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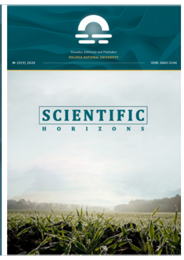

Sustainable weeds management in maize cultivation: Evaluating agroecological practices and tillage systems

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Abstract. The study evaluated the effectiveness of agroecological approaches to weed control in maize crops. The experiment, conducted in 2023-2024, included three tillage systems (deep ploughing, disking, milling), two seeding densities (1.1 seeding units/ha and 1.3 seeding units/ha), and two herbicide control approaches (herbicide application and non-application), with a total of 12 variants in 36 replications. The largest weed level was recorded in the variant with disking, low seeding density, and no herbicides (S2H2A1) – 22.3 plants/m^2; the lowest – in the variant with ploughing, high seeding density, and herbicide use (S1H1A2) – 12 plants/m^2. Variants with compacted sowing, regardless of herbicide exposure, demonstrated a better ability to suppress weeds due to rapid closing of row spacings and reduced light access. Analysis of variance (ANOVA) showed that the greatest influence on the number of weeds was soil cultivation ($F = 95.28$; $p < 0.0001$), followed by sowing density ($F = 29.06$; $p < 0.000001$), while the contribution of herbicides was the smallest ($F = 5.37$; $p \approx 0.021$). The significant interaction between the cultivation system and density ($F = 62.85$; $p < 0.000001$) reflected the need for comprehensive planning of agrotechnical measures. Cluster analysis based on the Jaccard index revealed strong ecological relationships between weed species, specifically, *C. arvensis*, *E. repens*, and *R. sativum* had a similarity coefficient of 0.92, which allows predicting typical phytosocial combinations and developing targeted control measures. The findings indicated that agroecological strategies, including shallow tillage and compacted seeding, can successfully replace chemical methods, reducing the environmental burden and maintaining productivity stability. The practical value of this study lies in the proven possibility of minimising herbicide use while maintaining high maize yields by implementing adapted agrotechnical solutions

Keywords: agroecology; weed management; *Zea mays* L.; tillage systems; soil fertility; herbicide alternatives; plant productivity

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INTRODUCTION

Maize (*Zea mays* L.) is a crucial crop in agricultural production, occupying a substantial portion of cultivated land globally, including in Ukraine. The substantial output and many applications of these crops render them essential for food and feed security. O. Erenstein *et al.* (2021) emphasised that maize production encounters various obstacles, with crop weediness being one of the most significant. Weeds compete for essential resources – water, nutrients, and light – which can significantly reduce yield. O. Skydan *et al.* (2022) noted that widespread ways to control weeds, especially the use of herbicides, have many downsides, like creating weed species that do not die from these chemicals, harming the soil and environment, and being very costly. Therefore, it is imperative to ascertain alternative weed management practices that are ecologically sustainable and economically feasible. E. Radicetti and R. Mancinelli (2021) and A. Boutagayout *et al.* (2025) emphasised that agroecological approaches to weed management are gaining prominence in modern agriculture. These methods integrate mechanical, biological, and agrotechnical techniques to effectively reduce crop weediness while minimising environmental harm. Their application contributes to improved soil fertility, the preservation of agroecosystems, and lower cultivation costs.

O. Orlov *et al.* (2021) emphasised that weeds that are widely dominating crop fields typically require analogous growth and development conditions as the cultivated plants. Therefore, a comprehensive understanding of their adaptation strategies, typical responses to agricultural practices, and pesticide applications is essential for designing effective weed management systems that minimise crop losses. Over the past two decades, S. Fonteyne *et al.* (2022) observed significant and rapid shifts in the factors influencing the spread of weed species. These changes are largely driven by land use planning, the spatial configuration of agricultural zones, the introduction of short-rotation cropping systems, the adoption of minimal tillage practices, a reduction in technical interventions, and the limited use of organic fertilisers.

T. Fedoniuk *et al.* (2025) noted that throughout the last century, agricultural development has undergone several transformative phases aimed at restructuring land use practices. Although the government first acknowledged the strategic significance of maize in crop rotations in the early 1930s, large-scale expansion of maize cultivation did not begin until the late 1950s. This expansion coincided with debates between the grassfield concept – focused on maintaining soil fertility through perennial grasses – and the mineral concept, which emphasised mineral fertilisers. Furthermore, T. Fedoniuk *et al.* (2024) mentioned that between 1980 and 1984, the increased farming of row crops like maize and the use of herbicides such as atrazine and eradican in mineral oil emulsions caused major changes in the types of weeds found in crop fields. S. Cordeau (2022) claimed that it is possible to manage weeds effectively without chemical pesticides if a successful combination of mechanical, cultural, and biotechnical methods is used.

However, L. Schnee *et al.* (2023) warned that excessive tillage may facilitate the spread of perennial weeds through vegetative reproduction. B. Thapa and R. Dura (2024) noted that minimum tillage approaches, including no-till systems, minimise soil disturbance but can lead to the accumulation of weed seeds near the soil surface. Still, combining no-till practices with mulching and the use of cover crops has proven effective in suppressing weed emergence and growth. Furthermore, S. Liu *et al.* (2022) reported that dense crop planting can markedly reduce weed pressure. Densely sown maize forms a thick canopy that limits light penetration on the soil surface, thereby inhibiting weed germination and reducing competition for resources during the early growth stages of the crop. V. Mandić *et al.* (2024) demonstrated that optimised sowing densities of maize can play a crucial role in reducing weed density, thereby lessening their negative impact on crop productivity. However, the researchers also warned that planting too many maize plants can lead to competition among them, showing the significance of adhering to recommended planting rates to effectively control weeds without hurting crop growth. Thus, the purpose of the present study was to evaluate how well different eco-friendly methods work for controlling weeds in maize farming by combining various tillage systems, planting densities, and stopping the use of chemical herbicides, while also considering their effects on plant growth, productivity, and the overall farming environment.

MATERIALS AND METHODS

Experimental site and natural conditions. The experimental plot was situated inside the broader experimental field of Polissia National University (N 50°26′; E 28°4) (Fig. 1). The site mostly consists of Gleic Albic Luvisol, classified as Endoclayic, Cutanic, Differentic, Katogleyic, and Ochric types according to IUSS Working Group WRB (2022).

The climate of the research region is described as somewhat continental with humid conditions. The average annual air temperature is roughly 7-8°C, whereas the mean temperature in January is approximately 5°C. The summer temperature generally varies between 18°C and 20°C. Annual precipitation varies between 600 mm and 700 mm, primarily occurring in the summer months. The relative humidity of the air is significantly increased.

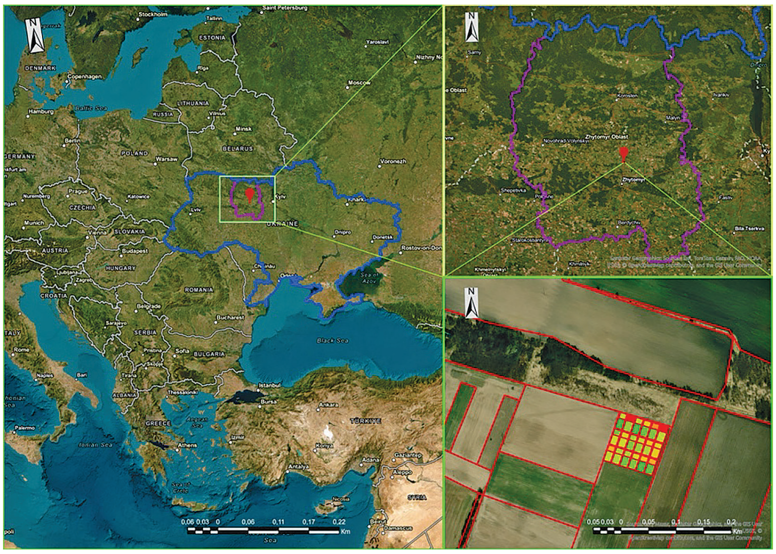

***Figure 1**. Location of the study area*
***Source:** generated in ArcGIS Pro software, digitised by the authors of this study based on factual field coordinates*

Experimental design and arrangement. Analysis of variance was employed to evaluate the effects of factors F1, F2, F3, and their interactions. The experiment was performed in three replications to minimise experimental error and improve the validity of the results. A 1-hectare area was partitioned into 12 experimental plots, with each plot replicated three times (Fig. 2). The study was conducted in 2023-2024. The research employed a factorial experimental design that included combinations of F1, F2, and F3. Each combination of F1×F2×F3 was performed in triplicate. The study investigated the impact of the following factors: F1 – tillage systems: S1 – deep soil ploughing at 18-20 cm (standard), S2 – soil disking at 10-12 cm (agroecological strategies – AES), S3 – soil milling at 5-7 cm (AES); F2 – sowing density: A1 – 1.1 sowing units per hectare (standard); A2 – 1.3 sowing units per hectare (AES); F3 – herbicide application: H1 – standard herbicide application; H2 – herbicide non-application (AES).

Data were collected weekly from each source. During field research, the parameters of main crops, cereal weeds, broadleaf, and short-leaved weeds were measured for height and density in each plot. The follow-up study was conducted in 2023-2024. The predicted expected impacts of various agroecological strategies are presented in Table 1.

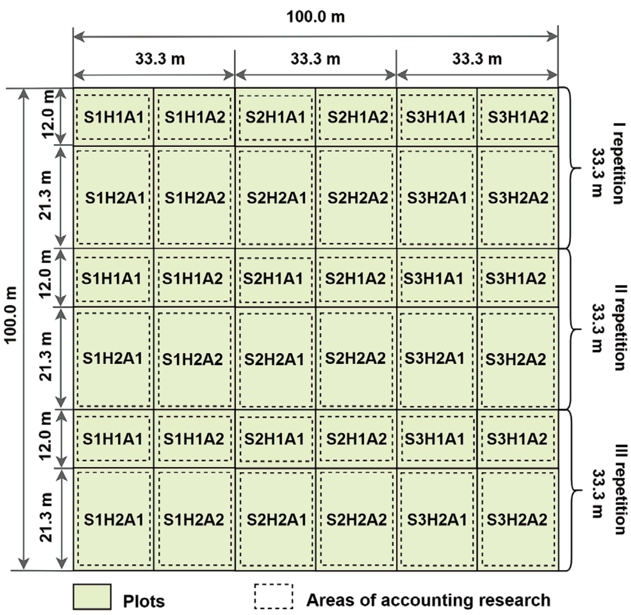

***Figure 2**. Experiment design*
***Source:** compiled by the authors of this study*

Table 1. Logic of applying weeds management strategies

Version	Impact of AE strategy
S1H1A1 S1H2A1	Standard maize seeding density when ploughing can help reduce competition for resources, but it also creates conditions for weed growth. In comparison with compacted crops, with a standard seeding density, plants are unable to quickly close the interrows, which allows weeds to actively develop. This reduces the effectiveness of weed control and can also negatively affect yields due to lower seeding density.
S1H1A2 S1H2A2	The high density of maize sowing allows the plants to close the interrows faster, reducing the number of weeds. This effectively limits the space for the development of weeds and increases the effectiveness of their control. The yield in this case is usually greater due to less competition between plants and better development of the root system.
S2H1A1 S2H2A1	With medium seeding density and disking, maize will compete better with weeds, while the interrows will close faster. This will increase the effectiveness of weed control and improve yields compared to low densities. However, in case of heavy weeding, the efficiency of disking may not be sufficient for complete control over weeds.
S2H1A2 S2H2A2	High seeding density against the background of disking allows maximising the competitive ability of maize against weeds. Maize quickly closes the rows, reducing the risk of weeding. This leads to greater yields, as plants make better use of soil resources and have less competition with weeds.
S3H1A1 S3H2A1	With medium seeding density, maize can provide more effective weed control. Tilling promotes a more even distribution of seeds and improves the structure of the soil, which promotes better plant development. Yields at this seeding density are usually stable and optimal because there is less competition with weeds and maize makes effective use of moisture and nutrients.
S3H1A2 S3H2A2	The high density of maize seeding during milling provides the best soil coverage and reduces weediness. Maize forms a dense leaf cover, which significantly limits the access of weeds to light and nutrients. This leads to high yields, as plants actively use resources and effectively compete with weeds.

Source: *compiled by the authors of this study*

Soil sample collection and physicochemical property analysis. The study was executed using a multi-phase experimental methodology. The experimental design was first established, subsequently leading to the evaluation of soil health, plant health, and weed prevalence. A total of 108 soil samples were collected and analysed at the Measurement Laboratory of PNU. The soil health of the experimental plots was evaluated using standardised methods grounded in internationally acknowledged protocols. Soil sampling was performed according to ISO 18400-201 (2017) series standards, assuring uniformity in the selection, safety, and methodology of sample collection. The granulometric composition was ascertained using the pipette method modified by N.A. Kaczynski, following DSTU 4730:2007 (2008). Soil compaction density and moisture content were assessed using the ISO 11272:2017 (2002) standard and the thermostatic-weight method, respectively. Organic matter, soil organic carbon density (SOCDb), and carbon balance (C:N ratio) were assessed using Tyurin's approach as modified by Simakov (DSTU 4289:2004, 2005). Supplementary factors including pH, electrical conductivity, accessible nitrogen, mobile phosphorus, potassium, sodium adsorption ratio, and cation exchange capacity were evaluated according to national and international standards pertinent to each indicator.

Weed accounting. Weed species and density were assessed weekly in 36 experimental plots from May to August 2024 according to the Handbook of Weed Management (2024). The current weediness of the crops was assessed using route surveys conducted annually during the emergence of all primary weed species. The primary survey for grain crops occurs during the earing period, while for row crops, it took place during their vegetative growth. Concrete strategies for herbicide application during the post-emergence phase were formulated based on weed records collected in the spring following the widespread emergence of seedlings. In each crop rotation field or its segment covering up to 50 hectares, a minimum of 10 monitoring sites must be established, each measuring 2-3 m^2 for perennial weeds and 0.25-1 m^2 for most annual weeds. Approximate accounting method: the density of weeds in the field was evaluated using point scales (Table 2).

For convenience, the scale of projective weed coverage of the soil surface was employed (in points and percentages) (Fig. 3).

Table 2. Six-point scale for assessing soil covered by weeds

Grade	Covering degree	Description
0		no weeds present
1		weeds present individually, with a covering density of around 0.1-3 weeds per 10 m^2
2	up to 5%	3-5 weeds per m^2
3	5-20%	5-15 weeds per m^2, cultivated plants predominate over weeds
4	20-50%	20-30 weeds per m^2, cultivated plants continue to prevail over weeds
5	50-70%	the number of weeds is equal to or greater than the number of cultivated plants, the culture is under threat
6	75-100%	persistent obstruction, weeds substantially dominate cultivated vegetation

Source: *Determination of the actual weediness of crops (n.d.)*

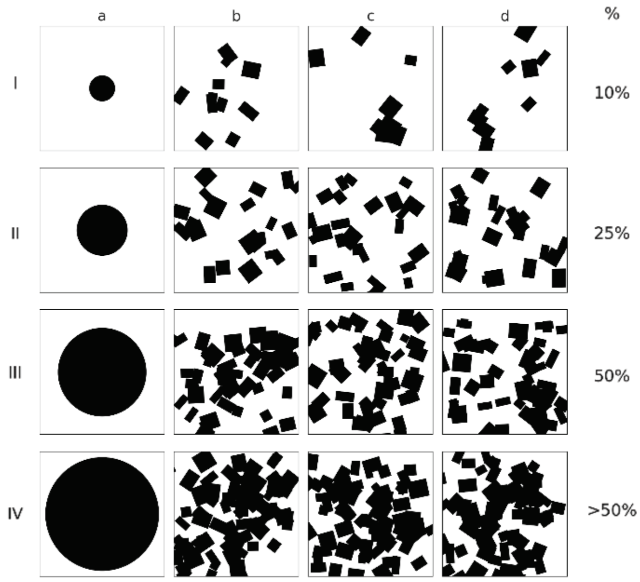

***Figure 3**. Cubic scale for evaluating weediness based on projected weed coverage of the soil surface (in points and percentages)*
***Note:** a, b is the consistent distribution of weeds across the area; c is the cellular coverage; d is the solid coverag*
***Source:** Determination of the actual weediness of crops (n.d.)*

The quantitative accounting method relies on enumerating the cultivated plants and weeds at the designated recording sites. Simultaneously, they use frames of suitable dimensions. Upon enumerating the weeds within the frames, the average quantity per frame and per meter is calculated, alongside a proportion of the cultivated plants, designated as 100%. The extent of crop blockage is assessed using the designated scale (Table 3).

***Table 3**. Scale for determining the degree of weeding of crops*

Number of weeds per 1m^2	Rating	Degree of weeding
1–5	1	Very weak
6–15	2	Weak
16–50	3	Average
51–100	4	Strong
Over 100	5	Very strong

***Source:** Determination of the actual weediness of crops (n.d.)*

The quantitative-weight accounting approach involves enumerating the quantity of weeds by species and their aggregate count, assessing their height, developmental stage, and biomass. All weeds are extracted at the registration site, their roots severed and weighed, thereafter dried to an air-dry condition and reweighed. The Jaccard Index was employed to analyse biodiversity data, which quantifies the similarity between two sets and is widely used in ecology to evaluate species commonality across different areas and experimental conditions.

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}, \quad (1)$$

where $|A \cap B|$ is the number of species common to both sites (variants); $|A \cup B|$ is the total number of species occurring in at least one of the sites.

The index varied from 0 to 1, where 1.00 is complete coincidence (species always occur together); 0.00 is no coincidence (species never occur together)

Statistical analysis methods. ANOVA and several statistical methods were used to assess the influence of pesticides and seeding density on weed density. Regression analysis was used to create models for predicting maize development levels. Only factors that maintained statistical significance post-correction were considered credible. The study was conducted following the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

Soil conditions. Before initiating the field experiment, a thorough assessment of the site's soil characteristics was conducted using soil profile analysis and an extensive review of physicochemical data. The soil was categorised as light grey forest loamy medium loam on loamy deposits, designated under the IUSS Working Group WRB (2022) classification as Gleic Albic Luvisol (Endoclayic, Cutanic, Differentic, Katogleyic, Ochric). The soils of experimental plots S1, S2, and S3 exhibited a mildly acidic reaction (pH 4.53-4.71), characteristic of podzolic or acidic soils. The organic carbon percentage varied between 1.68% and 1.9%, signifying a moderate supply of organic matter. The humus concentration was at a moderate level (1.68-1.9%), indicating a moderate buildup of humus (Table 4).

***Table 4**. Changes in agrochemical parameters depending on cultivation*

AS	S1		S2		S3	
	A	Cv, %	A	Cv, %	A	Cv, %
pH sol.. of/pH	4.71 ± 0.39	8.38	4.71 ± 0.71	15.17	4.53 ± 0.43	9.51
Organic carbon, %	0.97 ± 0.3	31.17	1.1 ± 0.3	27.41	1.03 ± 0.32	31.05
Hummus, %	1.68 ± 0.52	31.2	1.9 ± 0.52	27.43	1.78 ± 0.55	31.02
Alkaline hydrolysed nitrogen, mg/kg	75.64 ± 14.4	19.04	77.05 ± 15.41	20	76.28 ± 13.4	17.57
Mobile phosphorus, mg/kg	161.13 ± 93.33	57.92	143.9 ± 67.63	47	139.21 ± 52.84	37.95
Exchangeable potassium, mg/kg	107.38 ± 42.19	39.29	96.95 ± 63.04	65.03	108.62 ± 52.51	48.34
Iron content, mg/kg	5.04 ± 2.52	49.99	9.3 ± 11.63	125.08	6.92 ± 4.82	69.69
Copper content, mg/kg	0.18 ± 0.05	30.64	0.19 ± 0.07	37.22	0.17 ± 0.05	28.89
Zinc content, mg/kg	0.85 ± 0.37	43.56	0.86 ± 0.47	54.79	0.86 ± 0.94	109.82
Hydrolytic value, mmol/100g	2.74 ± 0.52	18.83	2.95 ± 1.04	35.11	3.27 ± 0.76	23.17
Sum of absorbed bases, mmol/100g	5.73 ± 1.98	34.58	6.37 ± 3.57	56.04	5.77 ± 1.93	33.49
Degree of bases saturation, %	65.74 ± 11	16.73	63.66 ± 18.39	28.89	62.11 ± 11.86	19.1

***Source:** compiled by the authors of this study*

The alkaline hydrolysable nitrogen concentration ranged within 75.64-77.05 mg/kg, reflecting a moderate nitrogen supply. The available phosphorus varied within 139.21-161.13 mg/kg, signifying a substantial quantity of phosphorus feeding. The exchangeable potassium concentration ranged within 96.95-108.62 mg/kg, reflecting a medium-to-high potassium availability. The micronutrient makeup included iron at 5.04-9.3 mg/kg, copper at 0.17-0.19 mg/kg, and zinc at 0.85-0.86 mg/kg. The maximum iron concentration was recorded in plot S2. Hydrolytic acidity varied within 2.74-3.27 mmol/100 g, whereas the total absorbed bases ranged within 5.73-6.37 mmol/100 g. The base saturation degree ranged within 62.11%–65.74%, signifying a substantial saturation of the soil's cation exchange capacity with bases. The coefficient of variation (Cv, %) for most indicators varied within 15%-65%, signifying medium-to-high variability of the soils, especially for potassium, iron, and micronutrient levels. The soils of the experimental plots exhibited modest acidity, moderate humus content, adequate nitrogen supply, and elevated levels of accessible phosphorus and potassium, which are conducive to the cultivation of most agricultural crops, contingent upon the neutralisation of acidity.

Weed biodiversity observation. The average height of the main crop ranged from 153.3 cm (S2H2A1) to 176.7 cm (S1H1A2). Variants with H1 generally showed greater crop height than variants with H2, which may reflect better growing conditions. The amount of the main crop was stable for all variants: 8 plants/m^2 for conventional seeding rates and 10 for compacted crops. To control the number of weeds, the herbicide Premium Gold 4.5 L+ Quiet was used, which, according to farmer surveys, is an effective preparation in controlling a wide range of weeds in maize crops. Specifically, the results showed that in H1 variants, some annual cereals were practically absent, namely, *E. crus-galli*, *S. glauca* etc., which were found everywhere in these fields. However, some weeds stayed partially or completely: resistant dicotyledons: *Convolvulus arvensis*, *Raphanus sativum*, as well as perennial grasses: *Elymus (Elytrigia) repens (L.) Gould*. Clearly, weed biodiversity was more widespread in H2 variants. *C. album*, *R. sativum*, etc., were quite widespread.

The variants also differed in the number of weed plants, the largest number of weeds was observed in S2H2A1 (22.3 pcs), the smallest number in S1H1A2 (12.0 pcs). Variants with H2 had slightly more weed cover compared to H1, but the difference was not significant. Weed species were represented unevenly between variants. In some variants such as S3H1A1, they were dominated by a few key species, while in other variants, e.g., S3H2A2, greater diversity was observed. A smaller number of weed species (e.g., S1H1A1) may suggest that certain species dominated and suppressed others. Some weed species were dominant: *Co. arvensis*: highest abundance among all variants, especially in S2H2A2; *Setaria pumila*: significant abundance in many variants, especially in S3H1A1 and S2H1A1; *Equisetum arvense*: found in some variants such as S2H1A1. Other species, e.g., *Capsella bursa-pastoris* or *A. retroflexus*, were represented to a lesser extent or not at all in most variants. The greatest number of weeds was observed in variants S2H2A1 and S3H2A2. This indicates that the conditions of these variants contributed to their growth. In the S1H1A1 variant, the number of weeds was smaller, and their species composition was limited.

Some weed species were concentrated in certain variants, which may be related to agrotechnical conditions. *Chenopodium album* (quinoa): the highest abundance in S1H1A2; *Persicaria lapathifolia*: found only in a few variants, *R. sativum* (wild radish): widespread in almost all variants, but with varying quantities. Therefore, the growing conditions in the variants significantly affected the species composition and number of weeds. The variants with the greatest weed burden (e.g., S2H2A2) required additional weed management to reduce weed numbers and minimise competition with the main crop. During the present study, over 300 weed species were documented growing continuously in fields and uncultivated roadsides. As presented in Figure 4, weed groups in a single field typically consisted of 17-26 species, although in some cases there may be a sizeable number (53-200 species) (Fedoniuk *et al.*, 2024). Within the weed communities, dicotyledonous plants were the dominant species, accounting for 89% of the total. Most of the species consisted of winter weeds, (43%), whereas summer weeds made up only 16%. Regardless of the time of observation, all the current fields surveyed had four species of weeds: *E. repens*, *Co. arvensis* L., and *Sonchus arvensis*. Based on their share of the weed group of *E. repens*, *Co. arvensis*, and *S. arvensis* had a major impact on maize, as the most active portion of the weed block. Without exception, all observed fields contained these species, with mean numbers of during the period of growth of 6-20 pcs/m^2, whereas the projective coverage and ground mass were 16% and 9%, and 250 g and 90 g, respectively.

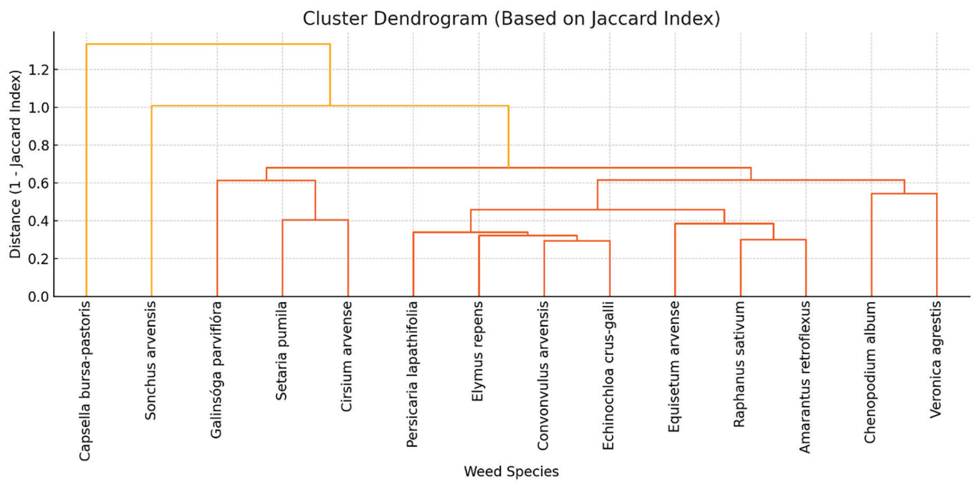

Figure 4*. Cluster structure of weed species, created based on the Jaccard index, which indicates the similarity of their presence in maize agrophytocenoses*

Source: *compiled by the authors of this study*

Cluster analysis of weed species, performed using the Jaccard index, elucidated ecological similarities among species based on their presence in maize agrophytocenoses across 12 experimental variants. The Jacquard index served as a metric for the co-occurrence of two species under identical growth conditions. The study revealed that several weed species exhibited distinct clusters, signifying their ecological resemblance. *Co. arvensis*, *R. sativus*, *E. repens*, *E. arvense*, and *E. crus-galli* were identified as the closely associated species, consistently occurring in analogous combinations of soil management, seeding rates, and herbicide use. The similarity index was 0.92, indicating frequent co-occurrence in the same areas. This commonality is likely attributable to shared demands for moisture provision or the structural and mechanical makeup of the soil. Species of moderate prevalence, particularly those from the families *Setaria*, *Galinsóga*, and *Amaranthus*, exhibited less dense aggregations, suggesting greater adaptation potential to alterations in the agro-environment or competition from the primary crop (0.80). Conversely, *C. bursa-pastoris*, *S. arvensis*, and *Veronica agrestis* were allocated to distinct branches of the dendrogram, indicating their infrequent occurrence or reaction to a set of circumstances. These findings are of significant practical relevance: they facilitate the prediction of typical weed associations and the selection of control measure combinations, considering the co-occurrence of species. This is particularly advantageous for devising integrated crop protection strategies for maize. Clustering can be employed for the ecological assessment of weed composition in fields. Subsequent research may involve examining the interrelation of experimental variants and investigating the association between weed species composition and the agricultural characteristics of maize. The cluster technique utilising the Jaccard index is an excellent method for evaluating the composition of the weed component within agrophytocoenosis.

Weed amount observation. In contemporary agricultural production, weed management is a critical aspect influencing the efficacy of maize cultivation. Weeds compete with the primary crop for moisture, light, and nutrients, while also complicating mechanised field cultivation and diminishing yield and product quality. Consequently, in the context of the present study, which encompassed diverse tillage strategies, sowing density, and herbicide treatment, weed control is an essential variable. It facilitates the evaluation of the biological and economic viability of alternative technical options, particularly with the transition to energy-efficient agricultural systems (Fig. 5). The greatest weed development was noted in variants S1H1A2 and S1H2A2, whereas the least weed infestation occurred in S2H2A2. This suggests that the incorporation of surface tillage by disking, the exclusion of pesticides, and increased seeding density (AES) is more effective in weed management compared to conventional techniques. The results of the one-way analysis of variance (ANOVA) on changes in weed infestation were as follows: F-statistic: 13.42; p-value: 3.40×10^{-11}. This reflects statistically significant differences across the experimental variants for the number of weeds ($p < 0.001$). Table 5 presents the results of the analysis of variance (ANOVA), which allows assessing the influence of agrotechnical factors on the number of weeds in maize crops.

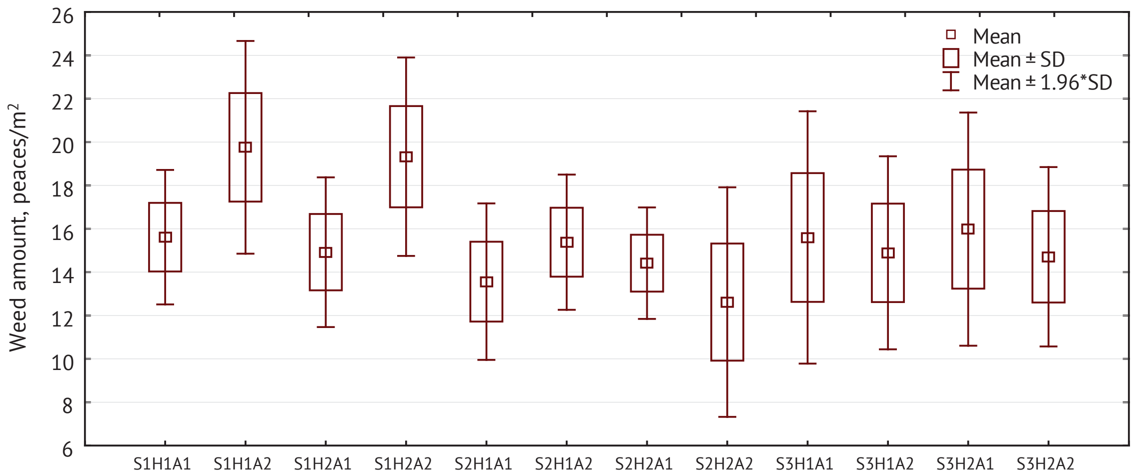

Figure 5*. Box plot depicting the mean and standard deviation of weed infestation (number of weeds per square meter) across 12 versions of the agro-experiment*

Source: *compiled by the authors of this study*

Table 5*. Analysis of variance (ANOVA) results for a three-factor experiment*

Effect	sum_sq	df	F	PR(>F)
C(F1)	924.4801	2	95.28186	2.66E-35
C(F2)	140.9995	1	29.06432	1.13E-07
C(F3)	26.06264	1	5.37231	0.020901
C(F1):C(F2)	609.8311	2	62.85245	7.79E-25
C(F1):C(F3)	22.25571	2	2.293792	0.102046
C(F2):C(F3)	50.01987	1	10.31063	0.001416
C(F1):C(F2):C(F3)	81.32895	2	8.382196	0.000266
Residual	2212.189	456		

Source: *compiled by the authors of this study*

The study considered three factors: tillage system (F1), seeding rate (F2), and herbicide treatment (F3). The results of the analysis of variance indicated that all three studied factors had a different degree of influence on the dependent variable. The most significant was the influence of the F1 factor. Its contribution to the total variation was the largest, and the corresponding p-value was extremely small, which reflected a statistically significant influence of this factor ($F = 95.28$, $p < 0.0001$). This means that different tillage methods do affect the degree of crop litter, and it is likely that milling (as one of the methods of surface tillage) contributes to the reduction of weed numbers by mechanically destroying their seeds or improving the conditions for maize growth. Seeding density, represented by factor F2, also has a statistically significant effect, although less pronounced compared to F1 ($F = 29.06$, $p < 0.000001$). Increasing the seeding rate

(1.1-1.3 seeding units per hectare) probably leads to a thickening of maize crops, which limits access to light and space for weeds, reducing their development.

Factor F3, which describes the use of herbicides, also turned out to be significant, but its effect was the smallest among all three main factors ($F = 5.37$, $p \approx 0.021$). This may suggest that under the conditions of this experiment, the herbicide did not provide the expected effectiveness. Possible reasons are the development of resistance in weeds, the mismatch of the type of herbicide to the spectrum of weeds, or errors in agricultural application techniques. Additionally, alternative methods of mechanical tillage were used in the herbicide-free treatment variants, which provided the desired effect. Furthermore, the analysis of variance revealed a significant interaction between the F1 and F2 factors. This means that the efficiency of seeding density depends on the soil cultivation system used. Such an interaction requires special attention when interpreting the findings, since the same density level can affect the result differently depending on the type of cultivation. At the same time, the interaction between F1 and F3 was not statistically significant, which indicates the absence of a noticeable combined effect between the soil cultivation system and the use of herbicides. Overall, tillage and seeding rates had the greatest impact on weed abundance in maize, while herbicide treatment was ineffective. This highlights the significance of agronomic decisions in an integrated weed control system and indicates the feasibility of improving tillage and seeding approaches.

The findings of this study confirmed the value of agroecological strategies for sustainable weed management in maize agroecosystems. The conducted analysis of variance (ANOVA) revealed a statistically significant influence of tillage systems, which allows concluding that surface tillage, especially milling, markedly reduces the weed load and at the same time promotes the development of cultivated plants due to the improvement of the soil structure and the reduction of the weed seed bank plants in the upper soil layer. These data are consistent with the findings of S. Selvakumar and R. Ariraman (2022) that reducing the intensity of tillage disrupts the germination cycles of weed seeds and improves the conditions for growing maize. One of the key results is the minimal effect of herbicides on the level of crop contamination. Analogous findings emphasise the need to transition to integrated weed management systems, which focus on mechanical and agrotechnical methods. The data are consistent with the conclusions of N. Colbach *et al.* (2025), where, upon modelling sustainable weed management systems in three European cases, the researchers showed that the greatest contribution to sustainability is made by integrated agrotechnical measures adapted to local conditions, including the combination of minimal tillage and optimal sowing times. N. Sharma and M. Rayamajhi (2022) emphasised that the success of integrated weed management in maize crops depended on a complex combination of mechanical, agrotechnical, and biological methods adapted to concrete climatic and soil conditions.

The significance of sowing density deserves special attention. The increase in density provided both the suppression of weeds due to the accelerated closing of the rows, and the improvement of the competitiveness of maize. This result confirms the data of R. Leskovšek *et al.* (2025), where the significance of the density of the standing of cultivated plants for the development of a dense canopy and the reduction of soil illumination was emphasised, which complicates the successful germination for weeds. K. Nthebere *et al.* (2025) also showed that in systems of conservation agriculture based on minimal tillage and mulching, improvements in soil quality and crop stability in arid climates are achieved, which confirms the universality of the revealed patterns.

A valuable discovery of the present study was the absence of a significant interaction between soil treatment and the use of herbicides. This indicates that agroecological mechanical methods can completely replace chemical means of plant protection in certain conditions without losing the effectiveness of weed vegetation management. At the same time, the revealed significant interaction between the tillage system and the density of sowing emphasises the need for a systematic approach to the planning of agrotechnical measures. Cluster analysis using the Jaccard index revealed stable ecological and coenotic relationships between the primary types of weed plants. A stable coexistence of *C. arvensis*, *E. repens*, and *R. sativum* species was established under various cultivation technologies, which indicated their pronounced adaptability. These data are significant for forecasting weed complexes and developing targeted measures to combat them, which was also noted by N. Colbach *et al.* (2025) within the framework of approaches to spatial modelling of sustainable management systems.

Thus, the findings of the present study confirmed the expediency of the transition to the paradigm of agroecological intensification in the cultivation of maize. Such an approach reduces dependence on chemical means of plant protection, contributes to the preservation of soil fertility, biodiversity, and ensures the long-term stability of agroecosystems. Prospective areas for further research include the evaluation of the long-term ecological consequences of the proposed methods, their economic efficiency in the conditions of commercial agriculture, as well as the study of the synergistic effect of combining with cover crops and the use of organic fertilisers.

CONCLUSIONS

The research results validated the efficacy of agroecological weed management techniques in maize agroecosystems. The tillage system had the most substantial effect in diminishing field litter. Specifically, surface tillage, particularly milling, resulted in a notable decrease in weed populations and a concurrent enhancement in crop output due to enhanced soil structure and a reduction in the weed seed bank in the upper layer. Augmenting the seeding density positively influenced the suppression of weed germination, as the extensive coverage of the soil by the maize leaf surface restricted light penetration to the soil, hence inhibiting the proliferation of undesirable vegetation. The influence of herbicides was less significant than other factors, suggesting the possibility of diminishing reliance on chemical protective agents through the implementation of good agronomic methods.

The demonstrated correlation between tillage system and crop density underscored the necessity for a comprehensive approach to agroecosystem management. The integration of surface tillage and heightened crop density yielded optimum outcomes in weed management. Consequently, methodical planning of crop rotation, mechanical tillage, and optimisation of crop density are essential for effective weed control and consistent yields. The results validated the viability of agroecological intensification in maize production as a sustainable method that mitigates environmental burdens, enhances soil fertility, and guarantees the long-term stability of agricultural ecosystems. Future studies should focus on evaluating the long-term ecological consequences of these methods, assessing their economic viability in commercial farming contexts, and investigating synergistic effects with cover cropping and organic amendments. This study provides valuable empirical evidence endorsing the scalability and ecological viability of integrated weed management in maize cultivation.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Boutagayout, A., El Bouiamrine, H., Synowiec, A., El Oihabi, K., Romero, P., Rhioui, W., Nassiri, L., & Belmalha, S. (2025). Agroecological practices for sustainable weed management in Mediterranean farming landscapes. *Environment, Development and Sustainability*, 27, 8209-8263. doi: 10.1007/s10668-023-04286-7.

[2] Colbach, N., Chauvel, B., Klompe, K., Ruggeri, M., Sønderskov, M., & de Wolf, P. (2025). Evaluating and identifying the drivers of sustainability of integrated weed management systems in three European case studies with in silico tools. *European Journal of Agronomy*, 170, article number 127736. doi: 10.1016/j.eja.2025.127736.

[3] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[4] Cordeau, S. (2022). Conservation agriculture and agroecological weed management. *Agronomy*, 12(4), article number 867. doi: 10.3390/agronomy12040867.

[5] Determination of the actual weediness of crops. (n.d.). Retrieved from https://agroscience.com.ua/herba/43-vyznachennya-faktychnoi-zaburyanenosti-posiviv.

[6] DSTU 4289:2004. (2005). *Soil quality. Methods of determination of organic matter*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=56400.

[7] DSTU 4730:2007. (2008). *Quality of soil. Determination of granulometric composition by the pipettemethod for modification AN Kaczynski*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=95597.

[8] DSTU ISO 11272-2001. (2002). *Soil quality. Determination of bulk density on dry mass (ISO 11272:1998, IDT)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=58941.

[9] Erenstein, O., Chamberlin, J., & Sonder, K. (2021). Estimating the global number and distribution of maize and wheat farms. *Global Food Security*, 30, article number 100558. doi: 10.1016/j.gfs.2021.100558.

[10] Fedoniuk, T., Zhuravel, S., Kravchuk, M., Pazych, V., & Bezvershuck, I. (2024). Historical sketch and current state of weed diversity in continental zone of Ukraine. *Agriculture and Natural Resources*, 58(5), 631-642. doi: 10.34044/j.anres.2024.58.5.10.

[11] Fedoniuk, T.P., Pyvovar, P.V., Topolnytskyi, P.P., Rozhkov, O.O., Kravchuk, M.M., Skydan, O.V., Pazych, V.M., & Petruk, T.V. (2025). Utilising remote sensing data to ascertain weed infestation levels in maize fields. *Agriculture,* 15(7), article number 711. doi: 10.3390/agriculture15070711.

[12] Fonteyne, S., Leal Gonzalez, A.J., Osorio Alcalá, L., Villa Alcántara, J., Santos Rodriguez, C., Núñez Peñaloza, O., Ovando Galdámez, J.R., Gopal Singh, R., & Verhulst, N. (2022). Weed management and tillage effect on rainfed maize production in three agro-ecologies in Mexico. *Weed Research,* 62(3), 224-239. doi: 10.1111/wre.12530.

[13] Handbook of Weed Management. (2024). Retrieved from https://cordis.europa.eu/project/id/101084084/results.

[14] ISO 18400-201. (2017). *Soil quality – Sampling – Part 201: Physical pretreatment in the field*. Retrieved from https://surl.li/xsfqxw.

[15] IUSS Working Group WRB. (2022). Retrieved from https://www.isric.org/sites/default/files/WRB_fourth_edition_2022-12-18.pdf.
[16] Leskovšek, R., Eler, K., & Zamljen, S.A. (2025). Weed suppression and maize yield influenced by cover crop mixture diversity and tillage. *Agriculture, Ecosystems & Environment*, 383, article number 109530. doi: 10.1016/j.agee.2025.109530.
[17] Liu, S., Ma, Z., Zhang, Y., Chen, Z., Du, X., & Mu, Y. (2022). The impact of different winter cover crops on weed suppression and corn yield under different tillage systems. *Agronomy,* 12(5), article number 999. doi: 10.3390/agronomy12050999.
[18] Mandić, V., Đorđević, S., Brankov, M., Živković, V., Lazarević, M., Keškić, T., & Krnjaja, V. (2024). Response of yield formation of maize hybrids to different planting densities. *Agriculture*, 14(3), article number 351. doi: 10.3390/agriculture14030351.
[19] Nthebere, K., Tata, R., Bhimireddy, P., Chandran, L. P., Gudapati, J., Admala, M., Sinha, N.K., Srikanth, Th.B., & Prasad, K. (2025). Impact of conservation agriculture on soil quality and cotton-maize system yield in Semi-Arid India. *Sustainability*, 17(3), article number 978. doi: 10.3390/su17030978.
[20] Orlov, O.O., Fedoniuk, T.P., Iakushenko, D.M., Danylyk, I.M., Kish, R.Ya., Zimaroieva, A.A., & Khant, G.A. (2021). Distribution and ecological growth conditions of *Utricularia australis* R. Br. in Ukraine. *Journal of Water and Land Development*, 48(I–III), 32-47. doi: 10.24425/jwld.2021.136144.
[21] Radicetti, E., & Mancinelli, R. (2021). Sustainable weed control in the agro-ecosystems. *Sustainability,* 13(15), article number 8639. doi: 10.3390/su13158639.
[22] 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. doi: 10.3390/land12040926.
[23] Selvakumar, S., & Ariraman, R. (2022). Effect of tillage on weed shift and its managements: A review. *Agricultural Reviews*, 44(3), 364-369. doi: 10.18805/ag.R-2223.
[24] Sharma, N., & Rayamajhi, M. (2022). Different aspects of weed management in maize (*Zea mays* L.): A brief review. *Advances in Agriculture*, 2022(1), article number 7960175. doi: 10.1155/2022/7960175.
[25] Skydan, O.V., Dankevych, V.Y., Fedoniuk, T.P., Dankevych, Y.M., & Yaremova, M.I. (2022). European green deal: Experience of food safety for Ukraine. *International Journal of Advanced and Applied Sciences*, 9(2), 63-71. doi: 10.21833/IJAAS.2022.02.007.
[26] Thapa, B., & Dura, R. (2024). A review on tillage system and no-till agriculture and its impact on soil health. *Archives of Agriculture and Environmental Science,* 9(3), 612-617. doi: 10.26832/24566632.2024.0903028.

Стале управління бур'янами у посівах кукурудзи: оцінка агроекологічних практик та систем обробітку ґрунту

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Анотація. У дослідженні оцінювалася ефективність агроекологічних підходів боротьби з бур'янами у посівах кукурудзи. Експеримент, проведений у 2023-2024 роках і включав три системи обробітку ґрунту (глибока оранка, дискування, фрезерування), дві густоти посіву (1,1 та 1,3 посівних одиниць/га) та два підходи до застосування гербіцидів (застосування та незастосування гербіцидів), загалом 12 варіантів у 3 повтореннях. Найвищий рівень забур'яненості було зафіксовано у варіанті з дискуванням, низькою густотою посіву та без гербіцидів (S2H2A1) – 22,3 рослини/м^2; найнижчий – у варіанті з оранкою, високою густотою посіву та застосуванням гербіцидів (S1H1A2) – 12 рослин/м^2. Варіанти з ущільненим посівом, незалежно від застосування гербіцидів, продемонстрували кращу здатність до пригнічення бур'янів завдяки швидкому змиканню міжрядь та зменшенню доступу світла. Дисперсійний аналіз (ANOVA) показав, що найбільший вплив на кількість бур'янів мав обробіток ґрунту ($F = 95{,}28$; $p < 0{,}0001$), далі йшла густота посіву ($F = 29{,}06$; $p < 0{,}000001$), а внесок гербіцидів був найменшим ($F = 5{,}37$; $p \approx 0{,}021$). Значна взаємодія між системою обробітку та густотою посіву ($F = 62{,}85$; $p < 0{,}000001$) свідчить про необхідність комплексного планування агротехнічних заходів. Кластерний аналіз на основі індексу Жаккара виявив сильні екологічні зв'язки між видами бур'янів — зокрема, *C. arvensis*, *E. repens* та *R. sativum* мали коефіцієнт подібності 0,92, що дозволяє прогнозувати типові фітосоціальні комбінації та розробляти цілеспрямовані заходи боротьби. Результати засвідчили, що агроекологічні стратегії, включаючи поверхневий обробіток ґрунту та ущільнений посів, можуть успішно замінити хімічні методи, зменшуючи навантаження на довкілля та підтримуючи стабільність продуктивності. Практична цінність дослідження полягає у доведеній можливості мінімізації використання гербіцидів при збереженні високої врожайності кукурудзи шляхом впровадження адаптованих агротехнічних рішень

Ключові слова: агроекологія; боротьба з бур'янами; *Zea mays* L.; системи обробітку ґрунту; родючість ґрунту; альтернативи гербіцидам; продуктивність рослин