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The impact of primary tillage and soil herbicides on sunflower productivity in the right-bank forest-steppe zone of Ukraine

Abstract. Sunflower is one of Ukraine's most important oil crops, which is of great economic importance due to the export of sunflower oil. The growth in sunflower sowing areas is due to high profitability and market demand. At the same time, sunflower cultivation technology is complex, and production efficiency depends on many factors, including primary tillage and herbicide protection systems. The aim of the study was to investigate the effect of different options for primary soil cultivation and herbicide protection on the yield and quality of sunflower seeds in the conditions of the right-bank forest-steppe of Ukraine. The research was conducted in 2022-2024 on typical low-humus chernozem at the private enterprise "Shans" (Cherkasy region). Ploughing and non-ploughing soil cultivation were used, as well as various herbicide protection options, including manual weeding. The main indicators were yield, basket diameter, weight of 1,000 seeds and seed quality. It was found that the use of effective herbicide schemes and mouldboard tillage significantly increased sunflower yield (up to 4.1 t/ha) compared to the control. Weeds significantly reduced crop yield (by 0.4-1.1 t/ha), reducing yield parameters and seed quality. Manual weeding provided a high level of control, but was labor-intensive and economically inefficient. The best results were obtained with the use of Primextra TZ Gold (4.5 l/ha) and Challenge (5.0 l/ha) herbicides in combination with mouldboard tillage. It was found that combining mouldboard tillage with an optimally selected herbicide protection scheme resulted in better indicators of basket diameter, seed weight per basket, and weight of 1,000 seeds. The results demonstrated the importance of integrating soil cultivation and chemical protection techniques to increase sunflower crop productivity. The results of the study can be used to optimise sunflower cultivation technologies in the region and increase production efficiency

Keywords: crop structure; weeds; yield; mouldboard tillage; non-mouldboard tillage; Challenge; Primextra TZ Gold

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INTRODUCTION

Sunflower is one of the strategically important crops for agricultural production in Ukraine, as it provides the majority of oil production for domestic and export markets. With growing global demand for oilseed products, particularly vegetable oil, it is important not only to expand sunflower cultivation areas, but also to increase its yield and stability of productivity in modern climatic conditions. To achieve these goals, it is necessary to improve cultivation technologies, in particular those elements that most significantly affect the growth, development and formation of the crop structure. In particular, it is especially important to optimise the system of primary soil cultivation in combination with effective herbicide protection of crops, which allows for more efficient use of moisture, reduces weed load and ensures favourable conditions for the development of cultivated plants. In this regard, there is a need for scientific justification of adaptive elements of sunflower cultivation technology that would meet modern requirements for resource conservation and environmental safety.

In recent years, scientific works have paid considerable attention to studying the impact of basic soil cultivation measures on the agrophysical properties, soil fertility and yield formation of field crops. Authors H. Pinkovskyj & S. Tanchyk (2020) studied the impact of depth and method of cultivation on sunflower productivity and noted that under forest-steppe conditions, reducing the depth of cultivation with the correct selection of aggregates does not reduce crop yield but contributes to improving the water regime of the soil. In turn, Y. Gadzalo *et al.* (2022) emphasised that sunflower yield depends to a large extent not only on the hybrid and weather conditions, but also on the effectiveness of each technological element – tillage, sowing, weed control and nutrition. V. Gurtovenko & O. Tsyuk (2023) found in their research that the choice of the main soil cultivation system significantly affects the density, moisture capacity and temperature regime of the arable layer, which is directly related to the initial growth rates of sunflowers and overall crop formation. At the same time, authors E. Achankeng & W. Cornelis (2023) drew attention to the potential risks of excessive intensification: the unjustified use of deep tillage or its complete avoidance (no-till) can worsen germination conditions and increase weed infestation of crops.

The problem of weeds remains relevant in modern intensive agriculture. Y. Joshan *et al.* (2019) noted that the presence of weeds in sunflower crops significantly reduces yield – during the active growing season, they compete with the crop for moisture, nutrients and light, and also complicate mechanised harvesting. That is why herbicide protection, especially under conditions of simplified or minimal tillage, must be adaptive and differentiated. In the modern conditions of climate change, when there is an increase in the average annual temperature and a decrease in the amount of effective precipitation during the growing season, adaptive farming systems are of particular importance. According to research by A. Molla *et al.* (2022), the use of minimum tillage in combination with agronomic measures to conserve moisture contributes to the increased efficiency of sunflower cultivation in crop rotation systems. They found that even under conditions of reduced water supply, conservation agriculture ensures stable crop formation. Similar conclusions were reached by A. Sher *et al.* (2021), who pointed out that preserving soil structure when using surface or zero tillage reduces evaporation and improves conditions for the action of soil herbicides. Thus, studying the interaction between the main tillage system and herbicide protection in sunflower cultivation allows to justify effective adaptive technologies for the conditions of the Right-Bank Forest-Steppe of Ukraine. Scientific research shows that sunflower yield is influenced by a complex of technological factors, among which the main tillage system, agrochemical support and herbicide protection are of particular importance.

In the course of modern field studies in Ukraine, considerable attention is paid to the impact of basic soil cultivation methods on moisture retention and sunflower productivity. A study by Z. Pacanoski & A. Mehmeti (2021) found that different tillage methods significantly determine crop yield and energy efficiency. In particular, minimum and partial tillage help reduce energy and water consumption without

a noticeable decrease in yield compared to traditional ploughing. Thus, after maize, the yield of sunflower with traditional tillage was 2.78 t/ha, while with shallow tillage it was 2.65 t/ha. A similar pattern was observed after soybeans, although this predecessor had a generally negative effect on the yield. Thus, with mouldboard tillage, the yield reached 2.56 t/ha, and with shallow tillage, only 2.41 t/ha. In addition, the tillage method also affected the quality characteristics of the seeds: with shallow tillage, the oil content decreased by 2.4-3.6% compared to plowing.

Research by Y. Havrylyuk & N. Matsai (2019) showed that both the quantity and species composition of weeds affect sunflower yield. In the complete absence of weeds, the sunflower yield was 2.5 t/ha, and in the presence of 25 weeds/m^2, the yield decreased to 2.19 t/ha. With 50 weeds per m^2, the yield was even lower – 1.74 tonnes. The work of Z. Degtyareva & S. Kudrya (2023) analysed the agroecological aspects of herbicide protection of sunflowers depending on weather conditions in the forest-steppe zone of Ukraine. The authors note that the effectiveness of soil herbicides largely depended on the amount of precipitation in the post-emergence period: under drought conditions, the effectiveness decreased to 40-60%, while in the presence of moisture, it reached 85-90%. In addition, the use of combined protection schemes with the use of insurance herbicides ensured a stable reduction in weed infestation and an increase in yield regardless of weather conditions.

The aim of the study was to assess the impact of different systems of primary soil tillage and herbicide protection on the elements of yield structure and sunflower productivity in the conditions of the forest-steppe zone of Ukraine.

MATERIALS AND METHODS

The research was carried out during 2022-2024 in the right-bank forest-steppe zone at the private enterprise "Shans" in Cherkasy region (Ukraine). The soil cover of the experimental site was typical low-humus chernozem. According to soil analysis, the 0-30 cm layer contained: humus – 2.1-2.3%; easily hydrolysable nitrogen – 10.3-11.5 mg/kg; available phosphorus – 153.1-160.3 mg/kg; available potassium – 130-140 mg/kg; pH 6.7-6.8. The preceding crop was maize for grain. The hybrid grown in the NK Kondi studies is characterised by traditional cultivation technology. It should be noted that only soil herbicides were used in this chemical protection experiment; no other treatments were carried out. The experiment design is shown in Table 1.

Table 1. Field experiment scheme

Variant No.	Primary soil tillage, cm (Factor A)	Scheme of soil-applied weed control (Factor B)
1	Mouldboard tillage at 25-27 cm	Without herbicides (control)
2		Manual weeding
3		Primextra TZ Gold (312.5 g/l s-metolachlor, 187.5 g/l terbuthylazine) – 4.5 l/ha (Etalon)
4		Racer (fluorochloridone, 250 g/l) – 3.0 l/ha
5		Prometrex (prometryn, 500 g/l) – 3.0 l/ha
6		Challenge (aclonifen, 600 g/l) – 5.0 l/ha
7		Prometrex 1.5 l/ha + Racer 1.5 l/ha
8		Challenge 2.5 l/ha + Prometrex 1.5 l/ha
9		Challenge 2.5 l/ha + Racer 1.5 l/ha
10		Challenge 2.5 l/ha + Aspect Pro (terbuthylazine, 333 g/l + diflufenican, 200 g/l) – 2.0 l/ha
11		Prometrex 1.5 l/ha + Aspect Pro – 2.0 l/ha
12		Racer 1.5 l/ha + Aspect Pro – 2.0 l/ha

Table 1, Continued

Variant No.	Primary soil tillage, cm (Factor A)	Scheme of soil-applied weed control (Factor B)
1	Non-mouldboard tillage at 25-27 cm	Without herbicides (control)
2		Manual weeding
3		Primextra TZ Gold (312.5 g/l s-metolachlor, 187.5 g/l terbuthylazine) – 4.5 l/ha (Etalon)
4		Racer (fluorochloridone, 250 g/l) – 3.0 l/ha
5		Prometrex (prometryn, 500 g/l) – 3.0 l/ha
6		Challenge (aclonifen, 600 g/l) – 5.0 l/ha
7		Prometrex 1.5 l/ha + Racer 1.5 l/ha
8		Challenge 2.5 l/ha + Prometrex 1.5 l/ha
9		Challenge 2.5 l/ha + Racer 1.5 l/ha
10		Challenge 2.5 l/ha + Aspect Pro (terbuthylazine, 333 g/l + diflufenican, 200 g/l) – 2.0 l/ha
11		Prometrex 1.5 l/ha + Aspect Pro – 2.0 l/ha
12		Racer 1.5 l/ha + Aspect Pro – 2.0 l/ha

Source: developed by the author

The following materials and methods were used during the research: field experiment, laboratory analysis, data processing and summarisation. The total area of the experiment, including the protective strip, was 0.18 hectares. The area of the sowing plot was 18 m^2 (3m*6m), and the accounting plot was 10 m^2 (2m*5m) with four repetitions. The placement of variants was randomised. Under the gradation of factor A, the influence of basic soil cultivation on sunflower yield was located. Mouldboard tillage was performed using a PLN-3-35 unit (Ukraine), which was characterised by ploughing at a depth of 25-27 cm. Non-mouldboard tillage was performed using an AGR-1.7 chisel unit (Ukraine) at a depth of 25-27 cm. Under gradation B, there are various options for soil herbicides, as well as a control (without the use of any weed control) and options with manual weeding. The study included a comprehensive agronomic analysis, which included measuring sunflower yield, 1,000-seed weight, and yield structure. The weight of 1,000 seeds was determined by weighing replicated seed samples selected from each treatment. To assess the yield structure, the ratio of the main components of the yield was analysed: seeds, husks and waste.

Statistical data processing was performed using analysis of variance (ANOVA) with the calculation of the least significant difference (LSD) at a significance level of 0.05, which allowed determining the reliability of differences between the mean values of the indicators. During the years of research, uneven precipitation distribution and significantly extreme air temperature increases were observed, which had a negative impact on sunflower yield. At the same time, weather conditions in the research years made it possible to study their impact on the effectiveness of the factors under study. During the years of research, the start of the growing season varied, which affected the timing of sunflower sowing. Thus, in 2022, it took place on 1 May, in 2023 – on 11 May, and in 2024 – on 11 April. During the 30 days after sowing sunflowers in 2022, 27 mm of precipitation fell, and in 2023, 17 mm. The spring of 2024 was wet with heavy rains: 55 mm of precipitation fell during the 30 days after sowing.

The study was conducted in accordance with the ethical standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1976).

RESULTS AND DISCUSSION

Yield indicators and seed quality characteristics are important when studying the effectiveness of herbicide protection of crops, since both quantitative and qualitative parameters of the harvest largely depend on the level of weed control. It should be noted that mechanical methods of weed control do not always ensure their complete destruction, which reduces the overall effectiveness of this approach. Despite its relative effectiveness, manual weeding is

labour-intensive, which makes it economically unfeasible in modern agricultural production (Mazur & Matusevych, 2023). Sunflower yields varied throughout the years studied, which can be explained by different climatic weather conditions (Fig. 1).

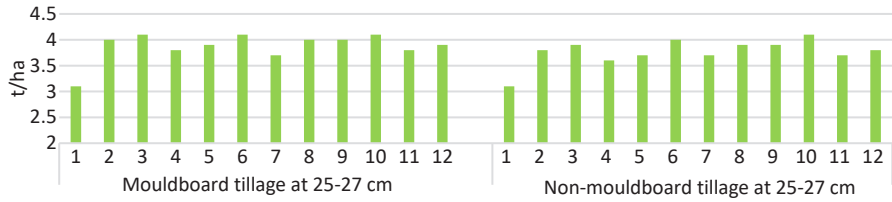

Figure 1. Sunflower yield depending on primary tillage options and weed protection, average for 2022-2024, t/ha, PE "Shans"

Source: developed by the author

In the experiment, the resource provision for sunflower seed yield was calculated at 3.5 t/ha. The manual weeding option provided a yield of 4.0 t/ha with mouldboard tillage and 3.8 t/ha without mouldboard tillage. The yield increase compared to the control variant was 0.9 t/ha. At the same time, despite its high efficiency, this method is too labour-intensive for use on large areas. The maximum average yield within the experiment reached 4.1 t/ha. This result was obtained both with the use of individual preparations and in tank mixture variants. Among individual herbicides, the highest yield was achieved with Primextra TZ Gold at a rate of 4.5 l/ha and Challenge at a dose of 5 l/ha. Among tank mixtures, the best result was observed with the combined use of Challenge (2.5 l/ha) and Racer (1.5 l/ha). Other products demonstrated yields within the range of 3.0-3.9 t/ha, which is statistically significantly lower than the reference option ($LSD_{0.5}$ = 0.41 t/ha). Most tank mixtures with yields of 3.5-4.0 t/ha were also inferior in terms of yield and weed control efficacy compared to the most effective treatment schemes. Similar dependencies were confirmed by the results of other studies. L. Peleh & O. Onufriichuk (2024) found that the effectiveness of soil herbicides is largely determined by the type of primary tillage, the moisture content of the seedbed, and the uniformity of application; in case of precipitation deficit after application, the effectiveness decreased by 30-40% regardless of the dose, especially in no-till systems. Similarly, D. Chuyko *et al.* (2021) noted that under conditions of minimum tillage, it is advisable to combine mechanical and chemical methods to increase the effectiveness of weed control.

Similar results were obtained by M. Hussain *et al.* (2018), who emphasised that the use of herbicides in combination with optimal agronomic measures reduces competitive pressure from weeds and increases sunflower yield by 15-20%. In studies, the increase in yield when using the most effective herbicides exceeded this figure, which indicates the high efficiency of the applied preparations and the compliance of agricultural technology with modern requirements. Authors A. Babenko (2017) and N. Meena *et al.* (2019) focused on the impact of weather conditions on the effectiveness of herbicide protection, in particular the role of precipitation during the treatment period. The data confirm this dependence and also show that the use of tank mixtures of herbicides contributes to a more stable action of the preparations under different climatic conditions. V. Borysenko (2024) and V. Kozechko & O. Ivanchenko (2025) noted the limitations of mechanical methods of weed control due to their labour intensity and incomplete effectiveness, which is consistent with the conclusions of the study. The combination of mechanical and chemical measures increases the overall effectiveness of the protection system.

It has been established that the use of different options for primary soil cultivation and herbicide protection systems significantly influenced the formation of sunflower yield components. This dependence is explained by a reduction in competitive pressure from weeds as a result of the effective action of soil herbicides,

which contributed to improved conditions for the growth and development of cultivated plants and increased their productivity. Thus, the diameter of the basket in the control variant was 14 cm, which is 18-34% less than in other variants of the experiment. In the variants with the use of the reference herbicide and manual weeding, the largest baskets were formed, with a diameter of 18 cm, which is a significant increase compared to the control indicators (Fig. 2).

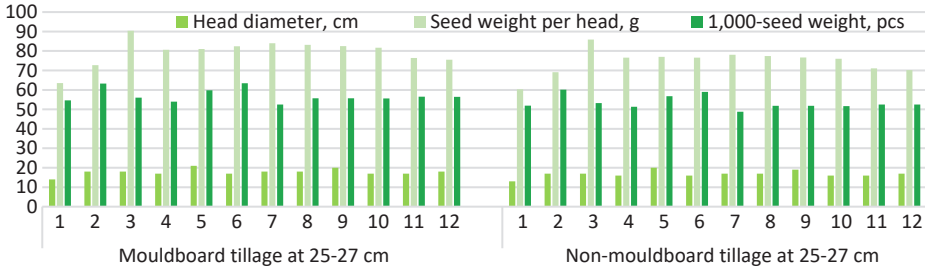

Figure 2. Sunflower yield components depending on the herbicide protection system for the crops, average for 2022-2024, at PE "Shans"
Source: developed by the author

A similar relationship can be observed with regard to the weight of seeds from a single basket: the larger the diameter of the basket, the higher the weight of the seeds, which indicates the direct impact of herbicide protection on the structural elements of the crop. The experimental variants significantly exceeded the control indicator in terms of the weight of 1,000 seeds: manual weeding provided an increase of 13.7%, and treatment with the herbicide Challenge at a rate of 5.0 l/ha provided an increase of 13.8%. Other variants showed a tendency to exceed the control by 1-3%.

It is important to note that the structure of the yield – basket diameter, weight of seeds from one basket, weight of 1,000 seeds – are informative indicators of yield quality that closely correlate with the level of weed control. Similar conclusions were made by V. Kaminskyi *et al.* (2022) and I. Mostoviak *et al.* (2024), who also noted the positive impact of effective herbicide protection on these indicators in their work. The study by S. Shcherban *et al.* (2023) also confirmed the importance of integrated agricultural technologies in achieving high crop quality, in particular emphasising the relationship between herbicide load and morphological characteristics. Thus, the comparative analysis shows that the results of the study are closely related to current scientific data, while supplementing them with new information about the impact of herbicide tank mixtures and the role of tillage systems. This highlights the relevance and practical value of the proposed agrotechnological measures for increasing sunflower productivity in a changing climate.

CONCLUSIONS

It has been established that the presence of weed vegetation has a significant negative impact on sunflower productivity. Weeds caused a significant reduction in crop yields ranging from 0.4 to 1.1 t/ha, depending on the degree of weed infestation. The highest sunflower seed yields in the field trial – 4.1 t/ha – were recorded when using the reference herbicide Primextra TZ Gold (4.5 l/ha) and when using the product Challenge (5.0 l/ha) in combination with mouldboard tillage. Analysis of all herbicide protection options showed that even less effective products contributed to higher yields compared to the control, providing results in the range of 3.0-3.9 t/ha. This indicates the general feasibility of using herbicides as an important component of the sunflower crop protection system, particularly in conditions of intensive farming.

A comparison of the main soil cultivation systems revealed the advantages of the mouldboard tillage method, which provided higher yields compared to the non-mouldboard tillage method. Mouldboard tillage in combination

with herbicide protection improved conditions for sunflower growth, reduced the competitive influence of weeds and created a more favourable soil water and air regime, confirming the need to adapt agricultural techniques to the specific soil and climatic conditions of the right-bank forest-steppe of Ukraine. The use of tank mixtures of herbicides has demonstrated the potential to improve weed control under various weather conditions, which is an important advantage in a changing climate. At the same time, the labour intensity of manual weeding limits its use on large areas, although it contributes to improved yield performance. Therefore, the comprehensive use of effective herbicides in combination with mouldboard tillage is a feasible and effective agronomic measure to increase yields and improve the quality characteristics of sunflowers in the right-bank forest-steppe zone of Ukraine.

Promising areas for further research include optimising herbicide application rates and timing in different primary tillage systems, studying the impact of herbicides on soil biocenoses, and developing the agroecological sustainability of crops. It is also advisable to study combined protection systems that combine chemical, mechanical and biological methods of weed control in order to increase the efficiency, environmental safety and economic feasibility of sunflower cultivation in the region.

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CONFLICT OF INTEREST

None.

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Вплив основного обробітку ґрунту та ґрунтових гербіцидів на продуктивність соняшнику в умовах правобережного лісостепу України

Анотація. Соняшник є однією з найважливіших олійних культур України, яка має велике економічне значення через експорт соняшникової олії. Зростання посівних площ соняшника обумовлене високою рентабельністю та попитом на ринку. Водночас технологія вирощування соняшника є складною, а ефективність виробництва залежить від багатьох факторів, зокрема основного обробітку ґрунту та системи гербіцидного захисту. Метою дослідження було вивчення впливу різних варіантів основного обробітку ґрунту та гербіцидного захисту на врожайність і якість насіння соняшника в умовах правобережного Лісостепу України. Дослідження проводились у 2022-2024 роках на чорноземі типовому малогумусному в приватному підприємстві «Шанс» (Черкаська область). Використовувалися полицевий та безполицевий обробіток ґрунту, а також різні варіанти гербіцидного захисту, включно з ручним прополюванням. Основними показниками були врожайність, діаметр кошика, маса 1000 насінин та якість насіння. Встановлено, що застосування ефективних гербіцидних схем і полицевого обробітку значно підвищувало врожайність соняшника (до 4,1 т/га), порівняно з контролем. Бур'яни істотно знизили врожайність культури (на 0,4-1,1 т/га), зменшуючи параметри врожаю та якість насіння. Ручне прополювання забезпечило високий рівень контролю, проте було трудомістким і економічно неефективним. Найкращі результати отримано за застосування гербіцидів Примекстра TZ Голд (4,5 л/га) та Челендж (5,0 л/га) у поєднанні з полицевим обробітком. Встановлено, що при поєднанні полицевого обробітку з оптимально підібраною схемою гербіцидного захисту формуються кращі показники діаметра кошика, маси насіння з кошика та маси 1000 насінин. Результати засвідчили важливість інтеграції технологічних прийомів ґрунтообробітку та хімічного захисту для підвищення продуктивності посівів соняшника. Результати дослідження можуть бути використані для оптимізації технологій вирощування соняшника в регіоні та підвищення ефективності виробництва

Ключові слова: структура врожаю; бур'яни; врожайність; полицевий обробіток; безполицевий обробіток; Челендж; Примекстра TZ Голд