JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(6), 315–328
https://doi.org/10.12911/22998993/202749
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.02.19
Accepted: 2025.04.03
Published: 2025.04.15

Bioindication characteristics of trees in solid protection forest strips depending on intensive agriculture

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ABSTRACT

The article presents promising types of bioindicators in agroecosystems – forest shelterbelts, which are closely adjacent to crops and are often themselves contaminated due to the ingress of mineral fertilizers and pesticides onto the leaves or into the sub-stem soil layer, and during mechanical tillage – undergo significant pollination. The main crops of the forest-steppe of Ukraine are corn and winter wheat, therefore it is their cultivation that can have the greatest impact on the functioning and ecological state of forest shelterbelts. It has been established that the main factors influencing the technologies of growing agricultural crops on the agro-ecological state of forest shelterbelts are the main soil tillage, the application of mineral fertilizers, synthetic pesticides, growth regulators and other preparations. One of the most typical reactions of trees to pollution due to the intensification of agriculture is the manifestation of chlorosis and necrosis on the leaves of plants. Our observations among the tree and shrub vegetation of the main shelterbelts revealed necrosis on the leaves of Tatar honeysuckle plants in the amount of 1–12% of leaves, common maple – on 12–30% of leaves, common ash – on 12–15% of leaves. On the leaves of trees of auxiliary shelterbelts, necrosis was widespread on 15% of holm oak leaves and 5–8% of common ash leaves. The surface area of necrosis development on the leaves of the tree and shrub vegetation of the main shelterbelts was: in Tatar honeysuckle plants – 4–20%, in common maple plants – 7–60%, in common ash plants – 7–12%. In plants of auxiliary shelterbelts, the proportion of necrosis on the leaf of common oak plants was 15%, and in common ash – 5–12%. The spread of spotting on the tree-shrub vegetation of the main shelterbelts was detected on the leaves of common ash in the amount of 35% of the total volume of leaves on the tree crown, on the leaves of common maple – in the amount of 10–20% and on the leaves of white acacia – in the amount of 30% of the total volume of leaves of the crown of one tree. In the trees of the auxiliary shelterbelts, the spread of spotting was detected on 60% of the leaves of common oak, common maple and common ash. The proportion of the surface of one common ash leaf with spotting was about 20%, common maple – 40–60%, white acacia – 30%. In the trees of the auxiliary shelterbelts, the proportion of the surface of a common oak leaf with spotting was 85%, common maple and common ash – 60%. The manifestation of the general degradation of tree-shrub-herbaceous vegetation of the main shelterbelts in the studied area was 7–18%, and of the auxiliary shelterbelts – 7–15%. The greatest manifestation of the degradation of tree-shrub-herbaceous vegetation was found in shelterbelts adjacent to winter wheat and corn crops, and the least – in those adjacent to soybean crops.

Keywords: agricultural crops, winter wheat, corn, field protection forest strips, bioindicative assessment.

INTRODUCTION

Bioindication is used in agro-ecological research as a method of detecting anthropogenic load on the biocenosis. The method of bioindicators is based on the study of the impact of changing environmental factors on various characteristics of biological objects and systems. Biological systems or organisms most sensitive to the studied factors are chosen as bioindicators. Changes in the behavior of the test object are evaluated in comparison with control situations taken as a standard (Alaru, 2014; Rozhkov, 2016). The widespread use of trees as bioindicators is caused by the fact that they can constantly accumulate pollutants and show external deviations throughout the growing season. Coniferous trees are very sensitive bioindicators (Honcharuk, 2022).

Bioindication assessment of the state of the environment is widely used to determine the ecological state of cities, where anthropogenic pollution is very powerful. Unlike urban ecosystems, the use of bioindication studies in agroecosystems has not been widely used. The reasons for this are the short growing season of field crops, their frequent change in crop rotation, which does not allow for systematic observations (Pantsyreva, 2024; Snitynskyi, 2024).

For bioindication, it is necessary to choose the most sensitive species of tree and shrub vegetation of forest shelterbelts. Among perennial plants, the sensory organ for bioindication is leaves. Under the influence of anthropogenic pollution, the morphology of leaves in plantations can change, in particular its asymmetry, the surface area of the leaf blade decreases, chlorosis, necrosis, premature yellowing and leaf fall, their deformation, twisting, the appearance of spotting, and others occur.

It has been established that reliable bioindicators in cities can be birch leaves, whose trees are characterized by high absorbing abilities. When forming a leaf plate of trees under conditions of accumulation of toxic substances in it, growth processes are slowed down, leaf deformation is observed, photosynthesis processes are slowed down or stopped, physiological metabolism in the leaf is disturbed. It becomes vulnerable to the influence of pests and diseases and undergoes changes. However, such reactions of plants to air and soil pollution are usually non-specific, that is, they can be caused not only by environmental pollution, but also by unfavorable conditions of meteorological factors (drought, frost, severe frosts) as well as the influence of diseases and pests. Therefore, methods of bioindication of environmental pollution are an additional source of obtaining ecological information (Tkachuk, 2024).

The damage of tree leaves by toxic substances is accelerated at the initial stages of vegetation, and the visual manifestation of leaf suppression is better detected on the leaves at a later time – in late summer – early autumn, when the leaf blades are fully formed (Tkach, 2023).

For tall trees of field shelterbelts, it is more expedient to process the vegetation of the lower tiers: lower branches of trees, bushes, shrubs, undergrowth, etc. Since the mentioned works within the agroecosystems were practically not carried out, and birch, the study of bioindication manifestations of which in urban ecosystems is sufficient, is not widespread in the field shelterbelts of Ukraine, then the detection of changes in the condition of the leaves of field shelterbelts, caused by the intensification of agriculture, is an urgent and important task (Dubik, 2024).

A promising type of bioindicators in agroecosystems can be field protection forest strips, which are closely adjacent to crops and are often themselves contaminated due to the ingress of mineral fertilizers and pesticides on the leaves or in the substem layer of the soil, and in the case of mechanical cultivation of the soil – undergo significant pollination. Such pollution leads to the suppression of plants, monitoring of which can reveal technological operations and cultivated crops that most pollute the environment of both the agroecosystems themselves and the adjacent natural ecosystems: forests, steppes, meadows, reservoirs, and others (Palamarchuk, 2023).

For bioindication, it is necessary to choose the most sensitive types of tree-shrub vegetation of field protection forest strips. Among perennial plants, leaves are the sensory organ for bioindication. Under the influence of anthropogenic pollution, the morphology of leaves in plantations can change, in particular its asymmetry, the surface area of the leaf plate decreases, chlorosis, necrosis, premature yellowing and falling of leaves, their deformation, twisting, the appearance of spots, and others occur. For tall trees of field protection forest strips, it is best to examine the vegetation of the lower tiers: the lower branches of trees, bushes, shrubs, undergrowth, and others. Such works within field protection agroecosystems were practically not carried out, therefore, establishing changes in the appearance of leaves of field protection forest strips caused by the intensification of the agricultural sector is an urgent and important task (Dumpis, 2021; Tkachuk, 2025; Petrychenko, 2025; Razanov, 2023).

One of the important factors affecting the agro-ecological condition of the field protection forest strips in the forest steppe of Ukraine today is the use of mineral fertilizers at high rates of application, repeated use of synthetic pesticides, excessive plowing of roads and zones adjacent to forest strips, excessive felling of trees in the field protection forest strips for firewood harvesting or their complete destruction (Bakhmat, 2023; Pantsyreva, 2023; Razanov, 2024).

In such conditions, field protection forest strips cannot effectively perform their environmental protection functions in agro-ecosystems. Thus, their spatial distribution role in normalizing the microclimate in the surface layer of the atmosphere is violated. This leads to overdrying of the soil and plants; deterioration of wind protection functions. The result is an increase in dry spells and deflationary winds that redistribute soil dust particles in summer and blizzards in winter that blow snow from fields (Mazur, 2021; Petrychenko, 2024; Razanov, 2025).

The drying of small-leaved linden, white acacia, and black poplar can be observed in the forest field protection strips; dry tops of pine and other species; there is damage to trees by arbitrary felling, by fire during harvest stubble burning. The plantations located not far from the settlement are a place for storing household and other garbage, they are used for excess livestock grazing. The negative effects of snowmelt and thickened undergrowth are also noted (Monarkh, 2019).

A significant increase in the use of agricultural intensification measures in recent years, which include the repeated use of synthetic pesticides by aerial spraying to protect agricultural crops from pests, the introduction of high rates of synthetic fertilizers by continuous surface spreading, the use of powerful and heavy agricultural machinery that emits large volumes exhaust gases, contributed to the significant suppression of field protection forest strips, which suffer not only from the anthropogenic load caused by atmospheric pollution, but also from the deposition of dust of heavy metals and other toxicants on the surface of the soil and tree crowns (Hnatiuk, 2019).

This leads to premature fall of leaves, drying of branches and death of trees in field protection forest strips. Natural climatic cataclysms also worsen the ecological condition of trees in such plantations – a sharp and significant increase in air temperature, an increase in the volume of moisture evaporation from the soil and a decrease in the amount of atmospheric precipitation lead to the development of pests and diseases on plants, a decrease in their resistance to adverse environmental factors, and the death of individual trees, who are most depressed by such changes. White acacia, poplar and common oak are the most sensitive to these violations (Puyu, 2021; Didur, 2024).

MATERIALS AND METHODS

Field observations

Field observations were conducted during 2021–2023 in the natural zone of the forest-steppe of Ukraine in the Vinnytsia region. The soils of the studied territory are podzolized chernozems and leached chernozems, the relief is a wide undulating plain, low, since the territory is located within the Dnieper Highlands. 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. In the studied area, westerly winds prevail in summer and easterly winds in winter. The research area is characterized by a long, not hot, fairly humid summer and a relatively short, not severe winter. The average temperature in January is minus 5.8 °C, in July +18.3 °C.

Data collection

Observations were carried out separately for the main and auxiliary field protection forest strips according to the following groups of indicators: anthropogenic impact, incl. caused by agricultural activity, in particular intensive farming activities; the ecological condition of field protection forest strips – was determined by the complex of detection of bioindicative signs of plantations, in particular chlorosis, necrosis, suppression of leaves.

The anthropogenic influence during cultivation of agricultural crops on the condition of field protection forest strips was determined by the indicators: agricultural lands adjacent to the forest strip on both sides – visually; crops grown on both sides of the forest strip – visually; the distance of the nearest row of trees to the field, m on both sides – with a measuring tape; the presence of a field road between the forest strip and the field, its width, m – visually and with a tape measure; projection of the crown of the outermost row of trees of the forest strip protruding above the field, m – measuring tape.

The influence of the technological operations of growing the main agricultural crops on the ecological condition of the field protection forest strips in the conditions of the right bank forest steppe was determined according to the technological maps of cultivation according to the following indicators: the main tillage for the cultivation of the main agricultural crops; application of mineral fertilizers for the cultivation of the main agricultural crops; introduction of pesticides for the cultivation of the main agricultural crops; foliar fertilization for the cultivation of the main agricultural crops.

The bioindicative stability of field-protecting forest ecosystems was determined by indicators of the spread of chlorosis and necrosis of leaves: the spread of necrosis on leaves, % of leaves – visually; proportion of necrosis on a leaf, % of leaf surface – visually; spread of chlorosis on leaves, % of leave visually; proportion of chlorosis on the leaf, % of the leaf surface – visually.

Manifestation of suppression of leaves of plantations of field protection forest strips was determined by the indicators: share of premature yellowing of leaves on trees, % – visually; share of premature leaf fall on trees, % – visually; share of twisted leaves on trees, % – visually; spread of spotting on leaves, % of leaves – visually; percentage of spotting on the leaf, % of the leaf surface – visually.

Analysis

The general ecological condition of the plantations of the field protection forest strips of the right bank forest steppe was determined by the following indicators: manifestation of tree-shrub-herbaceous vegetation degradation, %; life status of trees by damage to the crown and trunk. Research was conducted in several stages. The agricultural lands adjacent to the designated main and auxiliary field protection forest strips and crops grown on them were determined. Metric observations involved measuring the distance from the nearest row of trees of the field protection forest strips to the field on both sides; availability and width of the field road adjacent to the forest strip and separating it from the field; projections of the crown of the outermost row of trees of the forest strip protruding above the field. A tape measure 20 m long was used for these measurements. All quantitative measurements were performed in quadruplicate. The next stage of our observations involved the analysis of modern intensive technologies for growing the main agricultural crops that are most widespread in the studied region. For this purpose, appropriate technological maps were used. The analysis was carried out for the purpose of identifying those technological operations that can potentially affect the ecological condition of the field protection forest strips. The species composition of trees, bushes and shrubs was determined within the established test plots, and the agricultural crops grown in the fields adjacent to the researched field protection forest strips were noted.

When conducting the main research, the methods of registration bioindication were used, that is, the amount of spread of necrosis, chlorosis, premature yellowing and falling of leaves from trees, their curling and spotting on the leaves from the total number of trees within the limits of the test plots were recorded. The proportion of the affected surface was visually determined within the leaves. The types of agricultural land adjacent to the field protection forest strips on both sides were determined visually according to the nature of the intended use of the land: during annual cultivation of the soil, its sowing with annual crops – it was defined as arable land; in the case of long-term cultivation of herbaceous plants with domestic animals (cows) grazing on them – it was defined as pasture. In total, an area of 2,139 hectares was developed, in which the share of agricultural land is 91%, and arable land – 87%. The forest typological survey of plantations was carried out on the basis of forestry and ecological typology. A qualifier was used to specify and establish species names. Mathematical processing of the obtained numerical results was carried out using Microsoft XL, Statistics computer programs.

RESULTS AND DISCUSSIONS

All studied field protection forest strips are located within agricultural lands. Among the main field protection forest strips, 85.7% are located between fields of arable land (arable land) on both sides and 14.3% – between arable land (arable land) on one side and pasture on the other. At the same time, all auxiliary field protection forest strips are placed between arable lands (Table 1). The main crops grown on arable land adjacent to the researched field protection forest strips were winter wheat, corn, sunflower, soybeans, and vegetables. Corn crops were most often adjacent to the main field protection forest strips studied – in 50.0% of the field protection forest strips. Winter wheat was adjacent to 21.4% of field protection forest strips, sunflower – to 14.3%, vegetable crops – to 7.2% of field protection forest strips from their total number that were studied. Corn crops were also most often adjacent to auxiliary field protection forest strips – in 50.0% of forest strips, winter wheat – up to 25.0% of forest strips, soy and vegetable crops – each in 12.5% of field protection forest strips from their total number that were investigated. Therefore, the most intense influence on field protection forest strips is carried out by crops of corn and winter wheat, which together are adjacent to 71.4–75.0% of all studied main and auxiliary field protection forest strips.

A characteristic feature of modern intensive land use is the plowing of land in the shelter of field protection forest strips (Pawlewicz, 2019; Pantsyreva, 2024). We determined the distance of the nearest row of trees to the plowed field. Among the main field protection forest strips, this distance ranged from 0.5 m to 10.0 m depending on the forest strip, the overgrowth of shrubs between the outer row of trees of the forest strips and the field, and the presence of a field road between the forest strips and the field.

Most often, the fields were plowed at a distance of 1.5 m from the outer row of trees on both sides of the forest strip. Such were found in 42.9% of the main forest strips from their total number that were subject to research. The distance between the outer row of trees in the auxiliary field protection forest strips and the plowed field was 1.0–4.0 m. Most often, fields were plowed at a distance of 1.0 m to the auxiliary field protection forest strips. Such field protection forest strips were found in 50% of all auxiliary field protection forest strips, which were subject to investigation. Plowing the fields close to the trees of the field protection forest strips at a distance of

Table 1. Anthropogenic influence during the cultivation of agricultural crops on the condition of the protective forest strips of the forest steppe of Ukraine, 2021–2023, M±m

Indicator	Type of forest strip			
	Basic		Basic	
	Indicator parameter	Part, %	Indicator parameter	Part, %
Agricultural land adjacent to the forest strip on both sides	Arable land / arable land	85.7	Arable land / arable land	100
	Pasture / arable land	14.3		
Cultivated crops on both sides of the forest strip	Winter wheat / corn	28.6	Winter wheat / soy	25.0
	Winter wheat / pasture	14.3	Corn / corn	25.0
	Sunflower / vegetables	14.3	Winter wheat / corn	25.0
	Corn / corn	28.6	Corn / vegetables	25.0
	Corn / sunflower	14.3		
The distance of the nearest row of trees to the field, m on both sides	0.5 ± 0.2/0.5±0.2	14.3	1.0 ± 0.2/1.0 ± 0.2	50.0
	0.5 ± 0.2/4.5±0.3	14.3	2.0 ± 0.3/2.0 ± 0.3	25.0
	1.0 ± 0.2/1.0 ± 0.2	14.3	4.0 ± 0.5/4.0 ± 0.4	25.0
	1.5 ± 0.2/1.5 ± 0.2	42.9		
	2.0 ± 0.3/2.0 ± 0.2	14.3		
	10 ± 1.0/10 ± 1.0	14.3		
The presence of a field road between the forest strip and the field, its width, m	there is no	28.6	there is no	25.0
	3 ± 0.4	14.3	3 ± 0.4	50.0
	4 ± 0.3	28.6	4 ± 0.3	25.0
	7 ± 0.4	14.3		
Projection of the crown of the outermost row of trees of the forest strip protruding above the field, m	1 ± 0.4	14.3	5 ± 0.5	25.0
	5 ± 0.8	14.3	6 ± 0.5	25.0
	6 ± 0.4	14.3	7 ± 0.6	50.0
	7 ± 0.4	14.3		
	8 ± 0.5	28.6		
	12 ± 0.8	14.3		

1.0–1.5 m can cause damage to the root systems of trees with soil tillage tools, and the application of synthetic pesticides can cause damage to the above-ground part of plants.

Today, there are frequent cases of plowing of roads along field protection forest strips, which significantly increases the area of arable land and can negatively affect the stability of field protection forest strips, as the distance between the outermost row of trees of the field protection forest strip and the plowed field decreases. Our research established that among all the main field protection forest strips, 28.6% of plantations did not have field roads at all, and the rest had field roads. Their width ranged from 3.0 to 7.0 m. Forest strips with field roads 4 m wide prevailed. Such were 28.6% of all main field protection forest strips that were subject to observation. Among all auxiliary field protection forest strips, 25.0% did not have field roads. In other forest strips, the width of the field roads was 3.0–4.0 m. Auxiliary forest strips, which had field roads 3.0 m wide, predominated. Such were 50.0% of all investigated auxiliary field protection forest strips.

The close plowing of fields to the outermost row of trees in the field protection forest strips, the absence of field roads between the field and the forest strip, as well as the significant age of the forest strips themselves causes the growth of tree crowns and their hanging over the plowed field, which can also affect the functioning of the field protection forest strips, especially when synthetic pesticides are applied for crops (Jansson, 2020). We studied the projections of the crowns of the outer row of trees of the field protection forest strips onto the field. This distance in the main field protection forest strips ranged from 1.0 to 12.0 m. Most often, the projection of tree crowns on the crops was 8.0 m. This was found in 28.6% of the main field protection forest strips from their total number that was subject to research. Auxiliary forest strips had a projection of the crown on the fields of 5.0–7.0 m, most often – 7.0 m. Such a projection was found in 50.0% of auxiliary forest strips from their total number that were subject to observation.

Since the main crops of the Forest Steppe of Ukraine are corn and winter wheat, it is their cultivation that can have the greatest impact on the functioning and ecological condition of field-protecting forest strips (Poore, 2019). The main factors influencing the technologies of cultivation of agricultural crops on the ecological condition of field protection forest strips are the main cultivation of the soil, the introduction of mineral fertilizers, synthetic pesticides, growth regulators and other drugs. Tillage can affect the damage to the root system of trees in field protection forest strips. Surface application of mineral fertilizers by spreading can cause fertilizers to fall on the leaves of the lower branches of trees, as well as the application of synthetic pesticides and other drugs that are applied by spraying. This can cause burns, spots, chlorosis, necrosis and premature yellowing, drying and falling of leaves from the trees of field protection forest strips (Keres, 2020; Kuht, 2016).

The analysis of technological maps of the intensive technology of growing corn and winter wheat showed that for corn, deep main tillage is used in the form of plowing to a depth of 25–27 cm. For sowing winter wheat, surface disc tillage is carried out to a depth of 10–12 cm. damage to the root systems of the trees of the field protection forest strips can be caused by deep cultivation of the soil for sowing corn (Zhao, 2021).

When growing corn, about 350 kg/ha of the active substance of the main mineral fertilizers are applied: nitrogen, phosphorus, potassium. When growing winter wheat, the rate of application of the active substance of mineral fertilizers is about 250 kg/ha. In terms of physical weight, 850 kg/ha of mineral fertilizers should be used when growing corn, and 650 kg/ha when growing winter wheat. In addition to direct nutrients, mineral fertilizers contain heavy metals, acids, salts and other toxicants, which can have a negative effect on field protection forest strips, especially when mineral fertilizer dust is released during their spreading application (Ramakrishnan, 2021).

The most common mineral fertilizers among nitrogen fertilizers are ammonium nitrate, which contains about 34.5% of mineral nitrogen, and the rest is ballast; among phosphates – double superphosphate, containing about 48% of mineral phosphorus; among potash – potassium chloride with a nutritional potassium content of about 60%. Among complex mineral fertilizers, nitroammophoska with a nitrogen, phosphorus and potassium content of 16% is most often used. Phosphorous-potassium mineral fertilizers are applied once in the fall both under corn and under winter wheat, and nitrogen fertilizers are applied in several ways: under corn – before sowing and in top dressing; under winter wheat – in spring in 2–3 fertilizing. Complex mineral fertilizers are applied together with sowing once in a small starting dose. Synthetic pesticides are applied 6 times when growing corn and winter wheat: when growing corn, herbicides, fungicides, and insecticides are applied 2 times each, and when growing winter wheat, herbicides are applied 1 time, fungicides 3 times, and insecticides 2 times. Also, when growing winter wheat and corn, foliar fertilization with microfertilizers, growth stimulants, and liquid fertilizers is used, in general 2–3 times for each crop. Thus, during the growing season of winter wheat and corn, synthetic preparations for each culture are applied by spraying 8–9 times. For high-growing corn, part of the late treatments with a tractor sprayer can be replaced by the aviation method (drones, unmanned aerial vehicles, helicopters, airplanes).

A feature of modern pesticides is a low application rate, which is 0.5–3.0 l/ha. However, their damage to field protection forest strips can be manifested by the ingress of concentrated drugs on the surface of the lower leaves of trees. The danger of this increases with the aerial method of spraying crops. The species composition of the tree-shrub vegetation of the main field protection forest strips of the Forest Steppe of Ukraine is represented by common maple, common ash, small-leaved linden, white acacia, common hornbeam, common oak, Tatar honeysuckle, white willow, walnut, wild cherry and other species. In the auxiliary field protection forest strips, plantations are represented by common oak, common maple, common ash, wild cherry, common rowan, wild pear, common hornbeam, hanging birch and other species (Giampieri, 2022).

One of the most typical reactions of trees to pollution due to the intensification of agriculture is the manifestation of chlorosis and necrosis on plant leaves. Necrosis is the premature death and destruction of leaf cells under the influence of pollution factors. According to our observations, among the tree-shrub vegetation of the main field protection forest strips, the manifestation of necrosis was detected on the leaves of Tatar honeysuckle plants in the amount of 1–12% of leaves, common maple – 12–30% of leaves, common ash – 12–15% of leaves. On the leaves of the trees of the auxiliary field protection forest strips, necrosis was spread to 15% of the leaves of the common oak and 5-8% of the leaves of the common ash (Table 2).

The surface area of the development of necrosis on the leaves of the tree-shrub vegetation of the main field protection forest strips was: in Tatar honeysuckle plants – 4–20%, in common maple plants – 7–60%, in common ash plants – 7–12%. In plants of auxiliary field protection forest strips, the proportion of necrosis on the leaves of common oak plants was 15%, and common ash – 5–12%.

Our research established that the largest area of necrosis on the leaves of Tatarian honeysuckle plantations was manifested in field protection forest strips adjacent to winter wheat crops, the smallest area of necrosis was found on the leaves of Tatarian honeysuckle, forest strips adjacent to crops of vegetable crops and potatoes, and the average – to corn crops. Therefore, the intensive measures of chemical treatment used in the cultivation of winter wheat are most clearly manifested in the reaction of the leaves of Tatar honeysuckle in the form of necrosis.

The greatest manifestation of necrosis on the leaves of common maple trees was found in field protection forest strips adjacent to corn crops, and the least manifestation of leaf necrosis on common maple trees was observed in forest strips adjacent to winter wheat crops.

On the leaves of common ash trees, no clear differences in the manifestation of necrosis of field-protecting forest strips adjacent to crops of winter wheat and corn were found. Therefore, we believe that it is not advisable to use common ash plants as bioindicators to detect the impact of agricultural chemicals based on the indicators of necrosis on their leaves.

The manifestation of chlorosis on the leaves of trees is due to insufficient production of chlorophyll in plants. Chlorosis is manifested when the process of photosynthesis stops, the absence of certain nutrients in the soil, as well as when some types of pesticides fall on the leaves. Chlorosis of tree-shrub vegetation in our studies of the main field protection forest strips was widespread on all leaves of white acacia, on 80% of leaves of common hornbeam, on 4–85% of leaves of common maple and on 7–85% of leaves of common ash. On the trees of the auxiliary field protection forest strips, chlorosis was detected only on the leaves of common ash with a proportion of 8% affected. The proportion of white acacia and common hornbeam leaves affected by chlorosis was 20% each, common maple and common ash – 10–15%, and common ash of auxiliary field protection forest strips – 12% of the leaf area.

According to the results of our research, *Robinia pseudoacacia*, *Carpinus betulus*, *Acer*

Table 2. Manifestation of necrosis and chlorosis on the leaves of plantations of field protection forest strips of the forest steppe of Ukraine, 2021–2023

Indicator	Type of forest strip			
	Basic		Auxiliary	
	Type of tree-shrub vegetation	Share, %	Type of tree-shrub vegetation	Share, %
Species composition of forest strips	*Acer platanoides* L., *Fraxinus excelsior* L., *Tilia cordata*, *Robinia pseudoacacia*, *Carpinus betulus* , *Quercus robur* L., *Lonicera tatarica* L., *Salix alba* L., *Juglans regia* L., *Prunus avium*	-	*Quercus robur* L., *Acer platanoides* L., *Fraxinus excelsior* L., *Prunus avium* L., *Sorbus aucuparia* L., *Pyrus communis* L., *Carpinus betulus* L., *Bétula péndula* L.	-
Spread of necrosis on leaves, % of leaves	*Lonicera tatarica* L.	7.7* 1.0-12.0	*Quercus robur* L.	15.0
	Acer platanoides L.	19.3 12.0-30.0	*Fraxinus excelsior* L.	6.5 5.0-8.0
	Fraxinus excelsior L.	13.5 12.0-15.0		
The share of necrosis on the leaf, % of the leaf surface	*Lonicera tatarica*	12.0 4.0-20.0	*Quercus robur* L.	15.0
	Acer platanoides L.	34.8 7.0-60.0	*Fraxinus excelsior* L.	8.5 5.0-12.0
	Fraxinus excelsior L.	9.5 7.0-12.0		
Spread of chlorosis on leaves, % of leaves	*Robinia pseudoacacia*	100.0	*Fraxinus excelsior* L.	8.0
	Carpinus betulus	80.0		
	Acer platanoides L.	44.5 4.0-85.0		
	Fraxinus excelsior L.	46.0 7.0-85.0		
The share of chlorosis on the leaf, % of the leaf surface	*Robinia pseudoacacia*	20.0	*Fraxinus excelsior* L.	12.0
	Carpinus betulus	20.0		
	Acer platanoides L.	12.5 10.0-15.0		
	Fraxinus excelsior L.	12.5 10.0-15.0		

Note: *The numerator is the average value; the denominator is a range of values.

platanoides L. and *Fraxinus excelsior* L. can be clear bioindicators of intensive agricultural chemicalization based on the manifestation of chlorosis on the leaves of trees. Mass chlorosis of white acacia leaves was detected in field protection forest strips adjacent to crops winter wheat, hornbeam – in forest strips adjacent to corn crops. A significant manifestation of chlorosis on the leaves of common ash and common maple was observed in field protection forest strips adjacent to sunflower crops, and the least – to winter wheat crops (Tkach, 2024; Honcharuk, 2024).

Premature yellowing of tree leaves is a sign of adverse abiotic or biotic factors, in particular measures of agricultural intensification. Such a phenomenon, with a strong degree of premature yellowing of the leaves, can gradually turn into premature leaf fall, which is also a sign of a violation of the normal processes of plant growth and development due to the strengthening of adverse factors, in particular, agricultural influence. Premature yellowing of the leaves was detected by our research only on common maple trees of the main field protection forest strips in the amount of 3–20% of trees. Premature falling of leaves from trees was not detected by our research at all.

Curling of tree leaves can be caused by a lack of moisture, nutrients in the soil or toxic substances with the subsequent impact of pests and diseases on a weakened plant. Also, such a sign can be detected when certain types of pesticides or mineral fertilizers fall on the leaf. According to our research, twisted leaves were found only on wild cherry trees in the main field protection forest strips in the amount of 3–4% of the total share of leaves on the trees and in hornbeam trees in the auxiliary field protection forest strips in the amount of 2% of leaves from the total number of leaves on the trees (Table 3).

Our research established that maple trees can be a bioindicator of the manifestation of the intensification of the chemicalization of agriculture based on the parameters of premature yellowing of leaves. A more pronounced premature yellowing of the leaves of common maple trees in field protection forest strips is observed near corn crops, while in trees in field protection forest strips near winter wheat crops, premature yellowing of common maple leaves is minimal.

At the same time, taking into account the very low percentage of twisted tree leaves, it is impractical to use this bioindicative feature to assess the magnitude of the negative impact of agricultural intensification measures on the state of field protection forest strips.

Spotting of leaves on trees can be caused by both infectious diseases and adverse environmental factors, in particular, the effect of pesticides and mineral fertilizers. Our research revealed spots on the leaves of the trees of the field protection forest strips. In particular, the spread of spotting on the tree-shrub vegetation of the main field protection forest strips was detected on the leaves of common ash in the amount of 35% of the total volume of leaves on the crown of the tree, on the leaves of the common maple – in the amount of 10–20% and on the leaves of white acacia – in the amount of 30% from the total volume of leaves of the crown of one tree. In the trees of the auxiliary field protection forest strips, the spread of spotting was detected in 60% of the leaves of the common oak, common maple, and common ash trees. The share of the surface of one common ash leaf with spots was about 20%, common maple – 40–60%, white acacia – 30%. Among the trees of the auxiliary field protection forest strips, the share of the leaf surface of common oak with spots was 85%, common maple and common ash – 60% each.

Our research has established that it is quite difficult to carry out bioindication of air pollution based on the mottling of the leaves of the trees of the field protection forest strips, because such signs on the leaves can indicate the development of plant diseases, in particular, we found signs of powdery mildew on the leaves of trees. This may affect the objectivity of bioindicative observations. Therefore, in our opinion, it is not advisable to use this feature as the main one.

We determined the degree of general degradation of all the vegetation of the field protection forest strips in the complex. Manifestation of the general degradation of the tree-shrub-herbaceous vegetation of the main field protection forest strips in the studied territory was 7–18%, and of the auxiliary field protection forest strips – 7–15% (Table 4).

The greatest manifestation of the degradation of tree-shrub-herbaceous vegetation was found in field protection forest strips adjacent to winter wheat and corn crops, and the lowest – in those adjacent to soybean crops.

The vital condition of the trees in terms of damage to the crown and trunk corresponded to the indicator «healthy – weakened» with damage

Table 3. Manifestation of suppression of leaves of plantations of field protection forest strips of the forest steppe of Ukraine, 2021–2023

Indicator	Type of forest strip			
	Basic		Basic	
	Type of tree-shrub vegetation	Type of tree-shrub vegetation	Type of tree-shrub vegetation	Type of tree-shrub vegetation
Species composition of forest strips	*Acer platanoides* L.	9.5* / 3.0-20.0	-	-
Spread of necrosis on leaves, % of leaves	-	-	-	-
The share of necrosis on the leaf, % of the leaf surface	*Prunus avium*	3.5 / 3.0-4.0	*Carpinus betulus* L.	2.0
Spread of chlorosis on leaves, % of leaves	*Fraxinus excelsior* L.	35.0	*Quercus robur* L.	60.0
	Robinia pseudoacacia	30.0	*Acer platanoides* L.	60.0
	Acer platanoides L.	15.0 / 10.0-20.0	*Fraxinus excelsior* L.	60.0
The share of chlorosis on the leaf, % of the leaf surface	*Fraxinus excelsior* L.	20.0	*Quercus robur* L.	85.0
	Robinia pseudoacacia	30.0	*Acer platanoides* L.	60.0
	Acer platanoides L.	50.0 / 40.0-60.0	*Fraxinus excelsior* L.	60.0

Note: *The numerator is the average value; the denominator is a range of values.

Table 4. The general ecological condition of the plantations of the field protection forest strips of the right-bank Forest-Steppe, 2021–2023

Indicator	Type of forest strip	
	Basic	Basic
Manifestation of degradation of tree-shrub-herbaceous vegetation, %	12.3* 7.0-18.0	10.8 7.0-15.0
Vital status of trees by damage to the crown and trunk	Healthy – weakened: damage to trees 0–30%	Healthy – weakened: damage to trees 0–30%

Note: *The numerator is the average value; the denominator is a range of values.

to trees up to 30%. The life status of trees based on damage to the crown and trunk was determined according to Table 5.

The belonging of the trees of the field protection forest strips to the weakened ones is determined by the fact that the damage to the leaves in the form of chlorosis, necrosis, and spotting in the total surface area of the leaf blade was about 30%. The bioindicative manifestation in field protection plantations showed that the most typical types of reactions of trees to pollution are necrosis, chlorosis and leaf spotting. Necrosis was most often manifested on the leaves of common maple– in 19.3% of leaves; ordinary oak – in 15.0% of leaves; common ash – in 13.5% of leaves and Tatar honeysuckle – in 7.7% of leaves (Fig. 1).

The spread of chlorosis of the leaves of the trees of the field protection forest strips is much greater. In particular, this manifestation was found in 100% of white acacia leaves, 80% of common hornbeam leaves, 46% of common ash leaves, and 44.5% of common maple leaves (Fig. 2).

Table 5. A scale for assessing the vital state of a tree based on damage to the crown and trunk

Condition assessment trees	The nature of damage to the crown and trunk
Healthy tree – 0%	The crown and trunk have no external signs of damage. Individual dry branches, as well as those that are dying, are concentrated in the lower part of the crown. Leaves and needles that have stopped growing are green or dark green in color. Any damage to leaves and needles is insignificant (less than 10%) and does not affect the condition of the tree
Weakened (damaged) tree – 30%	At least one of the following signs is mandatory: a) the density of the crown is less by 30% (25–40%) due to premature fall or underdevelopment of leaves (needles) or thinning of the frame part of the crown; b) the presence of 30% (25–40%) of dry or drying materials branches, in the upper half of the crown; c) damage (eating, twisting, burns, chlorosis, necrosis, etc.) and loss of assimilation capacity of 30% of the entire leaf area (needles) due to the vital activity of harmful insects, pathogenic microorganisms, due to fire, atmospheric pollution or for unknown reasons . This category also includes trees with the simultaneous presence of signs ”a”, ”b”, ”c” and others, which appear to a lesser extent, but lead to a total weakening of the tree’s vital condition by 30%
Very weakened (very damaged) – 60%	At least one of the following signs is observed in the upper half of the crown: a) crown density is 60% lower due to premature fall or underdevelopment of leaves (needles), or liquefaction of the frame part; b) the presence of 60% of dry or drying branches in the upper part of the crown; c) damage (eating, twisting, burns, chlorosis, necrosis, etc.) and loss of photosynthetic function by 60% (50–70%) of the entire leaf area (needles) as a result of vital activity harmful insects, pathogenic microorganisms, due to fire, atmospheric pollution or for unknown reasons. This category also includes trees with the simultaneous presence of signs ”a”, ”b”, ”c” and others, which appear to a lesser extent, but lead to a total weakening of the tree’s vital condition by 60%
Dying tree – 95%	The main signs of tree dying: the crown is broken, its density is less than 15-20% compared to a healthy tree; more than 70% of the branches of the crown (including in its upper part) are dry or almost dry. Leaves (conifers) preserved on the tree are chlorotic: that is, it has a pale green, yellowish, yellow or orange-red color; necrosis has a whitish, brown or black color. In the bud and middle parts of the trunk, signs of colonization by trunk pests are possible
Deadwood – 100%	In the first year after death, there may be remnants of dry needles or dry leaves on the tree. Signs of colonization by xylophagous insects are often observed. In the future, branches and bark are gradually lost

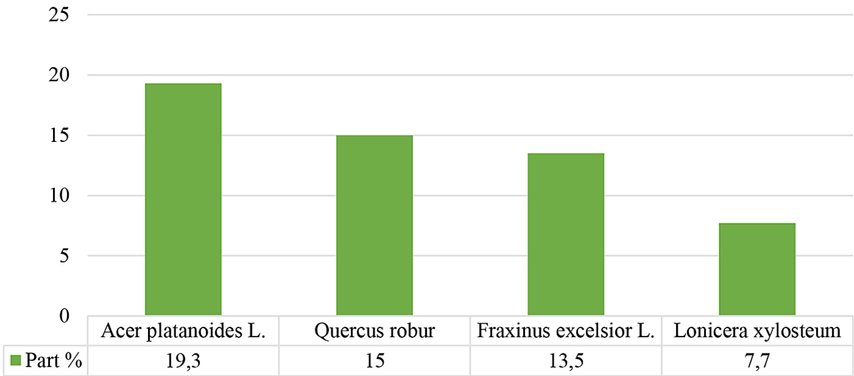

Figure 1. The prevalence of leaf necrosis depending on the species of the field protection forest strips of the right bank forest steppe, %

A similar situation was detected with the manifestation of spotting on the leaves of the trees of the field protection forest strips. In particular, spots were found on 60% of the leaves of oak, maple and ash trees, as well as on 30% of white acacia leaves (Fig. 3).

Therefore, our research has established that the leaves of the common maple, which grows in the field protection forest strips as the main species, show necrosis, chlorosis, spots and premature yellowing of the leaves. The greatest manifestation of these bioindicative signs is spotting – 60%

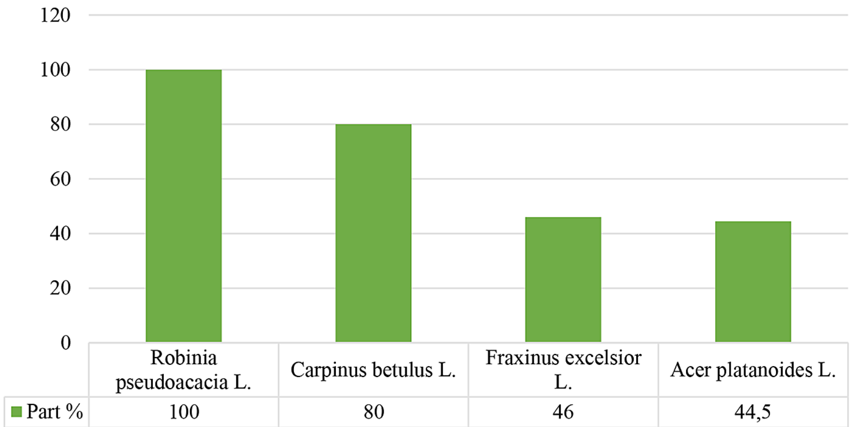

Figure 2. Spread of chlorosis of leaves depending on the species of field protection forest strips of the forest steppe of Ukraine, %

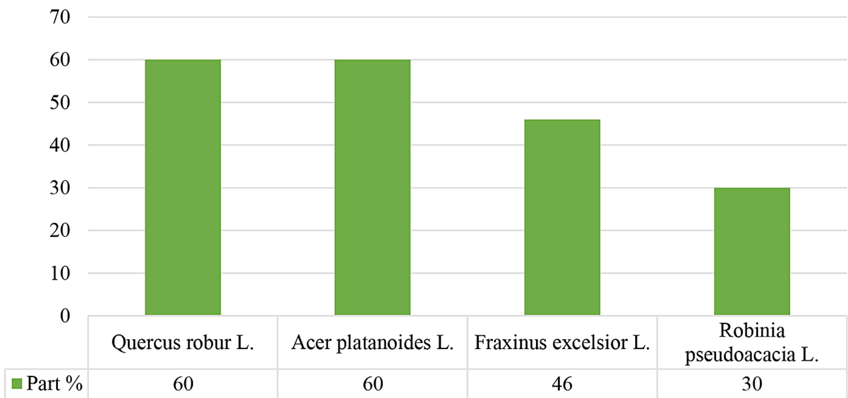

Figure 3. The spread of leaf spotting depending on the species of the field protection forest strips of the right bank forest steppe, %

of leaves, chlorosis – 44.5% of leaves, necrosis – 19.3% of leaves, premature yellowing – 9.5% of leaves. Necrosis, chlorosis, and spotting were found on the leaves of common ash, which grows as the main species of field protection forest strips. In particular, spotting is most evident – on 60% of leaves, chlorosis – on 46% of leaves, and necrosis – on 13.5% of leaves. Among the secondary tree species of the field protection forest strips, the bio-indicative manifestation was found on the leaves of common oak, common hornbeam, white acacia, and Tatar honeysuckle. Common hornbeam has the greatest suppression of leaves. In particular, chlorosis was detected on 80% of its leaves and twisted leaves on 2.0%. In common oak, spotting was found on 60% of the leaves and necrosis on 15% of the leaves. In white acacia, chlorosis was found on 100% of the leaves, and spotting on 30% of the leaves.

CONCLUSIONS

One of the most typical reactions of trees to pollution due to the intensification of agriculture is the manifestation of chlorosis and necrosis on the leaves of plants. According to our observations, among the tree and shrub vegetation of the main shelterbelts, the manifestation of necrosis was detected on the leaves of Tatar honeysuckle plants in the amount of 1–12% of leaves, common maple – on 12–30% of leaves, common ash – on 12–15% of leaves. On the leaves of trees of the auxiliary shelterbelts, necrosis was widespread on 15% of pedunculate oak leaves and on 5–8% of common ash leaves. The surface area of necrosis development on the leaves of the tree and shrub vegetation of the main shelterbelts was: in Tatar honeysuckle plants – 4–20%, in common maple plants – 7–60%, in common ash plants – 7–12%. In plants of auxiliary shelterbelts, the proportion of necrosis on the leaf of holm oak was 15%, and of common ash – 5–12%. The spread of spotting on the tree-shrub vegetation of the main shelterbelts was detected on the leaves of common ash in the amount of 35% of the total volume of leaves on the crown of a tree, on the leaves of common maple – in the amount of 10–20% and on the leaves of white acacia – in the amount of 30% of the total volume of leaves of the crown of one tree. In trees of auxiliary shelterbelts, the spread of spotting was detected on 60% of leaves in trees of common oak, common maple and common ash. The proportion of the surface of one leaf of common ash with spotting was about 20%, common maple – 40–60%, white acacia – 30%. In trees of auxiliary shelterbelts, the proportion of the leaf surface of common oak with spotting was 85%, and that of common maple and common ash was 60% each. It is modern intensive technologies for growing corn and winter wheat that have the greatest negative impact on the suppression of trees in forest shelterbelts. Therefore, when growing these crops, it is necessary to adjust technologies in order to ecologize them.

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