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Weed species composition and diversity in maize as affected by tillage and fertilization in the Northern steppe of Ukraine

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Abstract. The structure of weed phytocenoses in maize crops is determined by the adaptive capacity of weeds and the specific characteristics of crop area distribution in rotation systems. The main factors driving weed dominance include herbicide resistance, a broad germination range, morphological plasticity, and the presence of neotenic traits. The use of shallow non-inversion mulching tillage methods (such as chisel plowing and flat-cut loosening) in maize cultivation increases weed infestation levels by 1.4–1.8 times, necessitating additional applications of pre-emergence and post-emergence herbicides to control weeds and prevent yield reduction. Research indicates that plow tillage and chisel plowing provide a slight advantage in maize grain productivity on unfertilized soils and under fertilization with $N_{30}P_{30}K_{30}$. This advantage arises from improved nutrient availability and reduced weed infestation levels. However, with increased nitrogen application ($N_{60}P_{30}K_{30}$), shallow flat-cut loosening becomes more effective, yielding similar results to plow tillage and chisel plowing, thus mitigating earlier disadvantages. At low overall weed infestation levels (9.0–12.6 plants/m²), primary soil tillage methods have no significant impact on maize grain quality. The application of mineral fertilizers, particularly nitrogen, increases protein content in maize grain while reducing carbohydrate levels, particularly starch.

Keywords: maize, mulching tillage, weed infestation, fertilization, mineral fertilizers, yield.

1. Introduction

An important limiting factor in maize cultivation technology is the level of weed infestation, which significantly reduces the effectiveness of all measures aimed at increasing grain yield. Despite the active implementation of modern, highly effective herbicides, weeds remain harmful elements that reduce maize grain productivity by more than one-third (Brandsaeter et al., 2018; Beckie et al., 2020; Zhuolin et al., 2024; Onopriienko et al., 2025).

The interaction between crops and weeds is profound, shaped by the conditions and peculiarities of their evolutionary development in agroecosystems. Weeds cannot be considered separately as they are integral components of the system. Changes in their density and composition are primarily influenced by ecological shifts, the duration of successions, cultivation techniques, crop rotation, and specific methods of soil tillage (Lundgren & Anderson, 2023; Kumar et al., 2024a; Romashchenko et al., 2025).

Over the past decades, the potential weed infestation of chernozem soils in the arable layer has increased significantly due to crises in agriculture and a decline in cultivation practices. The number of vegetative reproductive organs reaches 150,000–300,000 shoots per hectare, while seed numbers range from 0.5 to 1.0 billion per hectare. A "clean" soil (in a cultivated state) contains fewer than 1,000 perennial weed roots and up to 10 million viable seeds of annual weeds per hectare in the arable layer. However, in row crops, up to 1,500–2,000 annual weed seedlings and 15–30 perennial weed sprouts or shoots per square meter may emerge during the growing season (Maqsood et al., 2018; Ali et al., 2022; Ghosh et al., 2023; Schnee et al., 2023; Md-Akhir et al., 2023; Onopriienko et al., 2024).

Scientific data regarding changes in weed infestation levels, phytosanitary conditions, and soil's agro-physical and anti-erosion properties under systematic soil conservation tillage in crop rotations may serve as a valuable resource for timely ecological monitoring (Nath et al., 2022). This will help optimize machinery and tools for performing essential operations in crop cultivation technologies, such as primary tillage, sowing, herbicide application, and fertilizer incorporation (Abrell et al., 2024; Namatsheve et al., 2024; Onopriienko et al., 2024; Zhang et al., 2024;).

Many researchers confirm that post-harvest stubble plowing followed by fall plowing is the most effective measure to control weeds. This is achieved by burying seeds in deeper soil layers, where they lose their ability to germinate (Idziak et al., 2022). However, Kumar et al. (2024) disputes this claim, emphasizing that weed seeds buried at certain depths or evenly distributed within the soil profile are often brought back to the surface during subsequent plowing, entering a zone where germination becomes possible. This view is supported by other scientists (Lacroix et al., 2024; Masson et al., 2024), who note that no-till systems, combined with annual herbicide application, do not lead to increased weed infestation compared to continuous plowing.

The aforementioned points illustrate that there is no consensus among scientists regarding the impact of soil tillage systems on weed infestation levels. Further studies on this issue remain relevant, especially in light of recent trends toward minimal tillage and the introduction of highly effective herbicides, which partially mitigate the impact of "soil tillage" on weed infestation in field crops.

Recently, shallow (mulch) tillage, which excludes the turning of the arable layer, has gained prominence in maize cultivation technology (Tsyliuryk, 2023 Mytsyk et al., 2024). However, limited data exist on the efficiency of this method for maize cultivation, and scientists have differing opinions on various tillage techniques. This necessitates continued research to create optimal conditions for plant growth and development and to achieve maximum grain yields with minimal production costs and high profitability.

The objective of this study was to determine the patterns of weed species composition and analyze their quantitative dynamics. It also aimed to study the impact of different primary soil tillage methods in maize fields on weed agrophytocenosis development rates and infestation levels.

Furthermore, the study sought to establish maize grain yield and quality levels depending on the primary tillage methods and fertilization practices.

2. Materials and methods

Field experiments were conducted under the conditions of the State Enterprise "Dnipro Experimental Farm" of the State Institution "Institute of Grain Crops" of the National Academy of Agrarian Sciences of Ukraine. The study site was located near Dnipro (48°16'N, 34°56'E) in the northern steppe zone of Ukraine. The field experiments were carried out under the framework of a five-field crop rotation system: clean fallow – winter wheat – sunflower – spring barley – maize. The trials were implemented in the laboratory of crop rotations and soil conservation systems as part of long-term studies conducted during 1988–1990 and 2011–2024 (Steel et al., 1997; Ushkarenko et al., 2008). The agricultural technology used for maize cultivation, involving hybrids Dniprovs'kyi 273 AMV, Bilozirs'kyi 295 SV, and DN Astra, adhered to generally accepted standards for the steppe zone (Pabat, 1988; Lebed et al., 2012).

Three primary tillage methods were applied to the maize fields: moldboard tillage (control) – plowing with a PO-3-35 plow to a depth of 23–25 cm; chisel (mulch) tillage – performed with a chisel plow to a depth of 14–16 cm; flat-cut (mulch) tillage – performed using a heavy cultivator (KSHN-5.6 "Resident") to a depth of 14–16 cm.

Before pre-sowing cultivation, mineral fertilizers were applied at the following rates: control – without fertilizers + post-harvest residues of the predecessor crop; moderate fertilization – $N_{30}P_{30}K_{30}$ + post-harvest residues of the predecessor crop; high fertilization – $N_{60}P_{30}K_{30}$ + post-harvest residues of the predecessor crop.

Weed infestation levels in maize fields were evaluated using quantitative-weight and species-specific methods. Sampling was performed diagonally across each plot with five replications.

The data analysis was performed using Statistica 12.0 software (StatSoft Inc.). Results were presented as the mean ($\bar{x}$) ± standard deviation (SD). To compare differences between the control and experimental treatments, Tukey's post hoc test was applied, with statistical significance set at $p < 0.05$. The Bonferroni correction was used to adjust for multiple comparisons. Crop capacity was determined using mathematical statistics (dispersion method).

3. Results and Discussion

Weed infestation in maize fields before the first inter-row tillage demonstrated a tendency to increase with higher nitrogen fertilizer application rates, both in terms of quantity and weight ratio, regardless of the soil tillage method. This phenomenon was particularly observed for nitrophilous species such as common lamb's quarters (*Chenopodium album* L.) and common pigweed (*Amaranthus retroflexus* L.).

The number and weight of weeds varied significantly depending on the soil tillage method used: plowing – weed infestation ranged from 9.7 to 12.7 plants/m² (2.6–3.0 g/m²); chiseling – weed infestation ranged from 9.1 to 10.3 plants/m² (2.9–3.5 g/m²); flat-cut tillage – weed infestation ranged from 13.2 to 15.7 plants/m² (3.4–5.1 g/m²).

The lowest quantitative and weight indicators of weed infestation were observed under chiseling and plowing. At the same time, the use of flat-cut tillage led to an increase in weed infestation in maize fields due to the higher localization of weed seeds in the upper soil layers (Table 1).

Table 1. Species composition and weed density in maize crops (average for 2011–2024, x ± SD, n = 8).

Weed species	Soil tillage (factor A)					
	mouldboard plough (23-25 cm)		chisel plough (14-16 cm)		flat-cut loosening (14-16 cm)	
	dates for determining					
	before the first inter-row tillage	harvesting	before the first inter-row tillage	harvesting	before the first inter-row tillage	harvesting
no fertilization (factor B)						
Convolvulus arvensis L.	0	1.3	0.3	0.8	0.6	0.5
Ambrosia artemisiifolia L.	0.5	3.1	0.3	3.3	3.3	4.3
Chenopodium album L.	0.9	0.7	1.2	0.4	0	0.7
Amaranthus retroflexus L.	0.2	0.5	0.3	2.1	0.5	2.1
Poaceae spp. (annuals)	5.9	1.1	5.6	1.6	6.9	3.4
Helianthus annuus L. (volunteers)	2.6	0	2.4	0.3	2.3	0
Total, pcs/m²	9.7±0.3	6.2±0.2	9.6±0.2	8.0±0.2	13.2±0.4	10.6±0.2
Weed biomass, g/m²	2.6±0.2	13.2±0.2	2.9±0.1	14.4±0.3	3.4±0.2	19.4±0.3
$N_{30}P_{30}K_{30}$ (factor B)						
Convolvulus arvensis L.		0.9	0.5	0.6	0.7	0.5
Ambrosia artemisiifolia L.	0.5	2.7	0.3	3.1	3.3	4.1
Chenopodium album L.	1.1	0	1.3	0	0	0.5
Amaranthus retroflexus L.	0.3	0.3	0.5	2.3	0.5	1.9
Poaceae spp. (annuals)	6.5	0.7	4.5	1.3	7.3	3.1
Helianthus annuus L. (volunteers)	2.2	0	2.5	0	2.5	0
Total, pcs/m²	10.2±0.3	4.3±0.2	9.1±0.2	7.0±0.2	13.9±0.3	9.7±0.2
Weed biomass, g/m²	2.8±0.2	11.7±0.3	3.2±0.1	13.5±0.3	4.4±0.2	19.0±0.3
$N_{60}P_{30}K_{30}$ (factor B)						
Convolvulus arvensis L.	0.2	0.8	0.5	0.5	0.7	0.3
Ambrosia artemisiifolia L.	0.6	2.3	0.4	2.9	3.5	2.6
Chenopodium album L.	1.3	0	1.6	0	0	0.3
Amaranthus retroflexus L.	0.6	0.4	0.6	2.1	0.7	1.1
Poaceae spp. (annuals)	7.5	0.9	4.6	1.3	7.9	3.3
Helianthus annuus L. (volunteers)	3.0	0	3.1	0	3.3	0
Total, pcs/m²	12.7±0.3	4.1±0.2	10.3±0.3	6.5±0.2	15.7±0.3	7.2±0.2
Weed biomass, g/m²	3.0±0.2	9.1±0.3	3.5±0.2	13.0±0.4	5.1±0.2	17.0±0.5

At the time of harvest, weed infestation in maize fields decreased depending on the soil tillage method by 1.2–3.1 times (to 4.1–10.6 plants/m²) and fertilization ($N_{30}P_{30}K_{30}$) by 1.3 times. This was due to the increased competitiveness of maize crops against weeds at later stages of growth and development. In the floristic composition of weeds, common ragweed (*Ambrosia artemisiifolia* L.) predominated, accounting for 40–60%. Other dominant species included annual grasses (Poaceae), common lamb's quarters (*Chenopodium album* L.), and sunflower volunteers, the presence of which was associated with the ability of seeds to remain viable in the soil for several years. The overall weed infestation was higher under flat-cut tillage, ranging from 7.2 to 10.6 plants/m² (17.0–19.4 g/m²).

Weed germination activity in the free ecological zone of the maize field after six rotations of a five-field crop rotation decreased due to a reduction in potential weed contamination. During the 2011–2015 growing season, under mouldboard plowing, 64.5 plants/m² germinated, while under mulch chisel tillage, 80.2 plants/m² germinated, which was 1.3–1.6 times less than at the beginning of the crop rotation development (Table 2).

In addition to the overall decrease in weed germination activity, a significant restructuring of their species composition was observed. In maize crops, the presence of such species as pearl millet (*Setaria glauca* L.), barnyard grass (*Echinochloa crus-galli* L.), redroot pigweed (*Amaranthus retroflexus* L.), and common lambsquarters (*Chenopodium album* L.) decreased most significantly. Depending on the primary tillage method (mouldboard plowing or chisel plowing), the activity of these weed species decreased by 0.9–23.1 plants/m². The main reason for the loss of dominance by these annual weeds was the application of herbicides such as Harness, Maister, and others, which exhibit high selectivity towards this group of weeds.

Table 2. Weed germination in maize crops under different tillage methods, pcs/m² (x ± SD, n = 12).

No.	Weed species	Soil tillage			
		mouldboard plough		chisel plough	
		1*	2*	1	2
1	Setaria glauca (L.) P.Beauv.	$37.6±1.6^c$	$14.6±0.8^a$	$21.2±1.2^b$	$15.8±0.8^a$
2	*Echinochloa crus-galli* (L.) P.Beauv.	$20.5±1.0^b$	$16.4±0.9^a$	$27.6±1.3^c$	$17.9±0.9^a$
3	*Amaranthus retroflexus* L.	$27.4±1.1^b$	$14.8±1.0^a$	$33.9±1.5^c$	$17.9±0.9^{ab}$
4	*Salsola tragus* L.	$2.0±0.2^b$	$0.7±0.1^a$	$2.5±0.2^c$	$1.5±0.2^{ab}$
5	*Amaranthus blitoides* S.Watson	$6.3±0.2^b$	$2.5±0.2^a$	$4.8±0.2^{ab}$	$2.9±0.2^a$
6	*Chenopodium album* L.	$3.4±0.2^b$	$1.9±0.2^a$	$3.1±0.2^{ab}$	$2.3±0.2^a$
7	*Polygonum convolvulus* L.	$1.6±0.1^a$	$1.0±0.1^a$	$1.3±0.1^a$	$1.2±0.1^a$
8	*Ambrosia artemisiifolia* L.	$3.6±0.2^a$	$11.4±0.4^b$	$5.6±0.3^{ab}$	$16.6±0.5^c$
9	*Sisymbrium loeselii* L.	0	0	$0.3±0.2^a$	$0.2±0.1^a$
10	*Lepidium ruderale* L.	0	0	$1.5±0.2^a$	$1.3±0.2^a$
11	*Carduus acanthoides* L.	$0.6±0.1^a$	$0.1±0.2^a$	$1.1±0.1^a$	$0.3±0.1^a$
12	*Sonchus arvensis* L.	0	0	$0.3±0.1^a$	0
13	*Convolvulus arvensis* L.	$1.4±0.2^b$	$0.3±0.1^a$	$1.7±0.2^b$	$0.6±0.1^a$
14	Species that are rarely encountered	$1.2±0.2^a$	$0.7±0.1^a$	$3.7±0.2^b$	$2.9±0.2^b$

Total			104.6±2.9[b]	64.4±2.0[a]	107.3±3.0[b]	80.2±2.2[a]

Note: 1* – 1988–1990, 2* – 2011–2024; Different letters indicate values that significantly differ within rows of Table 2, as determined by Tukey's test ($P < 0.05$) with Bonferroni correction.

Notably, the increased resistance of common ragweed (*Ambrosia artemisiifolia* L.) to existing phytotoxic substances, combined with its exceptional adaptive flexibility, has heightened its threat to agriculture and the environment alike.

In the process of determining maize grain yield, a pattern was identified in which plowing and chiseling demonstrated a slight advantage over the untreated background and the application of $N_{30}P_{30}K_{30}$. This was attributed to somewhat better nutrient availability and lower weed infestation in the crops (Table 3). As the nitrogen dose increased ($N_{60}P_{30}K_{30}$), shallow flat-cut loosening produced better results, yielding outcomes comparable to plowing and chiseling, due to the neutralization of the aforementioned factors. Given the minimal differences in yield between the experimental variants, which fell within the margin of allowable error, it can be confidently concluded that the primary tillage methods for maize studied are equivalent in effectiveness.

Table 3. Yield and quality of maize grain depending on tillage and fertilization methods, t/ha (average for 2011–2024, x ± SD, n = 8).

Soil tillage	Fertilization	Yield, t/ha	Content (% dry matter)	
			protein	starch
Mouldboard plough (23-25 cm)	no fertilization (control)	4.88±0.10[a]	9.9±0.2[ab]	68.2±0.4[ab]
	$N_{30}P_{30}K_{30}$	5.33±0.11[b]	9.4±0.1[a]	70.5±0.4[b]
	$N_{60}P_{30}K_{30}$	5.60±0.12[c]	9.4±0.1[a]	70.2±0.4[b]
Chisel plough (14-16 cm)	no fertilization (control)	4.83±0.09[a]	10.3±0.2[ab]	67.1±0.3[a]
	$N_{30}P_{30}K_{30}$	5.29±0.11[b]	9.6±0.2[a]	69.8±0.4[b]
	$N_{60}P_{30}K_{30}$	5.56±0.11[c]	9.6±0.2[a]	68.7±0.3[ab]
Flat-cut loosening (14-16 cm)	no fertilization (control)	4.81±0.10[a]	10.8±0.3[b]	67.4±0.3[a]
	$N_{30}P_{30}K_{30}$	5.28±0.11[b]	10.5±0.2[ab]	68.8±0.3[ab]
	$N_{60}P_{30}K_{30}$	5.62±0.12[c]	10.1±0.2[ab]	69.2±0.4[ab]
Least significant difference (LSD), t/ha (p = 0.05)				
For factor A		0.08		
For factor B		0.10		
For interaction AB		0.12		

Note: Different letters indicate values that significantly differ within columns of Table 3, as determined by Tukey's test ($P < 0.05$) with Bonferroni correction.

The application of mineral fertilizers $N_{30}P_{30}K_{30}$ increased grain yield under mouldboard plowing (23–25 cm) and chisel plowing (14–16 cm) by 0.45–0.46 t/ha (8.4–8.6%), while shallow flat-cut loosening (14–16 cm) resulted in a yield increase of 0.47 t/ha (8.9%). Doubling the nitrogen dose in the full mineral fertilizer application ($N_{60}P_{30}K_{30}$) led to a grain yield increase of 0.72–0.73 t/ha (12.9–13.1%) and 0.81 t/ha (14.4%), respectively.

It should be noted that in the early stages of crop rotation, under conditions of high potential and actual weed infestation, insufficient effective fertility of chernozem soils, and low productivity of maize hybrids, the crop yield in the respective variants was 0.25–0.38 t/ha lower.

Primary tillage methods had little effect on grain quality parameters, with only a tendency toward increased protein content in grain under the mouldboard plowing method, attributed to improved nitrogen nutrition. The application of mineral fertilizers, particularly nitrogen, had a more pronounced effect on maize grain quality. Using mineral fertilizers combined with crop residue from the predecessor crop increased protein content by 0.4–1.1% while reducing starch content by 0.7–1.7%.

4. Conclusions

Thus, the evolutionary adaptation of weeds demonstrates strong regenerative energy, enabling them to overcome technological barriers implemented for weed control. The biological diversity of weeds cannot be entirely neutralized; it can only be managed to maintain their harmfulness at a minimum level below the economic threshold.

The structure of weed phytocenoses is shaped by their adaptive capacities and the specific characteristics of arable land for agricultural crops. The main factors driving weed dominance in species composition are herbicide resistance, a broad germination range, morphological plasticity, and the presence of neotenic traits.

The use of shallow non-inversion mulch tillage (chisel plowing, flat-cut loosening) in maize cultivation technology increases weed infestation levels by 1.4–1.8 times, necessitating additional regulation in the application of pre-emergence and post-emergence herbicides. These herbicides effectively control maize weed infestations and prevent yield reductions.

Mouldboard plowing and chisel plowing show a minimal advantage in maize grain yield on unfertilized plots and with $N_{30}P_{30}K_{30}$ application due to better nutrient availability and lower weed infestation levels. With an increased nitrogen share ($N_{60}P_{30}K_{30}$) in fertilization, shallow flat-cut loosening proves to be more effective, ensuring yields comparable to those of mouldboard and chisel plowing by neutralizing the aforementioned factors.

Primary tillage methods have no significant effect on maize grain quality under conditions of low overall weed infestation (9.0–12.6 plants/m²). The application of mineral fertilizers (particularly nitrogen) promotes a tendency to increase protein content in the grain while reducing carbohydrate content, specifically starch.

Ecologically, conservation (mulch) tillage together with higher N inputs increased total weed abundance (by 1.4–1.8) and shifted dominance toward nitrophilous ruderals (e.g., *Ambrosia*, *Amaranthus*, *Chenopodium*), signalling altered phytobiodiversity and a drift from ecological balance; agrotechnically, however, grain yield and quality were largely stable across primary tillage systems under effective herbicide programs, with $N_{60}P_{30}K_{30}$ effectively equalizing productivity among mouldboard, chisel and flat-cut tillage.

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References

Abrell, T., Naudin, K., Bianchi, F., Aragao, D., Tittonell, P. & Corbeels, M., 2024, Shifting cultivation in decline: An analysis of soil fertility and weed pressure in intensified cropping systems in Eastern Amazon. Agriculture, Ecosystems & Environment 360, 108793 https://doi.org/10.1016/j.agee.2023.108793

Ali, S., Hanif, M. A., Umar, M., Manzoor, A., Shafique, O., Khan, B.A. & Ahmed, I., 2022, Broad leaved weed's seed bank and flora dynamics in wheat as affected by different herbicides. Pakistan Journal of Agricultural Research 35(1): 58–69. https://dx.doi.org/10.17582/journal.pjar/2022/35.1.58.69

Beckie, H.J., Owen, M.J., Borger, C.P., Gill, G.S. & Widderick, M.J., 2020, Agricultural weed assessment calculator: An Australian evaluation. Plants 9(12), 1737. https://doi.org/10.3390/plants9121737

Brandsaeter, L.O., Netland, J. & Meadov, R., 2018, Yields, weeds, pests and soil nitrogen in a white cabbage-living mulch system. Biological Agriculture and Horticulture 16(3): 291–309. https://doi.org/10.1080/01448765.1998.10823201

Ghosh, S., Das, T.K., Nath, C.P., Bhatia, A. & Biswas, D.R., Bandyopadhyay K.K., Yeasin Md., Raj R., 2023, Weed seedbank, above-ground weed community and crop yields under conventional and conservation agriculture practices in maize-wheat-mungbean rotation. Weed Research 63(4): 270–281. https://doi.org/10.1111/wre.12589

Idziak, R., Waligóra, H. & Szuba, V., 2022, The influence of agronomical and chemical weed control on weeds of corn. Journal of Plant Protection Research 62(2): 215–222. https://doi.org/10.24425/jppr.2022.141362

Kumar, S., Kumari, S., Rana, S., Rana, R., Anwar, T., Qureshi, H., Saleh, M., Alamer, K., Attia, H., Ercisli, S. & Aghayeva, S., 2024, Weed management challenges in modern agriculture: The role of environmental factors and fertilization strategies. Crop Protection 185, id.106903. https://doi.org/10.1016/j.cropro.2024.106903

Lacroix, C., Vandenberghe, C., Monty, A. & Dumont, B., 2024, Effect of long-term tillage and residue managements on weed flora and its impact on winter wheat development. Agriculture, Ecosystems & Environment 366, 108937. https://doi.org/10.1016/j.agee.2024.108937

Lebed, E.M., Tsykov, V.S. & Pashchenko, Y.M., 2012, Methods of conducting field experiments with maize. Methodical recommendations. Dnipropetrovsk: Institute of Grain Management of the National Academy of Sciences (in Ukrainian).

Lundgren, J.G. & Anderson, R.L., 2023, Suppression of weed communities by granivores over time in an agroecosystem. Ecosphere 14(8), e4641. https://doi.org/10.1002/ecs2.4641

Maqsood, Q., Abbas, R.N., Khaliq, A. & Zahir, Z.A., 2018, Weed seed bank dynamics: weed seed bank modulation through tillage and weed management. Planta Daninha 36, article number e018166706. https://doi.org/10.1590/s0100-83582018360100083

Masson, S., Rueda-Ayala, V., Bragazza, L., Cordeau, S., Munier-Jolain, N. & Wirth J., 2024, Reducing tillage and herbicide use intensity while limiting weed-related wheat yield loss. European Journal of Agronomy 160, 127284. https://doi.org/10.1016/j.eja.2024.127284

Md-Akhir, A.H.B., Isa, N. & Mispan, M.S., 2022, Natural distribution of weed seedbank in different land activities due to abandoned land reclamation for agriculture. Applied Ecology and Environmental Research 20(3): 2597–2607. https://doi.org/10.15666/aeer/2003_25972607

Mytsyk, O., Havryushenko, O., Tsyliuryk, O., Shevchenko, S., Hulenko, O., Shevchenko, M., & Derevenets-Shevchenko, K. (2024). Reclamation of derelict mine land by simply growing crops. International Journal of Environmental Studies 81(1): 230–238. https://doi.org/10.1080/00207233.2024.2330283

Namatsheve, T., Cardinael, R., Chikowo, R., Corbeels, M., Rugare, J.T., Mabasa S. & Ripoche A., 2024, Do intercropping and mineral nitrogen fertilizer affect weed community structures in low-input maize-based cropping systems?. Crop Protection 176, pp.106486. DOI: 10.1016/j.cropro.2023.106486

Nath, C.P., Hazra, K.K., Kumar, N., Singh, S.S., Praharaj, C.S., Singh, U., Singh, N.P. & Nandan R., 2022, Impact of crop rotation with chemical and organic fertilization on weed seed density, species diversity, and community structure after 13 years. Crop Protection 153, article number 105860. https://doi.org/10.1016/j.cropro.2021.105860

Onopriienko, D., Makarova, T., Hapich, H., Chernysh, Y. & Roubík, H., 2024, Agroecological transformation in the salt composition of soil under the phosphogypsum influence on irrigated lands in Ukraine. Agriculture 14(3), 408. https://doi.org/10.3390/agriculture14030408

Onopriienko, D., Hapich, H., Tkachuk, A., Dent, D., Kovalenko, V., Makarova, T., & Roubík, H., 2025, Fertigation with sprinklers: Food and water security on the Ukrainian steppe. Journal of Ecological Engineering 26(6): 150–161. https://doi.org/10.12911/22998993/202346

Pabat, I.A., 1988, The soil protection system of agriculture. Kyiv (in Ukrainian).

Romashchenko, M., Faybishenko, B., Onopriienko, D., Hapich, H., Novitskyi, R., Dent,D., Saidak, R., Usaty S., Roubik H., 2025, Prospects for restoration of Europe's biggest irrigation system. Water International 50(2) 104–120. https://doi.org/10.1080/02508060.2025.2472718

Schnee, L., Sutcliffe, L.M.E., Leuschner, C., & Donath, T.W., 2023, Weed seed banks in intensive farmland and the influence of tillage, field position, and sown flower strips. Land 12(4), article number 926. https://doi.org/10.3390/land12040926

Shevchenko, S., Tkalich, Yu., Shevchenko, M., Kolesnykova, K. & Derevenets-Shevchenko, K., 2023, The evaluation of total weed density and seed bank of agricultural landscapes as an example of the Steppe Zone of Ukraine. Scientific Horizons 26(11): 80–89. https://doi.org/10.48077/scihor11.2023.80

Steel, R.D., Torrie, J.H. & Dickey, D., 1997, Principle and procedure of statistics. a biometrical approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York, 466. https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1855584

Tsyliuryk, O.I., 2023, Modern systems of mulching soil cultivation in the Northern Steppe: monograph. Dnipro: Oldi-Plus, 294. https://oldiplus.ua/suchasni-sistemi-mulchuvalnogo-obrobitku-gruntu-v-pivnichnomu-stepu/

Ushkarenko, V.O., Nikishenko, V.L., Holoborodko, S.P. & Kokovikhin S.V., 2008, Dispersion and correlation analysis in agriculture and crop production: a textbook. Kherson: Ailant, 272 pp.

Zhang, J., Zhao, J., Sun, J., He, Y., Xie, Y., Liang, Q., Jing, J., Tao, Y., Yu, P., Jia, C. & Zhao, E., 2024, Herbigation combined with plastic film mulching to control weeds in maize (Zea mays L.) fields in the Hexi Corridor region, Northwest China. Crop Protection 176(3), 106485 DOI: 10.1016/j.cropro.2023.106485

Zhuolin, Li., Dashuai, W., Qing Y., Minghu, Z., Xiaohu, Wu. & Xiaoguang Liu, 2024, Winter wheat weed detection based on deep learning models. Computers and Electronics in Agriculture 227, id. 109448. https://doi.org/10.1016/j.compag.2024.109448