THE ROLE OF SHELTERBELTS IN ENSURING ENVIRONMENTAL SAFETY IN SOUTHERN UKRAINE

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Forest ecosystems play a pivotal role in the functioning of the biosphere. Due to their high biological productivity, capacity for energy accumulation, and regulation of biochemical processes, they hold global ecological significance [1]. Forests serve as a key element in maintaining the planet's natural equilibrium, ensuring the stability of nutrient cycling and energy flows within natural systems [2]. Through the process of photosynthesis, they sequester significant amount of solar energy, facilitate the synthesis of organic matter and regulate the atmosphere gas composition [3]. At the same time, forest degradation and deforestation reduction lead to the disruption of fundamental ecosystem functions, including energy transformation, biogeochemical cycles, the structural organization of natural complexes and the mechanisms maintaining their dynamic equilibrium. In this regard, expanding the area of forest plantations is considered one of the most effective natural ecological and economic measures for stabilizing the environment and maintain ecological balance in landscapes [4]. Forests perform a multifunctional role within the structure of both natural and anthropogenically transformed territories, acting as a vital regulator of interaction between individual components of geosystems [2]. Conserquently, they serve as an effective tool for managing ecological processes across various types of forest site conditions. Forest plantations are widely utilized in the formation and optimization of the spatial structure of landscapes, as well as in the design of geosystems, natural-territorial and socio-territorial complexes, natural-economic systems, and other functional territorial units.

In the context of modern intensive land resources use and increasing anthropogenic pressure, the implementation of comprehensive measures aimed at enhancing agricultural productivity and preventing land degradation is of particular importance. A key instrument for implementing such measures is the establishment and maintenance of a system of shelterbelt systems designed for various functional purposes [5]. These include field-protective shelterbelts, anti-erosion plantations, riparian buffer strips, water-protection zones and recreational forest areas.

In the scientific literature, such plantations are regarded as integral components of protective forest melioration systems, forming a spatially organized network of conservation elements within the structure of agricultural landscapes [1].

The functioning of these systems ensures a comprehensive impact on natural processes, contributes to the stabilization of the environmental state of territories, enhances the efficiency of land resource use, and creates the prerequisites for the sustainable development of rural areas [6]. In this context, protective forest plantations are regarded as a crucial instrument for the ecological optimization of agrolandscapes and safeguarding their long-term environmental safety.

Under the prevailing conditions in Southern Ukraine, agroforestry and protective afforestation remain among the key national priorities [7].

These lines of activity fulfill a range of critical socio-economic and environmental objectives by leveraging the ecological role of forests in agrolandscapes: protection farmlands from the adverse effects of natural and anthropogenic factors, ensuring the stable functioning of agroecosystems, and creating favorable conditions for the effective development of national economic sectors and the well-being of the population [8]. In the context of Ukraine's intensifying cooperation with the European Union, the ecological role of forest ecosystems is becoming increasingly significant, particularly regarding their integration into programs for designing balanced agricultural landscapes, conserving biodiversity, and implementing sustainable nature management practices on an ecosystem-landscape basis.

Southern Ukraine belongs to the steppe landscapes zone, characterized by increased climate continentality, moisture deficit, significant wind loads and a high level of anthropogenic development [8]. A high degree of lands arability, combined with the natural characteristics of the steppe, creates the prerequisites for the development of erosion processes, soil cover degradation, and a decline in agroecosystems productivity.

Under such conditions, shelterbelts serve as an important element of the ecological infrastructure of agricultural landscapes, capable of mitigating the negative impact of natural factors [9].

Protective forest plantayions create a specific microclimate in adjacent areas, reducing speed, facilitating snow accumulation, and promoting soil moisture conservation [10]. Conserquently, this enhances the resilience of agricultural crops to droughts and temperature fluctuations. Furthermore, shelterbelts perform a vital anti-erosion function by preventing the wind erosion of fertile topsoil. In steppe conditions, they act as a natural barrier that limits the occurrence of dust storms and dry winds.

The problem of preserving and restoring field-protecting shelterbelts takes on particular importance in the context of current climate change [11]. Over recent decades, Southern Ukraine has experienced a rise in average annual air temperatures, a decrease in effective precipitation, and an increasing frequency of arid periods.

Climate transformation lead to the intersification of aridification in steppe regions and the depping of desertification processes [12]. Under such conditions, the role of protective forest plantations as a stabilizing element of agricultural landscapes increases significantly.

Shelterbelts contribute to maintaining the water balance of territories, enhcancing the infiltration of atmospheric precipitation and reduce surface runoff. They also play a vital role in supportimg the biodiversity of agricultural landscapes. Within shelterbelts, habitats are formed for numerous species of plants, insects, birds and small mammals [8]. Thus, protective plantetions act as a unique ecological corridor that facilitate migration and the conservation of various species' populations.

Within the structure of modern agricultural landscapes in Southern Ukraine, shelterbelts function as natural regulators of ecological balance. They contribute to the formation of resilient biogeocenoses and maintain the environmental stability of the region. The presence of an extensive network of protective forest plantations ensures increased productivity of agricultural land and reduces the risk of land degradation [1]. Conserquently, agroforestry measures are regarded one of the key tools for adaptating the agricultural sector to climate change.

At the same time, a significant portion of the field-protective shelterbelts established in the second half of the 20th century are currently in poor condition. Over the past few decades, there has been a gradual reduction in the area of protective plantings, as well as their degradation and fragmentation. The main reasons for this are a lack of proper maintenance, illegal logging, changes in land-use patterns, insufficient funding for forest restoration measures, and an outdated legal framework [13]. As a result, the effectiveness of the field-protective forest strip system is significantly reduced.

Warfare, which broke out across Ukraine in early 2022, has become an additional factor negatively impacting the state of shelterbelts (fig. 1). A significant portion of the southern regions has been directly affected by military operations, leading to the destruction of natural ecosystems and a disturbance of the ecological balance. The shelterbelts system in frontline regions has proven particularly vulnerable, suffering further from hostilities, landmining, fires and the movement of heavy military vehicles [14]. Specific studies note that shelterbelts were frequently used fore military positions, shelters and equipment deployment, leading to direct mechanical and explosive damage to the forest stand, as well as soil contamination with explosive remnants and combustion by-products.

Figure 1. Shelterbelts in the Snigurivka district of the Mykolaiv region damaged by military operations

Fires resulting from shelling led to the loss of significant areas of woody vegetation [15]. In addition to the direct destruction of forest stands, the hostilities caused soil degradation and the contamination of areas with explosive remnants and toxic substances. This significantly hinders the processes of natural recovery of forest ecosystems. In many cases, the restoration of protective plantations will require considerable time and comprehensive environmental measures.

The consequences of military operations are also manifasted in the disruption of ecological connectivity between individual elements of agricultural landscapes. The destruction of shelterbelts leads to a decrease in biodiversity, deterioration of wildlife habitats, and a reduction in the environmental stability of the areas. The loss of these natural barriers exacerbates the negative impact of wind erosion and other degradation processes.

In the post-war period, the restarting and modernizing of the field-protective shelterbelts system take on particular relevant. The formation of an effective network of protective plantations is regarded as a vital direction for ensuring the state's environmental security [14]. The restoration of shelterbelts should become an integral component of comprehensive programs for the reconstruction of the agricultural sector and recovery of natural ecosystems.

Modern approaches to the development of agroforestry involve the application of sustainable natural management principles, ecosystem-based management, and climate change adaptation [3]. An crucial task is to create an optimal agrolandscape structure where shelterbelts serve as key elements of ecological stability. Such plantations must ensure not only the protection of agricultural land but also the maintenance of ecological balance at the regional level.

In the current context of global climate change, research into the processes of atmospheric carbon sequestration by terrestrial ecosystems has taken on particular significance. A vital elements of such ecosystems within the agricultural landscapes is field-protective shelterbelts, which are capable of accumulating substantial volumes of carbon in of woody biomass and the soil cover.

Through photosynthesis, woody plants absorb carbon dioxide from the atmosphere and transform it into organic matter, which accumulates in trunks, branches, foliage, root systems, and litter. Conserquently, forest plantations serve as vital natural carbon reservoirs and play a significant role in regulating the global carbon balance.

Despite their relatively small area compared to lager forest massifs, field-protective shelterbelts possess significant carbon accumulation potential due to their high biomass density and the long-term functioning of their forest stands. They form local pockets of increased biological productivity within agricultural areas, which facilitates the intensification of atmospheric carbon sequestration processes [22]. In addition to carbon sequestration in woody biomass, its accumulation in the soil-resulting from the input of plant residues, litterfall, and the development of root systems – plays an important role [23]. This process contributes to an increase in soil organic matter content and the improvement of its physical and chemical properties.

The study of the potential of carbon sequestration by forest shelterbelts is important for assessing their contribution to mitigating the effects of climate change. In modern conditions of increasing greenhouse gas concentrations in the atmosphere and increasing average annual air temperatures, the search for effective natural mechanisms for reducing carbon load is becoming one of the key areas of environmental policy [24]. Agroforestry plantations can be considered as a component of nature-based solutions [25] aimed at reducing the concentration of carbon dioxide in the atmosphere, mitigating the effects of climate change, and ensuring food and environmental security in the southern region.

Assessment of the carbon sequestration capacity of shelterbelts allows us to determine their role in shaping the regional carbon balance of agro-landscapes. Such studies are also important for substantiating measures for the restoration and optimization of the structure of protective forest stands [22]. The results obtained can be used in the development of strategies for adapting agriculture to climate change, as well as in land management programs and restoration of degraded areas.

In addition to the climate-regulating function, the processes of carbon sequestration in forest are closely related to other ecological effects, in particular, the preservation of soil fertility, the increase in biological diversity and the stabilization of agricultural landscapes. In combination, these processes contribute to the increase in the ecological sustainability of agricultural territories and the formation of more balanced landscape systems. Thus, the study of the sequestration potential of forest shelterbelts is an important direction of modern ecological research, which allows for a comprehensive assessment of their role in ensuring climatic stability and ecological safety of agricultural landscapes.

Research materials and methods

The study of carbon sequestration processes in man-made agroforestry plantations in southern Ukraine was conducted using field measurements, analytical calculations, and a synthesis of scientific sources on agroforestmelioration, forest ecology, and assessment of the carbon balance of terrestrial ecosystems. The methodological basis of the work is the approaches to assessing biomass and organic carbon stocks in tree plantations, which are used in studies of forest ecosystems and agroforestmelioration systems.

The object of the study is artificial forest shelterbelts formed within the agrolandscapes of the steppe zone of southern Ukraine (fig. 2). Such plantations mainly include tree species adapted to the arid conditions of the region, in particular, white locust *Robinia pseudoacacia* L., *Quercus robur* L., *Fraxinus excelsior* L., various species of the *Populus* spp., as well as related species – Acer platanoides, Gleditia triacanthos, Ulmus laevis.

Figure 2. The location of the studied shelterbelts sites

To assess the potential for carbon sequestration, a method was used to determine the phytomass reserves of tree stands with subsequent conversion into the stock of organic carbon [17, 18]. Field studies involve establishing trial plots within forest shelterbelts of different ages and species composition. A tax survey of tree stands is carried out on each trial plot, which includes determining the main biometric indicators of trees: trunk diameter at a height of 1.3 m, total tree height, stand density and species composition. The calculation of tree biomass was carried out using allometric equations that relate trunk diameter to the mass of woody vegetation [19, 20].

The generalized equation for determining the phytomass of an individual tree has the form:

$$B = a \cdot D^b,$$

where B – dry biomass of wood, kg;
D – trunk diameter at a height of 1.3 m, cm;
a, b – empirical coefficients depending on tree species [19-21].

The obtained values – of biomass of individual trees are summed up and converted into indicators per unit area (tons / hectare). After determining the above-ground biomass stock, an assessment of the stock of organic carbon accumulated in woody vegetation is carried out. According to generally accepted approaches in forest ecosystem studies, it is believed that the average carbon content in dry biomass of trees is about 50%. Therefore, the carbon stock is determined by the formula:

$C = B \times 0,5,$

where C – organic carbon stock, t;
B – dry biomass of woody vegetation, t.
IPCC recommends using 0,47–0,5 for woody biomass [19,20].

To assess the climate impact of carbon accumulation, the results are additionally converted into carbon dioxide equivalent. The conversion is carried out using a factor of 3,67, which reflects the ratio of molecular masses of CO_2 and carbon:

$CO_2 = C \cdot 3,67$

where CO_2 – amount of bound carbon dioxide, t [19].

The coefficient is obtained from the ratio of molecular masses:

$44/12=3,67$

In addition to aboveground biomass, the study also takes into account the proportion of belowground biomass represented by tree root systems. To estimate it, the aboveground to belowground biomass ratio is used, which for most hardwoods is 0,20–0,30. This determines the additional organic carbon stock accumulated in the root system.

Soil organic carbon also plays a significant role in the overall carbon balance of agricultural landscapes. Within the shelterbelts, there is a gradual accumulation of organic matter due to leaf fall, dead roots and other plant residues. This contributes to the formation of litter and an increase in the humus content in the upper soil horizons. Within the framework of the study, soil carbon can be assessed by taking soil samples at different depths with subsequent laboratory determination of the organic matter content.

To analyze the efficiency of different tree species in terms of carbon accumulation, a comparative assessment of their productivity and biomass accumulation rates is carried out. Particular attention is paid to species characterized by rapid growth and high adaptability to the arid conditions of the steppe zone. These include *Robinia pseudoacacia* L., various species of the genus *Populus* L., *Fraxinus excelsior* L., *Sophora japonica* L., and others. It is known that fast-growing species provide more intensive biomass accumulation at the initial stages of plantation development, while long-lived species form significant carbon reserves in the long term.

The analysis of the obtained data is carried out using methods of statistical processing and comparative analysis. This allows us to assess the impact of species composition, age of plantations and density of stands on the total potential of carbon sequestration by shelterbelts. The generalization of the research results makes it possible to determine the most effective types of agroforestry plantations for increasing the carbon capacity of agricultural landscapes of southern Ukraine.

The results obtained can be used to justify measures to restore and optimize the structure of shelterbelts, as well as to assess their role in mitigating the effects of climate change and increasing the ecological security of the steppe regions of Ukraine.

Research results

We analysed the CO_2 sequestration potential of the main tree species used in the shelterbelts of the steppe zone of Ukraine. The data are based on a generalization of agroforestry studies, stand productivity, and biomass estimates. Below are indicative figures for stands aged 20–30 years, which is typical for a significant part of the shelterbelts of southern Ukraine.

Table 1. CO_2 sequestration potential of tree species in shelterbelts of the steppe zone of Ukraine

Wood species	Average biomass reserve, t/ha	Carbon stock, t C/ha	Equivalent of bound CO_2, t/ha	Average annual CO_2 sequestration, t/ha/year	Features for the steppe zone
Robinia pseudoacacia L.	80–120	40–60	147–220	5–7	Fast growth, high drought tolerance, nitrogen fixation
Ulmus pumila L.	80-100	40-55	147-202	4-6	High drought resistance, suitable for steppe
Ulmus laevis Pall.	70-100	35-50	128-184	4-5	Forms protective stands well
Elaeagnus angustifolia L.	50-80	25-40	92-147	3-4	Resistant to salinity and drought
Populus spp.	100–150	50–75	184–275	6–9	Very rapid accumulation of biomass
Populus alba L.	100-150	50-75	184-275	6-9	Very fast growth
Populus pyramidalis Roz.	90-140	45-70	165-257	6-8	Very rapid accumulation of biomass
Fraxinus excelsior L.	90–130	45–65	165–240	5–7	High productivity, forms stable stands
Fraxinus lanceolata Borkh.	90-120	45-60	165-220	5-7	Well adapted to steppe conditions
Quercus robur L.	70–110	35–55	128–202	4–6	Slower growth but long-term carbon storage
Acer platanoides L.	60–90	30–45	110–165	3–5	Forms a second tier well
Acer negundo L.	90-120	45-60	165-220	5-7	Well adapted to steppe conditions
Gleditsia triacanthos L.	70–100	35–50	128–184	4–6	Drought-resistant species for steppe conditions
Pinus sylvestris L.	80–120	40–60	147–220	4–6	Effective on dry sandy soils
Morus alba L.	60-90	30-45	110-165	3-5	Drought resistant
Morus nigra L.	60-85	30-42	110-154	3-5	Forms a dense crown
Armeniaca vulgaris Lam.	40-70	20-35	73-128	2-4	Average biomass
Amygdalus communis L.	35-60	17-30	62-110	2-3	Drought-resistant species
Sophora japonica L.	80-110	40-55	147-202	4-6	Tolerates urban and steppe conditions well
Juglans regia L.	90-120	45-60	165-220	4-6	High density wood
Platanus orientalis L.	110-160	55-80	202-294	6-9	Very high biomass
Lonicera tatarica L.	20-40	10-20	37-73	1-2	Shrub, forms undergrowth
Corylus colurna L.	30-50	15-25	55-92	2-3	Forms a shrub layer well
Ligustrium vulgare L.	20-35	10-18	37-66	1-2	Dense protective plantings
Amorpha fruticosa L.	25-45	12-22	44-81	1-2	Average biomass
Tamarix ramosissima Led	30-50	15-25	55-92	2-3	High salt and drought resistance

Analysis of the indicators given in Table 1 shows significant differences between tree and shrub species in terms of biomass accumulation potential and atmospheric carbon dioxide sequestration in the shelterbelts of the steppe zone of Ukraine. As can be seen from the table, the highest biomass indicators and, accordingly, stocks of bound carbon are characterized by fast-growing tree species, in particular, various species of the genus *Populus* and *Platanus orientalis* L. In particular, *Platanus orientalis* forms one of the largest biomass reserves – up to 110–160 t/ha, which ensures the accumulation of up to 55–80 t C/ha and corresponds to approximately 202–294 t/ha of bound CO_2. Similar indicators are also found in *Populus balsamifera* L. and *Populus alba* L., which are characterized by high growth rates and intensive accumulation of organic matter.

High carbon sequestration potential is also demonstrated by *Robinia pseudoacacia*, *Fraxinus excelsior*, *Fraxinus lanceolata* Borkh., *Acer negundo* L. and *Juglans regia* L., which form significant reserves of woody biomass – within 80–130 t/ha. These species are characterized by the accumulation of 165 to 240 t/ha of CO_2 equivalent. Of particular importance among them is *Robinia pseudoacacia*, which combines rapid growth with the ability to fix nitrogen, which contributes to increasing soil fertility and improving the growth conditions of other components of agroforestry plantations.

Among the species with average biomass indicators, it is worth noting *Ulmus pumila* L., *Ulmus laevis* Pall., *Gleditsia triacanthos* L., *Quercus robur* L. and *Sophora japonica* L. Their biomass reserves are usually 70–110 t/ha, which provides the accumulation of approximately 128–202 t/ha of CO_2. An important feature of these species is their high ecological stability and adaptability to the arid conditions of the steppe zone, which makes them promising for the formation of long-lasting and stable protective forest plantations.

Some species, such as *Elaeagnus angustifolia* L., *Acer platanoides* L., *Morus alba* L. and *Morus nigra* L., are characterized by somewhat smaller biomass reserves - within 50–90 t/ha. Accordingly, their carbon sequestration potential is approximately 110–165 t/ha CO_2. However, these species play an important role in the formation of the multi-tiered structure of forest belts, and are also distinguished by increased drought resistance and the ability to withstand adverse soil and climatic conditions of steppe regions.

Fruit trees, in particular *Armeniaca vulgaris* Lam. and *Amygdalus communis* L., have relatively lower biomass accumulation rates – in the range of 35–70 t/ha, which corresponds to 62–128 t/ha of bound CO_2. Despite their lower sequestration potential, these trees can be used as an additional component of agroforestry systems, especially in arid and low-yielding lands.

The lowest carbon accumulation rates are characterized by shrub species such as *Lonicera tatarica* L., *Ligustrium vulgare* L., *Amorpha fruticosa* L., *Tamarix ramosissima* Led and *Corylus colurna* L. Their biomass stock usually does not exceed 20–50 t/ha, which corresponds to 37–92 t/ha of bound CO_2. However, these species have an important functional value in protective forest stands, as they form undergrowth, increase the density of forest belts, contribute to soil consolidation and reduce wind speed.

Thus, the analysis of the carbon accumulation potential shows that the fastest growing tree species, in particular various species of *Populus* and *Robinia pseudoacacia, Platanus orientalis*, have the greatest ability to bind CO_2 among the studied species. These species are capable of accumulating up to 250–290 t of CO_2 per hectare of plantations at the age of 25–30 years. *Fraxinus lanceolata, Ulmus laevis*, *Sophora japonica* and *Juglans regia* are also characterized by quite high indicators. Long-lived species, such as *Quercus robur*, are characterized by lower rates of biomass accumulation, but provide long-term storage of carbon in wood. Shrub species that form the shrub layer have a much lower potential for carbon accumulation, but play an important role in the formation of the multi-tiered structure of shelterbelts and contribute to the additional accumulation of organic matter in the soil. Such plantations are capable of providing annual sequestration of 4–9 t CO_2/ha, making them an important tool for mitigating the effects of climate change in the agro-landscapes of the steppe zone of Ukraine.

Analysis of the table 1 shows that the maximum climate-regulating effect in the field shelterbelts of the steppe zone is achieved through the use of fast-growing tree species with high biomass productivity. At the same time, the formation of effective agroforestry plantations requires a combination of such species with species more resistant to drought conditions, as well as the inclusion of a shrub layer. It is the multi-component structure of plantations that provides not only effective binding of atmospheric carbon, but also increases the ecological stability of agricultural landscapes, helps protect soils from erosion and creates favorable conditions for the functioning of biodiversity.

The role of shelterbelts in preventing soil erosion and dust storms

One of the important ecological functions of shelterbelts is to restrain wind erosion processes and prevent the formation of dust storms. In the steppe regions of Ukraine, where natural landscapes are characterized by significant openness of the territory and high wind speed, forest belts play the role of natural barriers that reduce the intensity of air flows and stabilize the surface layer of the soil. It is known that the system of protective forest plantations is capable of reducing wind speed in adjacent territories by 30–70%, and the zone of their protective influence can extend to a distance that is 20–30 times the height of the tree stand.

The problem of dust storms in the steppe zone of Ukraine has a long history and is directly related to the state of vegetation cover and the structure of agricultural landscapes. The most extensive manifestations of wind erosion were observed in the first half of the twentieth century, when significant areas of steppe territories were intensively plowed, and natural protective elements of the landscape practically disappeared. In the 1920s and 1930s, powerful dust storms were regularly recorded in the southern and eastern regions of Ukraine, accompanied by the movement of significant masses of soil material over long distances. According to researchers, during periods of strong dry winds, losses of the fertile soil layer could reach several tens of tons per hectare, which led to a sharp decrease in the productivity of agricultural lands and the degradation of land resources [1, 2].

In response to large-scale manifestations of deflation and soil degradation in the second half of the 20th century, a comprehensive program of agroforestry reclamation measures was developed. An important stage in this process was the adoption in 1948 of the state program for the creation of a system of field shelterbelts aimed at stabilizing the agrolandscapes of the steppe and forest-steppe regions. The implementation of this program provided for the formation of an extensive network of shelterbelts that were to perform anti-erosion, climate-regulating and soil-protective functions. Over the following decades, tens of thousands of kilometers of field shelterbelts were created in the steppe zone of Ukraine, which significantly changed the structure of agrolandscapes [26, 27].

Scientific studies of the second half of the 20th century showed that the creation of a system of shelterbelts led to a significant reduction in the intensity of wind erosion. Protective plantings reduced wind speed, contributed to the accumulation of snow and increased soil moisture, which largely prevented the formation of dust storms. In many areas of the steppe zone, their frequency and intensity significantly decreased, and agro-landscapes became more ecologically stable [3, 28].

However, at the end of the 20th and beginning of the 21st centuries, the situation began to gradually change. A significant part of the shelterbelts created in previous decades was in unsatisfactory condition due to aging stands, lack of proper care, illegal logging, and changes in land use. As a result, the efficiency of the agroforestry and reclamation network has significantly decreased. At the same time, the manifestations of climate change have intensified, characterized by an increase in air temperature, a decrease in the amount of effective precipitation, and an increase in the frequency of dry periods.

An additional factor aggravating the problem was the consequences of hostilities in Ukraine, which caused significant damage to natural ecosystems, including forest protection strips [15]. Fires, explosions and the movement of heavy machinery led to the destruction of part of the protective plantings and the degradation of the soil cover [14]. In combination with the increased aridity of the climate, this creates the prerequisites for the reactivation of wind erosion processes and the emergence of dust storms in the steppe regions, in particular in the territory of the Left Bank of Ukraine.

Thus, historical analysis shows that the formation and maintenance of a system of shelterbelts plays a key role in containing dust storms and ensuring the ecological stability of agrolandscapes. Restoration and modernization of agroforestry plantations in modern conditions is considered an important direction for increasing the ecological security of the steppe regions of Ukraine.

However, over the past decades, a significant part of the shelterbelts of southern Ukraine has been in a degraded state. The aging of the stands, the lack of proper care and the partial destruction of woody vegetation have led to a decrease in the efficiency of the functioning of the agroforestry system. In combination with the increasing aridity of the climate, this creates the prerequisites for the intensification of soil deflation processes.

As mentioned above, the situation has been significantly complicated by hostilities, which have damaged or destroyed a significant part of the forest ecosystems of the Left-Bank Ukraine. The destruction of shelterbelts, fires and soil degradation contribute to the formation of conditions for the occurrence of dust storms. Such phenomena pose a serious threat to agricultural landscapes, as they are accompanied by the loss of the fertile soil layer, deterioration of atmospheric air quality and a decrease in the productivity of agricultural lands.

In this context, the restoration and modernization of the system of shelterbelts is considered one of the key areas for increasing the ecological sustainability of agricultural landscapes in southern Ukraine and preventing the development of dangerous natural and anthropogenic processes.

Analysis of the indicators given in Table 1 shows that the use of the specified tree and shrub species in the composition of shelterbelts can significantly reduce the manifestations of wind erosion of soils and prevent the formation of dust storms in the steppe zone of Ukraine. This is due primarily to the significant biomass of tree stands, developed crown and the ability to form dense or openwork-blown structures of shelterbelts, which effectively reduce the wind speed above the soil surface.

The most effective in forming the anti-erosion framework of agrolandscapes are fast-growing species with a large biomass reserve, in particular various species of Populus, Robinia pseudoacacia, species of Fraxinus and Platanus. According to the table, these species form the largest reserve of organic mass - up to 100–160 t/ha, which ensures high crown density and significant height of stands. Due to this, they create a powerful aerodynamic barrier, which is able to reduce the speed of wind flows at a distance that is 10–15 times higher than the height of the forest belt. As a result, the ability of air flows to lift and carry small soil particles, which are the main source of dust storms, is sharply reduced.

An important role in protecting soils from deflation is also played by medium-yielding species, in particular *Ulmus pumila*, *Ulmus laevis*, *Gleditsia triacanthos*, *Quercus robur* and *Sophora japonica*. These species are characterized by high ecological stability and the ability to form long-lasting stands with a branched root system. Tree roots fix the soil cover, reducing its loosening and increasing the soil structure. This significantly reduces the risk of wind erosion, especially in open steppe areas.

Drought-resistant species such as *Amygdalus angustifolia*, *Tamarix ramosissima*, *Morus alba* and *Morus nigra* are equally important in the structure of field protection stands. They are well adapted to the extreme conditions of the steppe, in particular to moisture deficiency, high temperatures and saline soils. The presence of such species in the composition of forest belts ensures the stability of stands even in adverse climatic periods, which is an important factor in the long-term functioning of anti-erosion systems.

Shrub species, in particular *Lonicera tatarica*, *Ligustrium vulgare*, *Amorpha fruticosa* and *Corylus colurna*, form the lower tier of shelterbelts and play an important role in reducing the speed of the surface layer of air. It is in the surface layer that the main part of deflation processes takes place, since small soil particles are lifted by the wind to a height of several tens of centimetres. The shrub layer reduces the turbulence of air flows and contributes to the settling of dust particles, which significantly reduces the intensity of dust storms.

Thus, the effectiveness of forest shelterbelts in combating wind erosion is determined not only by the growth rate of individual species, but also by the correct selection of their combination in the composition of the stands. The most effective are multi-tiered forest belts, which combine tall fast-growing trees, medium-sized resistant species and a dense shrub layer. Such a structure provides uniform braking of air flows at different heights, contributes to soil consolidation and reduces the risk of dust storms. As a result, shelterbelts are an important element of ecological stabilization of agrolandscapes of the steppe zone and an effective natural mechanism for restraining wind erosion processes.

Conclusions

In the current conditions of Ukraine's development, agroforestry reclamation and the creation of protective forest plantations remain one of the important strategic directions of the state environmental policy and rational nature management. Their importance is due to the need to ensure the ecological stability of agricultural landscapes, preserve soil fertility and increase the resistance of agricultural production to adverse natural and anthropogenic influences. The development of agroforestry reclamation systems is particularly relevant in the context of modern climate change, which is accompanied by an increase in the frequency of dry periods, an increase in air temperature and an increase in degradation processes in the soil cover. In such conditions, protective forest plantations play the role of an important stabilizing element of agricultural landscapes, contributing to the adaptation of the agricultural sector to new climatic challenges.

In the context of the intensification of integration processes and the deepening of cooperation between Ukraine and the European Union, the role of forest ecosystems in the implementation of modern approaches to natural resource management is significantly increasing. European environmental policy pays significant attention to the formation of balanced landscapes, the preservation of biological diversity and the implementation of the principles of sustainable development. In this regard, forest plantations are considered an important tool for implementing programs to design ecologically balanced agricultural landscapes, form an ecological network and maintain natural balance in anthropogenically transformed territories.

The introduction of an ecosystem-landscape approach to natural resource management involves the integration of forest elements into the structure of agro-landscapes, which allows increasing their ecological sustainability and ensuring more rational use of land resources. In this context, agroforestry is one of the key mechanisms for implementing the principles of sustainable nature management and ensuring long-term ecological security of territories.

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