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Optimisation of mineral nutrition norms for sunflowers to increase yield

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Abstract. The aim of the study was to determine the optimal mineral nutrition rates for sunflower that ensured maximum yield and stable seed quality indicators within the Forest-Steppe zone of Ukraine. The methodology involved a two-year field experiment with four fertilisation variants (control, $N_{120}K_{80}$, $N_{120}P_{80}K_{80}$ and $N_{150}P_{80}K_{80}$), the assessment of morphometric parameters and yield, as well as laboratory analysis of the chemical composition of seeds. Statistical processing of the results was carried out using a comparative analysis approach with an evaluation of the relative increase in indicators compared to the control. It was found that sunflower responded to the level

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of mineral supply already at the early stages of development, with a strengthening effect during the formation of reproductive organs. It was established that the diameter of the head served as a sensitive indicator of fertilisation efficiency, with the highest values recorded under the $N_{120}P_{80}K_{80}$ variant. The yield dynamics were examined and a clear advantage of complete mineral nutrition was identified, ensuring an 83.3% increase in yield compared to the control. The oil output per hectare was analysed and found to rise to 0.73 t/ha under optimal fertilisation, indicating the efficient realisation of the crop's potential. It was summarised that excessive nitrogen supply did not always provide additional benefits, as it might lead to a redistribution of nutrients towards vegetative mass. It was confirmed that balanced NPK nutrition contributed not only to high yield formation but also to stable oil accumulation in seeds. The practical significance of the study lay in the possibility of applying the obtained recommendations by agricultural producers and agronomic services to optimise sunflower nutrition systems under conditions of climate change and resource constraints

Keywords: fertilisation; seed quality; oil content; photosynthetic activity; head diameter; agrotechnologies

INTRODUCTION

Sunflower (*Helianthus annuus* L.) was classified as a strategically important oilseed crop in Ukraine, as it formed the basis of the export potential of the agricultural sector and ensured food stability. Improving seed quality and cultivation efficiency was essential for industrial processing, while changing climatic conditions and unstable water regimes intensified the need for adapted plant nutrition technologies. The system of mineral nutrition served as a key factor in yield formation, maintenance of biochemical balance in the soil, and enhancement of plant tolerance to stress conditions. Therefore, the optimisation of fertiliser rates for modern sunflower hybrids was considered a relevant direction in agrarian science and practice, determining the efficiency of soil resource utilisation and production profitability.

Scientific studies confirmed a strong relationship between mineral element application rates and the morphological parameters of sunflower. According to V. Tsyhanskyi (2020), the adjustment of the soil nitrogen-phosphorus regime promoted propera development of seed chambers and increased the stability of reproductive growth. Similar conclusions were reported in the study by V. Hanhur *et al.* (2022), which demonstrated that the combination of NPK in balanced rates stimulated head growth and ensured uniform yield structure. It was evidenced that during the flowering stage, nutrient deficiencies most significantly disrupted the productive potential of the crop. The research by V. Petrenko *et al.* (2023) traced the territorial differentiation of oil content, confirming the dependency of seed quality on phosphorus availability. Several authors focused on the bioenergetic aspects of nutrition. According to V. Hanhur and O. Kosminsky (2024), proper dosing of mineral fertilisers influenced water consumption and the intensity of photosynthesis, which was particularly important in the Forest-Steppe zone.

One important aspect concerned the response of hybrids to mineral fertilisation. The significance of sowing time and nutritional management was highlighted in the work of O. Trembitska *et al.* (2025), where a combination of agrotechnical factors ensuring maximum crop productivity was established. It was also essential to consider the risks associated with excessive nitrogen input. According to O. Sydiakina and M. Ivaniv (2023), exceeding the optimal fertiliser rates led to hypertrophic growth of vegetative biomass, which reduced seed quality and the efficiency of nutrient use. Hence, the need emerged to determine the threshold of technological feasibility for fertiliser application.

In international studies, particular emphasis was placed on the microbiological processes responsible for nutrient assimilation. The research by Y. Sun *et al.* (2025) revealed a dependence between the structure of the microbial community and phosphorus nutrition, which indirectly influenced the formation of reproductive organs. This position aligned with the findings of L. Hellal *et al.* (2025), who demonstrated that the combination of potassium and trace elements was capable of accelerating oil accumulation in seeds even under unstable water supply. The importance of a comprehensive approach to mineral nutrition was emphasised, with consideration of physiological, soil, and microbiological factors.

Thus, previous studies outlined general tendencies of increased sunflower reactivity to mineral nutrition; however, the parameters of optimal fertilisation rates for the soil and climatic conditions of the Forest-Steppe zone of Ukraine remained insufficiently specified. In this context, scientific interest was directed towards assessing the efficiency of different nutrition systems with regard to the physiology of modern hybrids and the stability of yield quality indicators. Therefore, the aim of the research was to determine the optimal mineral nutrition rates for sunflower that ensured the highest yield and superior seed quality under the experimental conditions.

MATERIALS AND METHODS

The research was conducted in 2023-2024 on the premises of BEL-AGRO LLC, located in the Berdychiv district of Zhytomyr region within the Forest-Steppe zone. The climate of the area was moderately continental with sufficient moisture, yet characterised by an unstable

distribution of precipitation during the vegetation period, which necessitated the optimisation of mineral nutrition to ensure stable sunflower productivity. The experimental plot was predominantly composed of dark grey podzolised soils, with the following nutrient contents recorded at the beginning of vegetation: nitrogen – 98 mg/kg (DSTU ISO 14255:2005, 2006), phosphorus – 104 mg/kg (DSTU 7865:2015, 2016), potassium – 112 mg/kg of soil (DSTU 7865:2015, 2016), and soil pH – 5.8 (DSTU 8346:2015, 2017). Four nutrition variants were established in the experiment, forming a gradient of NPK availability: control (no fertiliser), $N_{120}K_{80}$, $N_{120}P_{80}K_{80}$, and $N_{150}P_{80}K_{80}$. The experimental scheme allowed the assessment of not only the overall fertilisation effect but also the determination of the threshold of technological feasibility for nutrient application.

The experimental design aimed to determine the limit of technological expediency for mineral element application and to verify whether the increased nitrogen dose was economically justified. Fertilisers were applied both during primary tillage and as supplementary feeding. The sources of nutrients were ammonium nitrate (34.6%), double superphosphate (40%), and potassium chloride (60%). The research object was the hybrid sunflower 'Sumiko', sown within the optimal period for the cultivation zone at a rate of 55 thousand seeds per hectare and a row spacing of 70 cm. Agrotechnical practices were implemented according to regionally accepted technology.

Plant monitoring was carried out throughout the vegetation period with the recording of reproductive organ development, while primary measurements were conducted during the full maturity phase. The impact of mineral nutrition was assessed according to three groups of indicators:

- morphometric characteristics – head diameter as an indicator of reproductive potential formation;
- productivity – yield (t/ha) and weight of 1000 seeds;
- seed quality properties – oil content and oil output per unit of area.

Oil content was determined under laboratory conditions using mechanical pressing, which enabled the identification of the actual volume of oil potentially obtainable from 1 hectare of crops. Statistical data processing was conducted using comparative analysis with the calculation of relative increases in indicators compared to the control variant. This approach enabled the evaluation of both the agronomic and technological feasibility of each fertilisation level and the identification of the optimal boundaries for mineral fertiliser application. The authors adhered to the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The conducted research demonstrated that the application of mineral fertilisers had a positive effect on this indicator. In the variant without fertiliser application, the head diameter measured 14.8 cm, which was the lowest among all experimental treatments. This indicated insufficient plant nutrition, which restricted growth and hindered the development of reproductive organs (Fig. 1).

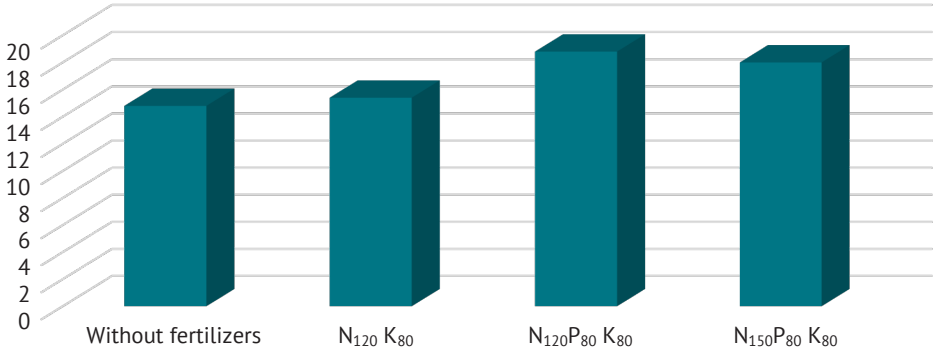

Figure 1. *Head diameter at the full seed maturity stage of sunflower, cm (average for 2023-2024)*
Source: *created by the authors*

The application of nitrogen-potassium fertilisation at a rate of $N_{120}K_{80}$ increased the average head diameter to 15.4 cm, which exceeded the control by 0.6 cm. This confirmed the positive role of nitrogen and potassium in the formation of generative organs. The largest head diameter was recorded in the treatment with complete mineral nutrition – $N_{120}P_{80}K_{80}$ – where it reached 18.8 cm. Compared to the control, this value was higher by 4.0 cm (27.0%), indicating a substantial effect of phosphorus in combination with nitrogen and potassium on the development of the reproductive part of the plant. In the variant with an elevated nitrogen rate (N_{150} $P_{80}K_{80}$), the head diameter measured 18.0 cm, which also significantly exceeded the control (by 3.2 cm), although it was slightly lower than the optimal fertilisation variant. This may indicate that excessive nitrogen nutrition did not always provide an additional advantage and could lead to the redistribution of

nutrients towards vegetative biomass. Overall, the strongest positive effect on head diameter was observed in the $N_{120}P_{80}K_{80}$ treatment, which confirmed the expediency of applying a complete complex of mineral fertilisers in balanced rates.

The formation of high sunflower yield depended on a range of factors, among which rational mineral nutrition was one of the key determinants. Properly selected doses and proportions of nutrient elements – primarily nitrogen, phosphorus, and potassium – supported full plant growth and development, the formation of generative organs, and consequently an increase in yield and improvement in seed quality indicators. Therefore, particular importance was attached to studying the response of modern sunflower hybrids to different fertilisation backgrounds, which enabled the scientific substantiation of optimal agrotechnical practices to achieve maximum productivity under specific soil and climatic conditions. The obtained results demonstrated a significant influence of mineral fertilisation on sunflower yield. The lowest yield was recorded in the control variant, where no fertilisers were applied – 1.8 t/ha (Fig. 2). The application of nitrogen-potassium fertiliser at the $N_{120}K_{80}$ rate increased the yield to 2.2 t/ha, which represented a 0.4 t/ha (22.2%) rise compared with the control. This confirmed the important role of nitrogen and potassium in the processes of growth, photosynthesis, and seed formation.

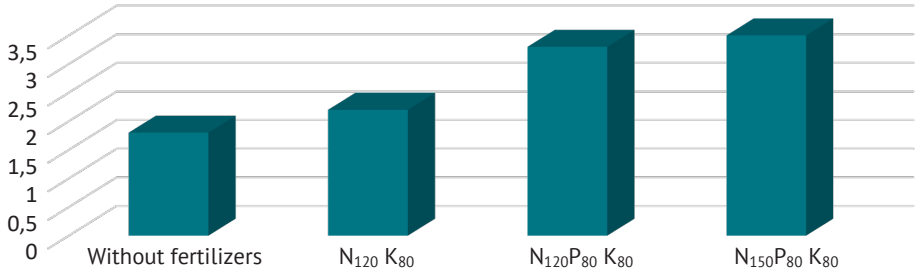

***Figure 2**. Effect of different fertiliser rates on sunflower seed yield, t/ha (average for 2023-2024)*
***Source:** created by the authors*

The highest efficiency was demonstrated by the treatments with complete mineral nutrition. In the $N_{120}P_{80}K_{80}$ variant, the yield reached 3.3 t/ha, which exceeded the control by 1.5 t/ha (83.3%). The application of an increased nitrogen rate in the N_{150} $P_{80}K_{80}$ treatment resulted in the maximum yield – 3.5 t/ha, which was 1.7 t/ha (94.4%) higher than the control and 0.2 t/ha (6.1%) greater than in the previous variant. According to the research findings, a clear trend was identified in the alteration of the chemical composition of sunflower seeds under the influence of different mineral fertilisation rates and the weather conditions of the cultivation years. The most pronounced variations occurred in the indicators of crude protein content and oiliness, which were the key quality parameters of oilseed raw material. During dry years, when plants experienced water deficit in critical development stages (flowering and seed filling), a reduction in seed fat content was observed due to the disruption of photosynthetic processes and lipid assimilation.

The application of mineral fertilisers contributed to more active oil accumulation in sunflower seeds. The most significant increase in oil content was observed when balanced fertiliser rates were used, namely $N_{120}P_{80}K_{80}$ or N_{150} $P_{80}K_{80}$, which supplied the plants with essential nutrients throughout the entire vegetation period. The oil output was determined under laboratory conditions using a mechanical press. The lowest oil content recorded during the research period – 40.7% – occurred in the unfertilised variant. Under the N_{150} $P_{80}K_{80}$ treatment, the oil content was 8.6% higher than in the control, while under complete mineral fertilisation it was 6.4% higher, and 2% lower compared with the increased nitrogen rate. The calculation of oil yield per hectare of sunflower seed was performed (Fig. 3).

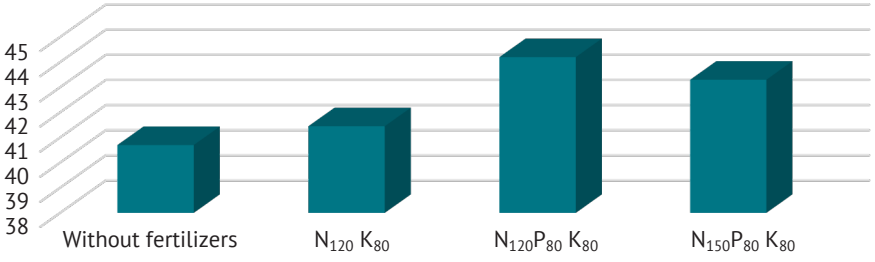

***Figure 3**. Oil output from seeds depending on different fertiliser rates, % (average for 2023–2024)*
***Source:** created by the authors*

Over the two years of field research, the amount of oil that could be obtained from 1 hectare of sunflower crops was determined. On average, this indicator reached 0.73 t/ha, which was considered a rather high result for this zone. The highest oil output was recorded in the variants where mineral fertilisers were applied at optimal and elevated rates. Under optimal mineral nutrition, the oil yield increased by 37.5% compared with the control treatment, where no fertilisers were applied. Even better results were observed under the elevated fertiliser rate, where oil yield rose by 44.4% relative to the control and by 6.9% compared with the $N_{120}P_{80}K_{80}$ variant. This indicated that the application of mineral fertilisers had a positive effect not only on seed yield but also on oil content.

The obtained results indicated that balanced mineral nutrition using the full fertiliser complex at the $N_{120}P_{80}K_{80}$ rate provided the most pronounced positive impact on morphometric parameters, yield, and oil output of sunflower under Forest-Steppe conditions. The increase in head diameter to 18.8 cm and the rise in yield to 3.3-3.5 t/ha corresponded well with the position that an optimal nutrition regime formed not only the mass of the yield but also the structure of reproductive organs. Similar trends were described in the monograph by Ye. Domaratskyi *et al.* (2020), which emphasised that an environmentally balanced system of sunflower fertilisation, with a focus on balanced NPK rates, ensured a substantial productivity increase alongside stable soil conditions.

The sunflower's sensitivity to the mineral nutrition background identified in the research correlated with the findings of O. Sakharchuk and L. Garbar (2018), who demonstrated that the optimisation of nutrition conditions could increase yield by 60-90% compared with the control due to the rational proportion of nitrogen, phosphorus, and potassium. In the conducted study, the yield increase reached 83.3% in the $N_{120}P_{80}K_{80}$ treatment and 94.4% in the N_{150} $P_{80}K_{80}$ treatment, which fell within the range comparable to the cited data. However, the results additionally highlighted that excessive nitrogen nutrition was not accompanied by a corresponding improvement in morphometric parameters, particularly head diameter.

The plant response to different nutrition variants also corresponded to the concept of resource provision in productivity formation, as outlined in the study by G. Pinkovsky *et al.* (2019), where it was demonstrated that a fertilisation system could simultaneously maintain soil fertility and ensure consistently high yields, provided crop rotation constraints were observed. The obtained data confirmed that under dark grey podzolised soils with moderate nutrient content, only complete mineral fertilisation enabled the realisation of the hybrid's productive potential. In this context, the results aligned with the conclusions of Z. Dehtiarova (2023), who emphasised that an increased share of sunflower in short-rotation crop rotations without balanced fertilisation led to soil depletion and a reduced crop response to mineral fertilisers.

The established dependency of yield and oil output on mineral nutrition rates was consistent with the findings of Ye. Domaratskyi *et al.* (2022), which highlighted the pivotal role of water consumption and nutrition in the productivity formation of high-oleic hybrids under increasing climatic variability. In the present study, higher fertiliser rates contributed to better utilisation of moisture and more stable yield formation, which was indirectly supported by the findings of L. Harbar *et al.* (2025), where it was shown that the water consumption regime of sunflower was significantly influenced by technological elements, including nutrition. Overall, the observed increase in yield and oil output could be regarded as the combined effect of mineral provision and water regime.

The improvement in morphometric parameters recorded in the treatments with complete mineral nutrition supported the conclusions of L. Harbar and V. Avramchuk (2024) concerning the sensitivity of hybrids' biometric parameters to nutrition conditions and growth regulators. In both cases, the enhancement of biometric characteristics was viewed as a key link mediating the influence of agrotechnical practices on yield level. In the conducted research, head diameter proved to be a sensitive indicator that clearly responded to changes in NPK rates, with the highest values recorded under balanced combinations of nitrogen, phosphorus, and potassium. Comparison of the study results with the data of H. Drobitko *et al.* (2024) revealed certain differences in approach. While their research focused on resource-saving technologies combined with adapted hybrids in southern regions, the present study concentrated on classical mineral nutrition under Forest-Steppe conditions. However, both studies highlighted that the effectiveness of technology was determined by the interaction between varietal-hybrid characteristics and a properly selected fertilisation system.

The data by V. Gurtovenko (2025) indicated that sunflower productivity in the Right-Bank Forest-Steppe depended not only on nutrition but also on the system of primary tillage and the use of soil herbicides. The current research complemented this perspective by clarifying that under standard technology, the $N_{120}P_{80}K_{80}$ treatment could be considered a baseline for achieving consistently high yield indicators without excessive nitrogen input. A promising direction for further optimisation of nutrition involved the integration of mineral fertilisers with biological preparations, as confirmed by the research of V. Bolokhovsky *et al.* (2024), where the possibility of increasing nutrient use efficiency and reducing chemical load through biological agents was demonstrated. In combination with the conclusions of Yu. Shkatula and

A. Kravets (2025), who examined mineral nutrition of sunflower in an agroecological context, the results of the present study indicated the feasibility of transitioning from mere intensification of NPK rates to the development of balanced nutrition models focused on agroecosystem sustainability.

Taking into account the conclusions of L. Xue *et al.* (2023) regarding differences in the chemical composition of edible oils and the importance of qualitative parameters of the lipid fraction, the increase in seed oiliness and oil output in the variants with complete mineral nutrition acquired not only agronomic but also technological significance. This highlighted that the optimisation of sunflower mineral nutrition should be viewed as a tool for enhancing the competitiveness of raw materials in the edible oil market rather than solely as a means of increasing gross yield. The conducted analysis confirmed the key role of balanced mineral nutrition in sunflower productivity formation. The most effective rate was $N_{120}P_{80}K_{80}$, which ensured an optimal balance of yield and seed quality without excessive resource expenditure. Alignment of the results with modern research confirmed the scientific validity of the experiment and its practical relevance for agro-technologies in the Forest-Steppe zone of Ukraine.

CONCLUSIONS

The conducted research confirmed that the mineral nutrition system was a decisive factor in shaping sunflower yield and seed quality characteristics. It was established that the crop response to NPK supply levels manifested already at the early stages of morphogenesis and intensified during the formation of generative organs, demonstrating a direct dependence of productive potential on the optimisation of mineral nutrition. A detailed analysis of morphometric indicators showed that head diameter, plant height, and leaf apparatus development were sensitive indicators of fertilisation efficiency. The lowest values of these parameters were recorded in the control treatment, indicating limitations in reproductive organ development under conditions of insufficient nutrition.

The optimal response was observed in the $N_{120}P_{80}K_{80}$ treatment, where not only an increase in biometric indicators was recorded, but also the highest yield level. The elevated nitrogen rate ($N_{150}P_{80}K_{80}$) ensured the maximum yield increase; however, the results indicated a likely shift toward excessive vegetative growth at the expense of seed quality, emphasising the need to identify an economically and physiologically justified nutrient balance. Analysis of the chemical composition of seeds demonstrated that balanced nutrition promoted active accumulation of protein and oil, and optimal fertiliser rates could compensate for climatic stresses, which was particularly important in zones with unstable moisture regimes.

The determination of oil yield per hectare confirmed the high effectiveness of optimal fertilisation, which resulted in a 37.5% increase compared with the control. The synthesis of results indicated that the $N_{120}P_{80}K_{80}$ combination created the most favourable conditions for realising the genetic potential of the hybrid and maintaining the agroecological sustainability of production. The research demonstrated that a rational nutrition system was key to production intensification without compromising seed quality or soil fertility. A promising direction for further studies involved the analysis of adaptive mineral nutrition schemes considering climate fluctuations and the use of biostimulants in combination with NPK systems.

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CONFLICT OF INTEREST

The authors of this study declare that there is no conflict of interest.

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Оптимізація норм мінерального живлення соняшнику для підвищення врожайності

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Анотація. Метою дослідження було встановити оптимальні норми мінерального живлення соняшнику, які забезпечують максимальну врожайність та стабільні якісні показники насіння в зоні Лісостепу України. Методологія включала проведення дворічного польового експерименту з чотирма варіантами удобрення (контроль, $N_{120}K_{80}$, $N_{120}P_{80}K_{80}$ та $N_{150}P_{80}K_{80}$), визначення морфометричних показників, урожайності та лабораторний аналіз хімічного складу насіння. Статистична обробка результатів здійснювалася за принципом порівняльного аналізу з оцінкою відносного приросту показників відносно контролю. У ході роботи було визначено, що реакція соняшнику на рівень мінерального забезпечення проявляється вже на ранніх фазах розвитку та посилюється при формуванні репродуктивних органів. Було встановлено, що діаметр кошика є чутливим індикатором ефективності живлення, а найбільші значення цього показника зафіксовано у варіанті $N_{120}P_{80}K_{80}$. Було досліджено динаміку урожайності та виявлено чітку перевагу повного мінерального живлення, яке забезпечило приріст урожайності на 83,3 % порівняно з контролем. Проаналізовано вихід олії з 1 гектара посівів, який збільшився до 0,73 т/га за оптимального удобрення, що свідчить про ефективну реалізацію потенціалу культури. Було узагальнено, що надмірне азотне живлення не завжди забезпечує додаткову перевагу, оскільки може спричиняти перерозподіл поживних речовин у бік вегетативної маси. Підтверджено, що збалансоване NPK-живлення сприяє не лише формуванню високого врожаю, а й стабільному накопиченню олії у насінні. Практична цінність дослідження полягає у можливості використання отриманих рекомендацій агровиробниками та агрономічними службами для оптимізації системи живлення соняшнику в умовах змін клімату та ресурсних обмежень

Ключові слова: удобрення; якість насіння; олійність; фотосинтетична активність; діаметр кошика; агротехнології