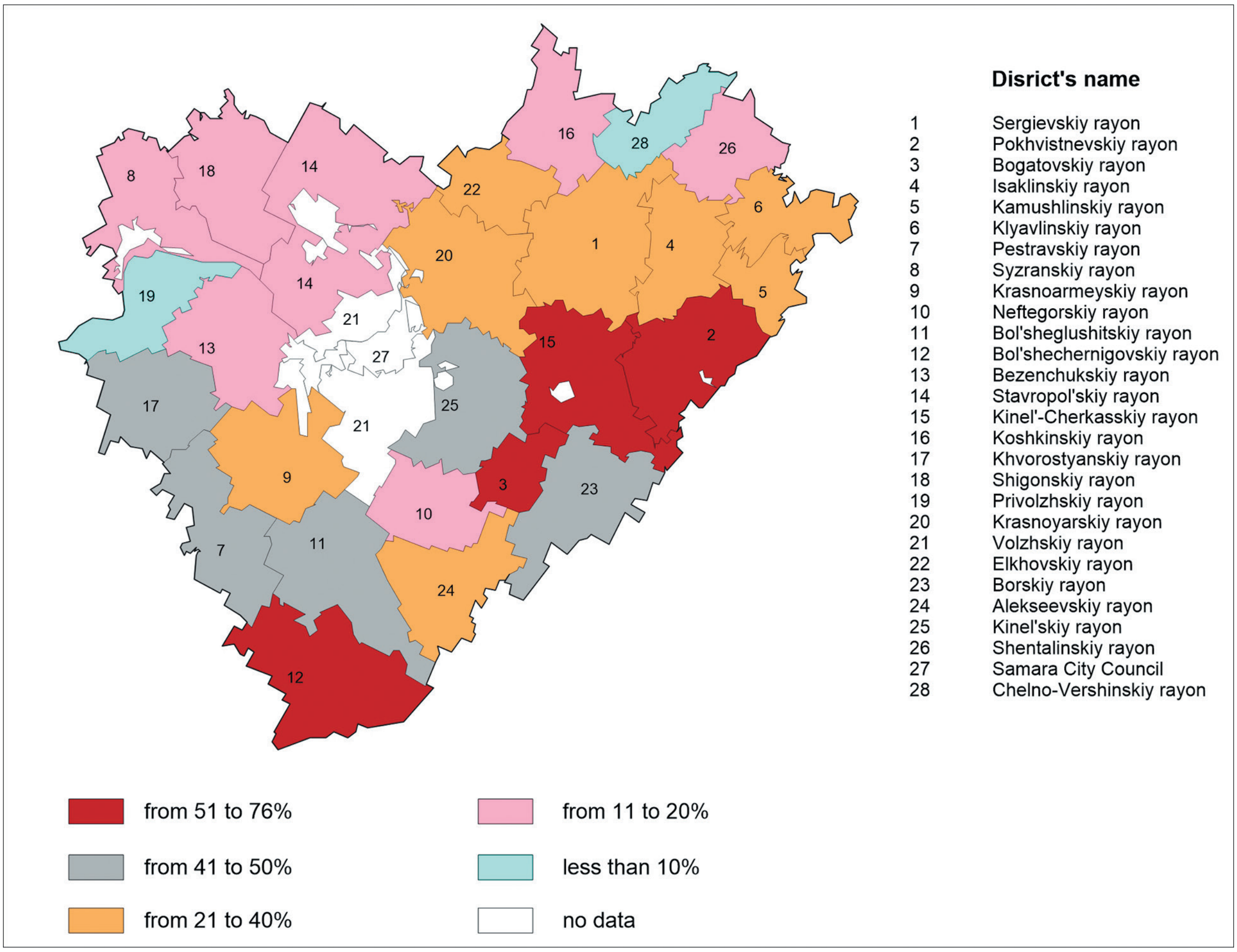

Fig. 1. *The share of degraded land in the agricultural areas of Samara region, %*
Source: Compiled by the author using data from Stolbovoy et al. (1999) and a map of the region with district borders sourced from an open-access photo on the Wikipedia page of Samara Oblast. URL: https://ru.wikipedia.org/wiki/Файл:Location_Of_Volzhsky_District_(Samara_Oblast).svg — latest access on 31 October 2024.

quality, noting that marginal land, when brought into production, often requires additional capital inputs compared to more fertile land. Similarly, Marshall (1890) acknowledged the natural fertility of soils but emphasized how human intervention and technology can enhance natural processes to improve the productivity of cultivated plots.

In the 20th century, particularly in post-war literature, these foundational concepts were empirically tested using data and primarily ordinary (log-linear) Cobb-Douglas production functions (see overviews in Heady & Dillon, 1973; Walpole, Sinden & Yapp, 1996). In these studies, land was typically treated as a spatial (terrestrial) input rather than a qualitative factor. Later, MacCallum (1967) identified soil erosion, or more broadly land degradation, as one of the most critical land quality variables influencing production outputs. MacCallum suggested that land degradation could be mitigated by increasing the application of certain inputs, such as fertilizers. While this approach can boost output, the gains are lower compared to production on non-degraded land. However, in cases of severe land degradation, such as extreme soil depletion, additional inputs may fail to restore productivity, resulting in a flat production curve despite increased input use (see Walpole, Sinden & Yapp, 1996 for a graphical interpretation).

This study aims to test this hypothesis using a stochastic frontier analysis (SFA) approach on data from farms in Russia's Samara Oblast. This method is particularly suitable because it assumes that firms produce below their potential output due to inefficiencies. The goal is to identify the key drivers of risk and inefficiency, which may arise not only at the firm level but also from external factors such as environmental or regional conditions. Land degradation is a prime example of such an external factor, making it a compelling case for this analysis.

Stochastic production frontier models were first introduced in the mid-1970s (Aigner, Lovell, and Schmidt, 1977; Meeusen and van den Broeck, 1977). Since then, they have become a prominent subfield in econometrics (see Kumbhakar and Lovell, 2000), particularly in agricultural economics (Kumbhakar, 2002). These models are frequently used to evaluate the drivers and extent of technical inefficiency in agricultural farms across specific territories (e.g., Kumbhakar, Lien & Hardaker, 2014 for Europe; Gataulina, Hockmann, and Strokov, 2014; Belyaeva, Hockmann, and Koch, 2014; Bokusheva and Hockmann, 2005 for Russia; and Karimov, 2014; Tleubayev et al., 2017 for Central Asia). Notably, none of these studies included land degradation—or even land quality—as a variable in their analyses. This paper seeks to address that gap by taking the first steps in incorporating land degradation into stochastic frontier models as either an input or a fixed-effect variable.

This paper employs an extended version of the conventional production function, known as the risk production function. This approach is particularly suitable because it hypothesizes that land degradation increases risks in agricultural production, leading to reduced output or diminished land productivity, as previously suggested by MacCallum (1967) and Walpole, Sinden & Yapp (1996). Unlike traditional methods, this model enables a clear distinction between

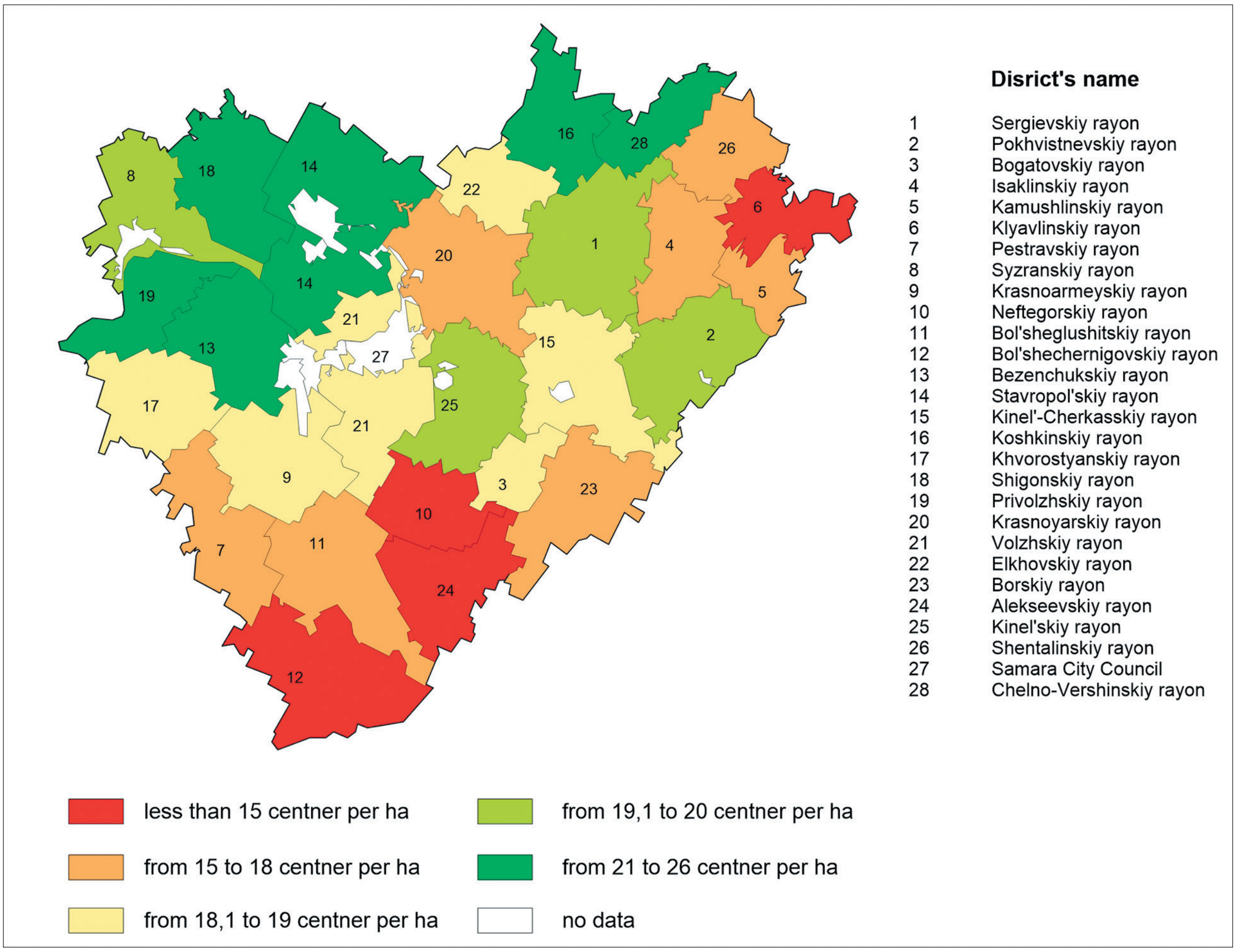

Fig. 2. *Average crop yields of grain equivalent in agricultural organizations of Samara Oblast, centner[1] per ha*
Source: made by the author using municipally aggregated data from Rosstat[2] and the map of the region[3]
Comment: The data for Figure 2 were compiled using production volumes of grain, sunflower, soybean, potatoes, and vegetables from 2012 to 2019 in agricultural organizations of each district. Each crop was then converted into grain equivalent using the coefficients specified in Russian Ministry of Agriculture Decree № 330 (6 July 2017): 1 for grain, 1.47 for sunflower, 1.17 for soybeans, 0.25 for potatoes, and 0.16 for vegetables. The grain equivalent for each crop was summed annually and divided by the total crop area of these five crops. Finally, the average 8-year grain equivalent yield was calculated for each district.
Comments: Soil erosion values for Kamushlinskiy and Klyavlinskiy districts were taken from Isaklinskiy district (located in the northern part of the region) because the European raster map showed these two districts as part of Isaklinskiy due to outdated boundaries on the European map, which made it impossible to separate the districts accurately.

[1] 1 centner = 10 kilograms.

[2] URL: https://rosstat.gov.ru/dbscripts/munst/ – latest access on 31 October 2024.

[3] See comment (6).

Table 1

Comparing soil erosion data with crop yield data for districts of Samara Oblast

District	Average crop yield for 2012-2019, centner of grain eq. per ha	Soil erosion average in 2001, t per ha per year	Soil erosion average in 2012, t per ha per year
Sergievskiy	19.50	0.77	0.77
Pokhvistnevskiy	19.40	0.58	0.58
Bogatovskiy	18.30	0.49	0.49
Isaklinskiy	16.36	0.40	0.40
Kamushlinskiy	15.63	0.40	0.40
Klyavlinskiy	14.64	0.40	0.40
Pestravskiy	17.60	0.34	0.34
Syzranskiy	19.30	0.33	0.33
Krasnoarmeyskiy	18.65	0.32	0.32
Neftegorskiy	14.57	0.32	0.32
Bol'sheglushitskiy	17.79	0.31	0.31
Bol'shechernigovskiy	14.36	0.29	0.29
Bezenchukskiy	23.38	0.34	0.28
Stavropol'skiy	24.59	0.26	0.26
Kinel'-Cherkasskiy	18.34	0.25	0.25
Koshkinskiy	24.35	0.24	0.24
Khvorostyanskiy	18.39	0.24	0.24
Shigonskiy	25.16	0.23	0.23
Privolzhskiy	21.08	0.26	0.23
Krasnoyarskiy	17.90	0.23	0.20
Volzhskiy	18.18	0.20	0.20
Elkhovskiy	18.18	0.17	0.17
Borskiy	16.13	0.14	0.14
Alekseevskiy	12.37	0.18	0.12
Kinel'skiy	19.10	0.11	0.11
Shentalinskiy	15.28	0.07	0.07
Samara City Council	n.a.	0.04	0.04
Chelno-Vershinskiy	21.98	0.02	0.02

Source: for soil erosion the Global Soil Erosion Map was used, and for crop yields, Rosstat data. See Comments for Figure 2.

the impacts of individual inputs on risk and efficiency. The risk production function was initially introduced by Just and Pope (1978) and later refined by Kumbhakar (2002). Detailed applications of this method in agricultural contexts, incorporating land acreage as one of the inputs, are described in Gataulina, Hockmann, and Strokov (2014). A prior study focusing specifically on Samara Oblast, using farm data from the 1990s, is found in Bokusheva and Hockmann (2005).

In this analysis, the following specification is applied:[1]

$$y = f(x, s; \alpha) + g(x; \gamma)v - q(x, s, c, h; \theta)u \quad (1)$$

with $f(x, s; \alpha)$ as production function;

$g(x; \gamma)$ as risk function;

$q(x, s, c, h; \theta)$ as inefficiency function.

In this analysis, y represents output, and x is a vector of inputs. For this case, s denotes the land degradation variable, h represents humus (organic) content in the soil, and c refers to climate indicators. α, γ, and θ are the parameter vectors to be estimated. This specification differs from previous studies (e.g., Gataulina, Hockmann, and Strokov, 2014) in that dummy variables are not used. Instead, fixed effects at the district level, such as land degradation, land quality (share of organic content in the district's soil), and climate indicators, are applied to analyze their impact on the production function, risk, and technical inefficiency functions.

As described by Gataulina, Hockmann, and Strokov (2014), output variation is decomposed into three components. First there is the production function f, which represents the impacts of inputs

[1] Symbols in bold represent vectors or matrices, while all other variables are scalars. Subscripts are omitted in the equations for improved readability.

(x), land quality and time on production. The second component g is assumed to capture the effects of risk on production. Due to cultivating eroded land, and/or poor weather conditions (like draughts) actual output can be lower or higher than its average level (MacCallum, 1967). Thus, it is straightforward to connect the risk function with a two-sided error component (v). At last, function q captures the impact of factor use on the exploitation of the production possibilities or technical efficiency. Here we also estimate different land quality and climate indicators, along with time variable, in order to capture not only farm-level, but district level and other external effects on inefficiency. This function transforms a one-sided error term u. The empirical analysis is based on the following assumption regarding the functional forms, utilizing a log-linear version of the Cobb-Douglas production function. The natural logarithm of the production function for this case is presented below:

$$\ln f(x) = a_0 + \alpha' \ln x + a_d s. \qquad (1a)$$

In this representation, it is assumed that the constant and first-order effects vary with land degradation (s) across different districts of the region (d). This variation is attributed to geographical and climatic differences: some districts are located near the Volga River, benefiting from more favourable climatic conditions, while others, particularly in the steppe regions to the east, experience arid climates and greater challenges with land degradation. Notably, the land degradation variable (s) is not in logarithmic form, as it is presumed to have a linear effect on the production function, consistent with the theoretical framework outlined in earlier research on land quality impacts on crop output (Walpole, Sinden & Yapp, 1996)[1]. As Walpole, Sinden & Yapp put it, "degradation represented as an input in the logarithmic form would exhibit increasing returns to given decreases in degradation and so reflects increasing return to given investments in conservation works. This situation seems unlikely because of the relatively fixed nature of the required conservation works within a homogenous region. Degradation represented as a linear or arithmetic variable implies constant returns to conservation works… The latter situation is more likely, and so the linear form is to be preferred" (Walpole, Sinden & Yapp, 1996; page 192).

The risk function is assumed to consist only of farm-specific inputs (g). As in Gataulina, Hockmann & Strokov (2014), we assume that the idiosyncratic component can be represented by a Cobb-Douglas functional form. Thus, we have

$$\ln g(x) = \gamma_0 + \gamma' \ln x \qquad (1b)$$

with only farm inputs (x) elasticities to be estimated.

The inefficiency function q was at first also considered to be a Cobb-Douglas type:

$$\ln q\,(x) = \theta_0 + \theta' \ln x + \theta_d s + \theta_d h + \theta_d t\,c, \quad (1c)$$[2]

which includes the input factors (x) from the farms, land degradation indicator (s) from the district level (fixed year effects), organic content value (h) at the district level, and climate effects (changing from year to year) at the district level (c). Following the approach of MacCallum (1967) and Walpole, Sinden, and Yapp (1996), which assumes that land degradation negatively impacts production output, the hypothesis is that district-level land degradation, combined with rising temperatures, increases farm inefficiency. Conversely, higher land quality, particularly in terms of organic content, is expected to reduce inefficiency due to the beneficial role of organic matter in the crop-growing process. For a broader literature overview, see Lukin (2016), and for the case of Samara Oblast, refer to Chekmarev and Obushenko (2016).

The model is estimated using the log-likelihood method within a stochastic frontier normal/half-normal framework, calculating all three stages (1a, 1b, 1c) simultaneously. The estimation procedure is implemented using the STATA_11 software (Gould, Pitblado, & Sribney, 2006). The Results section (see Table 3) presents the estimated elasticities for the model components (1a, 1b, 1c).

Before estimating the model, it is essential to describe the data used for the analysis. The farm-level data for Samara Oblast was sourced from the database of the Ministry of Agriculture (restricted access, provided by RANEPA) for the years 2013–2016. This dataset includes over 100 variables, such as production volumes for various crops, cropland areas, aggregated crop revenue and cost figures, detailed input costs (e.g., salaries, fertilizers,

[1] This linear specification of the land degradation variable was selected due to the lack of evidence suggesting increasing returns from soil conservation measures in Russia.

[2] In the final version of the paper, farm-level (x) factors, as well as land degradation and soil erosion variables, were excluded due to their statistical insignificance. Consequently, the inefficiency function was primarily dependent on humus content (h) and temperature as a climate factor (c). See Table 3 for detailed results.

seeds), workforce numbers, and subsidies, among others.

The output variable (y) for the model represents the crop production volume of five primary crops grown in the region—grain, sunflower, soybean, potato, and vegetables—converted into a grain equivalent (see Comments to Figure 2 infra). The inputs include capital, land, and labour. Capital was measured as the production costs associated with these five crops. To avoid potential collinearity with labour, salary and social payments were excluded from the aggregate production costs. This adjustment involved calculating the proportion of salary and social payments within the total crop costs for the farm. This proportion was then applied to the costs for the selected five crops, allowing the salary and social payments to be excluded. The resulting production costs were subsequently adjusted using a regional price index (sourced from Rosstat for Samara Oblast). This index, based on the cost of purchased manufactured inputs for agricultural organizations in the region, converted the data into comparable 2019 RUB values.

Land was represented as the total area sown with the five crops for which output data were available. Labour required additional processing. The dataset included the total number of workers in each organization, along with salary and social payment data specifically for crop-growing and animal production activities. To estimate labour for the five crops, the proportion of crop workers' salaries in the total salary was calculated. This proportion was then adjusted by the share of the five crops' sown area relative to the total cropland. This approach provided an approximation of the labour allocated to cultivating fields with the specified crops.

A panel dataset was prepared to form a balanced regression. The total database for agricultural organizations in Samara Oblast) contained 1,881 observations over 4 years[1]. The database was cleaned by removing the following observations: 146 with no reported cropland, 95 from farms with cropland areas exceeding 10 thousand hectares, 20 with missing district identification, 29 with incomplete data on the total area of the five main crops, and 24 with crop yields less than 2 centners[2] per hectare, 31 observations with yields more than 35 centners of grain equivalent per hectare. Next, 540 observations were removed for farms that lacked data for all four years. Additionally, 12 observations were excluded due to missing data on the number of workers, and 4 observations with exceptionally high costs per hectare (more than 80 thousand rubles per hectare, in constant 2019 prices). Following further investigation, 8 observations with costs exceeding 40 thousand rubles per hectare were also deleted to eliminate unusually expensive potato and vegetable farms. As a result, 972 observations remain in the dataset, representing 52 % of the original sample for these years.

The farm-level data for the selected organizations were used to estimate the main production function. Descriptive statistics of the final dataset for the balanced panel regression are presented in Table 2. This dataset also includes information on land degradation and climate variables for the districts of Samara Oblast to capture the relevant fixed effects.

As mentioned earlier, farm-level data on land degradation or soil erosion were unavailable. To test the main hypothesis, a variable representing the share of land degradation in the agricultural land of each district was used, based on data from the mid-1990s (Stolbovoy et al., 1999). Additionally, the average erosion rate (measured in tons per hectare of land) for each district was included, based on the Global Soil Erosion map (Borrelli et al., 2017). For the technical inefficiency function (1c), the organic content of the district's soil in 2016 (Samara Oblast Government, 2016)[3] was used to reflect the idea that farms with better lands have higher output.

Climate data were obtained from the open-source website Pogoda i Klimat, (translated as "Weather and Climate"), which collects data from weather stations[4]. Samara Oblast does not have a weather station in every district, but data on average temperature and total precipitation are available from 12 meteorological stations in the region. Districts were grouped according to their proximity to each weather station[5].

[1] In 2013, data were available for 441 organizations; in 2014, for 505 farms; in 2015, for 479 farms; and in 2016, for 456 organizations.

[2] 1 centner = 10 kilograms.

[3] Analysis of previous years' reports revealed no significant changes in organic content across the districts. Therefore, it is assumed that organic content remained constant throughout the focus period.

[4] URL: http://pogodaiklimat.ru/ Multiple access through 2021–2023 period. (date of access: on 31 October 2024).

[5] Weather station data were assigned to districts as follows: Avangard for Alekseevsky, Bogatovsky, Borsky, and Neftegorsky; Aglos for Volzhsky and Krasnoarmeisky; Bezenchuk for Bezenchukskiy and Khvorostyansky; Bolshaya Glushitza for Bolsheglushitzkiy, Bolshechernigovskiy, and Pestravskiy; Kinel-Cherkassa for Kinel-Cherkasskiy and Pohvistnenskiy; Klyavlino for Kamushlinskiy and Klyavlinsky; Novodevichiye for Schigonskiy; Samara capital for Kinelskiy

Table 2

Descriptive statistics

Variable	Acronym	Average	Min	Max	Unit
Crop production of grain, soy, sunflower, potato and vegetables	prod5	35 870	206	287 908	tons of grain equivalent
Production costs for 5 crops minus salary of workers	cost5	21 816 401	141 146	242 637 359	RUB (in 2019 constant prices)
Cropland area (sum for 5 crops)	crop5_area	2 224	15	9 292	ha
Labor in agricultural organization (calculated for 5 crops)	work5	18	0	189	number of workers
Share of degraded land among agricultural land of the district in 1999	degrad	38.5	5.7	76.0	% share of agricultural land
Soil erosion intensity in the district in 2012	eros_ave	0.27	0.02	0.77	tons per hectare of area
Share of organic content in agricultural soils in the district in 2016	humus	4.4	2.9	6.5	% of organic content in the soil
Average year temperature in the district	temp_ave	6.0	3.8	7.2	Celsius (°C)
Sum of precipitation per year in the district	precip_all	481	307	724	mm

Source: The estimate is based on data from the Russian Ministry of Agriculture, Rosstat, Stolbovoy et al. (1999), the Global Soil Erosion Map, the Samara Oblast Government (2016), and the climate data website Pogoda i Klimat (in Russian) URL: http://www.pogodaiklimat.ru (multiple access in 2021-2022, latest access on 31 October 2024).

The following section presents the results of estimating the stochastic frontier model using the database of Samara's agricultural organizations.

Results

To test the main hypothesis regarding the negative impact of land degradation on crop output, a stochastic frontier production function is presented. The results include all three components of the traditional stochastic frontier estimation procedure: coefficients for the production function, risk function, and technical inefficiency function (1a, 1b, and 1c, respectively). Estimations were performed using the STATA_11 software program, and the results are presented in Table 3.

The results in Table 3 reveal that land degradation ("degrad" abb.) has a negative influence on crop production output, which proves the initial hypothesis for production function (1a). This impact, however, is rather small and most of the variance is brought by traditional production function factors — capital (cost5), land acreage (crop5_area) and labour (work5). The sum of these elasticities is 1.03 (more than 1) k, which shows the increasing returns to scale.

In the risk function (1b), it is observed that increases in costs and the number of workers reduce production risk at the farm, while an expansion of land area under the five main crops increases risk. In the inefficiency function (1c), the variables for degradation and soil erosion were statistically insignificant and were therefore excluded from the final results, along with farm input variables[1]. An increase in organic content (humus) across districts appears to have a positive effect, as indicated by the negative ("–") sign. This suggests that higher organic content in soil reduces inefficiency, highlighting the importance of soil quality. The results also show that higher average temperatures in a district increase inefficiency, which points to

and Krasnoyarskiy; Sernovodsk for Isaklinskiy and Sergievsky; Suzran for Privolzhskyi and Suzraskyi; Tolyatti for Elkhovskiy and Stavropolskiy; and Chelno-Vershinskiy for Koshkinskiy, Chelno-Vershininskiy, and Shentalinsky.

[1] For early results with all variables, please contact the author. Additional tests for endogenous variables were conducted but were not included in the final version of the paper due to space constraints. The endogeneity issue was examined using the instrumental variables technique, confirming that only land degradation fits well within the original form of the production function. Other variables, such as soil erosion, temperature, and precipitation, were excluded due to their insignificant coefficients).

Table 3

Model results from the stochastic frontier analysis of crop production in agricultural organizations in Samara Oblast, based on panel data from 2013 to 2016

Function	Abb. of variables	Coef.	Std. err.	z
production function (1a)	cost5	0.455	0.022	20.26^{***}
	crop5_area	0.529	0.029	18.45^{***}
	work5	0.043	0.0127	3.34^{**}
	degrad	–0.001	0.0004	-2.75^{**}
	constant.	–1.048	0.21	-4.89^{***}
risk function (1b)	cost5	–1.37	0.18	-7.57^{***}
	crop5_area	1.09	0.24	4.50^{***}
	work5	–0.24	0.11	-2.18^{*}
	constant.	11.42	1.58	7.21^{***}
inefficiency function (1c)				
	humus	–0.178	0.074	-2.40^{*}
	temp_ave	0.361	0.092	3.89^{***}
	constant.	–3.241	0.774	-4.19^{***}
	Log likelihood	–215.8		
	N of observ.	972		

Source: the author's estimates for the stochastic frontier model using STATA_11. Comments: stars (*) show the level of statistical significance of estimated coefficient: *, **, *** denote significance at the 10 %, 5 % and 1 % level, respectively.

the risks of droughts and their negative impact on crop production in the region.

Discussion

Previous studies have reported land degradation and soil erosion in parts of Samara Oblast but often lack detail on the methods used or the time period when the data was collected (Tsarev, 2018). Some studies rely on older data from 1991–1992 (Ibragimova and Kazantsev, 2013) and fail to adequately examine the impacts of land degradation on crop production. This paper addresses that gap.

Using stochastic frontier analysis, the study estimates the effects of land degradation and soil erosion at the farm level in Samara Oblast for the 2013–2016 period. This approach not only evaluates the drivers of the production function but also assesses impacts in the risk and inefficiency functions—both critical aspects of farm-level crop production processes. Previous research has applied stochastic frontier analysis to study technical inefficiency in Samara farms using data from 1997–2003 but did not consider land degradation as a potential factor (Bokusheva and Hockmann, 2005).

The results confirm that land degradation negatively affects crop production and yields, supporting the main hypothesis established in earlier studies (MacCallum, 1967; Walpole, Sinden, and Yapp, 1996). However, the impacts of soil erosion and land degradation were found to be statistically insignificant in the inefficiency function. Instead, a positive effect of organic soil content on reducing inefficiency was observed, highlighting the importance of soil quality for crop production, albeit indirectly (Lukin, 2016). Additionally, the analysis reveals a growing influence of average temperature on inefficiency, underscoring the risks of climate change and drought in the steppe region of Samara, as shown by Pavlova and Varcheva (2017).

Conclusion

Land degradation is a key issue in contemporary agricultural and environmental science. However, the extent of land degradation remains ambiguous due to the use of different data aggregation methods. For Samara Oblast, there are data from various sources on land degradation and soil erosion that do not always align. Nevertheless, the study has shown a trend of increasing land degradation from west to east in the region, which appears to correlate with a decline in crop yields in some of its eastern and south-eastern districts. To provide stronger evidence, stochastic frontier analysis was applied to assess the impact of key factors on crop production and yields at the farm level.

The results reveal that land degradation negatively affects crop production and yields. However, land degradation and soil erosion did not influence the inefficiency function of the model. Instead, factors such as organic content in the soil and average yearly temperature had an impact on inefficiency, with organic content exerting a negative influence and temperature having a positive effect. These findings are consistent with previous research in this field.

Based on the study's findings, it is recommended that the Russian government revise the regulations for publishing agrochemical data at the regional level. Specifically, the Ministry of Agriculture of Russia should be required to publish soil erosion data every five years as part of the "Agricultural Soil Fertility Law" (this can be done by reinstating Article 12 of Chapter 4 of Federal Law 101-FZ (dated 16 1998[1]), which required the Ministry to publish the National Report on Soil Fertility of Agricultural Lands[2]). This will enrich the society on the knowledge of the current soil conditions and help researchers to have a friendly open-access monitoring system of agricultural land degradation, which will foster a more accurate research of ecological and production impacts in this area.

[1] The latest version of Law 101-FZ, "On State Regulation of Soil Fertility Management for Agricultural Land," is available here: https://base.garant.ru/12112328/ (latest access on 31 October 2024).

[2] Article 12 was removed from the law as of January 1, 2005, through amendments introduced by Law FZ-122 on August 22, 2024, see: https://docs.cntd.ru/document/901712929 (latest access on 31 October 2024)

References

Agheli, L. (2023). The Nexus between Economic Growth, Natural Resource Depletion and Foreign Direct Investment. *Ekonomika regiona [Economy of regions], 19*(2), 537-547. https://doi.org/10.17059/ekon.reg.2023-2-18

Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics, 6*(1), 21–37. https://doi.org/10.1016/0304–4076(77)90052-5

Belyaeva, M., Hockmann, H., & Koch, F. (2014). Impact of regional diversity on production potential: an example of Russia. 142nd EAAE Seminar: "Growing Success? Agriculture and rural development in an enlarged EU". https://doi.org/10.22004/ag.econ.168924

Bokusheva, R., & Hockmann, H. (2005). Production Risk and Technical Inefficiency in Russian Agriculture. *XIth Congress of the EAAE (European Association of Agricultural Economists), 'The Future of Rural Europe in the Global Agri-Food System'.* https://doi.org/10.22004/ag.econ.24610

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L., & Panagos, P. (2017). An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications, 8*(1), 2013. https://doi.org/10.1038/s41467-017-02142-7

Chekmarev, P.A., & Obuschenko, S.V. (2016). Monitoring of soil fertility in Samara region. *Zemledelie,* (8), 12-15. (In Russ.)

Cobb, C.W., & Douglas, P.H. (1928). A Theory of Production. *The American Economic Review, 18*(1), 139–165.

Fentahun, G., Amsalu, T., & Birhanie, Z. (2023). Farmers' perceptions about the influence of land fragmentation and land quality on sustainable land management in the upper lake Tana Basin: Evidence from Dera District. *Cogent Economics & Finance, 11*(1), 2160132. https://doi.org/10.1080/23322039.2022.2160132

Gataulina, E., Hockmann, H., & Strokov, A. (2014). Production Risk, Technology and Market Access in Different Organisational Forms: Evidence from Tatarstan and Oryol. *Quarterly Journal of International Agriculture, 53*(4), 293-318. https://doi.org/10.22004/ag.econ.199251

Gnedenko, V.V., & Obuschenko, S. V. (2013). Dynamics of soil fertility changes of Samara region. *Uspekhi sovremennogo estestvoznaniya [Advances in Current Natural Sciences],* (9), 148-151. (In Russ.)

Golosov, V., Yermolaev, O., Litvin, L., Chizhikova, N., Kiryukhina, Z., & Safina, G. (2018). Influence of climate and land use changes on recent trends of soil erosion rates within the Russian Plain. *Land Degradation and Development, 29*(8), 2658–2667. http://dx.doi.org/10.1002/ldr.3061

Gould, W., Pitblado, J., & Sribney, W. (2006). *Maximum Likelihood Estimation with Stata.* 3rd ed. Stata Press.

Heady, E.O., Dillon, J.L. (1973). *Agricultural Production Functions.* Iowa State University Press.

Ibrahimova, S.A., & Kazantsev, I.V. (2013). Impact of soil erosion on condition of agricultural landscapes of the Samara region. *Izvestiyia Samarskogo nauchnogo tsentra Rossiyskoi akademii nauk [Izvestia of Samara Scientific Center of the Russian Academy of Sciences], 15*(3), 256-259. (In Russ.)

Ivanov, M. A. (2018). Changes of cropland area in the river basins of the European part of Russia for the period 1985–2015 years, as a factor of soil erosion dynamics. *IOP Conf. Ser.: Earth Environ. Science, 107,* 012010. http://dx.doi.org/10.1088/1755–1315/107/1/012010

Just, R.E., & Pope, R. D. (1978). Stochastic representation of production functions and econometric implications. *Journal of Econometrics, 7*(1), 67-86. https://doi.org/10.1016/0304–4076(78)90006-4

Karimov, A.A. (2014). Factors affecting efficiency of cotton producers in rural Khorezm, Uzbekistan: Re-examining the role of knowledge indicators in technical efficiency improvement. *Agricultural and Food Economics, 2,* 7. https://doi.org/10.1186/s40100-014-0007-0

Kucher, A. (2019). Assessment of the impact of land quality on competitiveness of enterprises. *Agricultural and Resource Economics International Scientific E-Journal, 5*(2), 99-120. http://dx.doi.org/10.22004/ag.econ.290316

Kumbhakar, S. C. (2002). Specification and estimation of production risk, risk preferences and technical efficiency. *American Journal of Agricultural Economics, 84*(1), 8-22. https://doi.org/10.1111/1467–8276.00239

Kumbhakar, S. C., & Lovell, C. A. K. (2000). *Stochastic Frontier Analysis.* Cambridge University Press.

Kumbhakar, S. C., Lien, G., & Hardaker, J. B. (2014). Technical efficiency in competing data models: A study of Norwegian grain farming. Journal of *Productivity Analysis, 41*(2), 321-337. http://dx.doi.org/10.1007/s11123-012-0303-1

Kust, G., Andreeva, O., Lobkovskiy, V., & Annagylyjova, J. (2023). Experience in application and adaptation of the land degradation neutrality concept in the Russian Federation. *Land Degradation & Development, 34*(3), 573-590. https://doi.org/10.1002/ldr.4484

Litvin, L. F. (2002). *Geographyiya erozii pochv sel'skokhozyaistvennykh zemel' Rossii [Geography of soil erosion on agricultural lands of Russia].* Moscow: Akademkniga. (In Russ.)

Litvin, L. F., Kiryukhina, Z. P., Krasnov, S. F., & Dobrovol'skaya, N. G. (2017). Dynamics of agricultural soil erosion in European Russia. *Eurasian Soil Science, 50*(11), 1344–1353. https://doi.org/10.1134/S1064229317110084

Lukin, S. V. (2016). *Agroekologichesky sostoyaniye i produktivnost' pochv Belgorodskoy oblasti [Agroecological condition and productivity of Belgorod's soils].* Belgorod: KONSTANTA, 344. (In Russ.)

MacCallum, D. E. (1967). Soil Erosion Control and Resource Allocation. 10th Annual Australian Agricultural Economics Society Conference.

Malthus, T. R. (1796). *An Essay on Population* (1826 reprint of 6th ed. of 1826). Ward, Lock and Company.

Marshall, A. (1890). *Principles of Economics* (1961 reprint). English Language Book Society and Macmillan.

Meeusen, W., & van Den Broeck, J. (1977). Efficiency estimation from Cobb–Douglas production functions with composed error. *International Economic Review, 18*(2), 435–444. https://doi.org/10.2307/2525757

Nkonya, E., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J. &, Meyer, S. (2016). Global Cost of Land Degradation. In Nkonya E., Mirzabaev A., von Braun J. (Eds.), *Economics of Land Degradation and Improvement — A Global Assessment for Sustainable Development* (pp. 117–165). Springer. https://doi.org/10.1007/978-3-319-19168-3_6

Orlova, N. V., & Nikolaev, D. V. (2022). Russian agricultural innovations prospects in the context of global challenges: Agriculture 4.0. *Russian Journal of Economics, 8*(1), 29-48. https://doi.org/10.32609/j.ruje.8.78430

Patault, E., Ledun, J., Landemaine, V., Soulignac, A., Richet, J.-B., *Fournier M.*, *Ouvry J.*-F., *Cerdan O.*, & *Laignel B.* (2021). Analysis of off-site economic costs induced by runoff and soil erosion: Example of two areas in the northwestern European loess belt for the last two decades (Normandy, France). *Land Use Policy, 108,* 105541. https://doi.org/10.1016/j.landusepol.2021.105541

Pavlova, V. N., & Varcheva, S. E. (2017). Estimating the Level of Territory Vulnerability and Climate-related Risk of Significant Grain Crop Failure in Grain-producing Regions of Russia. *Russian Meteorology and Hydrology, 42*(8), 510–517. https://doi.org/10.3103/S1068373917080040

Ricardo, D. (1817). *The Principles of Political Economy and Taxation* (1926 Ed.). John Murray, Albemarle-Street.

Samara's region Government. (2016). *Ministry of Ecology report on the Current level of the Condition of Samara's Region Environment* (pp. 91-92). https://priroda.samregion.ru/wp-content/uploads/sites/11/2020/03/gd_-_2015_13.09.2016.pdf (Date of access: 31.10.2024). (In Russ.)

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L., & Panagos, P. (2019). A linkage between the biophysical and the economic: Assessing global market impacts of soil erosion. *Land Use Policy, 86,* 299-312. https://doi.org/10.1016/j.landusepol.2019.05.014

Seitov, S. K. (2023). Total Factor Productivity in Agriculture in Russian Regions. *Ekonomika regiona [Economy of regions], 19*(4), 1194–1208. https://doi.org/10.17059/ekon.reg.2023-4-18

Shagaida, N., & Ternovskiy, D. (2023). State of Agricultural Production and Food Security in Russia in 2022. *Russian Economy in 2022. Trends and Outlooks,* (44), 216-224. http://dx.doi.org/10.2139/ssrn.4499720

Simachev, Yu. V., Yakovlev, A. A., Golikova, V. V., Gorodnyi, N. A., Kuznetsov, B. V., Kuzyk, M. G., & Fedyunina, A. A. (2023). Russian industrial companies under the "second wave" of sanctions: Response strategies. *Voprosy Ekonomiki,* (12), 5-30. http://dx.doi.org/10.32609/0042–8736-2023-12-5-30 (In Russ.)

Stolbovoi, V. S., Savin, I. Y., Sheremet, B. V., Sizov, V., & Ovechkin, S. V. (1999). The geoinformation system on soil degradation in Russia. *Eurasian Soil Science, 32*(5), 589-593.

Tleubayev, A., Bobojonov, I., Götz, L., Hockmann, H., & Glauben, T. (2017). Determinants of productivity and efficiency of wheat production in Kazakhstan: A Stochastic Frontier Approach. *Discussion paper,* (160).

Tsarev, O. Yu. (2018). Erosion type of soil degradation in Samara region. Innovatsionnoe razvitie: zemleustroistva: *Sbornik nauchnykh trudov Mezhvuzovskoi studencheskoi nauchno-prakticheskoi konferentszii [Innovative Type of Land Tenure. Proceedings of Interuniversity Student Scientific and Practical Conference],* (pp. 76-77). Samara State Agricultural Academy. (In Russ.)

Ushachev, I. G., Kharina, M. V., & Chekalin, V. S. (2022). Long-term Forecast of Agricultural Development in Russia Based on an Economic and Mathematical Model. *Studies on Russian Economic Development, 33*(3), 282–292. http://dx.doi.org/10.1134/S1075700722030157

Uzun, V., Shagaida, N., & Lerman, Z. (2019). Russian agriculture: Growth and institutional challenges. *Land Use Policy, 83,* 475-487. http://dx.doi.org/10.1016/j.landusepol.2019.02.018

Walpole, S., Sinden, J., & Yapp, T. (1996). Land Quality as an Input to Production: The Case of Land Degradation and Agricultural Output. *Economic Analysis and Policy, 26*(2), 185-207.

Zhidkin, A. P., Komissarov, M. A., Shamshurina, E. N., & Mishchenko, A. V. (2023). Soil Erosion in the Central Russian Upland: A Review. *Eurasian Soil Science, 56,* 226–237. http://dx.doi.org/10.1134/S1064229322601743

Zhuang, Q., Wu, S., Huang, X., Kong, L., Yan, Y., Xiao, H., Li, Y., & Cai, P. (2022). Monitoring the impacts of cultivated land quality on crop production capacity in arid regions. *CATENA, 214,* 106263. http://dx.doi.org/10.1016/j.catena.2022.106263

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