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IDENTIFYING THE OPTIMUM NITROGEN RATE FOR MAXIMIZING WINTER WHEAT YIELD AND NITROGEN USE EFFICIENCY IN JIANGSU, CHINA

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Abstract

A field study was conducted to evaluate the response of winter wheat growth and yield attributes to different nitrogen application rates under cropland conditions. Treatments consisted of increasing nitrogen levels from N0 to N300 kg ha^{-1}. Results showed that all measured agronomic traits were significantly influenced by nitrogen application. Plant height, leaf length, and spike length increased progressively with higher nitrogen rates, with maximum values recorded at N300kg ha^{-1} (76 cm, 26 cm, and 8.3 cm, respectively), indicating enhanced vegetative growth under sufficient nitrogen supply. Yield components also improved significantly with nitrogen fertilization. Grains per spike increased from 38 in the control to 54 under N300kg ha^{-1}, while spikes per square meter more than doubled from 140 to 294, demonstrating improved tillering and reproductive development. Thousand-grain weight showed relatively limited variation but still increased slightly with nitrogen application, reaching a maximum of 50.55 g. Grain yield exhibited a strong response to nitrogen, rising from 2783.20 kg ha^{-1} in the control to 7064.58 kg ha^{-1} under N300kg ha^{-1}. However, yield gains began to plateau beyond N240-N300kg ha^{-1}, indicating diminishing returns at higher nitrogen levels. Although N300kg ha^{-1} produced the highest yield, differences among the highest nitrogen treatments were minimal, suggesting an optimal response range between N270 and N300kg ha^{-1} under the conditions studied. Overall, nitrogen application significantly enhanced winter wheat growth and productivity, primarily by improving vegetative growth, spike density, and grain number. However, the observed plateau at higher nitrogen rates highlights the need for optimized nitrogen management to maximize yield efficiency while avoiding unnecessary fertilizer inputs.

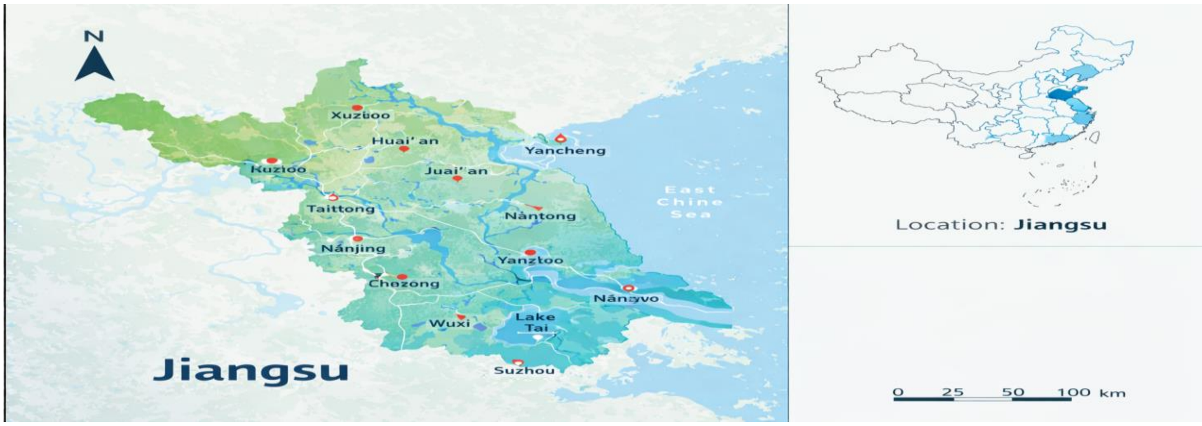
Keywords: *winter Wheat, Nitrogen application, Yield response, Growth parameters, Grain yield, Spike density, Agronomic traits, Nitrogen use efficiency, Cropland management, Fertilizer optimization.*

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple crops globally, playing a critical role in food security, particularly in high-yielding agricultural regions such as Jiangsu Province, China (Liu et al., 2016). However, achieving high winter wheat productivity while maintaining environmental sustainability remains a major challenge due to the excessive and inefficient use of nitrogen (N) fertilizers (Carrijo et al., 2017). Although nitrogen is essential for plant growth and grain formation, over-application often leads to diminishing returns in yield and significant losses through leaching, volatilization, and greenhouse gas emissions, thereby reducing nitrogen use efficiency (NUE) and increasing environmental risks(Manzoor et al., 2024;Ma et al., 2008).Recent studies have consistently shown that optimizing nitrogen input is crucial for balancing crop productivity and resource efficiency in intensive winter wheat-based systems (Bai et al., 2020). Meta-analyses across China have demonstrated that winter wheat yield and NUE are strongly influenced by nitrogen application rates, soil fertility status, and climatic conditions, with excessive N inputs failing to produce proportional yield gains (Man et al., 2014; Li et al., 2020) . Similarly, optimized nitrogen management strategies, such as split applications and site-specific fertilizer scheduling, have been reported to significantly enhance grain yield, photosynthetic efficiency, and nitrogen uptake efficiency in winter wheat systems (Kaleri et al., 2024;Zhang et al., 2020).In China's major winter wheat producing regions, including the Yangtze River Basin and Jiangsu croplands, nitrogen inputs are often higher than the crop demand, resulting in low NUE and environmental degradation. Recent evidence indicates that the yield response to nitrogen follows a plateau trend, where yield increases sharply at lower to moderate N rates but stabilizes or declines beyond an optimal threshold, suggesting that indiscriminate nitrogen application is economically and environmentally unsustainable (Nadeem et al., 2022; De Oliveira; Gadahi et al., 2024).Therefore, identifying the optimum nitrogen rate is essential to maximize winter wheat yield while improving nitrogen use efficiency under local agro-ecological conditions. This study focuses on determining the most efficient nitrogen application level for winter wheat production in Jiangsu, China.

Material and Methods

Study Area in China



Experimental location and materials

The field experiment was conducted at the Agricultural Meteorology Experimental Station of Nanjing University of Information Science and Technology (32.16◦N, 118.86◦E) from November 2024 to June 2025. This area is situated in the Subtropical Monsoon Climate Zone, featuring abundant rainfall, with an annual average temperature of 15.5 ◦C and an annual average precipitation of 1019 mm. The tested soil was yellow-brown in Jiangsu province. Before experiment, the pH of the surface soil (0–15 cm) was 6.2, the soil organic matter was 19.4 g kg^{-1}, the total nitrogen was 1.45 g N kg^{-1}, the alkaline-hydrolysable nitrogen was 80.3 mg N kg^{-1}, the available phosphorus was 16.2 mg P kg^{-1}, the available potassium was 113 mg K kg^{-1}, the clay content was 26.1 %, the field capacity was 27 %, and the bulk density was 1.37 g cm^3.

Statistical analysis

Statistical analysis was performed on the data collected through ANOVA via Statistix-8.1 Computer Software (Statistix, 2006). In cases where it remained deemed necessary, the LSD test was utilized to compare the superiority of different treatments.

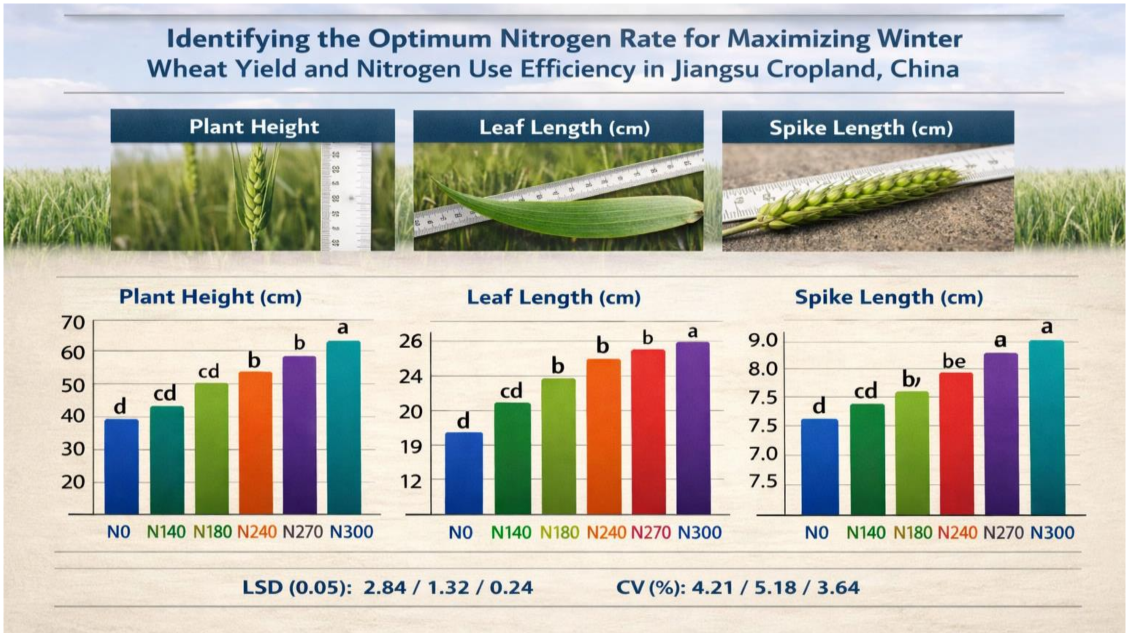
Results

Table 01. Identifying the Optimum Nitrogen Rate for Maximizing winter Wheat Yield and Nitrogen Use Efficiency in Jiangsu Cropland, China

Treatment	Plant Height (cm)	Leaf Length (cm)	Spike Length (cm)	Grains Spike-1	No. of Spikes	Weight (g)	Yield (kg/ha)
N0	58	16	7.6	38	140	48.60	2783.20
N140	62	18	7.8	41	225	49.90	5620.12
N180	64	22	7.9	47	241	50.05	5844.90
N240	67	23	8.0	51	273	50.40	6026.33
N270	72	24	8.1	52	287	50.50	6783.29
N300	76	26	8.3	54	294	50.55	7064.58

LSD (0.05)	**2.84**	**1.32**	**0.24**	**3.15**	**15.42**	**0.56**	**218.65**
CV (%)	**4.21**	**5.18**	**3.64**	**4.87**	**5.32**	**1.46**	**3.78**

Figure 01. Identifying the Optimum Nitrogen Rate for Maximizing winter Wheat Yield and Nitrogen Use Efficiency in Jiangsu Cropland, China



1. Plant Height (cm)

Plant height of winter wheat increased significantly with increasing nitrogen application rates (Table 01 and figure 01). The minimum plant height (58 cm) was recorded in the control treatment (N0), indicating poor vegetative growth under nitrogen deficiency. Application of nitrogen at 140 kg ha^{-1} increased plant height to 62 cm, while further increments were observed at higher nitrogen levels. The maximum plant height (76 cm) was recorded under N300kg ha^{-1}, representing a substantial improvement over the control. The steady increase in plant height suggests that nitrogen played a key role in enhancing vegetative growth and biomass accumulation. The LSD value (2.84) confirmed that differences among treatments were statistically significant.

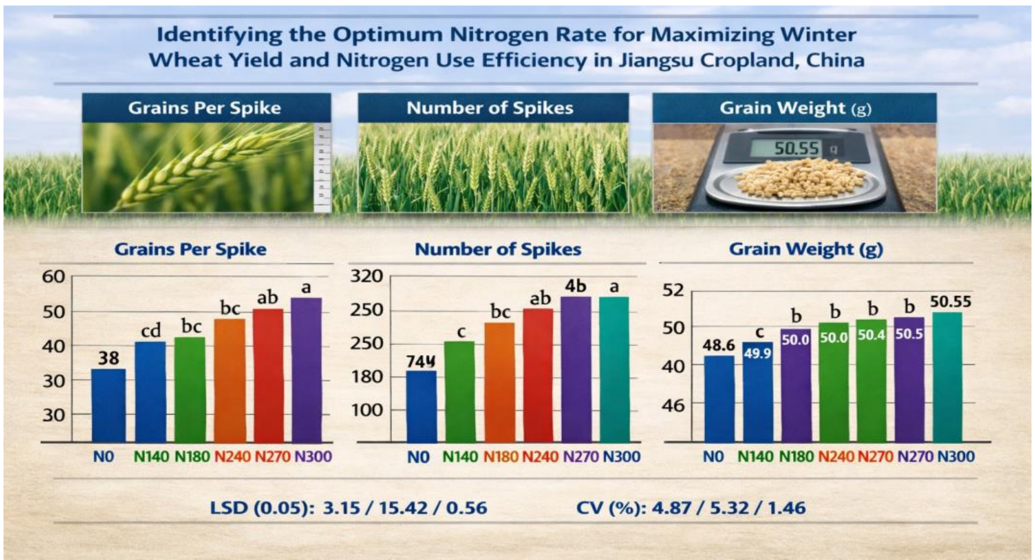
2. Leaf Length (cm)

(Table 01 and figure 01). Leaf length showed a consistent and significant response to nitrogen application. The lowest leaf length (16 cm) was observed in N0, while nitrogen application progressively increased leaf expansion. N140, N180, N240, N270, and N300kg ha^{-1} recorded leaf lengths of 18, 22, 23, 24, and 26 cm, respectively. The maximum leaf length under N300kg ha^{-1} indicates improved photosynthetic surface area under higher nitrogen availability. The LSD (1.32) confirmed that all treatment differences were statistically significant, while the low CV (5.18%) indicates good experimental precision.

3. Spike Length (cm)

(Table 01 and figure 01). Spike length increased slightly but consistently with nitrogen application. The control treatment produced the shortest spikes (7.6 cm), while N300kg ha^{-1}produced the longest spikes (8.3 cm). Intermediate nitrogen treatments showed gradual improvements from 7.8 cm (N140kg ha^{-1}) to 8.1 cm (N270kg ha^{-1}). Although the magnitude of change was relatively small compared to other traits, the increase was statistically significant (LSD = 0.24), indicating that nitrogen positively influenced reproductive structure development.

Figure 02. Identifying the Optimum Nitrogen Rate for Maximizing winter Wheat Yield and Nitrogen Use Efficiency in Jiangsu Cropland, China**.**



4. Grains per Spike

The number of grains per spike increased markedly with nitrogen fertilization. (Table 01 and figure 02). The lowest value (38 grains spike^{-1}) was observed in the control treatment, while the highest value (54 grains spike^{-1}) was recorded under N300 kg ha^{-1}. A progressive increase was observed across all nitrogen levels, indicating improved floret fertility and grain formation with increasing nitrogen availability. The LSD value (3.15) confirmed significant differences among treatments, while CV (4.87%) showed good experimental reliability.

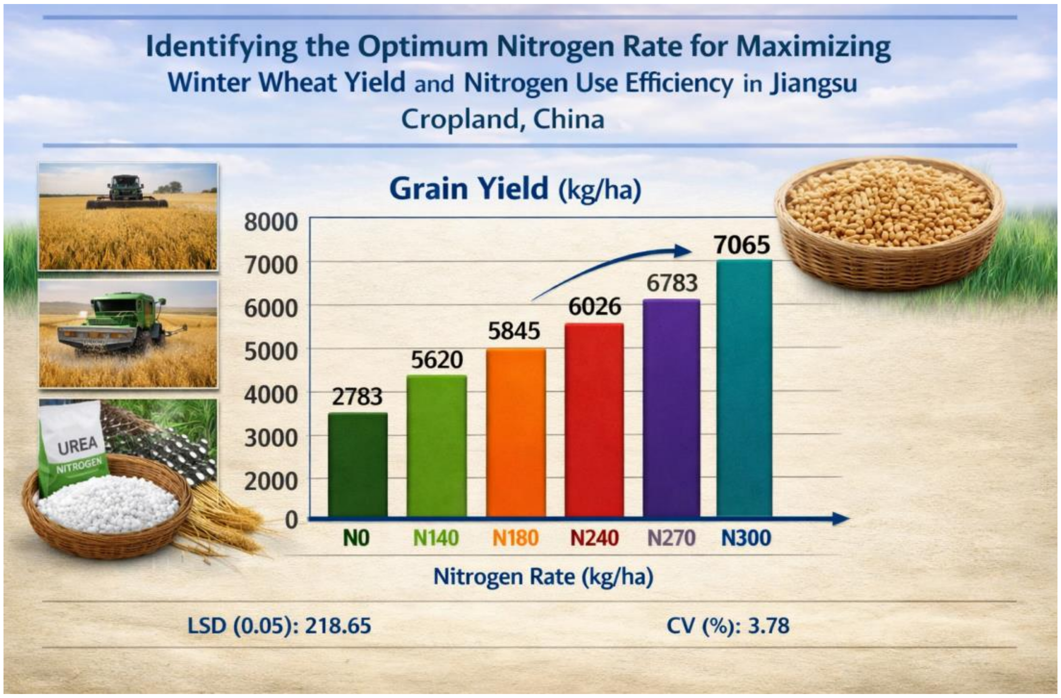
5. Number of Spikes (m^{-2})

(Table 01 and figure 02).The number of spikes per unit area responded strongly to nitrogen application. The control treatment produced the lowest spike density (140 spikes m^{-2}), whereas N300kg ha^{-1} resulted in the highest value (294 spikes m^{-2}). This represents more than a two-fold increase compared to the control. The steady increase across nitrogen treatments suggests that nitrogen significantly enhanced tillering capacity and productive stem formation. The LSD value (15.42) confirmed significant differences among treatments.

6. 1000-Grain Weight (g)

(Table 01 and figure 02).Thousand-grain weight showed comparatively less variation among treatments. The lowest value (48.60 g) was observed in N0, while the highest value (50.55 g) was recorded in N300kg ha^{-1}. Although the increase was modest, nitrogen application had a statistically significant effect (LSD = 0.56). The narrow range of variation indicates that nitrogen primarily influenced grain number and spike density rather than individual grain size.

Figure 03. Identifying the Optimum Nitrogen Rate for Maximizing winter Wheat Yield and Nitrogen Use Efficiency in Jiangsu Cropland, China



7. Grain Yield (kg ha^{-1})

Grain yield increased significantly with increasing nitrogen rates. (Table 1 and figure .03). The control treatment produced the lowest yield (2783.20 kg ha^{-1}). Yield increased sharply to 5620.12kg ha^{-1} under N140kg ha^{-1} and further improved to 5620.12 kg ha^{-1} under N180kg ha^{-1}. Slight increases were observed at higher nitrogen levels, with N240kg ha^{-1} (6026.33 kg ha^{-1}) and N270kg ha^{-1} (6783.29 kg ha^{-1}). The maximum grain yield (7064.58 kg ha^{-1}) was recorded under N300kg ha^{-1}. However, yield differences among N180, N240, N270, and N300kg ha^{-1} were relatively small, indicating a plateau effect at higher nitrogen levels. The LSD value (218.65) confirmed that yield differences were statistically significant, while CV (3.78%) indicated high experimental precision.

Overall Interpretation

All growth and yield parameters showed significant improvement with increasing nitrogen application. However, the rate of increase declined at higher nitrogen levels, particularly beyond N180–N270kg ha⁻¹, suggesting diminishing returns. While N300kg ha⁻¹ produced the highest values for most parameters, the marginal yield advantage over N270kg ha⁻¹was small, indicating that N270–N300kg ha⁻¹ may represent the upper threshold of nitrogen response under Jiangsu cropland conditions. These findings highlight the importance of optimizing nitrogen inputs to maximize winter wheat productivity while avoiding excessive fertilizer application.

Discussion

Optimum Nitrogen Rate for winter Wheat Yield and Nitrogen Use Efficiency in Jiangsu Cropland, China. The Plant height increased significantly with increasing nitrogen (N) application, ranging from 58 cm in control (N0) to 76 cm at N300. This improvement reflects enhanced vegetative growth under adequate nitrogen supply. Nitrogen is a key structural component of chlorophyll and amino acids, which promotes cell division and elongation. Similar responses have been widely reported in recent studies, where increasing nitrogen supply improved winter wheat canopy development and plant height due to enhanced photosynthetic activity and biomass accumulation (Zhang et al., 2020; Duncan et al., 2018). According to (Terrile et al., 2017), optimal nitrogen availability significantly increases internode elongation, leading to taller plants and improved early vigor. However, excessive vegetative growth may not always translate into higher yield if lodging risk increases (Yang et al., 2019). Leaf length also increased progressively from 16 cm (N0) to 26 cm (N300kg ha⁻¹), indicating improved leaf expansion under higher nitrogen availability. Increased leaf area enhances light interception and photosynthetic efficiency. Recent studies confirm that nitrogen fertilization significantly enhances leaf growth and chlorophyll concentration, thereby improving the photosynthetic capacity of winter wheat plants (Meng et al., 2013; Li et al., 2022). Enhanced leaf development is directly associated with higher biomass production and grain yield potential (Addy et al., 2020). Spike length showed a modest but significant increase from 7.6 cm (N0) to 8.3 cm (N300). Although the magnitude of change was smaller compared to vegetative traits, it indicates improved reproductive development under nitrogen supply. Similar findings were reported by (Cossani, & Sadras. 2018). who observed that nitrogen enhances spike development by improving assimilation availability during the reproductive phase. However, spike length is often less responsive than vegetative traits because it is strongly controlled by genetic factors (Deng et al., 2021). Grains per spike increased substantially from 38 (N0) to 54 (N300), indicating improved floret fertility and grain setting under nitrogen fertilization. This trait is highly sensitive to nitrogen availability during spike differentiation. Recent studies highlight that nitrogen improves pollen viability and reduces floret abortion, thereby increasing grain number per spike (Kaleri et al., 2023; Kubar et al., 2025). According to (Umrani et al., 2024), grain number per spike is one of the most nitrogen-responsive yield components in winter wheat. Spike density increased significantly from 140 spikes m⁻² (N0) to 294 spikes m^{-2} (N300), indicating strong enhancement of tillering capacity. Nitrogen stimulates tiller initiation and survival, leading to higher productive spike density. Recent research confirms that nitrogen is a key regulator of tiller formation and survival rate in winter wheat (Naqeebullah et al., 2024; Ahmed et al., 2023). However, excessive nitrogen beyond the optimum may lead to non-productive tillers, reducing nitrogen use efficiency (Zhou et al., 2024). Thousand-grain weight showed limited variation (48.60–50.55 g), indicating that nitrogen had a relatively minor effect on grain size compared to grain number and spike density. This trend aligns with recent findings where grain weight is considered a more genetically stable trait and less responsive to nitrogen compared to grain number (Shar et al., 2025; Rehman et al., 2022). However, slight increases under higher nitrogen may result from improved assimilate supply during grain filling (Memon et al., 2025). Grain yield increased significantly from 2783.20 kg ha^{-1} (N0) to 7064.58 kg ha^{-1} (N300kg ha^{-1}). However, yield gains plateaued beyond N245–N305, indicating diminishing returns at higher nitrogen levels. This trend is consistent with recent studies showing that winter wheat yield responds strongly to nitrogen up to an optimal threshold, beyond which nitrogen efficiency declines (Zhang et al., 2016). Excess nitrogen application often results in luxury consumption, reduced nitrogen use efficiency, and environmental losses (Fan et al., 2018). Overall, nitrogen application significantly improved winter wheat growth and yield components by enhancing vegetative growth, spike formation, and grain number. However, the response curve showed diminishing returns at higher nitrogen levels, particularly beyond N180–N270kg ha^{-1}. Recent agronomic research strongly supports the concept of an "optimal nitrogen threshold," beyond which yield gains plateau while environmental risks increase (Mustafa et al., 2021; Zhao et al., 2019). Therefore, N270–N300 may represent the upper response boundary under Jiangsu cropland conditions, but optimal economic and environmental efficiency may lie at slightly lower rates. These findings emphasize the importance of precision nitrogen management strategies, such as site-specific fertilization and split application, to maximize winter wheat productivity while minimizing nitrogen losses and environmental impact.

Conclusion

Nitrogen application significantly improved winter wheat growth and yield attributes under cropland conditions. Plant height, leaf length, spike length, grain number, and spike density increased progressively with rising nitrogen rates, reaching maximum values at N300 kg ha^{-1}. Grain yield also increased substantially from 2783.20 to 7064.58 kg ha^{-1}; however, yield response began to plateau beyond N180–N270. Although the highest yield was obtained at N300, differences among upper nitrogen levels were minimal. Overall, nitrogen enhanced winter wheat productivity mainly through improved vegetative growth and yield components. The results indicate an optimum nitrogen range of N270–N300, highlighting the importance of efficient nitrogen management.

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