

The Effect of Nitrogen Fertilizer Application Methods on Dry Matter Accumulation and Distribution in Maize

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Abstract: Maize is one of China's three major grain crops and a core grain crop in Heilongjiang Province. Its dry matter accumulation and distribution directly determine yield levels, and nitrogen fertilizer application methods are key factors in regulating this process. To identify a nitrogen management regimen suitable for the cold black soil region, this study employed split-plot field experiments using Zhengtai No. 1 maize. Two factors were set: nitrogen application depth (deep application at 15 cm and surface application) and nitrogen application rate (240, 270, 290 kg·hm⁻²) as the two main factors, while also including a control without nitrogen application, to systematically investigate the effects of different nitrogen application combinations on above-ground dry matter accumulation and organ allocation ratios during the maize maturity stage. The results showed that the aboveground dry matter yield of maize in all nitrogen-applied treatments was significantly higher than that of the no-nitrogen control. Dry matter yield initially increased with increasing nitrogen application rate before stabilizing, reaching a peak at 270 kg·hm⁻²; aboveground dry matter yield in the deep nitrogen application treatment was 5.2% higher than in the shallow application treatment at the soil surface, and nitrogen application rate was the dominant factor regulating maize dry matter accumulation. In terms of dry matter allocation, deep nitrogen application increased the proportion of dry matter allocated to the ear by 3.6% compared to shallow application, while the proportion allocated to vegetative organs such as stems and leaves decreased by 8.3%; The optimal proportion of dry matter allocated to the ear was observed at a nitrogen application rate of 270 kg·hm⁻²; in the DN2 treatment, the ear's proportion reached 59.41%, an increase of

4.55% compared to the control. Excessive nitrogen application up to 290 kg·hm⁻² reduced the efficiency of dry matter allocation to the ear. This study identified deep nitrogen application at 15 cm combined with a nitrogen rate of 270 kg·hm⁻² as the optimal application regimen for corn in cold-region chernozems, providing theoretical and technical support for achieving green high-yield corn production and efficient nitrogen utilization in the region.

Keywords: Deep Nitrogen Application; Reduced Nitrogen Application; Dry Matter Accumulation; Dry Matter Allocation

1. Introduction

Maize is one of China's three major grain crops and the primary grain crop in Heilongjiang Province; achieving high and stable yields is of significant strategic importance for ensuring national food security [1]. Nitrogen is a core nutrient that regulates maize growth and development, dry matter production, and yield formation; the proper application of nitrogen fertilizer is a key measure for enhancing maize productivity [2]. Currently, improper nitrogen fertilizer application in cold-region maize production leads to issues such as low nitrogen use efficiency and increased production costs. It also results in insufficient dry matter accumulation and an imbalance in nutrient allocation between vegetative and reproductive organs, thereby limiting yield potential [3]. Deep application of nitrogen fertilizer can reduce nitrogen volatilization losses and improve root absorption efficiency [4]. Reducing nitrogen fertilizer use aligns with the requirements of green agriculture [5]. Reducing nitrogen fertilizer application can prevent nutrient excess and balance maize vegetative and reproductive growth [6]. While there is extensive research on the effects of single nitrogen management

practices on maize growth, studies on the combined effects of nitrogen application depth and rate in cold-region black soil areas remain incomplete, and there is a lack of optimal nitrogen application models tailored to local conditions. Accordingly, using Zhengtai No. 1 as the experimental variety, a field trial was conducted in Yilan County, Harbin City, in 2025 to investigate the effects of nitrogen application depth, application rate, and application ratio on maize dry matter accumulation and distribution. The study aimed to identify suitable nitrogen application combinations for maize in cold regions, with the goal of providing scientific theory and technical support for green and high-yield maize production in Heilongjiang Province.

2. Materials and Methods

2.1 Study Area

The field experiment was carried out from May 3 to October 1, 2025, in Xiaobei Village, Yilan County, Harbin City, Heilongjiang Province (129°40'45"E, 46°8'56"N), which belongs to the central black soil area of Northeast China and is a typical high-yield maize planting area in cold regions. The region has a mid-temperate continental monsoon climate, with distinct four seasons, sufficient sunshine in the maize growing season, and concentrated rainfall. The annual sunshine hours suitable for crop growth are 1213 hours, accounting for 47% of the total annual sunshine hours, which can meet the light energy demand of maize photosynthesis. The annual average temperature is 3.1-3.6°C, the frost-free period is about 141 days, and the annual rainfall is 379 mm. The rainfall and temperature during the maize growth period (from sowing to maturity) are shown in Figure 1. The rainfall is concentrated in the jointing and tasseling stages of maize, and the temperature is suitable, which is conducive to the growth and dry matter accumulation of maize.

2.2 Experimental Design

The subject of this experiment was corn, specifically the Zhengtai No. 1 variety. Seeding took place on May 3, 2025, and harvesting on October 1, 2025, with a growth period of approximately 122 days from seeding to maturity. Each experimental plot featured 65 cm-wide ridges and 24 cm plant spacing, maintaining a plant density of 4,100 plants per

mu.

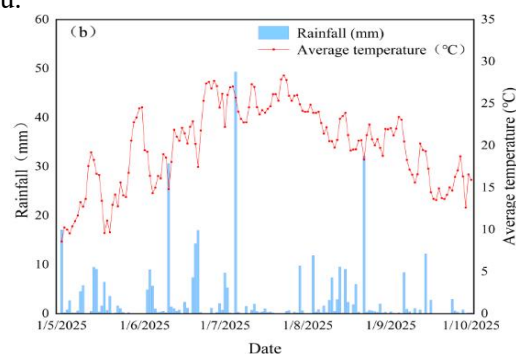


Figure 1. Meteorological Data during Maize Growth Stages

The nitrogen fertilizer used in this experiment was controlled-release urea with a primary nitrogen content of 46%; the phosphorus fertilizer was superphosphate with a primary phosphorus content of 12% P_2O_5 ; and the potassium fertilizer was potassium sulfate with a primary potassium content of 50% K_2O . Phosphate fertilizer (P_2O_5) at 125 kg/ha, potassium fertilizer (K_2O) at 95 kg/ha, and 30% of the total nitrogen requirement in the form of controlled-release urea were mixed uniformly and applied as a basal fertilizer to the experimental plots. During application, a distance of 3–5 cm was maintained between the seeds and the fertilizer to prevent seedling burn. The remaining nitrogen fertilizer was applied to the experimental plots according to the different nitrogen application ratios specified in the experimental design. Topdressing should be applied 7–10 cm from the plant base at a depth of 8–10 cm. Field management practices, such as weeding and pest control, were consistent with local farming practices.

The experimental design employed a split-plot design, with nitrogen application depth as the main factor and nitrogen fertilizer application rate as the sub-factor. The main plot utilized deep nitrogen application (D), while the sub-plots did not use deep nitrogen application (C). Nitrogen application rates were set at three levels (N1: 240 kg·hm⁻², N2: 270 kg·hm⁻², N3: 290 kg·hm⁻²) along with a control group without nitrogen application (CK), resulting in a total of 7 treatments. Each treatment was replicated three times, resulting in a total of 21 experimental plots. Each plot was 6.5 m wide and 6 m long, with an area of 6 m × 6.5 m = 39 m². Each plot contained 10 rows, with the two outer rows designated as buffer rows. The experimental factors, levels, and treatment combinations are shown in Tables 1 and 2 below.

Table 1. Levels of Experimental Factors

Factor	Factor	Factor
Nitrogen Application Rate	N1	240 kg·hm ⁻²
	N2	270 kg·hm ⁻²
	N3	290 kg·hm ⁻²
Nitrogen Application Depth	D	Nitrogen applied at a depth of 15 cm
	C	Nitrogen applied at the soil surface

Table 2. Table of Experimental Treatments

Treatment	Nitrogen Application Rate (kg·hm ⁻²)	Nitrogen Application Depth
CK	—	—
DN1	240	Nitrogen applied at a depth of 15 cm
DN2	270	Nitrogen applied at a depth of 15 cm
DN3	290	Nitrogen applied at a depth of 15 cm
CN1	240	Nitrogen applied at the soil surface
CN2	270	Nitrogen applied at the soil surface
CN3	290	Nitrogen applied at the soil surface

2.3 Test Parameters and Methods

Collection and Analysis of Crop Plants

Samples were collected at the time of corn harvest. The stems, leaves, and ears of the corn plants were separated. After being blanched in an oven at 105°C for 30 minutes, the samples were dried continuously at 75°C until constant weight was reached. Following cooling, the biomass of the whole corn plant and its individual parts was determined using an electronic balance with a precision of 0.01 g. Proportion of Ear Dry Matter to Above-Ground Dry Matter (EDR)

$$EDR = \frac{W_{\text{ear}}}{ADM} \times 100\% \quad (1)$$

Where: W_{ear} — dry matter mass of the ear (g); ADM — dry matter mass of the aboveground parts (g)

Stem Residue Ratio (SRR)

$$SRR = \frac{W_{\text{stem}}}{ADM} \times 100\% \quad (2)$$

Where: W_{stem} — dry matter mass of the stem (g); ADM — dry matter mass of the aboveground parts (g).

Leaf Residue Ratio (LRR)

$$LRR = \frac{W_{\text{leaf}}}{ADM} \times 100\% \quad (3)$$

Where W_{leaf} is the dry weight of leaves (g); ADM is the dry weight of aboveground biomass (g).

2.4 Data Processing and Analysis

All test data were sorted and calculated by Microsoft Excel 2019 to obtain the mean value and standard deviation. SPSS 25.0 software was used for analysis of variance (ANOVA) and Duncan's new multiple range test ($P < 0.05$) to analyze the significant differences among treatments. Origin 2025 software was used to draw charts of dry matter accumulation and organ partitioning ratio to visualize the test results.

3. Experimental Results and Analysis

3.1 Effect of Nitrogen Application Methods on Dry Matter Accumulation

Dry matter accumulation is the material basis of maize yield formation, and the aboveground dry matter weight at maturity directly reflects the biomass production capacity of maize. The effects of different nitrogen application treatments on aboveground dry matter weight of maize at maturity are shown in Figure 2. Compared with the control (CK) treatment, the above-ground dry matter yields of all nitrogen-applied treatments increased significantly. As the nitrogen application rate increased, the yields initially rose and then stabilized, reaching a maximum at the N2 treatment. When nitrogen application was further increased to 290 kg·hm⁻² (N3), dry matter yield did not increase significantly, indicating that excessive nitrogen application cannot further increase dry matter accumulation. Delaying nitrogen application had a minor effect on aboveground dry matter accumulation; nitrogen application rate was the primary factor influencing aboveground dry matter accumulation. The average aboveground dry matter accumulation for the deep nitrogen application treatment was 500 g, while that for the non-deep application treatment was 474.7 g, representing a 5.4% increase in the deep application treatment compared to the non-deep application treatment.

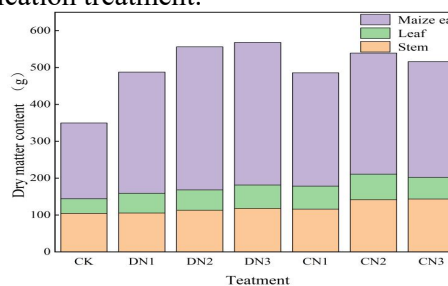


Figure 2. Dry Matter Yield of the Aboveground Biomass in Each Treatment

3.2 Effect of Nitrogen Application Methods on Dry Matter Allocation

Dry matter partitioning between vegetative organs (stems, leaves) and reproductive organs (ears) determines the harvest index and economic yield of maize. The effects of different nitrogen treatments on dry matter partitioning of maize at maturity are shown in Figure 3 and Figure 4. Nitrogen application rate significantly affected the biomass allocation ratio between economic and vegetative organs in the aboveground parts of maize. The proportion of corn ears in the control group (CK) was the lowest, at 58.80%. As nitrogen application rates increased, the proportion of corn ears first increased and then stabilized, reaching a maximum at the N2 application rate. The DN2 treatment reached a maximum of 69.8%, an increase of 11% compared to CK. At the N3 nitrogen application rate, the proportion of corn ears decreased slightly by 0.23% and 1.7%, but remained significantly higher than that of the CK and N1 treatments, indicating that excessive nitrogen application does not promote an increase in the ear proportion. The average proportion of corn ears in the deep nitrogen application treatment was 60.3%, compared to 56.7% in the non-deep application treatment. The deep application treatment had a 3.6% higher proportion of economic organs and an 8.3% lower proportion of vegetative organs than the non-deep application treatment, indicating that deep nitrogen application reduces the allocation of nutrients to vegetative organs. Deep nitrogen application increased the proportion of ear weight relative to total aboveground dry matter compared to the non-deep application treatment.

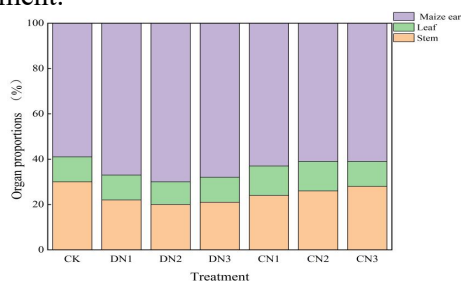


Figure 3. Proportion of Organs at Various Stages of Maturity

4. Discussion

4.1 Effects of Different Nitrogen Application Methods on Dry Matter Accumulation

This study found that nitrogen application significantly increased the dry matter yield of maize aboveground biomass, with the lowest dry matter accumulation observed in the treatment without nitrogen application. This is closely related to the fact that nitrogen is a key element for the synthesis of proteins, chlorophyll, and other essential substances in crops; an adequate supply of nitrogen ensures the photosynthetic physiological activities of maize and promotes biomass accumulation [7]. Nitrogen application rate plays a dominant role in dry matter accumulation. As the nitrogen application rate increased from 240 kg·hm⁻² to 270 kg·hm⁻², dry matter yield continued to rise; it continued to increase until reaching 290 kg·hm⁻², at which point it stabilized as soil nitrogen reached saturation. Plant nitrogen uptake and utilization reached a threshold, and dry matter no longer increased. This indicates that excessive nitrogen application merely results in nutrient waste and environmental risks, and cannot further enhance dry matter accumulation [8].

Deep application of nitrogen fertilizer significantly increased the dry matter yield of maize aboveground parts by 5.4% compared to shallow application. The primary reason is that deep application precisely delivers nitrogen fertilizer to the dense root zone, reducing ammonia volatilization and surface runoff, thereby improving nitrogen absorption and utilization efficiency and providing a continuous nutrient supply for plant growth [9].

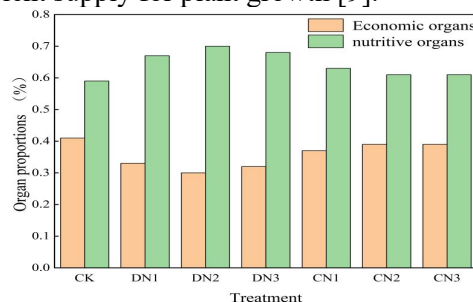


Figure 4. Ratio of Reproductive Organs to Vegetative Organs

4.2 Effects of Different Nitrogen Application Methods on Dry Matter Allocation

The proportion of dry matter allocated to the ear directly determines the economic yield of maize. In this study, nitrogen application methods significantly altered the distribution pattern of dry matter between vegetative and economic organs. Deep nitrogen application significantly increased the proportion of dry matter allocated

to the ear while reducing the proportion retained in vegetative organs such as stems and leaves. This is because deep application improves nitrogen use efficiency, prevents excessive vegetative growth in the early stages, promotes nutrient translocation to the ear in the later growth stages, and optimizes the source-sink relationship [10].

Nitrogen application at 270 kg·hm⁻² results in optimal allocation: at this rate, a balance is achieved between the vegetative and reproductive growth of maize, and dry matter transport efficiency is maximized; excessive nitrogen application leads to nitrogen excess in the plants, causing excessive stem and leaf growth, an imbalance between storage and utilization, and impeded dry matter transport to the ears, resulting in reduced allocation efficiency [11].

5. Conclusions

(1) Nitrogen application can significantly promote the aboveground dry matter accumulation of maize in cold black soil regions. The dry matter weight increases first and then stabilizes with the increase of nitrogen application rate, and 270 kg·hm⁻² is the optimal nitrogen application rate for dry matter accumulation. Nitrogen deep application at 15 cm increases the aboveground dry matter weight by 5.2% compared with surface application, and nitrogen application rate is the dominant factor regulating dry matter accumulation.

(2) Nitrogen application methods significantly affect the dry matter partitioning of maize. Nitrogen deep application can increase the ear dry matter ratio by 3.6% and reduce the vegetative organ dry matter ratio by 8.3%, optimizing the distribution pattern of dry matter. The ear dry matter ratio is the highest at 270 kg·hm⁻², and excessive nitrogen application (290 kg·hm⁻²) reduces the dry matter distribution efficiency to ears.

(3) The optimal nitrogen application mode for maize in cold black soil regions is 15 cm deep nitrogen application combined with 270 kg·hm⁻² nitrogen application rate, which can synchronously realize high-efficiency dry matter accumulation and high-proportion reproductive organ partitioning, improve nitrogen use efficiency, reduce nitrogen waste, and achieve green, high-yield and efficient production of maize.

(4) This study provides a scientific theoretical

basis and practical technical support for nitrogen fertilizer management of maize in cold black soil regions of Heilongjiang Province, and is of great significance for promoting the sustainable development of local maize industry and ensuring national food security.

Acknowledgments

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