Effects of Nitrogen Fertilizer on Post-Anthesis Biomass Production and Leaf Functional Characteristics of Maize Varieties with Different Low-Nitrogen Tolerance: Postprint

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Abstract

To clarify the post-anthesis matter production and leaf functional characteristics of different low-nitrogen-tolerant maize varieties, a field experiment was conducted using the low-nitrogen-tolerant maize variety ‘Zhenghong 311’ and the low-nitrogen-sensitive variety ‘Xianyu 508’ as experimental materials to investigate post-anthesis matter production and leaf functional characteristics under six nitrogen levels. The results showed that nitrogen application significantly increased maize dry matter accumulation, leaf area index, and leaf photosynthetic rate, delayed the decline in leaf chlorophyll content and total nitrogen content after anthesis, inhibited the increase in leaf C/N ratio during the late growth stage, thereby enhancing the final yield of maize. The low-nitrogen-tolerant variety ‘Zhenghong 311’ exhibited significantly higher post-anthesis dry matter accumulation, leaf photosynthetic rate, leaf area index, and yield than the low-nitrogen-sensitive variety ‘Xianyu 508’ , with ‘Zhenghong 311’ showing average increases of 30.5%, 9.2%, 35.0%, and 8.8% compared to ‘Xianyu 508’ , respectively. The difference in leaf chlorophyll content between the two varieties after silking was significant, with the low-nitrogen-tolerant variety ‘Zhenghong 311’ averaging 4.85% higher than the low-nitrogen-sensitive variety ‘Xianyu 508’ . The difference in leaf nitrogen content between the two varieties after silking was not substantial, but the total nitrogen content in leaves during the silking-maturity period decreased by 31.5% and 34.9% for ‘Zhenghong 311’ and ‘Xianyu 508’ , respectively, with the reduction being lower for ‘Zhenghong 311’ than for ‘Xianyu 508’ . The difference in post-anthesis leaf C/N ratio between the two varieties was significant, with ‘Xianyu 508’ averaging 5.95% higher than ‘Zhenghong 311’ . Compared with the low-nitrogen-sensitive variety ‘Xianyu 508’ , the low-nitrogen-tolerant variety ‘Zhenghong 311’ had higher post-anthesis leaf photosynthetic rates and larger leaf area index, while exhibiting lower decreases in leaf chlorophyll content and total nitrogen content and lower increases in C/N ratio, thereby delaying leaf senescence during the late growth stage, extending the functional period of leaves, and increasing dry matter accumulation and yield. Nitrogen application could effectively increase dry matter accumulation, leaf area index, and yield of 'Zhenghong 311' , and delay the increase in leaf C/N ratio during its late growth stage, whereas 'Xianyu 508' required higher nitrogen application levels to maintain its post-anthesis leaf photosynthetic rate and total nitrogen content.

Full Text

Effects of Nitrogen Fertilizer on Post-Silking Dry Matter Production and Leaf Function Characteristics of Maize Varieties with Different Low-Nitrogen Tolerance

Introduction

Low-nitrogen tolerant maize varieties maintain higher chlorophyll content and larger leaf area through the accumulation of organic osmotic adjustment substances such as soluble proteins, soluble sugars, and proline, combined with strong peroxidase (POD) activity that reduces membrane lipid peroxidation damage. These physiological mechanisms sustain photosynthetic production and enhance adaptation to low-nitrogen stress. In contrast, the low-nitrogen sensitive variety 'Xianyu 508' exhibits significant reductions in dry matter production and yield under low-nitrogen stress, with its yield advantages only realized under adequate nitrogen supply conditions.

Materials and Methods

Experimental Design A split-plot experimental design was employed, with maize variety as the main plot factor (A) and nitrogen fertilization level as the subplot factor (B). Two varieties were tested: the low-nitrogen tolerant cultivar 'Zhenghong 311' (A1) and the low-nitrogen sensitive cultivar 'Xianyu 508' (A2). Six nitrogen application rates were established: 0 kg(N) $\cdot$ hm^{-2} (B1), 90 kg(N) $\cdot$ hm^{-2} (B2), 180 kg(N) $\cdot$ hm^{-2} (B3), 270 kg(N) $\cdot$ hm^{-2} (B4), 360 kg(N) $\cdot$ hm^{-2} (B5), and 450 kg(N) $\cdot$ hm^{-2} (B6). Treatments B1 and B2 represented low-nitrogen stress conditions, while B5 and B6 represented adequate nitrogen supply. The experiment included three replications, totaling 36 plots, each with an area of 20 m^2 (5 m length × 4 m width). Maize was direct-seeded (three seeds per hole, then thinned to one plant) at a planting density of 50,000 plants $\cdot$ hm^{-2} with row spacing of (1.5 m + 0.5 m) × 0.2 m.

Nitrogen fertilizer (urea, 46% N) was applied in a 1:1 ratio as basal dressing to ear fertilizer (booting stage fertilizer). Additional basal fertilizers included 600 kg $\cdot$ hm^{-2} of calcium superphosphate and 150 kg $\cdot$ hm^{-2} of potassium chloride.

Other cultivation management practices followed local high-yield requirements and were kept consistent across all plots.

Leaf Area and Leaf Area Index Measurement At key growth stages (large trumpet stage, silking stage, and filling stage), four representative plants were sampled from each plot to measure green leaf area using the length-width coefficient method. Individual leaf area was calculated as length × width × 0.75 (where 0.75 is the correction coefficient). Leaf area index (LAI) was determined as the ratio of total leaf area per unit land area.

Dry Matter Determination Following leaf area measurement, plants were separated into stems/sheaths, leaves, and ears, then oven-dried at 105°C for 30 minutes and subsequently at 80°C to constant weight for dry mass determination.

Chlorophyll Content and Photosynthetic Parameter Measurement At silking, 10 days post-silking, 20 days post-silking, and 30 days post-silking, ear leaves were collected from four representative plants per plot for chlorophyll content (Chl) determination following the method of Zou Qi [30]. At the silking stage, photosynthetic parameters of ear leaves were measured using a LI-6400 portable photosynthesis system on five uniform plants per plot.

Total Carbon and Nitrogen Content Determination Total carbon content in ear leaves at silking, 10 days post-silking, 20 days post-silking, and 30 days post-silking was determined following the method of Bao Shidan [31]. Total nitrogen content was measured using the Kjeldahl method at the same growth stages. The carbon-to-nitrogen ratio (C/N) was calculated as total carbon divided by total nitrogen.

Yield Measurement Twenty consecutive plants from each plot were sampled for yield component analysis, including ear length, ear diameter, bare tip length, rows per ear, kernels per row, single ear weight, kernels per ear, and 1000-kernel weight. Final yield was determined by actual harvest per plot.

Data Analysis Data processing and statistical analysis were performed using Microsoft Excel 2007 and DPS 7.05 statistical software. Differences were tested for significance using the LSD method at $P < 0.05$.

Results

2.1 Differences in Dry Matter Accumulation Among Maize Varieties with Different Low-Nitrogen Tolerance Dry matter production forms the foundation of maize yield formation. As shown in

, the low-nitrogen tolerant variety 'Zhenghong 311' exhibited significantly higher pre-silking, post-silking, and total dry matter accumulation compared to the

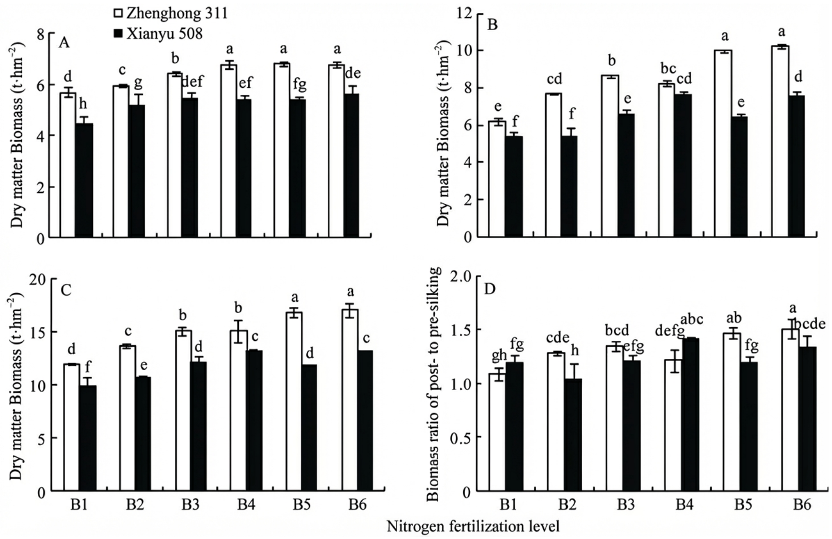

Figure 1: Figure 1

low-nitrogen sensitive variety 'Xianyu 508' . Across all six nitrogen levels, 'Zhenghong 311' averaged 21.3%, 30.5%, and 26.4% higher pre-silking, post-silking, and total dry matter accumulation than 'Xianyu 508' , respectively, indicating that differences between the two varieties primarily originated from the post-silking period.

Nitrogen application significantly increased pre-silking, post-silking, and total dry matter accumulation. Compared with B1, nitrogen treatments increased pre-silking, post-silking, and total dry matter accumulation in 'Zhenghong 311' by an average of 15.1%, 44.2%, and 30.3%, respectively, while in 'Xianyu 508' the increases were 20.9%, 25.3%, and 23.3%, respectively. These results demonstrate that pre-silking nitrogen had a greater promoting effect on dry matter accumulation in 'Xianyu 508' , whereas post-silking dry matter accumulation increased more substantially in 'Zhenghong 311' , with nitrogen fertilizer exerting a stronger overall promoting effect on dry matter accumulation in this variety. Post-silking dry matter production accounted for 57.0% and 55.2% of the entire growth period in 'Zhenghong 311' and 'Xianyu 508' , respectively, highlighting the critical importance of post-silking dry matter production for maize yield. The ratio of post-silking to pre-silking dry matter accumulation was 7.1% higher in 'Zhenghong 311' than in 'Xianyu 508' .

2.2 Effects of Nitrogen Fertilizer on Post-Silking Photosynthetic Production Capacity in Maize Varieties with Different Low-Nitrogen Tolerance Nitrogen application significantly increased net photosynthetic rate (Pn), stomatal conductance (Gs), intercellular CO_2 concentration (Ci), and transpiration rate (Tr) at the silking stage. As shown in , significant differences in photosynthetic parameters at silking were observed between maize varieties with different low-nitrogen tolerance. Under B1 treatment, the low-nitrogen tolerant variety 'Zhenghong 311' showed Pn, Gs, and Tr values 9.2%, 12.5%, and 28.2% higher than those of 'Xianyu 508', respectively, while Ci was 19.9% lower, indicating that 'Zhenghong 311' maintained higher photosynthetic rates under low-nitrogen conditions, ensuring adequate dry matter production.

Compared with B1, nitrogen treatments increased Pn, Gs, Ci, and Tr in 'Zhenghong 311' by an average of 11.0%, 42.2%, 48.2%, and 29.7%, respectively, whereas in 'Xianyu 508' the corresponding increases were 17.5%, 73.9%, 67.6%, and 69.2%, respectively. These results demonstrate that nitrogen fertilizer had a greater promoting effect on photosynthetic parameters at silking in 'Xianyu 508' than in 'Zhenghong 311'.

The magnitude and functional duration of leaf area index (LAI) during the growth period determine leaf photosynthetic capacity and consequently influence dry matter production. As shown in [FIGURE:2], 'Zhenghong 311' maintained significantly higher pre-silking, flowering, and post-silking LAI than 'Xianyu 508', with the difference between the two varieties increasing as the growth stage progressed. Nitrogen application significantly increased pre-silking, flowering, and post-silking LAI. Compared with B1, nitrogen treatments increased these parameters in 'Zhenghong 311' by an average of 16.9%, 27.0%, and 30.8%, respectively, while in 'Xianyu 508' the increases were 11.5%, 39.9%, and 31.6%, respectively. These results indicate that nitrogen fertilizer had a greater promoting effect on pre-silking LAI in 'Zhenghong 311' and on post-silking LAI in 'Xianyu 508'. Across all nitrogen treatments, 'Zhenghong 311' maintained 35.0% higher post-silking LAI than 'Xianyu 508', demonstrating that 'Zhenghong 311' could sustain higher LAI during the mid-to-late growth stages, ensuring greater post-silking dry matter production capacity.

2.3 Changes in Leaf Physiological Characteristics of Maize Varieties with Different Low-Nitrogen Tolerance During Post-Silking Period

Changes in leaf chlorophyll content effectively reflect leaf physiological status and senescence progression. As shown in , chlorophyll content generally increased with nitrogen application rate, exhibiting a temporal pattern of initial decrease, subsequent increase, and final decrease during the post-silking period, with the maximum value occurring at 20 days post-silking. The low-nitrogen tolerant variety 'Zhenghong 311' maintained chlorophyll content 2.3%, 7.1%, 1.7%, and 8.3% higher than 'Xianyu 508' at silking, 10 days post-silking, 20 days post-silking, and 30 days post-silking, respectively, with an average increase of 4.85%. These results indicate that the difference between the two varieties became more pronounced during the period of chlorophyll content decline, with 'Zhenghong 311' better maintaining leaf chlorophyll content to ensure higher dry matter production.

Nitrogen application significantly increased chlorophyll content at all post-silking stages. Compared with B1, nitrogen treatments increased chlorophyll content in ‘Zhenghong 311’ and ‘Xianyu 508’ by an average of 24.5% and 23.8%, respectively, suggesting similar promoting effects of nitrogen fertilizer on post-silking chlorophyll content in both variety types.

As shown in , total nitrogen content in functional leaves of both maize varieties continuously declined during the post-silking period, though the magnitude of decline differed between varieties. The average nitrogen content during the post-silking period was 25.3 $g \cdot kg^{-1}$ and 25.0 $g \cdot kg^{-1}$ for ‘Zhenghong 311’ and ‘Xianyu 508’, respectively, showing no significant difference. However, total leaf nitrogen content decreased by 31.5% and 34.9% from silking to maturity in ‘Zhenghong 311’ and ‘Xianyu 508’, respectively, with the decline being less pronounced in ‘Zhenghong 311’. This indicates that ‘Zhenghong 311’maintained higher nitrogen content during the late growth stage, reflecting vigorous nitrogen metabolism.

Nitrogen application significantly increased leaf nitrogen content during the post-silking period. Compared with B1, nitrogen treatments increased post-silking leaf nitrogen content by an average of 25.3% in ‘Zhenghong 311’ and 27.8% in ‘Xianyu 508’, suggesting that nitrogen fertilizer had a greater promoting effect on post-silking leaf nitrogen content in ‘Xianyu 508’. This indicates that higher nitrogen application rates are required for ‘Xianyu 508’ to maintain adequate post-silking leaf nitrogen content; under low-nitrogen conditions, substantial declines in leaf nitrogen content in this variety would lead to reduced photosynthetic capacity, premature senescence, and compromised final yield formation.

Plant photosynthesis and growth regulation depend on the plant’ s C/N ratio rather than carbohydrates alone. As shown in , the C/N ratio in leaves of both maize varieties increased during the post-silking period, reaching maximum values at maturity. Significant differences in post-silking leaf C/N ratio were observed between the two varieties, with ‘Xianyu 508’ showing values 7.4%, 2.1%, 7.1%, and 7.2% higher than ‘Zhenghong 311’ at the respective stages, representing an average increase of 5.95%. Nitrogen application significantly reduced the post-silking leaf C/N ratio, with nitrogen treatments decreasing this parameter by an average of 20.7% in ‘Zhenghong 311’ and 19.6% in ‘Xianyu 508’ compared with B1. These results indicate that nitrogen application was more effective in maintaining lower post-silking leaf C/N ratios in ‘Zhenghong 311’, thereby delaying leaf senescence and preserving higher photosynthetic capacity.

2.4 Yield Changes in Maize Under Different Nitrogen Levels As shown in [FIGURE:3], nitrogen application significantly increased maize yield. Significant yield differences were observed between maize varieties with different low-nitrogen tolerance, with ‘Zhenghong 311’ producing higher yields than ‘Xianyu 508’ across all nitrogen levels, averaging 8.8% higher yield. Compared with B1, nitrogen treatments increased average yields by 12.0% and 13.3% in ‘Zhenghong 311’ and ‘Xianyu 508’, respectively. The greater yield increase in the low-nitrogen sensitive variety ‘Xianyu 508’ indicates that nitrogen application was more beneficial for this variety’ s yield formation.

Discussion

Dry matter accumulation and distribution form the basis of crop yield formation, while post-silking canopy dry matter production capacity directly determines final maize yield. Pre-silking dry matter accumulation primarily contributes to the development of vegetative organs such as stems and leaves, establishing the foundation for yield formation, whereas post-silking photosynthate accumulation is the key determinant of yield. Sun et al. [22] reported that different maize varieties exhibit varying ratios of post-silking to pre-silking dry matter production and different final yield levels. Our results demonstrate that the low-nitrogen tolerant variety ‘Zhenghong 311’ achieved significantly higher pre-silking, post-silking, and total dry matter accumulation than the low-nitrogen sensitive variety ‘Xianyu 508’ , with the difference in post-silking dry matter accumulation being more pronounced than that in pre-silking accumulation. ‘Xianyu 508’ accumulated more dry matter pre-silking but showed a lower post-silking to pre-silking dry matter accumulation ratio and lower yield. In contrast, ‘Zhenghong 311’ accumulated more dry matter post-silking, maintained a higher post-silking to pre-silking dry matter accumulation ratio, and achieved higher yield, with these parameters being 7.1% and 7.7% higher than those of ‘Xianyu 508’ , respectively.

Nitrogen application significantly increased pre-silking, post-silking, and total dry matter accumulation while enhancing the post-silking to pre-silking dry matter accumulation ratio, ultimately increasing grain yield. However, the promoting effect of nitrogen was significantly greater in the low-nitrogen tolerant variety ‘Zhenghong 311’ than in the low-nitrogen sensitive variety ‘Xianyu 508’ . Our findings indicate that ‘Zhenghong 311’ could more effectively utilize nitrogen to enhance dry matter production capacity and increase post-silking dry matter accumulation, thereby establishing a stronger material basis for higher grain yield.

Post-silking dry matter production capacity determines final yield and is jointly determined by post-silking leaf photosynthetic rate and effective green leaf area. Maize varieties with greater post-silking dry matter production and higher yield exhibit slower declines in leaf chlorophyll content and Pn during the late growth stage, with extended high-photosynthesis duration ensuring adequate carbohydrate supply for grain filling [22,32-33]. The low-nitrogen tolerant variety ‘Zhenghong 311’ maintained higher Pn and transpiration rates at silking than ‘Xianyu 508’ , while showing lower intercellular CO_2 concentration. Nitrogen application significantly improved all photosynthetic parameters at silking, but the promoting effect was greater in ‘Xianyu 508’ than in ‘Zhenghong 311’ , suggesting that ‘Xianyu 508’ requires higher nitrogen levels to maintain high photosynthetic rates.

‘Zhenghong 311’ maintained significantly higher pre-silking, flowering, and post-silking LAI than ‘Xianyu 508’ , with the difference between varieties reaching maximum during the post-silking period. Nitrogen application had a greater promoting effect on pre-silking LAI in ‘Zhenghong 311’ and on post-silking LAI in ‘Xianyu 508’ . These results indicate that ‘Zhenghong 311’ could utilize nitrogen supply during early growth stages to substantially increase leaf area and extend the duration of high LAI, whereas ‘Xianyu 508’ required adequate nitrogen supply during later growth stages to prevent premature leaf senescence and maintain adequate LAI.

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