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RESEARCH ARTICLE

Effects of conservation tillage on weed infestation and maize yield under changing climate conditions

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Abstract

Climate change significantly affects agricultural production, altering weed population dynamics and reducing crop yields. Conservation tillage has emerged as a promising approach to mitigate these negative effects by improving soil structure and moisture retention. However, its impact on weed infestation and maize productivity in the Northern Steppe of Ukraine remains insufficiently studied. This study aimed to evaluate the effect of different conservation tillage methods on weed infestation levels and maize yield under varying fertilization regimes in the context of climate change. Field experiments were conducted in a long-term crop rotation system, comparing moldboard plowing (23 cm-25 cm), chisel plowing (14 cm-16 cm), and flat-cut loosening (14 cm-16 cm) under three fertilization levels: no fertilization, $N_{30}P_{30}K_{30}$, and $N_{60}P_{30}K_{30}$. The results showed that conservation tillage, particularly flat-cut loosening, increased weed infestation by 1.4-1.8 times compared to moldboard plowing. The dominant weed species included *Ambrosia artemisiifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., and *Echinochloa crus-galli* L., Nitrogen fertilization significantly influenced maize productivity, with the highest yield (5.62 t/ha) observed under $N_{60}P_{30}K_{30}$ combined with flat-cut loosening. However, grain quality parameters showed minimal variation across tillage methods. Thus, while conservation tillage increases weed infestation, the application of nitrogen fertilizers can partially compensate for yield losses. The results highlight the importance of integrating tillage and fertilization strategies to balance weed control and maize productivity in changing climate conditions.

Keywords: Soil management, Weed control, Nitrogen fertilization, Crop productivity, Climate adaptation, Agroecosystem sustainability

Introduction

A critical constraint in modern maize cultivation technologies is the prevalence of weed infestation, which substantially diminishes the efficacy of agronomic interventions designed to enhance grain yield. Although the widespread adoption of advanced and highly selective herbicides has improved weed management, undesirable plant species continue to exert considerable competitive pressure on maize crops. This competition leads to significant reductions in nutrient availability, moisture retention, and overall crop vigor. Consequently, weed interference remains a major agronomic challenge, often resulting in yield losses exceeding 30%, thereby undermining the productivity and economic sustainability of maize production systems (Brandsaeter, 2018; Beckie, 2020; Mytsyk,2024).

The dynamic interplay between crops and weeds is deeply rooted in their co-evolution within agroecosystems, where both components continuously adapt to environmental conditions and agronomic practices. Weeds should not be viewed in isolation, as they constitute an inherent part of agricultural landscapes, interacting with crops through competition for resources such as light, water, and nutrients. Variations in weed density and species composition are predominantly driven by ecological transformations, including climate fluctuations, soil properties, and biodiversity shifts. Additionally, the long-term effects of agricultural succession, the intensity and frequency of soil tillage, crop rotation schemes, and specific cultivation techniques collectively shape weed communities, influencing their persistence, adaptability, and impact on crop productivity. Understanding these complex interactions is essential for developing integrated weed management strategies that balance crop production with sustainable agroecosystem functioning (Lundgren, 2023; Sachin Kumar, 2024).

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, 2018; Ali, 2022; Ghosh, 2023; Schnee, 2023; Md-AKhir, 2023; Tsyliuryk, 2023).

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, 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 (Jinwei Zhang, 2024; Talent Namatsheve, 2024; Sachin Kumar, 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, Sachin Kumar (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 (Christophe Lacroix, 2024; Romashchenko, 2025), 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 (Tsyliuryk, 2023).

This study aimed to identify the patterns of weed species composition and assess their quantitative dynamics in maize agrocenoses. Additionally, it sought to evaluate the effects of various primary soil tillage methods on the development rates of weed communities and the extent of infestation in maize fields. Furthermore, the research focused on determining maize grain yield and quality parameters in relation to different tillage practices and fertilization strategies.

Materials and Methods

Field experiments were conducted at the State Enterprise "Dnipro Experimental Farm" of the State Institution "Institute of Grain Crops" of the National Academy of Agrarian Sciences of Ukraine. Additionally, research was carried out at the experimental field of the Research and Educational Center of Dnipro State Agrarian and Economic University. The study site was located near Dnipro 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, 1997; Ushkarenko, 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, 2012; Shevchenko, 2024).

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 cm-25 cm; chisel (mulch) tillage – performed with a chisel plow to a depth of 14 cm-16 cm; flat-cut (mulch) tillage – performed using a heavy cultivator (KSHN-5.6 "Resident") to a depth of 14 cm-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 was evaluated by species and weight, sampling diagonally across each plot with five replicates. Data analysis employed Statistica 12.0 software (StatSoft Inc.), presenting results 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 $p<0.05$ and the Bonferroni correction was used to adjust for multiple comparisons. Crop capacity was determined using mathematical statistics.

Results and Discussion

Before the first inter-row tillage, weed infestation in maize fields exhibited a clear trend of increasing with higher nitrogen fertilizer application rates, both in terms of plant density and biomass, regardless of the tillage system applied. This effect was particularly pronounced for nitrophilous weed species, such as common lamb's quarters (*Chenopodium album* L.) and common pigweed (*Amaranthus retroflexus* L.), which thrive under elevated nitrogen availability. The intensified weed pressure under fertilized conditions suggests that nitrogen not only supports crop growth but also enhances the competitive potential of certain weed species, potentially leading to higher infestations if not managed properly.

Weed density and biomass varied significantly across different tillage methods. Under mouldboard plowing, weed infestation ranged from 9.7 plants/m² to 12.7 plants/m², with a biomass accumulation of 2.6 g/m²-3.0 g/m². Chisel plowing resulted in slightly lower weed density (9.1 plants/m²-10.3 plants/m²), but biomass values were somewhat higher (2.9 g/m²-3.5 g/m²), likely due to the preservation of soil moisture and organic matter in the upper layers, which favored weed growth. The highest levels of weed infestation were observed under flat-cut tillage, where weed density reached 13.2 plants/m²-15.7 plants/m², with biomass ranging from 3.4 g/m² to 5.1 g/m². This increase can be attributed to the minimal soil disturbance associated with shallow tillage, which preserves the weed seed bank in the upper soil layers and promotes germination.

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 (Tab. 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 cm-25 cm)		**chisel plough (14 cm-16 cm)**		**flat-cut loosening (14 cm-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)						
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)						
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)						
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

By harvest time, weed infestation in maize fields decreased 1.2-3.1 times depending on the tillage method (to 4.1 plants/m²-10.6 plants/m²) and 1.3 times with $N_{30}P_{30}K_{30}$ fertilization. This reduction resulted from increased maize competitiveness in later growth stages. Common ragweed (*Ambrosia artemisiifolia* L.) dominated the weed composition (40%-60%), along with annual grasses (*Poaceae*), common lamb's quarters (*Chenopodium album* L.), and sunflower volunteers, whose seeds remained viable for years. Infestation was highest under flat-cut tillage (7.2 plants/m²-10.6 plants/m², 17.0 g/m²-19.4 g/m²).

Weed germination in maize fields declined over six crop rotations due to reduced seed contamination. From 2011-2024, germination under mouldboard plowing was 64.5 plants/m², and under chisel tillage, 80.2 plants/m², 1.3-1.6 times lower than at the start of crop rotation.

A significant shift in weed composition was observed, with declines in *Setaria glauca* L., *Echinochloa crus-galli* L., *Amaranthus retroflexus* L., and *Chenopodium album* L. Their reduction (0.9 plants/m²-23.1 plants/m²) varied by tillage method and was primarily due to herbicide application (Harness, Maister), which effectively controlled these species.

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	Pearl millet	37.6 ± 1.6^{c}	14.6 ± 0.8^{a}	21.2 ± 1.2^{b}	15.8 ± 0.8^{a}
2	Barnyard grass	20.5 ± 1.0^{b}	16.4 ± 0.9^{a}	27.6 ± 1.3^{c}	17.9 ± 0.9^{a}
3	American pigweed	27.4 ± 1.1^{b}	14.8 ± 1.0^{a}	33.9 ± 1.5^{c}	17.9 ± 0.9^{ab}
4	Common tumbleweed	2.0 ± 0.2^{b}	0.7 ± 0.1^{a}	2.5 ± 0.2^{c}	1.5 ± 0.2^{ab}
5	Mat amaranth	6.3 ± 0.2^{b}	2.5 ± 0.2^{a}	4.8 ± 0.2^{ab}	2.9 ± 0.2^{a}
6	Common lambsquarters	3.4 ± 0.2^{b}	1.9 ± 0.2^{a}	3.1 ± 0.2^{ab}	2.3 ± 0.2^{a}
7	Black bindweed	1.6 ± 0.1^{a}	1.0 ± 0.1^{a}	1.3 ± 0.1^{a}	1.2 ± 0.1^{a}
8	Common ragweed	3.6 ± 0.2^{a}	11.4 ± 0.4^{b}	5.6 ± 0.3^{ab}	16.6 ± 0.5^{c}
9	False london-rocket	0	0	0.3 ± 0.2^{a}	0.2 ± 0.1^{a}
10	Bastard cress	0	0	1.5 ± 0.2^{a}	1.3 ± 0.2^{a}
11	Boar thistle	0.6 ± 0.1^{a}	0.1 ± 0.2^{a}	1.1 ± 0.1^{a}	0.3 ± 0.1^{a}
12	Corn sow-thistle	0	0	0.3 ± 0.1^{a}	0
13	Bindweed	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 tab. 2, as determined by Tukey's test (P<0.05) with Bonferroni correction.

The rising resistance of common ragweed (*Ambrosia artemisiifolia* L.) to herbicides, coupled with its strong adaptability, poses a growing threat to agriculture and the environment.

Maize yield analysis revealed a slight advantage of plowing and chiseling over untreated fields and $N_{30}P_{30}K_{30}$ application due to improved nutrient availability and lower weed pressure. At $N_{60}P_{30}K_{30}$, flat-cut loosening achieved yields comparable to plowing and chiseling, neutralizing prior disadvantages. Given the minimal yield differences among tillage methods, their effectiveness can be considered equivalent.

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 cm-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 cm-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 cm-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		0.1		
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.

Applying $N_{30}P_{30}K_{30}$ increased maize yield by 8.4%-8.9%, with the highest gain under flat-cut loosening (0.47 t/ha). Doubling nitrogen ($N_{60}P_{30}K_{30}$) further raised yield by 12.9%-14.4%. In the early crop rotation stages, high weed infestation and low soil fertility reduced yield by 0.25 t/ha-0.38 t/ha.

Tillage had minimal impact on grain quality, though mouldboard plowing slightly increased protein content due to better nitrogen availability. Fertilization, especially with crop residue, raised protein by 0.4%-1.1% while reducing starch by 0.7%-1.7%.

Conclusions

Weeds possess high regenerative potential, enabling them to overcome control measures. Their biodiversity cannot be eliminated but must be managed to keep infestation below the economic threshold.

Weed community composition is determined by adaptive traits and field conditions. Key factors influencing weed dominance include herbicide resistance, broad germination, and morphological plasticity.

Shallow non-inversion tillage (chisel plowing, flat-cut loosening) increases weed infestation by 1.41.8 times, requiring enhanced herbicide use to prevent yield losses.

Moldboard and chisel plowing slightly improve maize yield under unfertilized conditions and with $N_{30}P_{30}K_{30}$ due to better nutrient availability. At $N_{60}P_{30}K_{30}$, flat-cut loosening provides similar yields by mitigating previous disadvantages.

With low weed infestation (9.0 plants/m²-12.6 plants/m²), tillage methods do not significantly affect grain quality, though nitrogen fertilization increases protein content while reducing starch levels.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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