Article

Economic Evaluation of Ecological Restoration of Degraded Lands through Protective Afforestation in the South of the Russian Plain

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Abstract: The latest international climate documents emphasize the great importance of protective forest stands in ensuring the sustainable development of agriculture, and the main requirement is the use of the forest-forming factor by landowners in the interests of improving the environment. In Russia, until recently, the ecological significance of forest plantations was underestimated, which created the ground for discussions about their effectiveness. In this regard, a new approach is proposed that emphasizes the positive impact of forests, including sustainable development, environmental security of the agricultural sector and reducing the degradation of agricultural land. The purpose of the work was an economic assessment and regularities of the dynamics of humus-regulating and nitrogen-phosphorus-potassium (NPK)-regulating efficiency of protective forest plantations on lands with deflation-hazardous soils. By means of a system analysis, the change in the soil cover of land use due to the influence of forest plantations on the balance of soil fertility elements in forested cells is comprehensively analyzed. The different spatial placement of trees from each other under different degrees of deflation in semiarid conditions is modeled. These models are used to determine the nature of the dynamics of soil nutrients in forested areas: in protection zones and outside protection. It is established that the anti-deflationary effect of agroforestry depends on the indicator of the protective forest cover of the land, the level of deflationary danger, and the operational life of the plantings. In semiarid conditions, it increases in proportion to the increase in the protection of land and amounts to EUR 376–EUR 4222 ha^{−1}. With an increase in the intensity of deflation to the level of dust storms, the prevented damage from the loss of soil nutrients increases almost four times. In systems of plantings from early-maturing fast-growing rocks, the anti-deflationary effect is 6–7% higher on an average annual basis than in systems of plantings from long-lasting, slow-growing rocks. The greatest efficiency of forest reclamation in ensuring a positive balance of humus and NPK substances in the soil (EUR 1002–EUR 4222 ha^{−1}) is achieved when placing plantings after 15 H. The study will confirm the need to subsidize the integration of trees into farm systems.

Keywords: agroforestry; deflation; agricultural land; soil nutrients; economic evaluation

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1. Introduction

Currently, the general imperative of the environmental strategy of economic development of the Russian Federation requires the transition of the agricultural sector to a “green” resource-saving model of land use. This is especially required in the southern regions of the country, where due to climatic anomalies, significant losses of soil fertility, serious violations of the soil structure, and their withdrawal from agricultural circulation are of particular concern.

A significant part of the lands of the south of the European territory of Russia (Central Russian, Volga, Ergeny, and other uplands) is subject to degradation. In a semiarid and arid climate, wind erosion is particularly dangerous. It is the cause of the loss of the fertile layer on huge areas of land. Within each soil type, the humus content in the arable layer

decreases— with average deflation by a third, with severe deflation by half [1]. The high risk of environmental and economic damage to land users and the withdrawal of land from agricultural circulation actualizes forest reclamation makes it necessary to integrate forests into farm systems.

The south of Russia is a region that plays an important role in solving grain and feed food problems. More than 5 million hectares of land require land protection from wind erosion and dust storms. Against the background of the imperfection of agrotechnical technologies for protecting the soil from destruction by wind, the positive influence of trees on the preservation of the fertility of adjacent territories is especially significant. It is based on their ability to weaken the wind, below critical speeds, and thereby prevent soil destruction [2].

The Food and Agriculture Organization of the United Nations (FAO, Rome, Italy) presents agroforestry as “a means of producing a variety of products to meet the needs for food, energy and nutrition at the household level in developed and developing countries” [3]. Regardless of the definitions of agroforestry in different countries and the specifics of its implementation, the World Bank and FAO have reoriented their forest policy to include agroforestry as an integral system of sustainable land use that produces private and public goods [4,5].

World experience shows [6,7] that protective afforestation is a long-term global strategy for sustainable land use that solves the problem of soil degradation. It has long been recognized as a serious problem for human sustainability [8].

The consequences of soil erosion for society can be serious. The European Union Thematic Strategy on Soils warns politicians about the need to protect the soil and presents the fight against soil erosion as a key priority for action. Within the framework of this thematic strategy is estimated the cost of degradation due to soil erosion at the level of EUR 0.7 to EUR 14.0 billion based on estimates made in the 13 largest EU Member States, where erosion is most common [9]. On a global scale, the annual costs of land degradation on arable land and pastures alone were estimated at about US \$300 billion [10].

The inclusion of trees in soil protection and erosion control measures is one of the most widely recognized and convincing agricultural practices. Agroforestry is believed to reverse land degradation, restore carbon and nutrient reserves, and improve soil fertility. Like most other natural resource management sciences, it is characterized by a highly complex structure and functions [11].

Agroforestry systems play an important role in optimizing the nutrient cycle, producing organic matter and reducing the need for external fertilization. The cycle of nutrients in the Earth's ecosystem includes an external and internal cycle. The external cycle includes the supply of nutrients from ecosystems. The internal nutrient cycle describes the processes responsible for the transfer of nutrients between ecosystem basins [12]. Nutrient budgets (or nutrient balances) are a valuable tool for facilitating the understanding of the nutrient cycle in agroecosystems. They can also provide sustainability indicators that are easy for practitioners and policy makers to understand [13].

Based on current knowledge, there are at least four main processes that determine the nutrient cycle in agroforestry systems: biological nitrogen fixation, biomass production and decomposition, deep nutrient capture, and reduction in nutrient losses due to erosion [14]. Although an analysis of all the above-mentioned systems is available, they do not take into account and do not economically describe all the short- and long-term benefits from the inclusion of forest plantations in the agricultural landscape and the influence of trees on the nutrient balance in agroforestry systems. The current net values presented in the literature are extremely variable, and it is not possible to make any quantitative generalizations for different natural areas or practices. The only conclusion reached on the basis of a review of economic information is that the potential of agroforestry in reducing nutrient losses due to erosion is real and it can be economically beneficial in a variety of circumstances.

In Russia, the problem of economic justification of the effectiveness of forest reclamation measures complicates their development and is the reason for the low attractiveness for

land users in deflation-dangerous agricultural regions, despite all its importance. Farmers are not interested in investing more financial resources in the creation of protective forest plantations than the cost of the crop, which they can receive additionally. At the same time, they do not take into account the additional costs of fertilizers that are necessary for the restoration of eroded soils. In Russia, this leads to the actual neglect of protective forest stands.

Traditionally, the effectiveness of forest plantations is assessed here by increasing the yield of agricultural crops in protected fields. However, during wet and dry years, crop increases differ significantly among themselves. These differences create the basis for discussions about the agro-economic efficiency of forest strips, which negatively affect the rates of afforestation of fields [15,16]. The academic community discusses the low attractiveness of this approach due to its low economic feasibility, based on the traditional practice of calculating only additional crop production without taking into account the environmental component [17,18].

Despite the fact that, in recent years, there has been a significant shift in research on the mechanics of the anti-deflationary effect of protective forest stands on fields, there is no such trend with regard to studying the issues of their economic efficiency. The latest special studies on the economics of protective afforestation, conducted in Russia, were recorded in the literature only at the end of the last century and at present, in the conditions of the country's transition to an environmentally oriented economy, they have lost their relevance.

In this regard, a new approach is required to assess the effectiveness of forest reclamation, emphasizing its anti-degradation impact on agricultural land. The only reliable source of quantitative assessment of the potential effectiveness of forest plantations in protecting land from erosion is the loss of organic and nutrient substances of the soil prevented by trees.

The article is based on a new approach to assessing the effectiveness of forest plantations. He emphasizes sustainable development and the anti-erosion effect of forests on agricultural land [19–21]. The effectiveness of forest plantations is proposed to be measured by the internal cycle of the humus and nutrients within the forested area based on the balance of these substances in protected and unprotected zones. By modeling several variants of the placement of forest stands in an agricultural landscape with different levels of danger and intensity of harmful winds in relation to the natural and climatic conditions of the steppe, it was possible to establish the dynamics of the anti-deflationary effect depending on the degree of protection of land use with different placement of trees from each other.

The new approach is updated with a scenario forecast of compensatory costs for replacing humus and the active substance nitrogen, phosphorus, and potassium (NPP) with organic and mineral fertilizers and determining the amount of damage/prevented damage from deflation of different intensity, taking into account the climate factor in open fields and in protective zones of tree influence.

The main purpose of this study was to analyze the humus-regulating and NPK-regulating effectiveness of protective forest stands on lands with deflation-hazardous soils and to determine the patterns of its dynamics to stimulate the development of agroforestry in Russia.

2. Materials and Methods

2.1. Case Study Sites

The research was carried out in relation to the natural and climatic conditions of the steppe zone. The steppe zone is a region of Russia where the agricultural sector is one of the most important sectors of the economy. The zone is located in the southwestern part of the Saratov region, occupying the main part of the interfluvium of the Medveditsa and Khopra rivers. Then, the zone extends to the Volgograd region (Figure 1).

Figure 1. Geographical location of the steppe zone of ordinary chernozems.

The soil cover is mainly represented by ordinary chernozems, which are the most highly fertile soils of the south of the Russian Plain. The carbonate horizon begins directly under the humus layer. Ordinary chernozems contain humus from 6.0 to 7.5%. The thickness of the humus horizon is 45–60 cm [22]. The region is dominated by ordinary chernozems of heavy mechanical composition, formed on heavy loess-like loams and syrtic clays. Only on high river terraces are there sandy loam chernozems.

The climate of the steppe zone is medium continental (the coefficient of continentality is 177–195). It is manifested in insufficient annual moisture, average and above average heat supply, and increasing severity of winter. The sum of active temperatures in the north-eastern part of the steppe zone is 2400–2800 °C (Saratov region), and in its south-western part (Volgograd region), 2800–3300 °C. According to the annual moisture content, the steppe zone is mainly arid and semiarid (the moisture coefficient is 0.44–0.81) [23].

The 10 year dynamics (2011–2020) of the main climatic indicators obtained on the basis of data from the reference weather stations of the steppe zone indicates the average continentality of the climate of the studied region (Figure 2).

A high temperature regime with a lack of precipitation throughout the steppe zone leads to a strong heating and drying of the soil surface, intensive warming of air masses and their rapid transformation, and, ultimately, the formation of droughts, which are genetically associated with dry winds [23].

The most active form of wind erosion is dust storms. In the south of the Russian Plain, they manifest themselves in a peculiar way: in the western regions, dust storms occur most often in winter and in the early spring period, in the eastern regions due to the increase in aridity of the climate—in summer and autumn. In November and December, when the highest humidity is observed everywhere, storms are rare [25].

Figure 2. Climatic characteristics of the steppe zone of the south of the Russian Plain (based on data from weather stations in the cities of Uryupinsk and Saratov). Location of the meteorological station in Uryupinsk (south-western part): latitude 50.80 longitude 42.00. Location of the meteorological station in Saratov (north-eastern part): latitude 51.60 longitude 46.00 [24].

Modeling of Systems of Protective Forest Stands and Crop Rotations

The research is based on the hypothesis that, if areas with deflation-dangerous lands are developed for crop rotation (plowed) without first creating a system of forest plantations, then after a relatively short time, the state of the soil cover degrades to the limits known to science [26,27]. These limits (parameters of soil destruction, loss of humus and soil nutrients, etc.) determined the anti-deflationary value of the forest for farms. They were taken by us to assess the prevented damage from wind erosion, as well as to develop simulation models of optimal agroforest landscapes with appropriate biological and technological solutions for placing forest stands within them [28].

The constructed engineering and technological models simulate various combinations of “plain-forest-land use” [29]. Using these models, the dynamics of nutrients in the soil with different spatial placement of trees from each other was studied using a system analysis. Thus, the following forest reclamation strategy of forest reclamation protection were studied:

Forest reclamation strategy 1—“typical”. The distance between the trees is taken on the basis of instructions for creating protective forest stands. For ordinary chernozems, it is 500 m. Approximately, this is 30 heights of trees (H).

Forest reclamation strategy 2—“intermediate”. The average range of the influence of the bands is equal to 22 heights of trees.

Forest reclamation strategy 3—“calculated” for full field protection. The average range of influence is equal to 15 heights of trees.

On the basis of the balance assessment method [1,25], reflecting the general direction of the blowing process in the entire inter-lane space, the length of the soil blowing zones between the forest strips was established. Next, the indicator of the protection of deflation-

dangerous lands was calculated—the deflation control coefficient—the percentage ratio of arable land and crops located in the zones of effective anti-deflationary influence of protective forest strips to the total area of fields or interstitial cells, along the borders of which this type of forest-reclamation plantings is located.

It is assumed that, in a protected area, deflation processes occur within safe limits and do not cause critical annual losses of the fertile soil layer. In an unprotected area, soil blowing processes take place and ecological and economic damage from these processes is observed [30].

2.2. Data Collection

The initial data on the ecological and economic damage from deflation for the beginning of modeling the effectiveness of each forest reclamation strategy were obtained using the basic assumptions described in the work of M.I. Dolgilevich [25]: with weak erosion, less than $\frac{1}{2}$ of the humus-accumulative horizon is demolished, and the humus content decreases to 15%. With average erosion, more than $\frac{1}{2}$ of the humus-accumulative horizon is demolished, and the humus content decreases by 15–40%. With strong erosion, the humus-accumulative horizon and part of the transition horizon are completely demolished. At the same time, more than 41–80% of humus is lost.

Information about the potential anti-deflationary effect of trees at different distances from each other on land plots, obtained from literary sources [1,14,19], was confirmed by the results of long-term field studies of the department of erosion of agroforest landscapes of the All-Russian Research Institute of Agroforestry, Volgograd, Russia (now the Federal Scientific Center of Agro-ecology, Complex Melioration and Protective Afforestation of the Russian Academy of Sciences).

The field experiments consisted of studying the processes of fine-earth transfer depending on the wind speed at different distances of trees from each other (15 H, 16–25 H and 30 H). The role of the forest plantation system in stopping these processes was revealed. The survey of the forest-reclaimed territory was carried out for the presence of foci of deflation, selective blowing of clay particles, and desalination of the upper arable soil layer at different inter-line spaces. Soil samples were taken at 3–10 soil sites for analysis in a layer of 0–100 cm. In the field, the density of dry soil was determined according to Kachinsky, in the laboratory; humus according to Tyurin; gross forms of nitrogen, phosphorus, and potassium (NPK) in one sample by burning in a mixture of sulfuric and perchloric acids according to Meshcheryakov [31]. In areas outside the protection of trees, the conclusions were confirmed by the data [25].

The experience of creating and maintaining forest stands in agricultural landscapes in semiarid conditions of the steppe zone of the south of the Russian Plain was also studied [32].

2.3. Data Analyses

2.3.1. Assessment of Ecological and Economic Damage from Loss of Soil Fertility as a Result of the Formation of Wind Erosion on the Site

The compensatory costs for restoring soil fertility losses as a result of wind erosion are obtained in the prices of 2021. They are calculated in rubles and converted into euros at the official exchange rate set by the Central Bank of Russia, Moscow, Russia on 15 June 2021.

When calculating, we used literary sources on soil science [22,33].

To determine the economic effect of the impact of forest reclamation on the sustainability of land use, the amount of initial damage as a result of soil deflation was determined (Damage_{defl}, EUR). It was calculated as the sum of the market value of humus (V_{humus}) and the active substance, N (nitrogen), P (phosphorus), or K (potassium) (V_{NPK}), of the degraded layer of the assessed lands, taking into account the climate factor (CF).

$$\text{Damage}_{\text{defl}} = (V_{\text{humus}} + V_{\text{NPK}}) \times \text{CF} \quad (1)$$

The compensatory costs of shifting the losses of humus (V_{humus}) to the level of non-eroded soils were determined by the costs of replacing these losses with organic fertilizers during humification, taking into account the costs of their delivery:

$$V_{\text{humus}} = H_W / K \times (P_1 + P_2) \quad (2)$$

In the formula, H_W is the weight of lost humus, ton; K is the coefficient of humification of the soil for manure; P_1 is the cost of fertilizers (litter manure), EUR ton⁻¹; P_2 is the cost of purchasing, transporting, storing and applying fertilizers, EUR ton⁻¹.

When calculating, it is assumed that the depth of the arable horizon is 0.2 m and the weight of one hectare of the arable horizon of the soil is 2200 ton. The humification coefficient for manure is 0.25. The calculation of the cost of compensating the active substance NPK (V_{NPK}) in the degraded layer of soil cover was carried out by analogs in simple (single-component) mineral fertilizers:

$$V_{\text{NPK}} = \text{NPK}_W \times K \times (P_1 + P_2) / 1000 \quad (3)$$

In the formula, NPK_W is the content of lost nitrogen, phosphorus and potassium in the soil, kg ha⁻¹; K is the conversion factor to physical weight; P_1 is the cost of fertilizers, EUR ton⁻¹; P_2 is the cost of purchasing, transporting, storing and applying fertilizers, EUR ton⁻¹; 1000 is the conversion of kg to ton.

To convert soil elements into mineral fertilizers, the coefficients used were, for ammonium nitrate, $K = 2.94$; for double granular superphosphate, $K = 2.17$; for potassium chloride, $K = 1.6$.

The climatic factor (the probability of loss of soil fertility due to deflation) is determined based on a single phenomenon with a certain period of repetition in the steppe zone of the south of the Russian Plain. It is established that, on average, according to the intensity of land destruction (in the range of weak–strong deflation), increased wind activity and dust storms occur every 3–6 years (on average 5 years) out of 10. Hence, their probability coefficient is 50% [1,34].

2.3.2. Assessment of the Impact of Forests on Reducing Degradation and Increasing the Sustainability of Land Use

The methodology for assessing the effectiveness of the impact of forest reclamation on the sustainability of land use (Eff_{defl} , EUR ha⁻¹ year⁻¹) was based on generally accepted principles for assessing ecosystem services of forest communities [35–37]. It was calculated based on compensation costs, taking into account the time factor and the growth dynamics of the main breed according to the balance of nutrients in the zones of protection of forest stands and outside of protection according to the formula

$$\text{Eff}_{\text{defl}} = \frac{\sum_1^T Q_t \frac{1}{(1+r)^t}}{Q_{\text{MAX}} \sum_1^T \frac{1}{(1+r)^t}} \sum_1^T (\text{Damage}_{\text{defl}} * \text{ZCD} - \text{Damage}_{\text{defl}} * \text{ZAD}) \quad (4)$$

In the formula, Q_t is the effect in t year, EUR; Q_{max} is the effect of forest plantations that have reached the design height, EUR; r is the discount rate; T is the functional service life of the plantation, years; $\text{Damage}_{\text{defl}}$ is the damage from soil fertility losses as a result of deflation, EUR; ZCD is the zone of controlled deflation, ha; and ZAD is the zone of active deflation, ha.

With a positive value of the anti-deflationary effect obtained from the system of protective forest plantations located on agricultural land, the strategy of agroforestry land use was recognized as sustainable, with a negative effect, the strategy of agroforestry was risky, without economic viability.

For comparison, two scenarios of forest-reclamation arrangement of land use have been developed, which differ in the durability and growth dynamics of the main forest—forming

species—long-lasting, slow-growing, and precocious fast-growing. These rocks reach an average design height of 16 m in semiarid steppe conditions [38].

2.4. Caveats of Study

A very important critical factor determining the effectiveness of trees against wind energy is the permeability of the protective strip, which has a braking effect on the air flow. The article proceeded from the fact that the greatest decrease in wind speed by trees within the interband cell is achieved when the permeability of forest stands is 40%. This type of permeability can be called moderately openwork, when only the general outlines of an object are visible through the leaves, but it is impossible to determine exactly what kind of object it is [26].

It should be noted that the values of the anti-deflationary efficiency of the systems of protective forest stands are calculated for the soil and climatic conditions of the steppe zone, provided that the forest stands are located strictly perpendicular to the wind flow. If there is a deviation from it, additional calculations are required, since the interband distances will be even smaller [1,39].

3. Results

3.1. Assessment of Ecological and Economic Damage from Loss of Soil Fertility as a Result of the Formation of Wind Erosion on the Site

A distinctive feature of agricultural production in the steppe zone of the south of the Russian Plain is the high risk of its implementation. This is due to the significant dependence of agricultural activity on continuously changing and difficult to predict natural conditions. Every 3–6 years, an emergency regime for droughts is introduced in the regions. At the same time, deflation of plowed soils remains the main problem of land users, since it causes significant damage from losses of soil fertility and the death of agricultural crops.

It was found (Table 1) that, with weak erosion of ordinary chernozems by wind, when the layer of lost soil is approximately 5 cm, the loss of humus is $24.2 \text{ ton}^{-1} \text{ ha}^{-1}$, and the loss of nutrients of nitrogen, phosphorus, and potassium is estimated at $3.27 \text{ ton}^{-1} \text{ ha}^{-1}$. An increase in the soil blowing layer to 10 cm causes an increase in organic and nutrient losses by 1.8–1.9 times. The catastrophic stage of wind erosion (dust storms) is the cause of very deep hollows blowing the entire arable horizon (more than 20 cm). At least 473 ton of manure and almost 27 ton of mineral fertilizers will be required to restore the fertility of 1 ha of such hollows. The introduction of such a large amount of fertilizers is impractical for farmers because of their high cost. Nevertheless, they still need to bear these costs, since these lands are dangerous hotbeds of deflation for neighboring fields.

It was found that, to restore the lost fertility of ordinary chernozems with a humus content of 7.1% during the destruction (blowing) of the soil layer, its compensation in terms of fertilizers in the amount of 121–473 ton of nitrogen-containing organic matter and 3–12 ton of the active substance NPK, depending on the intensity of the process, will be required.

At current prices, the range of the cost of a complex of organic and mineral fertilizers required for the restoration of deflated soils is EUR 4333–EUR 17176 $\text{ha}^{-1} \text{ year}^{-1}$. Of this total amount, 45% accounts for fertilizers equivalent to organic matter (humus), 22% for fertilizers equivalent to active substance N, 6% for fertilizers equivalent to active substance P, and 27% for fertilizers equivalent to active substance K.

At current prices, this volume is estimated at EUR 4333–EUR 17176 $\text{ha}^{-1} \text{ year}^{-1}$. If we take into account that the natural anomaly repeats in the steppe on average 5 years out of 10, we have a total average annual damage to the landowner taking into account the climate factor of EUR 2167–EUR 8588 $\text{ha}^{-1} \text{ year}^{-1}$.

Table 1. Annual ecological and economic damage from the loss of nutrients of ordinary chernozems as a result of wind erosion.

Calculated Indicators	Humus	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Total Quantity
Brand of mineral fertilizers that replace nutrients in the soil	Litter manure of cattle	Ammonium nitrate	Double granulated superphosphate	Potassium chloride	Nitrogen-containing and active substance
Losses of organic and mineral substances in the soil profile (A + B), ton ha ⁻¹ :	Organic fertilizer	NH ₄ NO ₃	Ca (H ₂ PO ₄) 2·H ₂ O	CHl	NPK
Low-intensity deflation	24.2	0.96	0.38	1.93	27.47
Medium-intensity deflation	44	1.8	0.72	3.6	50.12
High-intensity deflation (dust storms)	94.6	3.84	1.54	7.7	107.68
The amount of fertilizers equivalent to humus and the active substance NPK, ton ha ⁻¹ :					
Low-intensity deflation	121	2.82	0.82	3.08	127.72
Medium-intensity deflation	220	5.29	1.56	5.75	232.6
High-intensity deflation (dust storms)	473	11.29	3.34	12.32	499.95
Compensatory costs for the replacement of fertility losses, ha ⁻¹ :					
Low-intensity deflation	EUR 1957	EUR 959	EUR 242	EUR 1175	EUR 4333
Medium-intensity deflation	EUR 3560	EUR 1799	EUR 461	EUR 2194	EUR 8014
High-intensity deflation (dust storms)	EUR 7653	EUR 3838	EUR 986	EUR 4699	EUR 17176

3.2. Assessment of the Impact of Forests on Reducing Degradation and Increasing the Sustainability of Land Use

Due to the risk of early death of forest stands in arid natural and climatic conditions, the stability of forest use is ensured by the selection of tree species adapted to these conditions. For the conditions of the steppe zone of the south of the Russian Plain on agricultural lands, it is recommended to plant Petiolate oak (*Quercus robur* L.) and Hanging birch (*Betula pendula* Roth.). In the semiarid conditions of the steppe, these rocks reach an average design height of 16 m.

Plantings of Petiolate oak are created by sowing seeds (acorns). They are sown 15–20 cm apart from each other. Acorns are embedded in moist earth to a depth of 8–10 cm. This forest crop is a long-lasting breed. The tree grows relatively slowly, especially in the first years of life. The period of closing the crowns begins at the age of 10. From this age, the planting begins to have a full-fledged influence on the territory. The operational service life, during which the planting remains effective, is 50 years. This is the period of reforestation logging. Petiolate oak is a demanding tree species for soil fertility.

Hanging birch plantings are created by planting 1 year-old seedlings. The distances between the plants in the rows are 0.8–1.5 m. Planting is carried out by forest planting machines. Hanging birch is a precocious breed. The tree grows relatively quickly, especially in the period between 10 and 20 years. The period of closing the crowns begins from the age of 7. The operational service life, during which the planting has an effective impact on the territory, is 35 years. Hanging birch is a tree species that is undemanding to soil fertility. It grows well even on eroded soils.

It is established that the stability of agriculture on the fences is ensured by the convergence of the distances between forest stands from 30 to 15–22 H with a natural increase in the forest cover of the occupied land use by 2.0–2.2 times (Table 2). This makes it possible to control the degradation of the soil cover by reducing the critical wind speeds by 20–35%.

Table 2. Bioengineering modeling and capital intensity of measures for land use development by forest stands of the steppe zone of the south of the Russian Plain (based on 400 hectares of land use).

Calculated Indicators	Forest Reclamation Strategy 1		Forest Reclamation Strategy 2		Forest Reclamation Strategy 3	
The range of influence of trees, H	30		22		15	
Wind speed reduction, % of the speed in the open field [28]	10		20		35	
The main forest-forming breed	1	2	1	2	1	2
Forest stand–forest stand space, meters	500		350		240	
Coefficient of protection of land use (wind erosion control)	0.48		0.69		~1.00	
Width of forest stands, meters	12	9	12	9	12	9
Total number of forest stands, pieces	6		7		10	
Total area of forest stands, ha	14.4	10.8	16.8	12.6	24.0	18.0
Protective forest cover, %	3.6	2.7	4.2	3.2	6.0	4.5
Costs for the arrangement of land with forest plantations per 1 ha of agroforest landscape	EUR 26	EUR 32	EUR 34	EUR 43	EUR 41	EUR 52

Note: 1—Petiolate oak and 2—Hanging birch.

Petiolate oak plantings require approximately 30% more planting area than Hanging birch plantings. This is explained by the bioengineering features of creating forest plantations, when planting long-lasting forest crops is created from four rows, and early ripening ones from three rows. The total width of the plantings is, respectively, 12 and 9 m.

With an increase in forest cover from 2.7–3.6 to 4.5–6.0% to achieve 100% protection of land plots (by reducing the inter-lane distance from 30 to 15 H), the capital intensity of forest reclamation works increases by 1.5–1.6 times, that is, in proportion to the increase in protective forest cover of land ($r^2 = 99\%$). It is EUR 26 (Petiolate oak) and EUR 32 (Hanging birch) ha^{-1} agroforest landscape with typical forest cover and EUR 41 (Petiolate oak) and EUR 52 (Hanging birch) ha^{-1} agroforest landscape with optimal forest cover.

Forestry care measures are most expensive when maintaining Petiolate oak plantings. The cost of care is 19–20% of the total cost of creating them. Care of Hanging birch plantings is cheaper—it accounts for 10–11% of the total cost [40].

The ecological and economic result of the positive impact of forest strips on the sustainability of land use with deflation-dangerous soils is expressed in saving financial resources necessary for fertilizing degraded areas. In value terms, it is estimated by the area of forest reclamation (net). Based on the analysis of special studies of authoritative scientists in the field of protection of soil from wind erosion by forest stands [1,26,30,41], it was found that the wind speed perpendicular to the wind flow in the range of 0–15 H is reduced by forest strips below the threshold value, and deflation does not affect the natural soil formation process. In the range of 16 H and forest stands are not able to reduce critical wind speeds to safe limits; therefore, there is damage from soil fertility losses.

Calculations of soil fertility budgets (Figure 3) in the context of models of agroforestry complexes indicate that when the width of the interband space decreases from 30 to 15 H, the zone that is outside the active influence of protective plantings decreases, approaching zero, causing an increase in the anti-deflationary effect. Thus, with an inter-lane distance of 500 m (30 H), the width of the tree protection zone is only 240 m. With such a forest reclamation strategy, the balance of soil fertility on the site is negative. When the width of the interband cage is reduced to 350 m (22 H), the zone outside the protection of forest stands is reduced to 128 m. This increases the balance of organic and nutrients in the forested cell, making it positive. With the width of the interband cell of 240 m, the zone of active influence of deflation is approximately zero. This forest reclamation strategy has a maximum positive budget for the fertility of the site.

Figure 3. Dynamics of the annual anti-deflationary effect of protective forest stands that have reached the design height (taking into account the climate factor), determined by the replacement cost of humus, NPK nutrients, and their total amount, depending on the interband spaces at different intensity of deflationary processes.

The systems of protective forest stands that have entered the operational age make it possible to obtain an anti-deflationary effect per year on the ordinary chernozems of the steppe that are slightly eroded by the wind in the amount of up to EUR 2132 per hectare of a forested field. With an increase in the intensity of soil deflation, the soil protection efficiency of forest reclamation increases almost four times. This is due to the high costs

of fertilizers that are adequate for the restoration of highly ventilated lands, where the thickness of the A + B horizons decreases to 20 cm, and areas of fine-grained removal are observed everywhere, often up to the “sole” of the previous treatment.

Graphical analysis shows that the “zero” anti-deflationary effect (the protection zone overlaps the unprotected zone) begins at the point of 29 H (483 m). In this regard, forest reclamation measures to ensure a positive balance of nitrogen-containing organic matter and the active substance NPK on the forested area are appropriate and make financial sense if the planned distances between the trees do not exceed the specified limit.

In order to resist natural anomalies, forest stands must grow, rise to a height capable of resisting the wind, form a certain environment inside themselves, and accumulate the potential of useful forest properties. The annual economic effect of the influence of trees varies over time—from a negative value, starting from the year of planting of forest stands, to a positive and increasing value—in subsequent years. The forest plantation begins to provide full protection only after the crowns of the trees are closed. Therefore, in systems of plantings from precocious fast-growing rocks, due to an earlier period of crown closure, the anti-deflationary effect is 6–7% higher on an average annual basis than in systems of plantings from long-lasting, slow-growing rocks (Table 3).

Table 3. The average annual effect of the influence of the system of forest plantations on the stability of land use with deflation-dangerous soils, taking into account the dynamics of growth of the main breed per 1 ha of the agroforest landscape.

Calculated Indicators	Forest Reclamation Strategy 1		Forest Reclamation Strategy 2		Forest Reclamation Strategy 3	
	1	2	1	2	1	2
The main forest-forming breed						
Protective forest cover, %	3.6	2.7	4.2	3.2	6	4.5
Protection of forest land use, %	48	48	69	69	~100	~100
Average annual effect due to losses/prevented losses of soil fertility, ha ^{−1} :						
Low-intensity deflation	EUR −50	EUR −50	EUR 376	EUR 400	EUR 1002	EUR 1066
Medium-intensity deflation	EUR −157	EUR −157	EUR 696	EUR 741	EUR 1852	EUR 1970
High-intensity deflation (dust storms)	EUR −338	EUR −338	EUR 1487	EUR 1582	EUR 3968	EUR 4222
Effect for the operational life of the main forest-forming breed, ha ^{−1} :						
Low-intensity deflation	EUR −2476	EUR −1733	EUR 18779	EUR 13984	EUR 50111	EUR 37316
Medium-intensity deflation	EUR −7859	EUR −5501	EUR 34815	EUR 25926	EUR 92596	EUR 68955
High-intensity deflation (dust storms)	EUR −16887	EUR −11821	EUR 74350	EUR 55355	EUR 198417	EUR 147758
Sustainability of land use	−	−	+	+	+	+

Note: 1—Petiolate oak and 2—Hanging birch.

However, if we consider the long-term horizon of the functioning of trees in the agricultural landscape, the most effective are the plantings of Petiolate oak, which have a 34% higher anti-deflationary effect than those of Hanging birch. In addition, when choosing long-lasting plantings as a forest reclamation strategy, the need for expensive uprooting of forest stands for laying new forest crops is eliminated.

In general, the average annual value of the prevented damage from soil deflation, taking into account the time factor and the growth dynamics of the main forest-forming species, increases in proportion to the increase in land protection ($r^2 = 98\%$) and amounts to EUR 376–EUR 4222 ha^{−1}.

The soil protection efficiency for the entire period of service of the seed generation of the stand—before the resumption of logging—has similar dynamics. When the land is fully protected by a system of forest stands, the anti-deflationary efficiency is one third higher than when placing protective forest stands after 22 H and amounts to EUR 50111–EUR 198417 ha^{−1} for forest reclamation objects made of long-lasting, slow-growing rocks, and EUR 37316–EUR 147758 ha^{−1} for precocious fast-growing ones.

In the entire range of conditions in the south of the Russian Plain, the damage prevented by protective forest plantations from soil deflation remains significantly higher than the effect of the well-known agronomic anti-erosion techniques adopted in the agricultural sector of the country [25].

4. Discussion

4.1. Assessment of Ecological and Economic Damage from Loss of Soil Fertility as a Result of the Formation of Wind Erosion on the Site

In the world, soil erosion is one of the serious global environmental problems, and the study of soil erosion is the scientific basis for soil conservation. The global assessment of soil erosion is the most important for assessing land degradation and food security. One annual amount of ecological and economic damage from soil deflation (EUR 2167–EUR 8588 ha^{−1}year^{−1}) is enough to seriously destabilize the current activities of farmers.

In the United States, wind erosion is still the dominant problem on 75 million acres of land. At the same time, every year, from four to five million acres are damaged moderately or severely [42]. Wind erosion physically removes lighter, less dense soil components, such as organic matter, clays, and silts. Thus, it removes the most fertile part of the soil and reduces soil productivity. In the long term, the cost of wind erosion control methods can compensate for the cost of transplanting the destroyed crop [43].

Wind erosion poses a threat to numerous arable lands in the European Union. It affects both semi-arid areas of the Mediterranean region and areas with a temperate climate in the countries of Northern Europe. However, there is still a lack of knowledge that limits the understanding of where, when, and how much wind erosion affects European arable land [44].

Despite the fact that wind erosion proceeds unnoticed in the short term, a significant part of the topsoil rich in nutrients and organic substances is removed and, in the long term, damages agricultural productivity with a subsequent increase in the use of fertilizers [43]. According to [45], wind erosion may affect approximately a million hectares in western Denmark (approximately 38% of the agricultural area used), 170,000 hectares in Sweden (approximately 5.5%), almost two million hectares in Northern Germany (approximately 12%), 260,000 hectares in the UK (approximately 1.5%), and 97,000 hectares in the Netherlands (approximately 5.2%).

The cross-country analysis [44] showed the highest annual rate of soil loss in Denmark (3 Mg ha^{−1} year^{−1}), the Netherlands (2.6 Mg ha^{−1} year^{−1}), Bulgaria (1.8 Mg ha^{−1} year^{−1}), and, to a lesser extent, the UK (1 Mg ha^{−1} year^{−1}) and Romania (0.95 Mg ha^{−1} year^{−1}).

Wind erosion is one of the most important processes among land degradation or desertification in arid, semi-arid, and partially sub-humid regions of China. The total area of land subject to wind erosion reaches 160.74 × 104 km², which is 16.7% of the country's territory [46].

In general, 1252.79 thousand hectares of agricultural land are subject to wind erosion in the Russian Federation. Of these, there are 149.6 thousand hectares in the Saratov region and 111.97 thousand hectares in the Volgograd region [47]. Based on our calculations, with the median damage from the loss of organic and nutrients of ordinary chernozems EUR 5378 ha^{−1}year^{−1}, we get the total damage caused by wind erosion to land users—in the Saratov region EUR 804.55 million and in the Volgograd region EUR 602.17 million.

The estimates we have obtained are adequate to world estimates. Thus, the impact assessments made in the 13 largest EU member states included in the proposal for the EU Thematic Strategy on Soils estimated the annual cost of the impact of soil erosion on the ground at about EUR 40–EUR 860 million [48].

In general, due to differences in methodologies for estimating the costs of reducing agricultural productivity due to soil erosion, we observe ambiguous results.

Methodologies based on cost–benefit analysis [49] estimated the cost of erosion control in areas of severe erosion at EUR 296 ha^{−1} with soil losses >10 ton·ha^{−1} year^{−1} and estimated significant costs of approximately EUR 3.571 million per year. The methodology based on the market price of the soil for direct use estimated approximately USD 20 per ton [50].

The most well-known methodologies are the methods of recovery costs [51]. According to the data [52], the cost of NPK nutrient losses from soil depletion due to erosion in

Africa is <USD 1 million (Botswana, Mauritius), USD 328–378 million (Ethiopia), and USD 770–909 million (Nigeria).

4.2. Assessment of the Impact of Forests on Reducing Degradation and Increasing the Sustainability of Land Use

The positive impact of forest reclamation on the sustainability of agriculture, in a broad sense, is determined by the rational ratio of arable land and forest plantations, in which land use is sustainable; that is, a balance is maintained between the rate of erosion and the rate of soil formation. The ideal option is considered to be the complete protection of the field from deflation; that is, the systems of protective forest stands are built in such a way that the reproduction of fertility in soils does not require special costs, but is a consequence of forest reclamation measures [53,54]. In practice, it is difficult to achieve such a state, so more realistic goals are set [55,56].

The regulatory framework indicates that, if protective forest stands are located perpendicular to the wind direction, then in ideal conditions, the distance at which protection from wind erosion is provided is equal to thirty tree heights. Meanwhile, field studies [1,25,54] indicate that the specified theoretical dependence between the height of the strip and the protected space is very rarely observed in practice. A more realistic figure can be considered 12–15 heights of the strip. Moreover, if you deviate from the perpendicular to the wind flow, these distances will be even smaller.

Calculations show that, in the range of deflation of low–high intensity, the forest reclamation regime with typical interband spaces of 30 H has a negative value of the annual and average annual soil protection effect. The development of 1 hectare of land in accordance with this forest reclamation strategy is EUR 26 when using Petiolate oak and EUR 32 when using Hanging birch. Characterized by losses (negative balance) of humus and nutrients, agroforestry under such parameters is an extremely risky and not a viable strategy. The annual result of the functioning of this forest reclamation strategy is equal to EUR −50–EUR −338 ha^{−1} of the forested landscape.

With the interband parameters of agroforestry at 22 H, the overall balance of nitrogen-containing substance and active substance NPK in the forested areas will be positive, but land use will not be sufficiently stable, since certain soil losses will still occur. This strategy can be adopted by farmers for economic reasons with a limited amount of available financial resources. The capital intensity of this agroforest strategy is EUR 34 ha^{−1} when using Petiolate oak and EUR 43 ha^{−1} when using Hanging birch. When using Petiolate oak, the average annual prevented damage from soil fertility losses will be EUR 376–EUR 1487 ha^{−1}. When using Hanging birch, it will be equal to EUR 400–EUR 1582.

Forest-reclaimed land use with a distance between trees of 15 H can be considered optimal for farmers, since it is characterized by the best combination of capital intensity and soil protection effect, especially with a high risk of deflation. At the cost of equipping the land with protective plantings systems in the amount of EUR 41 per 1 ha of the agroforest landscape when using Petiolate oak and EUR 52 per 1 ha of the agroforest landscape when using Hanging birch, an economic result will be obtained in the form of prevented damage in the amount of, respectively, EUR 1002–EUR 3968 and EUR 1066–EUR 4222 ha^{−1}. In our opinion, it is not advisable to further reduce the distances between forest strips from the point of view of the capital intensity of forest reclamation measures [20].

An analysis of the literature on the anti-deflationary effectiveness of agroforestry shows that most of the studies on the influence of tree systems on the quality of eroded soil are limited to monitoring some soil properties. Not much effort has been made to economically assess the impact of various protective plantings systems on soil quality using soil profile data, since the task is obviously difficult.

There are scientific studies confirming the economic viability of agroforestry systems in various contexts. Thus, according to reliable field data on the assessment of agro-nomic productivity and economic viability of agroforestry systems, the gross profit of agroforestry was lower in Denmark (EUR 112 ha^{−1} year^{−1}) than in the United Kingdom (EUR 5083 ha^{−1} year^{−1}) [57].

It is noteworthy that the forest stands themselves are sources of providing available reserves of organic and mineral substances at the expense of forest litter. The mass of litter in forest-reclaimed landscapes is usually much higher than in forest ecosystems, since it contains accumulated impurities of deflation products. Thus, under 25–40 summer protective forest stands, the increase in humus in ordinary chernozem in a layer of 0–100 cm ($677.5 \text{ ton ha}^{-1}$) exceeded the initial humus reserves by 171 ton ha^{-1} , while the biological rates of humus accumulation did not exceed $1.5\text{--}2.0 \text{ ton ha}^{-1}$ [58].

Microeconomic modeling of the effectiveness of forest reclamation measures [59], based on a comparison of the discounted benefits from afforestation of plots with the costs required for these measures, shows that the ratios for all forest reclamation scenarios for the arrangement of fields that ensure sustainable land use are greater than 1. This indicates that the cultivation of forest stands in the region is a profitable activity that has economic viability, especially when using durable breeds.

Calculations based on the determination of the balance of nitrogen-containing organic matter (humus) and the active substance NPK in forested cells confirmed the feasibility of converging the rows of forest plantations and, consequently, the protective forest cover of the fields by at least two times. Despite the fact that this definitely increases the financial capacity of forest reclamation facilities, at the same time, it will become an important measure to create reliable protection of agriculture from natural anomalies and ensure its sustainable development.

5. Conclusions

In this study, it was found that, with wind erosion of ordinary chernozems, the total amount of annual damage is EUR 4333–EUR 17176 $\text{ha}^{-1}\text{year}^{-1}$. Taking into account the climatic factor (the probability of deflationary processes), the damage is equal to EUR 2167–EUR 8588 $\text{ha}^{-1}\text{year}^{-1}$. Of this total amount, 45% accounts for fertilizers equivalent to organic matter (humus), 22% for fertilizers equivalent to active substance N, 6% for fertilizers equivalent to active substance P, and 27% for fertilizers equivalent to active substance K.

An economic analysis of the humus-regulating and NPK-regulating effectiveness of protective forest stands on lands with deflation-hazardous soils showed that when placing forest stands in 30 H, land use will be unstable. The average annual anti-deflationary effect will be negative. It amounts to EUR -50 ha^{-1} at a low deflation intensity and EUR -338 ha^{-1} at a high deflation intensity of a forested landscape. With the parameters of the forested cell at 29 H, there will be zero anti-deflationary effect. The protection zone of forest stands will block the unprotected zone. At 15 H, there will be an optimal positive effect. The efficiency of forest stands is equal to EUR 1002–EUR 3968 (when using Petiolate oak) and EUR 1066–EUR 4222 (when using Hanging birch).

In the short-term planning horizon of forest reclamation anti-deflationary strategies in semiarid steppe conditions, the use of fast-growing forest-forming species has the greatest prospect, which is associated with an earlier period of entry of trees into operational age and a high average annual effect. As for the long-term planning horizon, the use of long-lasting forest-forming species has a special advantage here due to a higher effect over the entire operational life.

Calculations to determine the balance of nitrogen-containing organic matter (humus) and the active substance NPK in forested cells confirmed the feasibility of bringing the rows of forest plantations closer together and, consequently, the protective forest cover of fields by at least two times. Despite the fact that it increases the financial capacity of forest reclamation facilities (on average, of 1.6 times), at the same time, it will become an important measure to create reliable protection of agriculture from natural anomalies and ensure its sustainable development.

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References

- Dolgilevich, M.I.; Vasiliev, Y.I.; Sazhin, A.N. *Windbreak Systems and Wind Erosion*; Lesnaya promyshlennost': Moscow, Russia, 1981.
- Brandle, J.; Hodges, L.; Wight, B. Windbreak practices. In *North American Agroforestry: An Integrated Science and Practice*; Garrett, H.E., Rietveld, W.J., Fisher, R.F., Eds.; American Society of Agronomy: Madison, WI, USA, 2000; pp. 79–118.
- FAO (Food and Agriculture Organisation of the United Nations). *FAO's Work on Agroecology*; United Nations: Rome, Italy, 2018. Available online: <http://www.fao.org/3/i9021en/i9021en.pdf> (accessed on 15 May 2021).
- Current, D.; Lutz, E.; Scherr, S. *Costs, Benefits and Farmer Adoption of Agroforestry: Project Experience in Central America and the Caribbean*; World Bank: Washington, DC, USA, 1995. Available online: <https://link.springer.com/article/10.1007/BF00708915> (accessed on 1 May 2021).
- Hillbrand, A.; Borelli, S.; Conigliaro, M.; Olivier, A. *Agroforestry for Landscape Restoration: Exploring the Potential of Agroforestry to Enhance the Sustainability and Resilience of Degraded Landscapes*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2017. Available online: <http://www.fao.org/3/b-i7374e.pdf> (accessed on 1 May 2021).
- Wilson, M.H.; Lovell, S.T. Agroforestry—The next step in sustainable and resilient agriculture. *Sustainability* **2016**, *8*, 574. [CrossRef]
- Brandle, J.R.; Hodges, L.; Zhou, X.H. Windbreaks in North American agricultural systems. *Agrofor. Syst.* **2004**, *61*, 65–78.
- Lal, R. Soil erosion impact on agronomic productivity and environment quality. *Crit. Rev. Plant Sci.* **1998**, *17*, 319–464. [CrossRef]
- Kibblewhite, M.G.; Miko, L.; Montanarella, L. Legal frameworks for soil protection: Current development and technical information requirements. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 573–577. [CrossRef]
- Nkonya, E.; Mirzabaev, A.; von Braun, J. Economics of land degradation and improvement: An introduction and overview. In *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development*; Nkonya, E., von Braun, J., Mirzabaev, A., Eds.; Springer: Basel, Switzerland, 2016; pp. 1–14.
- Nair, P.K.R. *An Introduction to Agroforestry*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1993.
- Sileshi, G.W.; Mafongoya, P.L.; Akinnifesi, F.K.; Phiri, E.; Chirwa, P.; Beedy, T.; Makumba, W.; Nyamadzawo, G.; Njoloma, J.; Wuta, M.; et al. *Fertilizer Trees. Encyclopedia of Agriculture and Food Systems*; Elsevier: San Diego, CA, USA, 2014; Volume 1.
- Oenema, O.; Kros, H.; de Vries, W. Approaches and uncertainties in nutrient budgets: Implications for nutrient management and environmental policies. *Eur. J. Agron.* **2003**, *20*, 3–16. [CrossRef]
- Sileshi, G.W.; Mafongoya, P.L.; Nath, A.J. Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. In *Agroforestry for Degraded Landscapes*; Dagar, J.C., Gupta, S.R., Teketay, D., Eds.; Springer: Singapore, 2020; pp. 225–254.
- Tribunskaya, V.M. *Economic Efficiency of Protective Forest Plantations in the System of Soil Protection from Erosion*; Agropromizdat: Moscow, Russia, 1990.
- Rulev, A.S.; Pugachova, A.M. Formation of a new agroforestry paradigm. *Bull. Russ. Acad. Sci.* **2019**, *10*, 1044–1051. [CrossRef]
- Yin, R.S.; Hyde, W.F. The impact of agroforestry on agricultural productivity: The case of Northern China. *Agrofor. Syst.* **2000**, *50*, 179–194. [CrossRef]
- Buck, L.; Lassoie, J.; Fernandes, E. *Agroforestry in Sustainable Agricultural Systems*; CRC Press: Boca Raton, FL, USA, 1999.
- Bobylev, S.N. Sustainable development for future generations: Economic priorities. *World New Econ.* **2017**, *3*, 90–96.
- Korneeva, E.A. Efficiency of financing of forest reclamation measures for ensuring sustainable development of agricultural regions in the South of the European territory of Russia. *Econ. Reg.* **2020**, *16*, 871–883.
- Bobylev, S.N.; Solovyova, S.V. Sustainable development goals for the future of Russia. *Stud. Russ. Econ. Dev.* **2017**, *3*, 26–33. [CrossRef]
- Agrochemical Characteristics of Soils of the USSR. Volga Region*; Nauka: Moscow, Russia, 1966.
- Shashko, D.I. *Agro-Climatic Resources of the USSR*; Hydrometeoizdat: Leningrad, Russia, 1985.
- Open Portals of Climatic Data of Russia. Available online: <https://climate-energy.ru/material/> (accessed on 3 September 2021).
- Dolgilevich, M.I. *Dust Storms and Agroforestry Measures*; Kolos: Moscow, Russia, 1978.
- Morgan, R.P.C. *Soil Erosion and Conservation*, 3rd ed.; Blackwell Publishing: Oxford, UK, 2005.
- Kalyanov, K.S. *Dynamics of Wind Erosion Processes of Soils*; Nauka: Moscow, Russia, 1976.
- Burgess, P.J.; Graves, A.; García de Jalón, S.; Palma, J.H.N. Modelling agroforestry systems. In *Agroforestry for Sustainable Agriculture*; Mosquera-Losada, M.R., Prabhu, R., Eds.; Burleigh Dodds Science Publishing: Cambridge, UK, 2019; pp. 209–238.
- Ritchie, K. Shelterbelt plantings in semi-arid areas. *Agric. Ecosyst. Environ.* **1988**, *22*, 425–440. [CrossRef]
- Vasil'ev, Y.I. *The Effectiveness of the Systems of Forest Belts in the Fight against Deflation of Soils*; All-Russian Research Institute of Agroforestry: Volgograd, Russia, 2003.
- Koshelev, A.V.; Tubalov, A.A. Assessment of the fertility of irrigated lands of the Volgograd Volga region by modern research methods. *Sci. Agron. J.* **2020**, *4*, 35–42.

32. Manaenkov, A.S. *Forest Reclamation of Arid Zone Arenas*, 2nd ed.; Federal Scientific Center of Agroecology, Complex Melioration and Protective Afforestation Russian Academy of Sciences: Volgograd, Russia, 2018.
33. Kuznetsova, I.V.; Azovtseva, N.A.; Bondarev, A.G. Standards for changes in the physical properties of soils in the steppe, dry-steppe, semi-desert zones of the European territory of Russia. *Byulleten Pochvennogo Inst. Im. V.V. Dokuchaeva* **2011**, *67*, 3–19.
34. Pugacheva, A.M. The influence of homogeneous stands on the recovery of secondary virgin lands in agroforestry landscapes of dry steppes. *Biol. Bull.* **2021**, *2*, 184–192.
35. Jose, S. Agroforestry for ecosystem services and environmental benefits: An overview. *Agrofor. Syst.* **2009**, *76*, 1–10. [\[CrossRef\]](#)
36. Porter, J.; Costanza, R.; Sandhu, H.; Sigsgaard, L.; Wratten, S. The Value of Producing Food, Energy, and Ecosystem Services within an Agro-Ecosystem. *AMBIO* **2009**, *38*, 186–193. [\[CrossRef\]](#)
37. Liu, S.; Costanza, R.; Farber, S.; Troy, A. Valuing ecosystem services. Theory, practice, and the need for a transdisciplinary synthesis. *Ecol. Econ. Rev.* **2010**, *1185*, 54–78.
38. Manaenkov, A.S. Development of the basics of steppe and protective afforestation: Theoretical, applied aspects and tasks in modern conditions. *Bull. PSTU* **2016**, *2*, 5–23.
39. Korneeva, E.A. Forest reclamation as a factor of sustainable development of agricultural production in the Volgograd region. *AIC Econ. Manag.* **2019**, *6*, 55–63. [\[CrossRef\]](#)
40. Korneeva, E.A. Expenses for forest reclamation of degraded lands of the Volgograd region. *Agrar. Bull. Ural.* **2018**, *10*, 4–9. [\[CrossRef\]](#)
41. Wilson, S.J.; Cook, R.U. Wind erosion. In *Soil Erosion*; Kirkby, M.J., Morgan, R.P.C., Eds.; John Wiley & Sons: Chichester, UK, 1980; pp. 217–251.
42. Tatarko, J.; Trujill, W.; Schipansk, M. *Wind Erosion Processes and Control*; Colorado State University Extension: Fort Collins, CO, USA, 2019.
43. Lyles, L. Possible effects of wind erosion on soil productivity. *J. Soil Water Conserv.* **1975**, *30*, 279–283.
44. Borrelli, P.; Lugato, E.; Montanarella, L.; Panagos, P. A new assessment of soil loss due to wind erosion in European agricultural soils using a quantitative spatially distributed modelling approach. *Land Degrad. Develop.* **2016**, *28*, 335–344. [\[CrossRef\]](#)
45. Riksen, M.J.P.M.; De Graaff, J. On-site and off-site effects of wind erosion on European light soils. *Land Degrad. Dev.* **2001**, *12*, 1–11. [\[CrossRef\]](#)
46. Shi, P.; Yan, P.; Yuan, Y.; Nearing, M.A. Wind erosion research in China: Past, present and future. *Prog. Phys. Geogr.* **2004**, *28*, 366–386. [\[CrossRef\]](#)
47. *Report on the State and Use of Agricultural Lands of the Russian Federation in 2018*; FGBNU Rosinformagrotech: Moscow, Russia, 2020.
48. European Commission. European Commission—Thematic Strategy for Soil Protection. 2006. Available online: http://ec.europa.eu/environment/soil/three_en.htm (accessed on 5 September 2021).
49. Kuhlman, T.; Reinhard, S.; Gaaf, A. Estimating the costs and benefits of soil conservation in Europe. *Land Use Policy* **2010**, *27*, 22–32. [\[CrossRef\]](#)
50. Robinson, D.A.; Fraser, I.; Dominati, E.J.; Davísdóttir, B.; Jónsson, J.O.G.; Jones, L.; Jones, S.B.; Tuller, M.; Lebron, I.; Bristow, K.L.; et al. On the value of soil resources in the context of natural capital and ecosystem service delivery. *Soil Sci. Soc. Am. J.* **2014**, *78*, 685–700. [\[CrossRef\]](#)
51. Dixon, J.A.; Scura, L.F.; Carpenter, R.A.; Sherman, P.B. *Economic Analysis of the Environmental Impacts*, 2nd ed.; Earthscan Publication Ltd.: London, UK, 1994.
52. Enters, T. *Methods for the Economic Assessment of the On-and Off-Site Impacts of Soil Erosion*; International Board for Soil Research and Management (IBSRAM): Bangkok, Thailand, 1998.
53. García de Jalón, S.; Graves, A.; Palma, J.H.N.; Williams, A.; Upson, M.; Burgess, P.J. Modelling and valuing the environmental impacts of arable, forestry and agroforestry systems: A case study. *Agrofor. Syst.* **2017**, *92*, 1059–1073. [\[CrossRef\]](#)
54. Brandle, J.R.; Finch, S. How windbreaks work. *Pap. Nat. Resour.* **1991**, *121*, 1–5.
55. Heisler, G.; DeWalle, D. Effects of windbreak structure on wind flow. *Agric. Ecosyst. Environ.* **1988**, *22*, 41–69. [\[CrossRef\]](#)
56. Bhardwaj, D.R.; Navale, M.R.; Sharma, S. Agroforestry practices in temperate regions of the world. In *Agroforestry*; Dagar, J.C., Tewary, V.P., Eds.; Springer Nature: Singapore, 2017; pp. 163–187.
57. Lehmann, L.; Smith, J.; Westaway, S.; Pisanelli, A. Productivity and economic evaluation of agroforestry systems for sustainable production of food and non-food products. *Sustainability* **2020**, *12*, 5429. [\[CrossRef\]](#)
58. Kretinin, V.M. The soil-improving role of protective forest stands in the semiarid and arid regions of the North Caucasus and the south-east of the ETR. In *Theory and Practice of Forest Reclamation and Forest-Agrarian Development of Arid Territories*; Kulik, K.N., Ed.; All-Russian Research Institute of Agroforestry: Volgograd, Russia, 2001.
59. Stocking, M.; Bojo, J.; Abel, N. Financial and economic analysis of agroforestry: Key issues. In *Agroforestry for Sustainable Production: Economic Implications*; Prinsley, R.T., Ed.; The Commonwealth Secretariat: London, UK, 1990; pp. 13–119.