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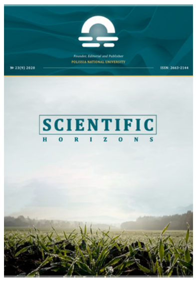

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The evaluation of total weed density and seed bank of agricultural landscapes as an example of the Steppe Zone of Ukraine

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Abstract. A high degree of weed infestation of agricultural ecosystems poses a significant threat to high crop yields, which determines the problem of weed control as one of the most urgent in steppe agriculture. The research aims to assess the level of total weed density and seed bank of various components of agroecosystems in the steppe zone of Ukraine. The methods used to determine the species composition of weeds, their quantitative and weight accounting and harmfulness were statistical and mathematical. It has been established that the main reason for the high negative

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impact of weeds is the weed seed bank of soils, which reaches 452 million seeds per hectare in land being actively used for agriculture and 11 million hectares in natural ecosystems. In agroecosystems, the decisive factor for effective regulation of weed seed banks is the sustainability of crops (as part of an ecosystem dominated by 1 plant species), methods of basic tillage and measures to prevent the generative productivity of weeds. According to the impact on the yield of winter wheat, corn, sunflower and spring barley, different tillage systems (ploughing, disc tillage, no-tillage) in the crop rotation were significant, where the no-tillage system was inferior to disc tillage, depending on the fertilization background, by 0.21-0.22 t/ha and ploughing – by 0.19-0.40 t/ha due to increased weed infestation of crops, as well as the presence of a significant amount of carrion and leaf mass of the predecessor on the field surface. The practical value is determined by an improvement of the system of weed control in crop rotations of adaptive agriculture and environmental safety

Keywords: agroecosystems; weed; crop rotation; soil tillage; yield; productivity

INTRODUCTION

Weeds remain one of the most damaging factors in agriculture, causing significant crop yield losses. An important part of weed control is the existing weed seed bank in the soil, which has a high degree of correlation with the degree of actual weed infestation. The topic of research is becoming extremely relevant due to the intense dynamics of the species and quantitative composition of weeds in agrocenoses and the need to predict the agrotechnological and chemical system of weed control for crops.

Modern herbicides used in grain growing technologies have a sufficiently high level of technical efficiency, however, even in this case, weeds with increased resistance to chemicals are not able to sufficiently prevent grain yield losses and the ecological spread of weeds (Fetyukhin *et al.,* 2021; Tkalich *et al.,* 2023). In this context, important results regarding the ecological and economic assessment of agrotechnologies recommended in agriculture were obtained by M. Spoth *et al.* (2022), who showed that weed control measures in many cases exceed the amount of grain production and the amount of profit received.

K. Alijani *et al.* (2023) determined in a study of crop weed infestation that the weed seed bank in the soil is an important determinant of aboveground floristic composition and weed density in agricultural systems. Quantitative and qualitative indicators of the weed seed bank can help producers predict the extent to which they face weed problems. By comparing different tillage systems in studying the dynamics of the weed seed bank and its species composition with the actual weed infestation of crops, it was also proved that the weed seed bank is more influenced by weather conditions than by different tillage systems.

A. Md-Akhir *et al.* (2022) and R. Idziak *et al.* (2022) considered the problem of weeds spreading in the areas of agricultural use for growing various crops as one that is formed not only directly in crops but also on lands that need restoration and reclamation with an existing seed bank in the soil. Significant transformations of pest ecosystems are observed in the context of climate change, global warming, and water availability, which necessitates adaptive technological measures in the production of field crops, in particular one of the most common crops in the world, winter wheat. This has been reliably confirmed by field experiments by Bajwa *et al.* (2020).

The findings of L. Butkeviciene *et al.* (2021) experimentally confirmed that in the context of climate change and intensive agriculture, long-term crop rotations increase crop productivity, reduce weeds and the weed seed bank in the soil, and thus contribute to maintaining the resilience of the agroecosystem. The initial field studies by S. Ali *et al.* (2022) on the effectiveness of weed control showed that one of the ways to improve the protective functions of grain-growing technology is the double use of herbicides. Thus, the authors believe, on a reliable scientific basis, that double treatment of wheat crops is accompanied by a 73% increase in grain yield, as well as a significant clearing of crops from weed seeds in the soil.

Significant positive results in weed control can be achieved by selecting the methods of basic tillage and addressing the peculiarities of weed seed movement in the soil depending on the depth of tillage and the distribution of weeds in the vertical section, this scientific position was confirmed by the research of Q. Maqsood *et al.* (2018). It has been proven that even when concentrated in the upper soil layer and provoking its germination, agrotechnical control measures provide a high degree of soil purification in crop rotation. Comprehensive studies by Beckie *et al.* (2020) have shown that soil weed seed banks can reflect the impact of long-term cumulative field management and crop sequences on weed communities. In addition, soil seed banks provide accurate estimates of future weed problems, as well as potential arable plant diversity and associated ecological functions. To this end, the authors evaluated the impact of different long-term cropping systems in the same crop rotation sequence on weed seed abundance, diversity, and collection, as well as on functional diversity and composition. An important conclusion based on many years of research was made by O. Kurdyukova and O. Tyshchuk (2019) that in the conditions of the high weed seed bank in Ukraine, to reduce the species and quantitative composition of weed seeds in the soil, it is necessary to apply a set of long-term agronomic, biological, phytocoenotic, chemical and organizational methods that complement and reinforce each other.

The literature review showed that the chosen topic has been studied insufficiently. Therefore, the research aims to assess the level of the weed seed bank and the actual weed infestation of various components of agroecosystems in the steppe zone of Ukraine.

MATERIALS AND METHODS

The following components of agroecosystems have been selected to study the mechanisms of conservation of weed taxonomic diversity and the spread of weed seeds: intact fallow land; areas under 60-year shelterbelts; and land under long-term cultivation (stationary field experiments). The study was conducted during 2018-2021. Research to determine the weed seed bank and actual weed infestation was conducted in stationary experiments of the Arable Lands State enterprise "Experimental farming Dnipro" Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine (SE"EF"Dnipro" IGC NAASU) (Vasylivka village, Solonyansky district, Dnipro region), the scientific research field of the Educational and Scientific Center of Dnipro State Agrarian and Economic University (SRF ESC DSAEU) (Oleksandrivka village, Dniprovsky district, Dnipro region), farming state "Olympus-2012" (Olympiadivka village, Petrivsky district, Kirovohrad region). As well as in shelterbelts near these stationary experiments; fallow lands near the village of Honcharka, Solonyansky district, Dnipro region and Oleksandrivka village, Dniprovsky district, Dnipro region.

The following methods and accounting ways have been used in the research.

1. The weed seed bank has been determined by taking soil samples with a Kalentiev drill along the diagonal of the field in five locations of the experimental plot, field protection forest belt, etc. The depth of sampling was 0-10, 10-20, 20-30, 30-40 cm. The collected soil sample has been washed on a sieve with 0.25 mm holes with a 5 cm high rim above the container. Large seeds with a diameter of more than 0.25 mm have been retained on the sieve. A solution of sodium chloride (NaCl) has been used to separate the small seeds that have been passed through the sieve from the sludge and water. In this case, heavy mineral particles of the soil have been settled to the bottom, while light weed seeds and organic residues have been floated to the surface. The surface of the solution, along with the seeds, has been poured onto filter paper, after which it has been dried. Then the seeds have been counted together with the previously strained seeds on a sieve.

After that, soil contamination with weed seeds has been calculated using the formula:

$$C_{ws} = \frac{10000 \times N_{ws}}{N_s \times \mathrm{A}}, \quad (1)$$

where C_{ws} – is weed seed contamination of the soil layer, pcs./m²; 10000 – is the area of 1 m² in cm²; N_{ws} – is the number of weed seeds in the sample, pcs; N_s – is the number of samples from which the sample was formed; A – is the area of the inner surface of the drill, cm².

Dividing the numerical value of C_{ws} by 100, the weed seed contamination of the soil was converted to millions of units/ha.

2. The actual weed infestation of crops has been accounted for by the quantitative weight method (using 1.0 m² plots). The surveys have been carried out during the eating phase of early grain crops, before the first inter-row cultivation in row crops, on natural fallow lands and field protection forest belts with simultaneous weed pulling to determine biological species and their mass in an air-dry state. The survey frames have been placed along the diagonal of the plot in 10 locations.

Crop accounting has been carried out by direct threshing (winter wheat, barley, peas) with a Sampo-500 combined, (sunflower – with a Niva-Effect combined) corn – by hand, considering the moisture content and weed infestation of the product at the stage of full grain ripeness. After determining grain contamination and moisture content, the harvest has been recalculated for 100% purity and 14% moisture content.

The data have been analyzed using Statistica 10.0 software (StatSoft Inc., USA). The data have been tabulated as x±SD (x ± standard deviation). The differences between values in control and experimental variants have been determined using Tukey's test, where differences have been considered significant at $P<0.05$ (with Bonferroni correction).

Experimental studies of plants (both cultivated and wild), including the collection of plant material, are conducted following the principles of bioethics and the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The influence of crop rotations and methods of basic soil cultivation on the peculiarities of migration and dislocation of weed seeds in the soil profile of arable land has been investigated. The methodology of wide involvement of variations in the factors that form weed infestation allows us to establish patterns of transformation of the degree of weed infestation, planning of weed control measures and evaluating the efficiency of agricultural systems.

The analysis of the weed seed bank of the lands of the agroecosystems demonstrates that human intervention in ecological and landscape complexes in the form of agricultural activities is accompanied by a significant increase in weed seed stocks in the soil (Table 1). For example, active soil cultivation in crop rotation on old arable lands has been accompanied by the accumulation of up to 452 million weed seeds in the 0-30 cm soil layer. The danger of such high degrees of potential weed seed infestation is also exacerbated by the soil profile of arable land containing a significant amount of seeds in each layer, which, when vertically migrating, in any case, creates a risk of high weed damage. For example, in the upper 0-10 cm soil layer with a high coefficient of stimulation of seed germination, the number of seeds was 133 million/ha.

Table 1. *The weed seed bank in the lands of agroecosystem components at different depths, million pcs/ha (average for 2018-2021, x±SD, n=12)*

Soils, the method of their use	Soil layers, cm			
	0-10	0-20	0-30	0-40
Fallow lands	6±1[a]	7±1[a]	8±1[a]	8±1[a]
Arable lands SE"EF"Dnipro" IGC NAASU	133±3[c]	306±7[c]	452±7[c]	464±8[c]
Farming state "Olympus-2012"	37±4[b]	128±5[b]	205±6[b]	223±5[b]
Forest protection strips	7±1[a]	9±2[a]	11±2[a]	11±2[a]
Scientific stationary experiments IGC NAASU	43±4[b]	140±5[b]	217±6[b]	228±5[b]
SRF ESC DSAEU	63±5[bc]	180±6[bc]	305±7[bc]	311±5[bc]

Note: *different letters denote values that significantly differ from each other within a column of Table 1 according to the results of comparison according to the Tukey test (P<0.05) with the Bonferroni correction.*
Source: *compiled by the authors*

The more conservative part of the seeds, which is located in the layer of 10-30 cm, is 306 pcs/ha, and carries a prolonged danger of increasing the degree of weed infestation of crops. The level of technological culture and implementation of a system of weed control measures is an effective means of reducing the weed seed bank, which has been experimentally proven. This is evidenced by the study of the degree of weed seed banks in stationary field experiments in research institutions where a full range of agrotechnical and chemical weed control measures has been carried out.

The problems of protecting field crops from weeds do not disappear if the level of weed seed bank is high, even with the latest effective weed control techniques. Understanding the processes of realization of the seed bank of conditionally natural components of agroecosystems will allow making effective decisions in farming practice.

The research of weed seed reserves of fallow lands and shelterbelts created in the 60s of the 20th century has shown that the processes of activation of seed resources on uncultivated lands are significantly slower. In the soils of fallow lands, where no agrotechnical measures are taken, a relatively stable grass cover has developed. Such an herbaceous cover can be characterized as a perennial type of weed infestation. This type of weed infestation must not be characterized by the supply of seeds of annual species in volumes critical for the natural succession development places. The weed seed bank of fallow soils in the topsoil is 6-7 million seeds/ha. In the deeper layers, only residual signs of weed seeds are observed at the level of 1-2 million seeds/ha. Thus, the degree of weed seed bank of arable land is 20-50 times higher than in natural succession development places.

Thus, in both natural and agricultural environments, the most important factors in transforming the weed seed bank are soil quality, plant species competitiveness, agrotechnological features of vertical seed migration and the effectiveness of weed control products. In the farming system, weed seed bank is the main factor that determines the degree of weed infestation, the level of negative impact of weeds and the amount of crop loss (Kurdyukova & Tyshchuk, 2019). The correlation between weed seed bank and crop yield is one of the highest among other factors, even though the sale of seed stocks largely depends on the occupation of ecological niches in agroecosystems, competitive tension at different stages of plant development, soil moisture, synchronization of agricultural cycles with the phases of biological awakening of weeds, and localization of seeds in the zone of active stimulation or long-term conservation (Nath *et al.,* 2022).

The study of the variability of weed seed bank indicators depending on crop rotation and tillage methods (namely, the establishment of the amplitude of oscillation in the arable layer in a rotary grid) allows us to determine the characteristics of variability and conservatism of the nature of weed seed bank. The research results show that the maximum value of weed seed bank in the arable layer has been observed at the beginning of spring fieldwork in the field of black fallow and barley spring, where its indicators were 449-499 million seeds per hectare. The regularity of such dynamics of weed seed bank is that the fields of black steam and spring barley are placed in crop rotation after row crops of sunflower and corn, which are sown at the end of the growing season and harvesting and contribute to the growth of weed seed bank (Table 2).

Table 2. *Influence of soil cultivation method and crop rotation on the weed seed bank, million pcs/ha (average for 2018-2021, x±SD, n=12)*

Crop rotation	Soil layer, cm	Soil tillage		
		moldboard plowing	disc tillage	no-tillage
Black fallow/fallow	0-10	60 ± 5^{a}	187 ± 8^{b}	231 ± 9^{bc}
	0-30	320 ± 9^{a}	388 ± 9^{b}	449 ± 10^{bc}
Wheat winter	0-10	42 ± 3^{a}	85 ± 6^{b}	98 ± 8^{bc}
	0-30	180 ± 9^{a}	242 ± 8^{b}	248 ± 9^{bc}
Sunflower	0-10	45 ± 3^{a}	98 ± 5^{b}	159 ± 8^{c}
	0-30	301 ± 9^{a}	335 ± 9^{b}	391 ± 9^{c}
Barley spring	0-10	72 ± 5^{a}	210 ± 8^{b}	245 ± 8^{bc}
	0-30	368 ± 9^{a}	399 ± 9^{b}	499 ± 10^{c}
Corn for grain	0-10	79 ± 5^{a}	112 ± 4^{b}	148 ± 8^{c}
	0-30	299 ± 9^{a}	354 ± 6^{b}	385 ± 9^{c}

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

The black fallow in the crop rotation has been characterized by a decrease in the degree of the weed seed bank in the winter wheat field by 202-253 million units/ha compared to no-till technology, where the weed seed bank in the crop rotation was maximum. The level of forecasting the degree of negative impact of weeds was the highest in row crops of corn and sunflower, which has been characterized by a high coefficient of realization of weed seed bank in the vegetative phase of weeds (the indicator of weed seed bank is 380-388 million units/ha). The study determined that the highest risk group included fields of black fallow and spring barley – 231-245 million units/ha in the 0-10 cm soil layer, while the lowest risk group included winter wheat crops – 98 million units/ha, and the middle position was occupied by corn and sunflower – 148-159 million units/ha.

An important element of the weed control system is the methods of basic tillage, along with effective regulation of weed infestation through crop rotation. The mechanisms of their influence on weed seed banks are based on the possibility of moving seeds between active and conservative soil layers and ensuring the quality of soil herbicide application. Moldboard ploughing is the most radical way to reduce weed infestation of crops in crop rotation by discharging weed seeds, primarily those that have fallen into the lower dead zone of arable land (Md-Akhir *et al.,* 2022).

As a result of such a migration algorithm of weed seeds in the upper soil layer under all crops, a minimum weed seed bank (41-80 million seeds/ha) has been formed against the background of moldboard ploughing. An increase in weed seed bank by 1.4-3.8 times has been recorded in the topsoil under disk tillage and no-till systems as a result of the concentration of weed seeds of the previous generation. Given that the circulation of weed seeds when implementing no-till methods of basic tillage occurs in a limited volume (0-10 cm), the dominant factor is not this circumstance, but the concentration of the reproductive resource of weeds in the upper layer of arable land. As a rule, this spatial distribution of weed seeds in the soil leads to an increase in active weed infestation against the background of minimized tillage by 1.7-2.3 times.

The regulatory ability of crop rotations and tillage to form weed seed banks is quite significant. For example, while the structure of winter wheat sowing on the background of moldboard ploughing contained 117 million seeds per hectare in the 0-30 cm layer, in the variant of spring barley with direct sowing (no-till), the weed seed bank has been increased to 499 million seeds per hectare. Despite the high cleaning efficiency of black fallow and the significant competitiveness of continuous crops, residual potential contamination always requires the use of herbicides to control weeds and prevent weed seeds from being seeded into the soil. The high biological adaptability of weeds to counteract negative factors allows them to continue to spread in the agroecosystem and remain integral components in the structure of crop rotations, despite the significant obstacles created by humans (use of agrotechnical, chemical, biological control measures, etc.).

The main source of the evolutionary aggressiveness of weeds is their extremely high reproductive capacity. There is no current and sufficient information about the diversity of weed seeds, the duration of the dormant period, stimulation of anabiosis, chemical methods of destroying their reserves, reactions to anaerobic conditions, etc. It is a scientifically proven fact that the main reserves of weeds are associated with agricultural lands, where they receive all the necessary environmental conditions for growth and development

(Schnee *et al.*, 2023). The visual stage of development of weed associations (active weed infestation) in different anthropogenic landscapes confirmed this conclusion. As can be seen (Table 3), the highest degree of weed infestation with weed seed forms has been observed on old arable lands, where it reached 85 units/m^2.

Table 3. *Features of the formation of weed phytocenoses on various technobiogenic land use objects, pcs/m^2 (average for 2018-2021, x±SD, n=12)*

Technobiogenic objects	Types of weeds			Total
	monocotyledons	dicotyledons	perennials	
Fallow lands	13±2^{ab}	17±2^{ab}	98±5^{c}	128±6^{d}
Arable lands SE"EF"Dnipro" IGC NAASU	24±3^{b}	62±4^{bc}	7±1^{a}	93±5^{c}
Farming state "Olympus-2012"	18±3^{b}	34±3^{b}	4±1^{a}	56±4^{bc}
Forest protection strips	8±1^{a}	7±1^{a}	15±2^{b}	30±3^{a}
Scientific stationary experiments IGC NAASU	20±3^{b}	37±3^{b}	5±1^{a}	62±4^{bc}
SRF ESC DSAEU	25±3^{b}	55±4^{bc}	5±1^{a}	85±5^{c}

Note: *different letters denote values that significantly differ from each other within a column of Table 1 according to the results of comparison according to the Tukey test (P<0.05) with the Bonferroni correction*
Source: *compiled by the authors*

In weed associations formed on natural pastures and perennial fallow lands and functioning through biological mechanisms without human agrotechnological involvement, the proportion of annual species decreased to 22-31 pcs/m^2. The perennial weeds that dominate the natural environment (98 plants/m^2) do not pose a threat of significant spread in agroecosystems due to their limited ecological diffusion. The dynamics of aboveground weeds in agroecosystems are subject to the laws of competition in the ecosystems of struggle and the level of efficiency of protective complexes. The most indicative relationship between total weed density and weed seed bank has been manifested in the black fallow field. During the growing season, 431 weeds per m^2 have been recorded in the fallow field on the background of ploughing, and under the no-till system, significantly more, up to 708 weeds per m^2, or 1.6 times (Table 4).

Table 4. *Formation of the degree of actual weediness of the crop rotation depending on the primary tillage, pcs/m^2 (average for 2018-2021, x±SD, n=8)*

Crop rotation	Soil tillage		
	moldboard plowing	disc tillage	no-tillage
Black fallow/fallow	431±4^{a}	607±5^{b}	708±6^{c}
Wheat winter	19±2^{a}	27±3^{ab}	43±4^{b}
Sunflower	34±3^{a}	50±4^{b}	78±5^{c}
Barley spring	29±3^{a}	125±5^{b}	292±6^{c}
Corn for grain	44±3^{a}	62±4^{b}	83±5^{c}

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

Soil clearing from weed seeds in the soil by black fallow and high competition in dense winter wheat crops contributed to a decrease in weed infestation in this crop to 18 units/m^2 in ploughing and up to 44 units/m^2 in direct sowing. The restraining nature of black fallow on the spread of weeds was also manifested in the crops of the next winter crop after wheat (sunflower), where the degree of weed infestation was in the range of 37-77 plants/m^2.

The threat of sunflower blight, a crop that can produce 150-220 thousand seedlings per hectare in next year's crops, is becoming more widespread. The effects of sunflower seeding alone are particularly noticeable against the background of moldboardless tillage methods. For example, in spring barley crops, the total number of weeds and sunflower residue on disk tillage and no-till has reached critical levels of 125-292 pcs/m^2. At the end of the crop rotation in the corn field, the weed infestation was high (44-83 plants/m^2) with a significant increase in moldboard tillage. In other words, crop rotation is an agrotechnical method of weed control through crop rotation and various methods of weed control (agrotechnical, chemical, biological).

Along with the quantitative characteristics of weed associations, the line of their evolution also goes through species transformations. As a result of biological and technological selection, 3-5 species have become the dominant weeds in agroecosystems: *Ambrosia artemisiifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crus-galli* L, *Setaria glauca* L., *Polygonum convolvulus* L. The share of these species in the crop rotation is 50-60%, and in row crops it reaches 80-85%.

In stationary experiments of scientific institutions, including the stationary experiment of the Institute of Cereals of the National Academy of Agrarian Sciences of Ukraine, a significant impact of total weed density and weed seed bank, methods of basic tillage, fertilizers and precursors on crop yields was determined. Thus, according to the research results, the yield of winter wheat, regardless of the tillage system in the crop rotation, was almost the same: ploughing – 5.88-6.15 t/ha, disc tillage – 5.93-6.28, no-tillage – 5.86-6.23 t/ha on different nutrition backgrounds (Table 5). The use of mineral fertilizers ($N_{24}P_{18}K_{18}$) on average for 4 years in plowing contributed to an additional 0.27, disc tillage – 0.35, no-tillage – 0.37 t/ha of grain. In terms of the impact on the yield of spring barley, the no-tillage system was inferior to disc tillage, depending on the fertilizer background, by 0.21-0.22 t/ha and ploughing by 0.19-0.40 t/ha.

Table 5. *The influence of the primary tillage and fertilization systems on the productivity of the crop rotation, t/ha (average for 2018-2021, x±SD, n=4)*

Crop sequence in the crop rotation	System of tillage and fertilization in the crop rotation					
	ploughing		disc tillage		no-tillage	
	post-harvest remains	post-harvest remains $+N_{24}P_{18}K_{18}$	post-harvest remains	post-harvest remains $+N_{24}P_{18}K_{18}$	post-harvest remains	post-harvest remains $+N_{24}P_{18}K_{18}$
Black fallow	-	-	-	-	-	-
Wheat winter	5.88±0.11[a]	6.15±0.12[b]	5.93±0.11[a]	6.28±0.12[b]	5.86±0.12[a]	6.23±0.11[b]
Sunflower	3.39±0.09[a]	3.55±0.10[b]	3.06±0.09[ab]	3.25±0.10[b]	2.62±0.09[ab]	2.89±0.10[b]
Barley spring	2.82±0.10[a]	3.16±0.11[b]	2.64±0.11[ab]	3.10±0.09[b]	2.42±0.09[a]	2.82±0.09[b]
Corn for grain	6.93±0.12[a]	7.36±0.12[b]	6.78±0.09[a]	7.20±0.11[b]	6.16±0.12[a]	6.50±0.10[b]

Note: *different letters indicate the values significantly differing one from another within a line of Table 1 on the results of comparison using the Tukey test (P<0.05) with Bonferroni correction*
Source: *compiled by the authors*

As for the effectiveness of mineral fertilizers for spring barley, an inverse relationship was observed in the experimental variants. The application of $N_{30}P_{30}K_{30}$ for pre-sowing cultivation with ploughing yielded 0.33, disc tillage – 0.46, and no-tillage – 0.47 t/ha of grain. Corn crops have formed yield indicators after ploughing in the range of 6.93-7.36 t/ha and 6.78-7.20 t/ha – under disc tillage. The use of no-tillage has resulted in a decrease in corn grain yield of 6.16-6.50 t/ha. The application of additional nitrogen on corn provided a slightly higher return on grain yield in the tillage system. This is due to the better moisture supply of plants and the normalization of the processes of mobilization of mobile compounds of macronutrients when a large amount of post-harvest plant residues is involved in the cycle. In sunflower crops, during the four years of research, a significant difference in different methods and systems of soil cultivation was noted (2.62-3.55 t/ha) with a tendency to increase yields from no-tillage to ploughing the soil. The yield of field crops generally determined the productivity of the five-field grain-steam-tilled crop rotation, which depended mainly on the dose of mineral fertilizers and the soil tillage system.

The analysis of the results of research on the study of the weed seed bank in the soil has shown that the parameters of this indicator on different soils are characterized by significant dispersion and therefore the interpretation of the degree of weediness by the number of seeds in the soil requires the most adequate methods. In the experiments of O.O. Ivashchenko and S.O. Remenyuk (2019), the results show a significant increase in the total reserves of weed seeds of various species in the soil layer of 0-10 cm in the Steppe zone and amount to 570 million units/ha. Objective data on weed seed reserves in the soil are given in the presented article, where this number does not exceed 6 million units/ha on fallow lands to 133 million units/ha in different agroecosystems. However, it is undeniable that significant yield losses will always occur, both at 133 million units/ha and 570 million units/ha. Therefore, as can be seen from the analysis, under any circumstances, reducing the cost of weed control systems for crops is possible primarily by reducing the amount of weed seeds in the topsoil.

When assessing the herbological situation of agrophytocenosis under different predecessors in the experiments of L.V. Peleh (2019), the species composition of weeds depended on the predecessor culture and the allopathic profile of crop plants in the crop rotation. In total, 36 species of weeds from 22 genera were identified. However, our results of research on the impact of crop rotation and individual crops on the species composition of weed agrocenosis show that in this case, it is also important to address the most harmful group of weeds, the presence of which in crops primarily affects the level of lost yield. In this case, the most harmful group includes 3-5 species of weeds such as *Ambrosia artemisiifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crus-galli* L., *Setaria glauca* L., *Polygonum convolvulus* L. It is also necessary to consider that, along with crops, the degree and type of weediness are actively influenced by the main soil cultivation and the use of organic and mineral fertilizers.

In the field experiments of N.V. Gytsyuk *et al.* (2022), in a long-term stationary experiment, it was found that the species composition of weed synopsis in crops of crop rotation did not show a significant pattern of its formation and did not depend on the fertilizer system. It was determined that the quantitative changes in weed infestation of crops primarily occurred under the influence of crop cultivation and were less dependent on the use of mineral and organic fertilizers. However, the authors unfairly do not consider the influence of fertilizers on the formation of the degree of weed infestation due to the growth of crop competitiveness and energy density of crops.

The fundamental issues of the dynamics of the weed seed bank in the soil, depending on deep ploughing, minimal and zero tillage using a cover mulch layer, are considered by J.G. Lundgren *et al.* (2023), and M. Akhter *et al.* (2023) who remains on the scientific position of the significant role of seed distribution in the vertical soil profile. However, the author does not consider what additional agricultural practices are included in the complex of ploughing and no-till and provide the advantage of the traditional system of soil loosening. According to the results of research by M.-J. Simard *et al.* (2022) and S. Ghosh *et al.* (2023), tillage methods that inhibit the germination of weed seeds and their negative impact on the yield of cereals and legumes play a significant role in the formation of a weed seed bank and increase the yield of cereals and legumes. However, the authors do not fully disclose the mechanisms of weed control, which generally creates a contradiction between the positive assessment of no-till and the conclusions presented in this article that no-till is accompanied by an increase in weeds and a complication of the system of their chemical control.

The discussion on the effectiveness of various weed control systems convincingly confirmed the significant progress of modern technologies and the achievement of high efficiency in reducing crop losses, but at the same time highlighted new problems related to determining the role of such factors in the formation of weed agrocenoses as crop rotation, energy density of individual crops, the dynamics of the location of weed seed reserves in the soil profile, the role of the mulch layer and methods of controlling weed damage.

CONCLUSIONS

The density and species structure of weed associations largely depend on the anthropogenic impact and the nature of land use under which they are formed. It has been established that the main reason for the high negative impact of weeds is the weed seed bank of soils, which reaches 452 million seeds per hectare in land being actively used for agriculture and 11 million hectares in natural ecosystems. The decisive factor for effective regulation of weed seed banks in agriculture ecosystems is the sustainability of crops (as part of an ecosystem dominated by 1 plant species), methods of basic tillage and measures to prevent the generative productivity of weeds.

According to the impact on the yield of winter wheat, corn, sunflower and spring barley, different tillage systems (ploughing, disc tillage, no-tillage) in the crop rotation were significant, where the no-tillage system was inferior to disc tillage, depending on the fertilization background, by 0.21-0.22 t/ha and ploughing – by 0.19-0.40 t/ha due to increased weed infestation of crops, as well as the presence of a significant amount of carrion and leaf mass of the predecessor on the field surface.

Stabilization of farming systems by such characteristics as specialized short-rotation crop rotations, regular differentiation of the ploughing tillage, reduction of risks of fertility loss based on conservation methods and minimization of mechanical impact on the soil will allow for consolidation of a stable agrocoenotic composition of weeds in areas with different specialization of use, to most accurately reflect the relationship between the spectrum of phytotoxic effects of herbicides and weed resistance. The obtained research results open up broad prospects for new scientific developments of crop rotation systems, optimization of the structure of sown areas, resource-saving tillage, environmentally friendly weed control, and effective monitoring and forecasting of agrophytocenoses.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Оцінка загальної щільності забур'яненості та банку насіння бур'янів агроландшафтів на прикладі степової зони України

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Анотація. Високий ступінь забур'яненості агроекосистем становить значну загрозу для отримання високих врожаїв сільськогосподарських культур, тому проблема боротьби з бур'янами є однією з найактуальніших у степовому землеробстві. Метою даного дослідження було оцінити рівень загальної щільності бур'янів та насіннєвого фонду різних компонентів агроекосистем степової зони України. Для визначення видового складу бур'янів, їх кількісно-вагового обліку та шкодочинності використовували статистичні та математичні методи. Встановлено, що основною причиною високого негативного впливу бур'янів є забур'яненість ґрунтів, яка досягає 452 млн. насінин на гектар на землях, що активно використовуються в сільському господарстві, та 11 млн. га в природних екосистемах. В агроекосистемах вирішальним фактором ефективного регулювання насіннєвого банку бур'янів є стійкість посівів (як частини екосистеми з домінуванням 1 виду рослин), способи основного обробітку ґрунту та заходи щодо запобігання генеративної продуктивності бур'янів. За впливом на врожайність пшениці озимої, кукурудзи, соняшнику та ячменю ярого різні системи обробітку ґрунту (оранка, дисковий обробіток, безполицевий) у сівозміні були суттєвими, де система безполицевого обробітку поступалася дисковому, залежно від фону удобрення, на 0,21-0,22 т/га, а оранка – на 0,19-0,40 т/га, що зумовлено підвищеною забур'яненістю посівів, а також наявністю значної кількості падалиці та листкової маси попередника на поверхні поля. Практична цінність полягає в удосконаленні системи контролю бур'янів у сівозмінах адаптивного землеробства та екологічної безпеки

Ключові слова: агроекосистеми; бур'ян; сівозміна; обробіток ґрунту; урожайність; продуктивність