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Ecological problems of the functioning of field protective forest belts of Ukrainian Forest Steppe

Oleksandr Tkachuk[1], Hanna Pantsyreva[1], Kateryna Mazur[1], Yaroskav Chabanuk[2], Tatiana Zabarna[1], Liudmyla Pelekh[1], Lina Bronnicova[1], Yurii Kozak[1], Nadia Viter[1]

[1] Vinnytsia National Agrarian University, 3 Sonyachna Str., 21002, Vinnytsia, Ukraine
[2] Institute of Agrobiology, Bulvar Vatslava Havela, 4, Kyiv, Ukraine
* Corresponding author's e-mail: apantsyreva@ukr.net

ABSTRACT

Field protective forest belts which were created 50–70 years ago in the Forest Steppe of Ukraine have reached a critical age and do not have proper maintenance. Together with the intense impact on their condition of measures of agricultural intensification, atmospheric anthropogenic pollution and global warming, they have significantly lost their environmental protection and stabilizing agro-ecosystem functions. The purpose of our research was to assess the current ecological condition of the field protective forest belts of the Forest-Steppe of Ukraine based on the indicators of tree resistance to environmental changes. The ecological condition of field protective forest belts was determined by the following indicators: the proportion of felled trees in forest belts, the proportion of dry trees, the proportion of drying trees, the presence of grass cover, the spread of necrosis on a leaf, the proportion of necrosis on a leaf, the spread of chlorosis on a leaf, the proportion of chlorosis on a leaf, the proportion of trampled vegetation in the forest belts. Our research has established that the greatest diversity of species was characteristic to the openwork protective forest belts, and the least – to the blowing ones. All the main forest belts were more biodiverse than the additional ones. In 80% of forest belts, common ash is the main species, and in only 20% – is common maple. The largest share of felled trees (35%) and drying trees (35%) was found in the main blowing forest strip. We installed a slightly smaller proportion of drying and felled trees in the main openwork forest strip. And the least cut and drying trees were found in the dense field protection forest strip. The highest spread of necrosis: 40% of hornbeam leaves and 35% of maple leaves, as well as chlorosis: 18% of hornbeam leaves and 25% of maple leaves was found in the additional openwork forest strip. Also, a high percentage of the spread of necrosis and chlorosis was detected on the leaves of the common ash of the additional blowing forest strip, 18% and 25%, respectively. Necrosis and chlorosis were the least evident on the leaves of trees in the dense of forest belt. Premature yellowing of the leaves was detected only in ordinary hornbeam of the additional openwork forest belts in the amount of 15% of the leaves. Also, this type of the tree had the highest percentage of twisted leaves – 20%. The largest proportion of leaves with spots was found on common ash trees of the main openwork forest belt – 60% and common maple trees of the dense forest belt. The obtained results will make it possible to choose the right measures for the protection and preservation of field protective forest belts and to determine the most resistant and vulnerable tree species to environmental factors.

Keywords: field protective forest belts, trees, ecological condition, suppression, environmental factors.

INTRODUCTION

Today, the ecological condition of field protective forest belts in Ukraine is critical. According to Tkachuk et al. (2023), the significant age of the field protective forest belts, which is 70–80 years, unauthorized felling of trees in them, clogging with household waste, lack of maintenance measures, the influence of pests, diseases, chemicals that are repeatedly used on crops, measures of intensive agriculture, the absence of an effective owner of the field protective forest strips, as well as military actions, make them extremely vulnerable to external and internal influences.

As noted by Mazur et al. (2021) and Tkachuk et al. (2021), the intensification of agriculture, manifested in the use of high rates of mineral fertilizers and repeated use of chemical plant protection agents, aggravates the problems of environmental pollution and degradation of natural and agroeco systems. As a result of the lack of systematic care for the trees of the field protective forest strips, their mass drying, premature death and decrease in the effectiveness of nature protection functions are observed. According to Mazur et al. (2021), recently the direct anthropogenic impact on field protective forest strips has significantly increased due to intensive agricultural activity in the fields. The specified problem regarding the impact of such atmospheric pollution on field protective forest plantations is determined by the concept of gas and dust resistance of plants. After all, plants resistant to atmospheric pollutants are able not only to improve the state of the environment in the zone of influence of forest strips, but also to significantly extend its longevity in plantations.

Research of Honcharuk et al. (2022) show that one of the important factors in stopping the development of the degradation processes of agricultural soils in Ukraine, caused by the development of erosion processes and their drying, is the highly effective functioning of field protective forest strips. However, in recent years, the agro-ecological functions of field protective forest belts have significantly decreased due to their unsatisfactory condition. Therefore, an important problem in this context is the analysis of the existing problems of the functioning of field protective forest strips on the basis of their bioindicative stability in order to increase the agro-ecological yield of agricultural lands.

The author Honcharuk et al. (2022) point out that field protective forest plantations are an important component of agroforestry landscapes, one of the most effective, long-term and relatively inexpensive measures to combat wind and water erosion of soils. They have a positive effect on the microclimate of the surrounding areas and are able to significantly increase the yield of agricultural crops.

According to Kaletnik et al. (2020), the ecological basis of agroecosystems is created by forest strips. But today their number and sanitary condition do not meet modern requirements. The average field protection forest cover in Ukraine is 1.3–1.5%, and the optimal one should be 3.0–4.5% depending on the natural and climatic zone. Based on this, for the effective protection of agricultural landscapes, the area of field protective forest strips should be increased by 2–3 times. At the same time, it is important to preserve all existing field protective forest strips. And for this, it is necessary to conduct their inventory and assess the current ecological state. However, statistics indicate the opposite: the area of the existing field protective forest strips has decreased by 90% compared to 1990.

As noted by Didur et al. (2020), in Ukraine, the main part of field protective forest strips was created in the 1950–1970s. Today, these forest strips have reached the age of 50–70 years. During the existence of the former Soviet Union, they were on the balance sheet of collective farms and state farms, depreciation deductions were allocated to them, for which these farms paid for the services of specialists in the creation and maintenance of forest strips.

Furdychko et al. (2010) established that one hectare of field protective forest strip protects 20–30 hectares of arable land, so today millions of hectares of arable land are under the protection of field protection forest strips in Ukraine, which ensures an increase in the efficiency of the use of these lands and reduces the cost of crop production. In order to stabilize the number of field protective forest strips and prevent their number and area from decreasing, approximately 6–7 thousand hectares of field protective forest strips should be created in Ukraine annually.

Hladun (2005) notes that the most quantity of field protective plantations were created in the 50–70s of the 20th century, today some of them are reaching a critical age and need reconstruction. However, the first stage should be an assessment of their current ecological state, on the basis of which the following measures for their reconstruction can be developed.

Mazur et al. (2021) point out that no nature protection measures for the preservation and restoration of field protective forest strips in Ukraine have been carried out so far. Therefore, the first step towards their preservation, protection and restoration should be to obtain objective information about the dynamics of field protective forest strips by conducting an inventory of all field protective forest plantations that do not belong to the lands of the forest fund.

Coop et al. (2020) divide the field protective forest strips according to their location relative to the prevailing winds into main and auxiliary ones, which differ not only in location, width, species composition, but also in elementary care. The set of main and auxiliary field protective forest strips should function as a single system of the forest reclamation complex, which performs the role of ecological protection of agroecosystems from adverse abiotic and biotic factors, where each element of such a system should complement each other, which contributes to the strengthening of the overall beneficial nature protection effect.

Gallagher et al. (2019) believe that field protective forest strips in the system of agrolandscapes contribute to the improvement of ecological, agroforestry and nature protection conditions and ensure sustainable functioning of agricultural production. However, the agroforestry infrastructure of protective forest plantations, which has developed in Ukraine today, is insufficiently effective. Evidence of this is the low productivity of agricultural crops in years with unfavorable climatic conditions. And annual ecological and economic losses due to soil erosion exceed UAH 9 billion. Therefore, until a stable agroforestry infrastructure is formed, the state will systematically suffer large losses in the field of agricultural production.

Therefore, the goal of our research was to assess the current ecological condition of the field protective forest belts of Ukrainian Forest Steppe by indicators of tree resistance to environmental changes.

MATERIALS AND METHODS

Field observations were conducted during 2022–2023 in the Right-bank Forest-steppe natural zone in the central part of Ukraine. In the studied territory, the western and northwestern winds prevail, with a frequency of recurrence during the year of 17.0% and 16.5%, respectively.

The soils of the studied area are highly fertile chernozems, podzolized and leached chernozems, the relief is a wide undulating plain, low. Climatic conditions of the studied territory have a moderate-continental character. The average annual temperature is about 7.0 °C, with its increase since 2000 to 8.0 °C. The amount of precipitation per year is 489–634 mm. The vegetation period lasts about 208 days.

The parameters of the placement of field protective forest strips of the Right Bank Forest Steppe were determined according to the indicators: placement relative to the cardinal points – with the help of a compass; construction of the forest strip – visually, according to the proportion of forest strip clearance (10% of clearance – dense forest strip, 20% of clearance - openwork forest strip; 40% of clearance – blowing forest strip). The species composition of the field protection forest strips of the right bank Forest Steppe was determined by the plant identifier according to the indicators: main species, secondary breed, single breeds, bushes (if available) (Thom et al., 2016).

The ecological condition of the field protective forest strips of the Right Bank Forest Steppe was determined by the indicators: the share of felled trees in the forest strips, % – visually; the share of dry trees in forest strips, % – visually; the share of drying trees in forest strips, % – visually; the presence of grass cover in forest strips, % of forest strips – visually; spread of necrosis on leaves, % of leaves – visually; proportion of necrosis on a leaf, % of leaf surface – visually; spread of chlorosis on leaves, % of leaves – visually; proportion of chlorosis on the leaf, % of the leaf surface – visually; the share of trampled vegetation in forest strips, % – visually (Seidl et al., 2017).

In total, 70 main field protective forest strips and 40 auxiliary field protective forest strips in the zone of intensive agricultural production were surveyed. The research was conducted at the end of August, allocating 100 m long test plots within each forest strip starting from the edge of the forest strip, located closer to the population centers in four repetitions. The division of forest strips into main and additional ones was carried out according to their location relative to the prevailing winds in relation to the sides of the world and their width. The main field protection forest strips are located perpendicular to the main winds and have 5–7 rows of trees. Additional field protection forest strips are located perpendicular to the main field protection forest strips and have 2–4 rows of trees (Pecchi et al., 2019).

Determining of the current ecological condition of field protective forest strips was carried out using a set of the following indicators: the share of felled trees in forest strips – by counting the number of tree stumps from the total number of trees within the test plots; the proportion of dry trees in forest strips – by counting the number of completely dry trees that had only trunks and branches without leaves from the total number of trees within the test plots (Coop et al., 2020); the proportion of drying trees in forest strips – by counting the number of trees that began to dry, i.e.

had at least one branch without leaves, but at most one branch with leaves, from the total number of trees within the test plots (Michotey et al., 2021).

RESULTS AND DISCUSSION

All field protective forest belts are divided by design into blowing, openwork and dense depending on the proportion of clearance in their transverse state. Each type of forest strip has its own characteristics both in terms of positive impact on agroecosystems and in terms of structure and biometric parameters.

According to another classification regarding the placement of field protective forest strips relative to the direction of the prevailing winds, they are divided into the main ones, which are placed transversely to the direction of the prevailing winds, and additional ones, which are placed transversely to the main field protective forest strips or along the direction of the prevailing winds. Our research has proved that blowing and openwork field protective forest strips are represented by the main and additional ones, and dense ones – only by the main ones. Such a combination of different types of field protective forest strips among themselves causes certain differences between them, which requires more detailed observations.

The analysis of the researched field protective forest strips by blowing, openwork and dense structures has shown that in the blowing and openwork main and additional field protective forest strips, common ash is the main tree species, and in dense main field protection forest strips – common maple is common. No secondary tree species were found in all of the investigated additional blowing field protective forest strips, and in the main blowing forest strips the secondary species was common oak. In the openwork main forest strips, common oak belonged to the detected secondary tree species, and in secondary ones –common hornbeam. In the dense main field protective forest strips, common ash was a secondary species (Table 1).

The isolated species in the main forest strip were heart-leaved linden; in the openwork main forest strip – white acacia, wild cherry, wild plum, and wild pear; in the openwork additional forest strip – wild cherry and wild pear, and in the main dense one – ordinary oak. Blowing additional field protective forest strip did not have individual tree species. The greatest diversity of shrubs was found in the openwork main field protective forest strip and was represented by common rosehip, common hazel, undergrowth of common ash and ash maple. Openwork additional field protective forest strip was represented by only one type of bushes: black elder. In the dense main field protective forest strip, black elder and common maple undergrowth belonged to the bushes. All the blown field protective forest strips did not have bushes in their composition.

So, it was established that openwork forest strips had the greatest diversity of species, and the ones with the least diversity – were blowing forest strips. Also, all main field protective forest strips were more diverse in species composition than auxiliary ones. In addition to the natural death of trees in the past, we discovered stumps of trees cut in the previous 5-10 years. The reasons for cutting could be drying of trees, unauthorized felling and others. We found the highest percentage of cut trees in the main forest strip 35%. No

Table 1. Species composition of field protective forest belts of the Forest Steppe of Ukraine, 2022–2023

Parameters of forest belts	Construction of forest belts				
	Blowing		Openwork		Dense
View of the forest belt in the direction of the prevailing winds	The main one	Additional	The main one	Additional	The main one
The main breed	Common ash	Common ash	Common ash	Common ash	Ordinary maple
Secondary breed	Common oak	-	Common oak	Common hornbeam	Common gum
Single breeds	Heart-leaved linden	-	White acacia, wild cherry, wild plum, wild pear	Wild cherry wild pear	Common oak
Bushes	-	-	Common rosehip, common hazel, undergrowth of common ash, ash-leaved maple	Black elder	Black elder, Undergrowth of ordinary maple

cut trees were found in the additional blown forest strip. In the openwork main and additional forest strips, the percentage of cut trees was similar: 5-4%, and in the dense forest strip – 7% (Table 2).

We also found standing, completely dry trees in the field protective forest strips. Most of them were in openwork additional forest strip - 15%. The dried trees here were mainly hornbeam. One of the reasons for significant drying of hornbeam trees is its susceptibility to leaf diseases. Also, a significant variety of species in this forest strip could have caused competition and suppression of hornbeam.

In the openwork main field protective forest strip, 8% of trees, mainly common ash, were completely dry – 2% of the trees were dry in the dense main and blowing additional protective forest strips: in the first case – common maple, and in the second – common ash. There were no dead trees in the blown main forest strip, but it was the sparsest.

We also found drying trees. Most of them were in the main blowing forest strip – 35%, represented mainly by common ash. However, there were only 2% of drying trees in the additional blowing forest strip, also represented by common ash. A rather high proportion of drying trees was found in the open-work main and additional forest strip: 15% each. However, in the main forest strip, these were mainly common ash trees, and in the additional one – common hornbeam. Only 2% of drying common maple trees were found in the dense field protective forest strip.

Observation of the presence of grass cover in the field protective forest strips showed that it was completely absent in the densest dense of field protective forest strip. A partial grass cover was found in the main blowing field protective forest strip and the main open-work forest strip, which was represented by common lily of the valley and a two-blast nettles. There was also a solid grass cover in the additional blowing and openwork field protective forest strips, represented by wheatgrass. In these forest strips, the share of trampled herbaceous vegetation was 10%.

We found a strong positive correlation between the share of felled trees and the share of drying trees in field protective forest strips. The correlation coefficient is r = 0.8794. This indicates that in those forest strips where there is the highest percentage of cut down trees, the more amount of them continue to dry out. Based on this, felled trees in the past were due to their drying, and not due to other reasons. Correlation-regression dependence between the percentage of felled trees and drying trees in field protective forest strips, as well as the regression equation between the studied factors is presented in Figure 1. The regression coefficient $R^2 = 0.7733$ indicates a 77% dependence between the studied factors.

One of the most common deviations in the functioning of field protective forest strips is the manifestation of necrosis and chlorosis on the leaves of trees. These signs appear when the leaf apparatus is affected by pollutants or when there is an increased content of toxicants in the soil. It can also be caused by adverse environmental factors: drought, frost, high temperatures, diseases, pests.

Necrosis – as a process of dying of leaf tissues, is an extreme form of deviation from the normal functioning of trees in field protective forest strips. The greatest manifestation of necrosis on the leaves of trees was found in the additional openwork field protective forest strip with 40% hornbeam leaves and 35% maple leaves. In the blowing additional field protective forest strip,

Table 2. Suppression of field protective forest belts of the Forest Steppe of Ukraine, 2022–2023

Parametres of forest belts	Consruction of forest belts				
	Blowing		Open-work		Dense
Kind of the forest belt according to direction of the prevailing winds	The main one	Additional	The main one	Additional	The main one
Share of felled trees, %	35	-	5	4	7
Share of dry trees, %, their species composition	-	2 –common ash	8 – common ash	15 – common hornbeam	2 – common maple
Share of drying trees, %, their species composition	35 – common ash	2 – common ash	15 – common ash	15 – common hornbeam	2 – common maple
The presence of grass cover in the forest strip	Partial	Solid couch grass	Available lily of the valley, two-blast nettles	Solid couch grass	absent
The share of trampled vegetation in the forest belt, %	-	10	-	10	-

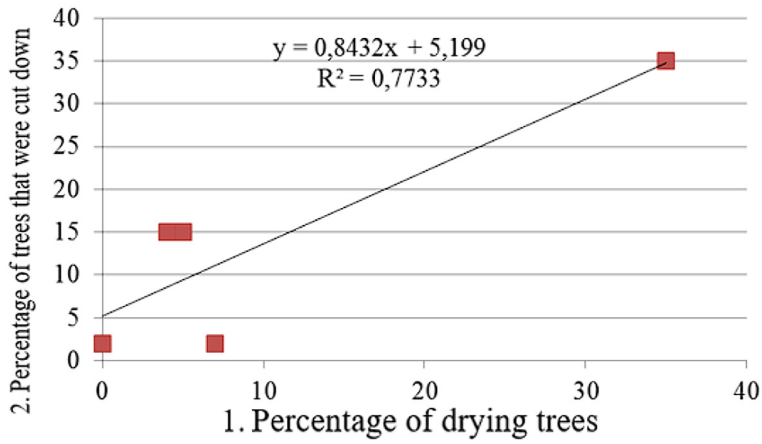

Figure 1. Correlation-regression relationship between the percentage of felled and drying trees in field protective forest strips

necrosis is widespread on 25% of common ash leaves. In other forest strips, necrosis was minimal: 5% of common ash leaves of the openwork main forest strip, and 2% of the main blowing forest strip, as well as 3% of common maple leaves. Corn was grown near field protective forest strips with the highest percentage of necrosis (Table 3).

Observation of the percentage of necrosis on a separate tree leaf showed that 25% of the surface of a common maple leaf and 18% of a common hornbeam leaf had this manifestation in the additional field protective forest strip. This was the highest proportion among all forest belts, and trees in this forest belt exhibited the highest percentage of leaf necrosis overall. A significant percentage of leaf necrosis was detected on the ash-leaved maple of the main blowing field protective forest strip, but this species is isolated and therefore does not have a significant impact on the general condition of the field protective forest strip. The common thing for these two forest strips was that corn grew near them. Also, in this forest strip, necrosis of 5% of the leaf plate of common ash was manifested.

In other forest strips, the proportion of necrosis on a leaf was insignificant: 8% of marginal necrosis on an ash leaf of the usual openwork main forest strip and 7% of an additional blowing forest strip, as well as 4% of a common maple leaf in main dense field protective forest strip. A similar dependence was observed in manifestation of chlorosis on the leaves of the trees of the field protective forest strips. In particular, the highest

Table 3. Manifestation of chlorosis and necrosis of the leaves of the field protective forest belts of the Forest Steppe of Ukraine 2022–2023

Parameters of forest belts	Construction of forest belts				
	Blowing		Open-work		Dense
Kind of the forest belt according to direction of the prevailing winds	The main one	Additional	The main one	Additional	The main one
Manifestation of necrosis on the leaf, % depending on tree species and their location on the leaf	2 – common ash	25 – common ash	5 – common ash	40 –common hornbeam; 35 – common maple	3 – common maple
The proportion of necrosis per leaf, % depending on the breed	15 – ash leaved maple; 5 – common ash	7 – common ash	8 – common ash	18 – common hornbeam 25 – common maple	4 – common maple
Manifestation of chlorosis on the leaf, % depending on tree species and their location on the leaf	7 – common maple	30 – common ash	5 – common ash	18 – common hornbeam 25 –common maple	7 – common maple
The proportion of chlorosis per leaf, % depending on the species	7 –common maple	30 – common ash	60 – common ash	40 – common hornbeam	7 – marginal common maple

percentage of leaf chlorosis was found in the common ash of the additional blown forest strip – 30%, as well as 25% of the leaves of the common maple and 18% of the hornbeam leaves of the additional openwork forest strip. Corn grew near these forest strips. The smallest manifestation of leaf chlorosis was detected in the main blowing, openwork and dense forest strips on common maple and common ash trees in the amount of 5–7% of leaves.

However, the highest proportion of chlorosis on a leaf was found in common ash of the main openwork field protective forest strip – 60% of the surface. Also, high rates of chlorosis on the leaf were found in hornbeam of the ordinary additional openwork forest strip in 40% of the surface and 30% of the surface of the ash leaf of the ordinary additional blown forest strip. At the same time, the share of the leaf surface under chlorosis was the smallest and amounted to 7% in the common maple of the main blowing and dense field protective forest strips. We found a strong positive correlation-regression relationship between the spread of necrosis on tree leaves and the proportion of necrosis on one leaf. The correlation coefficient r = 0.8355. The coefficient of determination R^2 = 0.698 shows that 70% of this dependence is determined by the studied factors. That is, the greater the spread of necrosis on the leaves of trees, the greater the proportion of necrosis on the leaf blade. The regression equation and graphical dependence between the studied factors are presented in Figure 2.

We have also established a strong positive correlation between the proportion of necrosis and chlorosis on the leaves of trees in the field protective forest strips. The correlation coefficient r = 0.7904. The coefficient of determination R^2 = 0.6248 shows that 62% of this dependence is determined by the studied factors. That is, the greater the spread of chlorosis on the leaves of trees, the greater is the spread of necrosis on the leaves of trees, as interconnected processes. The regression equation and graphical dependence between the studied factors are presented in Figure 3. Other signs of a leaf reaction to a violation of environmental

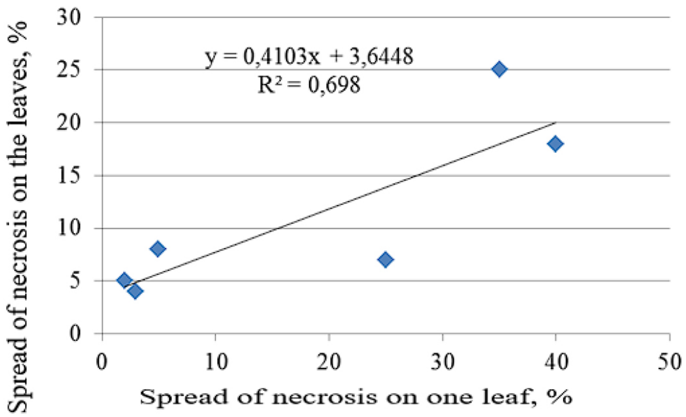

Figure 2. Correlation-regression relationship between the percentage of spread of necrosis on a leaf and the spread of necrosis on one leaf in field protective forest strips

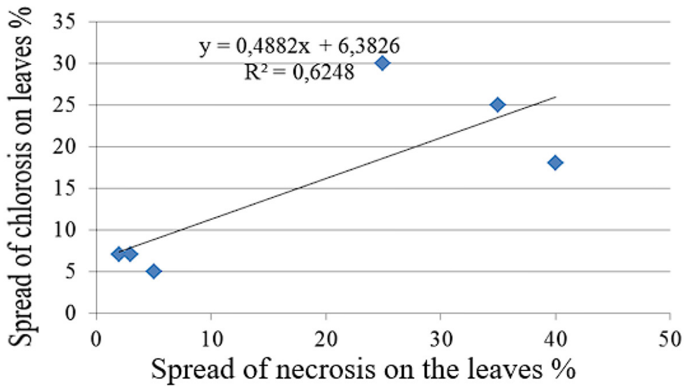

Figure 3. Correlation-regression dependence between the percentage of spread of necrosis and chlorosis on the leaves of field protective forest belts

conditions are its premature yellowing and falling. The most prematurely yellowed leaves were found on hornbeam trees of the additional openwork field protective forest strip in the amount of 15%. Corn crops were located near the field protective forest strip. In other forest strips, the share of prematurely yellowed leaves was extremely low – 1–3% (Table 4).

The largest number of trees with prematurely yellowed leaves was also established on the common hornbeam trees of the additional openwork field protective forest strip – 25%. Also, a significant percentage of trees with prematurely yellowed leaves was found in the main blowing field protective forest strip: common ash – 15% and common maple – 7%. In the rest of the forest strips, there was practically no premature yellowing of the leaves on the trees. Premature leaf fall was detected only in hornbeam trees of the additional openwork forest strip in the amount of 3% of leaves and trees. Premature leaf fall was not observed in the remaining forest strips.

We have established a strong positive correlation between the manifestation of premature yellowing of leaves and the share of trees with premature yellowing of the leaves of trees in field protective forest strips. The correlation coefficient r = 0.8978. The coefficient of determination R^2= 0.8061 shows that 81% of this dependence is determined by the studied factors. That is, the greater the spread of premature yellowing of leaves on a tree – the more trees with prematurely yellowed leaves are seen, as interconnected processes. The regression equation and graphical dependence between the studied factors are presented in Figure 4.

We also studied the processes of the spread of leaf curling and spotting. In particular, it was established that the most twisted leaves were

Table 4. Manifestation of premature yellowing and leaf fall of field protective forest belts of the Forest Steppe of Ukraine, 2022–2023

Parameters of forest belts	Construction of forest belts				
	Blowing		Openwork		Dense
Kind of the forest belt according to direction of the prevailing winds	The main one	Additional	The main one	Additional	The main one
Premature yellowing of leaves, % depending on tree species	3 – common maple; 2 – common ash	-	1 – common ash	15 – common hornbeam	1 – common maple
Share of trees with premature yellowing of leaves, %	15 – common ash 7 – common maple	-	1 – common ash	25 – common hornbeam	1 – common maple
Premature leaf fall, % depending on tree species	-	-	-	3 – common hornbeam	-
Share of trees with premature leaf fall, %	-	-	-	3 – common hornbeam	-

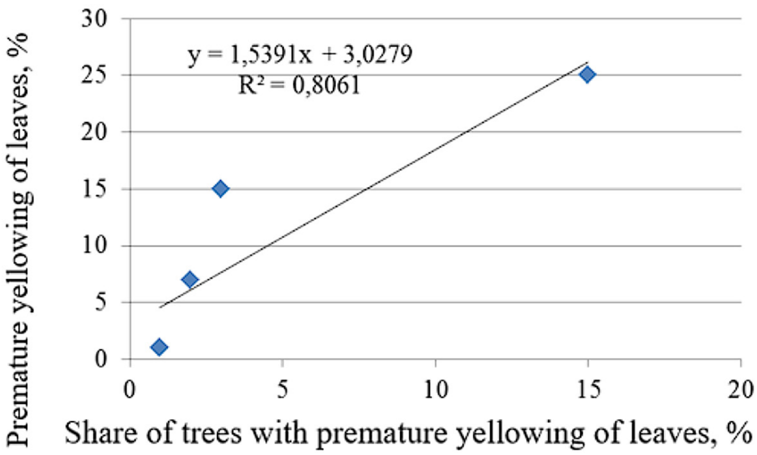

Figure 4. Correlation-regression relationship between the percentage of spread of prematurely yellowed leaves and trees with prematurely yellowed leaves in field protective forest strips

observed on common hornbeam trees of the additional openwork forest strip – 20% of the leaves. In common ash trees of the main blowing forest strip, the share of twisted leaves was 5%, and in the main openwork – 8%. No other manifestations of leaf curling were found on the trees of the field protective forest strips (Table 5).

The largest share of hornbeam trees with twisted leaves was found in the additional openwork forest strip – 20%. 12% of common ash trees and 6% of common maple trees with twisted leaves were found in the main blown forest belt. No other deviations were found.

The largest share of hornbeam trees with twisted leaves was also observed in the additional openwork forest strip – 20%. Also, a significant percentage of such trees was observed in common ash – 12% and common maple – 6% of the main forest strip. No trees with twisted leaves were found in other types of field-protective forest strips.

The most leaf spotting was found in common ash trees of the main openwork forest strip – 60% of the leaves. 40% of young maple leaves were spotted in the main dense forest zone and 20% in the main windy forest zone. In the additional blown forest strip, 6% of common ash leaves with spots were found, and in the additional openwork forest strip – 5% of common hornbeam leaves.

The largest share of spotting on one leaf was found in common ash in the additional blowing field protective forest strip – 40%. In the common maple of the main blowing forest strip, the share of spots on the leaf was 20%, and in the dense main forest strip – 10%. Common ash of the main openwork forest strip had 5% of spotting on the leaf, and 7% – common hornbeam of the additional openwork forest strip.

We have established a strong positive correlation between the proportion of twisted leaves and the proportion of trees with twisted leaves of the trees of the field protective forest strips. The correlation coefficient r = 0.7681. The coefficient of determination $R^2 = 0.59$ shows that 59% of this dependence is determined by the studied factors. That is, the greater the distribution of twisted leaves on a tree – the more trees with twisted leaves are, as interconnected processes. The regression equation and graphical dependence between the studied factors are presented in Fig. 5.

The main focus of our research was to identify deviations in the morphological and physiological characteristics of trees in field protective forest belts under the conditions of anthropogenic agricultural impact caused by the intensification of agriculture and global warming. We have established that such changes in vegetation can be manifested in the form of drying of trees, necrosis, chlorosis of leaves, premature yellowing and falling, twisting of leaves and their spotting. They can be effectively used to identify the causes of such reactions of trees, as well as to predict their changes. Harmful effects of climate change cause significant damage to the biodiversity of species and ecosystems, in particular, field protective forest belts. These negative consequences can be minimized by improving the forecasting

Table 5. Manifestation of twisting and spotting of leaves of the field protective forest belts of the Forest Steppe of Ukraine, 2022–202

Parameters of forest belts	Construction of forest belts				
	Blowing		Openwork		Dense
Kind of the forest belt according to direction of the prevailing winds	The main one	Additional	The main one	Additional	The main one
Curling of leaves, % depending on tree species	5 –common ash; 1 – common maple	-	8 – common ash	20 – common hornbeam	1 – common maple
Share of trees with twisted leaves of each species, %	12 – common ash 6 – common maple	-	1– common ash	20 – common hornbeam	1– common maple
Leaf spots, % depending on tree species	2 – common ash 20 – common maple	6 – common ash	60 – common ash	5 – common hornbeam	40 –common maple
The share of spots on a leaf, % depending on tree species	2 – common ash 20 – common maple	40 – common ash	5 – common ash	7 – common hornbeam	10 – common maple

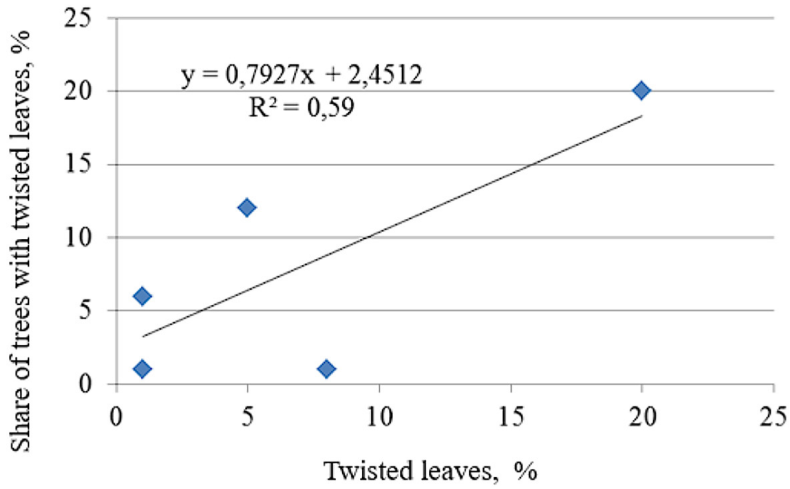

Figure 5. Correlation-regression relationship between the percentage of twisted leaves on a tree and trees with twisted leaves of field protective forest strips

efficiency of anthropogenic and natural risks (Jaupaj et al., 2023).

In this context, the signs of drought resistance of trees play an important role, especially in conditions of global warming. Drought-resistant species of trees to a lesser extent show changes caused by violation of the conditions of their growth and development. Therefore, the suppression of the leaves in them can be minimal. The research by the other authors did not reveal any connections between the plant's drought resistance and its shade tolerance. The selection of drought-tolerant tree species in field protective forest belts can be an essential guide in the selection of suitable species for silviculture and ecological restoration efforts (Khattar, 2023).

As droughts caused by extreme weather conditions have worsened and are occurring more and more frequently nowadays, it is extremely important to understand the ability of certain tree species of field protective forest strips to withstand drought in order to effectively perform their conservation functions (Kuo et al., 2022).

One of the common physiological disorders of the leaf apparatus of the trees of the field protective forest strips was their spotting. However, we believe that leaf spotting can occur not only as a reaction to atmospheric pollution, but also as a result of the manifestation of plant diseases. Research conducted in Taiwan revealed a significant spread of anthracnose disease in the form of leaf spotting of trees in field protective forest strips adjacent to agricultural land (Liu et al., 2021).

An important component of the assessment of the physiological and morphological condition of the trees of field protective forest belts is their drying, as a reaction to drought, diseases, pests, and pollution. We found a significant percentage of dry and drying trees. Also, a significant part of the missing trees was cut down due to their drying out. The space of the forest belts was filled with dry branches. Research conducted by other scientists established that the drying of trees is caused by droughts, windbreaks, and complex consequences of global climate change. Therefore, studies of dead and dry wood are justified (Kulbanska et al., 2023).

The main conclusion of our research is the study of the effective adaptation of the trees of field protective forest belts to anthropogenic and natural influences. This made it possible to identify those types of trees of field protective forest strips that have the lowest percentage of suppression due to the minimal manifestation of the processes of drying, necrosis, chlorosis, premature yellowing and falling of leaves, their twisting and spotting. It has been established that adaptation to climate change is the main task of forest management and field protective forest strips. They are, thanks to testing, an important tool for describing and understanding genetic variability and phenotypic plasticity of traits of interest for adaptation (Rihm, 2023).

The spread of tree drying processes in recent years has created a need among the forest management apparatus to find effective methods of collecting information about the level of tree death and establishing its cause. An important role in such observations belongs to field studies to solve certain inventory tasks (Mohammad et al., 2023).

CONCLUSIONS

Our research has established that the greatest diversity of species was characteristic of the openwork field protective forest belts, and the least – for the blowing ones. All the main field protective forest belts were more biodiverse than the additional ones. In 80% of forest belts, common ash is the main species, and in only 20% – it is common maple.

The largest share of felled trees (35%) and drying trees (35%) was found in the main blowing forest strip. We installed a slightly smaller proportion of drying and felled trees in the main openwork forest strip. And the least cut and drying trees are in the dense field protective forest strip.

The highest spread of necrosis: 40% of hornbeam leaves and 35% of maple leaves, as well as chlorosis: 18% of hornbeam leaves and 25% of maple leaves was found in the additional openwork forest strip. Also, a high percentage of the spread of necrosis and chlorosis was detected on the leaves of the common ash of the additional blowing forest strip, 18% and 25%, respectively. Necrosis and chlorosis were the least evident on the leaves of trees in the dense forest belt.

Premature yellowing of the leaves was detected only in hornbeam plants of the ordinary additional openwork forest belt in the amount of 15% of the leaves. Also, this type of the tree had the highest percentage of twisted leaves – 20%. The largest proportion of leaves with spots was found on common ash trees of the main openwork forest belt – 60% and of common maple trees of the dense forest belt.

REFERENCES

1. Branitskyi, Y., Telekalo, N., Kupchuk, I., Mazur, O., Alieksieiev, O., Okhota, Y. & Mazur, O. (2022). Improvement of technological methods of switchgrass (*Panicum virgatum* L.) growing in the Vinnytsia region. *Acta Fytotechnica et Zootechnica*. *25*(4), 311–318. https://doi.org/10.15414/afz.2022.25.04.311-318
2. Brzozowska, A., Dacko, M., Kalinichenko, A., Petrychenko, V.F., Tokovenko, I.P. (2018). Phytoplasmosis of bioenergy cultures. *Mikrobiolohichnyi Zhurnal*. *80*(4), 108–127. https://doi.org/10.15407/microbiolj80.04.108
3. Bulgakov V., Kaletnik H., Trokhaniak O., Lutkovska S., Klendii M., Ivanovs S., Popa L. & Yaropud V. (2024). Investigation of the energy indicators for the surface treatment of soil by a harrow with a screw-type working body. *INMATEH-Agricultural Engineering*. 2023, 71(3), 818–833. https://doi.org/10.35633/inmateh-71-72
4. Coop, J.D., Parks, S.A., Stevens-Rumann, C.S. & Rodman K.C. (2020). Wildfire-driven forest conversion in Western North American landscapes. *BioScience*, *70*(8) 659–673. https://doi.org/10.1093/biosci/biaa061
5. Didur, I., Bakhmat, M., Chynchyk, O., Pantsyreva, H., Telekalo, N., Tkachuk, O. (2020). Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. *Ukrainian Journal of Ecology*. *10*(5), 54–61. https://doi.org/10.15421/2020_206
6. Furdychko, O.I. & Stadnyk, A.P. (2010). Scientific bases of functioning of the system of protective forests and protective forest plantations in agrolandscapes of Ukraine. *Agroecological journal*. *4*, 5–12. https://doi.org/10.33730/2310-4678.4.2021.253095
7. Gallagher, R.V., Allen, S., & Wright, I.J. (2019). Safety margins and adaptive capacity of vegetation to climate change. *Scientific Reports*, *9*, 8241. https://doi.org/10.1038/s41598-019-44483-x
8. Hetman, N., Veklenko, Y., Petrychenko, V., Korniichuk, O., & Buhaiov, V. (2024). Agrobiological substantiation of growing Hungarian vetch in mixed crops. *Scientific Horizons*. *27*(4), 61–75. https://doi.org/10.48077/scihor4.2024.61
9. Hladun, H.B. (2005). The importance of protective forest plantations to ensure sustainable development of agricultural landscapes. *Scientific Bulletin*. *15*(7), 113–118. https://doi.org/10.1016/j.jnc.2023.126551
10. Hnatiuk, T.T., Zhitkevich, N.V., Petrychenko, V.F., Kalinichenko, A.V. & Patyka, V.P. (2019). Soybean diseases caused by genus Pseudomonas phytopathenes bacteria**.** *Mikrobiol. Z. 81*(3), 68–83. https://doi.org/10.15407/microbiolj81.03.068
11. Honcharuk, I., Yemchyk, T., Tokarchuk, D., Bondarenko, V. (2022). the role of bioenergy utilization of wastewater in achieving sustainable development goals for Ukraine. *European Journal of Sustainable Development*. *12*(2), 231–231. https://doi.org/10.14207/ejsd.2023.v12n2p231
12. Honcharuk, I., Matusyak, M., Pantsyreva, H., Prokopchuk, V., Telekalo, N. (2022). Peculiarities of reproduction of pinus nigra arn. In Ukraine. *Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering. 15*. 64(1), 33–42. https://doi.org/10.1038/s41598-019-44483-x
13. Jaupaj, O., Doko, A., Dervishi, A., Kadria, F., & Zaimi, K. (2023). Assessment of wildfires forecast performance in Albania: Case study. *Scientific Horizons*, *26*(9), 143–152. https://doi.org/10.48077/

scihor9.2023.143 https://doi.org/10.48077/scihor9.2023.143

14. Kaletnik H., Yaropud V., Lutkovska S., & Aliiev E. (2024). Studying the air flow heating process in the vertical type ground heat exchanger. *Przeglad Elektrotechniczny. 100*(10), 46–54. https://doi.org/10.15199/48.2024.10.08
15. Kaletnik, G., Honcharuk, I., Okhota, Y. (2020). The Waste-free production development for the energy autonomy formation of ukrainian agricultural enterprises. *Journal of Environmental Management and Tourism*, *11*(3), 513–522. https://doi.org/10.14505//jemt.v11.3(43).02
16. Khattar, J. (2023). The forest community surrounding juhu ecological park: a preliminary forest inventory and its ecological implications. *Taiwan J For Sci*, *38*(2), 171–179.
17. Kulbanska, I., Boiko, H., Shvets, M., Vyshnevskyi, A., & Savchenko, Yu. (2023). The role of aphyllophoroid macromycetes as indicators of forest ecosystem disruption and reducers of biomass accumulation. *Scientific Horizons*, *26*(3), 70–80. https://doi.org/10.48077/scihor3.2023.70
18. Kuo, Y.L., Jiang, J.X., Xu, Z.W., Yu, S.Y. (2022). Comparing the drought tolerance abilities of tree species in the Hengchun Coastal Forest and Lienhuachih Forest with two physiological indices. *Taiwan J For Sci*. *37*(4), 275–94.
19. Liu, T.Y., Chen, C.H., Wang, L.J., Hung, T.H., Hsu, M.H., Wu, M.L. (2021). Investigation of Camellia tree diseases in Taiwan and establishment of a rapid detection method for *Colletotrichum* spp. *Taiwan J For Sci, 36*(1), 1–19.
20. Lohosha R., Palamarchuk V., Krychkovskyi V. & Belkin I. (2024). An advanced European overview of the bioenergy efficiency of using digestate from biogas plants when growing agricultural crops. *Polityka Energetyczna*, *27*(1), 5–25. https://doi.org/10.33223/epj/127921
21. Mazur, V., Didur, I., Tkachuk, O., Pantsyreva, H., Ovcharuk, V. (2021). Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons*. *24*(1), 54–60. https://doi.org/10.48077/scihor.24(1).2021.54-60
22. Mazur, V., Didur, I., Tkachuk, O., Pantsyreva, H. & Ovcharuk, V. (2021). Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. *Scientific Horizons, 24*(1), 54–60. https://doi.org/10.48077/scihor.24(1).2021.54-60
23. Mazur, V., Tkachuk, O., Pantsyreva, H., Demchuk, O. (2021). Quality of pea seeds and agroecological condition of soil when using structured water. *Scientific Horizons*. *24*(7), 53–60. https://10.0.187.205/scihor.24(7).2021.53-60
24. Mazur. V., Tkachuk, O., Pantsyreva, H., Kupchuk, I., Mordvaniuk M., Chynchyk O. (2021). Ecological suitability peas (*Pisum sativum*) varieties to climate change in Ukraine. *Agraarteadus*. *Journal of Agricultural Science*. 32, 2, 276–283. https://doi.org/10.15159/jas.21.26
25. Michotey, C., Anger, C., Albet, A., & Fady, B. (2021). Metadata from common gardens of the Forest Genetics Network for Research and Experimentation (GEN4X). *Recherche Data Gouv*, *3*. https://doi.org/10.15454/50RS8C
26. Naseri, M.H., Jouibary, S.S. & Habashi, H. (2023). Analysis of forest tree dieback using UltraCam and UAV imagery. *Scandinavian Journal of Forest Research*, *38*, 6, 392–400, https://doi.org/10.1080/02827581.2023.2231349
27. Monarkh, V.V. & Pantsyreva, H.V. (2019). Stages of the environmental risk assessment. *Ukrainian Journal of Ecology*, *9*(4), 484–492. https://doi.org/10.15421/2019_779
28. Mostovenko, V., Mazur, O., Didur, I., Kupchuk, I., Voloshyna, O. & Mazur, O. (2022). Garden pea yield and its quality indicators depending on the technological methods of growing in conditions of Vinnytsia region. *Acta Fytotechnica et Zootechnica*. *25*(3), 226–241. https://doi.org/10.15414/afz.2022.25.03.226-241
29. Okrushko S. (2022). Allelopathic effect of couch grass (*Elymus repens* L.) on germination of common wheat seeds. *Zemdirbyste*. *109*(4), 323–328. https://doi.org/10.13080/z-a.2022.109.041
30. Pecchi, M., Marchi, M., Burton, V., Gianenetti, F., Moriondo, M., Bernetti, I., Bindi, M., & Chirici, G. (2019). Species distribution modelling to support forest management. A literature review. *Ecological Modelling*, 411, 108817. https://doi.org/10.1016/j.ecolmodel.2019.108817
31. Petrychenko V., Petrychenko O., Fedoryshyna L., Kravchuk O., Korniichuk O. & Nitsenko V. (2022). *Agricultural production in Ukraine: ecological challenges and impact on the quality of life*. Financial And Credit Activity-problems Of Theory And Practice. 4(45), 374–384. 10.55643/fcaptp.4.45.2022.3782
32. Petrychenko, V., Korniychuk, O., Lykhochvor, V., Kobak, S. & Pantsyrev, O. (2024). Study of Sowing Quality of Soybean Seeds Depending on Pre-Sowing Treatment of Seed. *Journal of Ecological Engineering. 25*(7), 332–339. https://doi.org/10.12911/22998993/188932
33. Petrychenko, V.F., Kobak, S.Ya., Chorna, V.M., Kolisnyk, S.I., Likhochvor, V.V. & Pyda, S.V (2018). Formation of the nitrogen-fixing potential and productivity of soybean varieties selected at the institute of feeds and agriculture of podillia of NAAS. *Mikrobiol. Z. 80*(5), 63–75. https://doi.

org/10.15407/microbiolj80.05.063

34. Razanov, S., Alieksieiev, O., Bakhmat, O., Bakhmat, M., Lytvyn, O., Alieksieieva, O., Vradii, O., Mazur, K., Razanova, A. & Mazurak, I. (2024). Accumulation of chemical elements in the vegetative mass of energy cultures grown on gray forest soils in the western forest steppe of Ukraine. *Journal of Ecological Engineering. 25*(9), 282–291. https://doi.org/10.12911/22998993/191439
35. Rihm, G., & Fady, B. (2023). Caractériser l'enveloppe climatique future des jardins communs forestiers: une approche essentielle pour mieux raisonner l'adaptation des essences. *Revue forestière française*, *74*(4), 495–506. https://doi.org/10.20870/revforfr.2023.7900
36. Seidl, R., Thom, D., Kautz, M., & Reyer, C.P. (2017). Forest disturbances under climate change. *Nature Clim Change, 7*, 395–402. https://doi.org/10.1038/nclimate3303
37. Thom, D., & Seidl, R. (2016). Natural disturbance impacts on ecosystem services and biodiversity in temperate and boreal forests. *Biological Reviews*, *91*(3), 760–781. https://doi.org/10.1111/brv.12193
38. Tkachuk, O., Verhelis, V. (2021). Intensity of soil pollution by toxic substances depending on the degree of its washout. *Scientific Horizons*. *24*(3), 52–57. https://doi.org/10.48077/scihor.24(3).2021.52-57
39. Tkachuk, O., Viter, N., Pankova, S., Titarenko, O., Yakovets, L. (2023). The current environmental state of the field protective forest belts of the Forest Steppe of Ukraine. *International Journal of Ecosystems and Ecology Science (IJEES)*, *13*(2), 1–8. https://doi.org/10.31407/ijees13.2
40. Vdovenko, S., Palamarchuk, I., Mazur, O., Mazur, O., & Mulyarchuk, O. (2024). Organic cultivation of carrot in the right-bank Forest-Steppe of Ukraine. *Scientific Horizons*, *27*(1), 62–70. https://doi.org/10.48077/scihor1.2024.62