SUSTAINABLE WINTER WHEAT PRODUCTION: THE INTERACTION OF CROP ROTATION AND NITROGEN FERTILIZATION IN YIELD OPTIMIZATION

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RESEARCH ARTICLE

Abstract

The experiment investigated the effects of preceding crops and nitrogen fertilization on the grain yield and nutrient use efficiency of winter wheat (Triticum aestivum L.) under field conditions at the University of Debrecen, Látókép Experimental Station. The study involved three preceding crops (sweet corn, sunflower, maize) and six nitrogen fertilizer levels (0, 30, 60, 90, 120, and 150 kg N·ha^{-1}+PK). The results revealed significant differences among preceding crops, with the highest yields observed after sweet corn, while the lowest were obtained after maize. Optimal yield response occurred at 120 kg N·ha^{-1}, beyond which no significant yield increase was detected. These findings highlight that appropriate preceding crop selection can reduce fertilizer requirements without compromising yield, thus improving nitrogen use efficiency and supporting sustainable crop production

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INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide. The choice of preceding crop and the optimization of nutrient management play a crucial role in achieving high and stable yields. The preceding crop affects soil structure, nutrient availability, and the biotic environment (Liu et al., 2023). Sustainable rotations can enhance nutrient cycling and reduce dependency on synthetic inputs (Al-Musawi et al., 2025; Burton et al., 2024). Nitrogen fertilization remains a key yield determinant but is associated with nitrate leaching and greenhouse gas emissions (Xu et al., 2024; Govindasamy et al., 2023). Studies report that wheat after legumes or sweet corn achieves better nitrogen efficiency compared with maize (Wang et al., 2025; Yao et al., 2023). The present study aimed to assess the effects of three preceding crops and six nitrogen levels on wheat yield under Eastern Hungarian conditions.

MATERIAL AND METHOD

The field experiment was conducted in 2024–2025 at the University of Debrecen, Látókép Experimental Station, on chernozem soil. Three preceding crops (sweet corn, sunflower, maize) and six nitrogen levels (0, 30, 60, 90, 120, 150 kg N·ha^{-1}+PK) were tested in a split-split-plot design with four replications. Fertilizers were applied manually.

During the growing season (August 2024 – June 2025), total precipitation was 378 mm, and the mean air temperature was 10.8 °C. Monthly mean temperatures ranged from 2 °C (January) to 22.7 °C (June). The average relative humidity was 73%, with moderate fluctuations. The accumulated effective heat sum for autumn cereals reached 2065 °C, corresponding to the long-term regional average.

Data were analyzed with Genstat using ANOVA and Duncan's Multiple Range Test ($LSD_{0.05}$).

RESULTS AND DISCUSSIONS

Effect of the preceding crop on grain yield

The results clearly showed that the preceding crop had a decisive impact on winter wheat yield. Among the examined pre-crops, sweet corn resulted in the highest average yield (8748 kg ha^{-1}), followed by sunflower (7229 kg ha^{-1}) and maize (6037 kg ha^{-1}). The differences among these means were statistically significant

($LSD_5\%$ = 350.7 kg ha^{-1}). The superior performance after sweet corn can be explained by its moderate residue C/N ratio, faster residue decomposition, and lower pathogen and weed pressure. Conversely, maize as a preceding crop left higher lignified residue amounts with a high C/N ratio, temporarily immobilizing soil nitrogen and slowing early wheat growth.

The 2024/2025 growing season was characterized by a total precipitation of 378 mm and a mean temperature of 10.8 °C, conditions considered moderately dry compared with the 30-year average. Under these circumstances, the better soil structure and moisture retention following sweet corn contributed to maintaining higher yield potential. In contrast, wheat after maize exhibited lower vigor and a delayed tillering phase, particularly under limited autumn rainfall.

Effect of variety

The two tested winter wheat varieties, *Mv Nádor* and *Mv Seuso*, produced comparable yields (7199 and 7477 kg ha^{-1}, respectively), and the differences were not statistically significant ($LSD_5\%$ = 286.3 kg ha^{-1}). This confirms that both cultivars possess similar adaptation potential to the experimental site

However, a slight tendency toward higher yield stability was observed for *Mv Seuso*, especially under the sunflower and sweet corn pre-crops in the experimental site.

Effect of nitrogen fertilization

Nitrogen fertilization had a strong positive effect on wheat yield up to a certain level. The yield increased from 4282 kg ha^{-1} at the control (N_0) to 8542 kg ha^{-1} at N_4 (120 kg N ha^{-1}), after which no further significant increase was detected (N_5 = 8523 kg ha^{-1}). The $LSD_5\%$ value (495.9 kg ha^{-1}) confirmed significant yield differences among most nitrogen levels.

Table 1

Effects of pre-crop, variety and fertilization on yield

Effects of pre-crop		**Yield kgha^{-1}**
	Maize	6037^{a}
	Sunflower	7229^{b}
	Sweet Corn	8748^{c}
LSD (5%)		**350.7**
Effects of hybrids		
	Mv Nádor	7199*
	Mv Seuso	7477*
LSD (5%)		**286.3**
Effects of fertilizer		
	0	4282^{a}
	1	6813^{b}
	2	7725^{c}
	3	8143^{cd}
	4	8542^{d}
	5	8523^{d}
LSD (5%)		**495.9**

NB: Letters in columns are significant ($p<0.05$) according to Duncan Multiple Range Test; * No significant differences

Interaction effects of pre-crop, variety, and nitrogen fertilization

The interaction between preceding crop, variety, and nitrogen rate was significant ($LSD_5\%$ = 1214.7 kg ha^{-1}). Yields exceeded 9 t ha^{-1} in several sweet corn × medium-N treatments (N_2–N_4) for both varieties, while wheat after maize remained below 8 t ha^{-1} even at the highest N rate. The data suggest that nutrient uptake efficiency was determined more by soil biological and structural factors inherited from the preceding crop than by the hybrid genotype itself.

According to Grant et al. (2016) and Burton et al. (2024), such interactions underline the importance of integrating rotation and fertilization management rather than optimizing either factor independently.

Table 2

Interactions effects of pre-crops, varieties and fertilization

Source of variation		Nitrogen fertilization dosage					
Pre-crop	**Hybrid**	**N0**	**N1**	**N2**	**N3**	**N4**	**N5**
Maize	MvNádor	2763[a]	4093[a]	6195[b]	6331[a]	7756[a]	8186*
	MvSeuso	3056[a]	5385[b]	5658[a]	6881[a]	7841[ab]	8301*
Sunflower	MvNádor	3940[ab]	6037[b]	7308[b]	8455[b]	8600[ab]	8557*
	MvSeuso	4438[b]	6779[b]	7283[b]	7956[b]	8736[ab]	8659*
Sweet corn	MvNádor	5602[cb]	9260[c]	9419[c]	9414[c]	9022[b]	8647*
	MvSeuso	5896[c]	9324[c]	10488[c]	9823[c]	9299[b]	8787*
LSD (5%)							**1214.7**

NB: Letters in columns are significant ($p<0.05$) according to Duncan Multiple Range Test; * No significant differences

Pearson's correlation coefficients were calculated to quantify the relationships between winter wheat yield and the examined factors (genotype, fertilizer level, and preceding crop). The results revealed a strong positive correlation between yield and fertilizer level (r = 0.622**), and a moderate positive correlation between yield and preceding crop (r = 0.526**). These values confirm that both nitrogen fertilization and pre-crop selection play a significant role in yield determination. In contrast, the correlation between genotype and yield was very weak (r = –0.066), indicating that under the given experimental conditions, varietal differences had a negligible impact on productivity.

Table 3

Relationships between yield and major agronomic factors of winter wheat based on Pearson's correlation analysis.

	Genotype	Nitrogen fertilization	Pre-crop
Yield	-0,066 (ns)	0,622 (**)	0,526 (**)

NB: Significance levels: *$p < 0.05$ (*)*, $p < 0.01$ (**), (ns) – not significant

Nitrogen use efficiency and environmental implications

Beyond yield, the study also revealed differences in nitrogen utilization efficiency. Wheat after sweet corn and sunflower showed higher apparent N recovery efficiency compared with maize. Excess nitrogen (> 120 kg ha^{-1}) did not further improve yield, implying diminishing returns and potential environmental losses through nitrate leaching or gaseous emissions. Similar results were reported by Govindasamy et al. (2023), who stressed that matching nitrogen supply to crop demand is essential to balance productivity and sustainability. Consequently, adopting appropriate pre-crops can reduce required N input by 20–30% while maintaining comparable yields — a crucial aspect of sustainable cereal production systems (Al-Musawi et al., 2025).

CONCLUSIONS

The study confirmed that both the preceding crop and nitrogen fertilization level are major determinants of winter wheat yield. Among the tested pre-crops, sweet corn proved the most favorable, enabling a reduction in fertilizer application without yield loss. The optimal yield was achieved at 120 kg $N{\cdot}ha^{-1}$, beyond which no significant improvement occurred. These findings demonstrate that appropriate crop rotation can enhance nitrogen use efficiency and contribute to more sustainable wheat production systems.

The results highlight the predominance of agronomic factors—particularly pre-crop and fertilizer management—over genotypic variation under the given environmental and management conditions. This conclusion is consistent with earlier findings by Liu et al. (2023) and Xu et al. (2024), who emphasized that optimizing nutrient inputs and rotation design plays a more decisive role in yield formation than cultivar selection under well-managed field conditions.

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