Effects of Nitrogen Fertilizer Management on Yield and Nitrogen Utilization of Direct-Seeded Cotton After Wheat (Postprint)

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Abstract

A study was conducted to investigate the effects of nitrogen fertilizer management on yield and nitrogen use efficiency of direct-seeded cotton after wheat harvest, aiming to develop appropriate nitrogen application strategies. Using the early-maturing cotton variety 'Zhongmiansuo 50' as experimental material, a split-plot design was employed to examine the effects of nitrogen application rates [0, 75, 150, 225, and 300 kg(N) · hm ^{2}] and application frequencies (once and twice) on biomass, yield, and nitrogen utilization efficiency of direct-seeded cotton after wheat. Results indicated that lint yield increased significantly with nitrogen rate from 0 to 150 kg(N) · hm ^{2}, but the increase was not significant when nitrogen rate exceeded 150 kg(N) · hm ^{2}. Lint yield with two applications was significantly higher than with a single application. The interaction between nitrogen rate and application frequency was significant, with lint yield reaching a relatively high level at a nitrogen rate of 150 kg(N) · hm ^{2} applied in two splits. Biomass and nitrogen accumulation increased with nitrogen rate and application frequency, whereas the nitrogen allocation coefficient to reproductive organs exhibited the opposite trend. Nitrogen apparent recovery efficiency (NARE), nitrogen agronomic efficiency (NAE), and nitrogen physiological efficiency (NPE) decreased with increasing nitrogen rate above 75 kg(N) · hm ^{2}; NARE and NAE increased with application frequency, while NPE showed the opposite pattern. Interaction analysis revealed that NARE and NAE were higher with nitrogen applied twice, whereas NPE was higher with a single application at nitrogen rates of 75–150 kg(N) · hm ^{2}. Correlation analysis showed that biomass and lint yield were significantly positively correlated with nitrogen accumulation, but not significantly correlated with nitrogen allocation coefficient; lint yield was not significantly correlated with nitrogen use efficiency indices. In conclusion, under the experimental conditions, a nitrogen application rate of 150 kg(N) ·

hm 2 split into two applications could achieve relatively high yield and improve nitrogen use efficiency for direct-seeded cotton after wheat harvest.

Full Text

Preamble

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Effect of nitrogen management on lint yield and nitrogen utilization of field-seeded cotton after barley harvest

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Abstract
This study investigated the effects of nitrogen management strategies on lint yield and nitrogen use efficiency in field-seeded cotton after barley harvest to develop appropriate nitrogen application protocols. Using the short-season cotton variety 'CCRI 50', a split-plot design was employed to examine the effects of nitrogen application rate [0, 75, 150, 225, and 300 kg(N) · hm 2] and application frequency (1 or 2 times) on biomass, yield, and nitrogen utilization efficiency. Results showed that lint yield increased significantly with nitrogen rates from 0 to 150 kg(N) · hm 2, with no further significant increase beyond 150 kg(N) · hm 2. Two fertilizer applications produced significantly higher lint yield than a single application. A significant interaction between nitrogen rate and application frequency was observed, with the highest lint yield achieved at 150 kg(N) · hm 2 applied in two splits. Biomass and nitrogen accumulation increased with both higher nitrogen rates and more frequent applications, while the nitrogen distribution coefficient to reproductive organs showed the opposite trend. Apparent nitrogen recovery efficiency (ANRE), agronomic nitrogen efficiency (ANE), and nitrogen production efficiency (NPE) decreased when nitrogen rates exceeded 75 kg(N) · hm 2. ANRE and ANE increased with application frequency, whereas NPE decreased. The interaction analysis revealed that ANRE and ANE were highest with two applications, while NPE was highest with a single application at nitrogen rates of 75-150 kg(N) · hm 2. Correlation analysis indicated that biomass and lint yield were significantly positively correlated with nitrogen accumulation but not with nitrogen distribution coefficient; lint yield showed no significant correlation with nitrogen utilization efficiency. In conclusion, under the experimental conditions, applying nitrogen at 150 kg(N) · hm 2 in two splits achieved high yield while improving nitrogen use efficiency in field-seeded cotton after barley harvest.

Keywords: Field-seeded cotton after barley harvest; Nitrogen management; Nitrogen application frequency; Lint yield; Biomass accumulation; Nitrogen use efficiency

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Introduction

Nitrogen application is a critical measure for regulating crop growth and yield formation, with traditional crop production relying on high nitrogen inputs to achieve high yields. However, research has demonstrated that excessive nitrogen application does not necessarily lead to higher yields and instead results in low nitrogen use efficiency, resource waste, and environmental pollution. Additionally, conventional cotton fertilization involves numerous applications throughout the growing season, increasing labor requirements, reducing profitability, and hindering efficient cotton field development. Therefore, investigating rational nitrogen reduction and simplified application techniques for cotton production is environmentally and economically significant.

The wheat-cotton double-cropping system is the primary planting regime in the lower Yangtze River cotton region. Compared with traditional transplanted cotton, field-seeded cotton after barley harvest offers advantages such as reduced labor costs and suitability for mechanized production, representing the future direction of cotton production in this region. The effective growing period for field-seeded cotton after barley harvest is short, requiring early-maturing conventional varieties and cultivation techniques focused on promoting early development, concentrated flowering, and rapid boll formation. Consequently, nitrogen management strategies for transplanted cotton cannot be directly applied to this system.

Previous studies have shown that optimal nitrogen rates vary significantly among different cotton genotypes and ecological conditions, and that application methods substantially affect both yield and fertilizer use efficiency. Few reports have addressed appropriate nitrogen management for field-seeded cotton after barley harvest in the lower Yangtze River region. Zhang et al. recommended a nitrogen rate of 150–180 $\text{kg(N)} \cdot \text{hm}^{2}$ for field-seeded cotton after barley harvest under straw return conditions, substantially lower than that for transplanted cotton. However, reports on suitable nitrogen management techniques for field-seeded cotton under non-mulched conditions remain scarce.

Based on the climatic and ecological conditions of the lower Yangtze River cotton region and the growth characteristics of field-seeded cotton after barley harvest, this study used the early-maturing variety 'CCRI 50' to investigate the effects of nitrogen management on yield and nitrogen use efficiency, providing a theoretical basis for developing rational nutrient management strategies for this production system.

Materials and Methods

1.1 Experimental Design

Field experiments were conducted in 2013 and 2014 at the experimental station of Jiangsu Academy of Agricultural Sciences in Nanjing, Jiangsu Province (118°50 E, 32°02 N). The soil was clay loam. In the two experimental years, the 0–20 cm soil layer had pH values of 6.0 and 5.9, organic matter content of 12.8 and 13.1 g · kg ^{1}, total nitrogen of 1.01 and 1.08 g · kg ^{1}, available nitrogen of 21.5 and 20.8 mg · kg ^{1}, available phosphorus of 36.8 and 36.1 mg · kg ^{1}, and available potassium of 152.5 and 153.1 mg · kg ^{1}, respectively.

The early-maturing cotton variety 'CCRI 50' was used as experimental material, with nitrogen rate and application frequency as experimental factors. A split-plot design was adopted, with nitrogen rate as the main plot factor and application frequency as the subplot factor. Five nitrogen rates were established: 0 kg(N) · hm ^{2} (N0), 75 kg(N) · hm ^{2} (N1), 150 kg(N) · hm ^{2} (N2), 225 kg(N) · hm ^{2} (N3), and 300 kg(N) · hm ^{2} (N4). Two application frequencies were implemented: one-time application (T1) and two-time application (T2). For T1, all nitrogen was applied one week after seedling emergence. For T2, nitrogen was split-applied at one week after emergence and at initial flowering in a 4:6 ratio. The experiment comprised nine treatment combinations with three replications, totaling 27 plots, each measuring 28 m^2 (4 m × 7 m).

In both years, cotton was direct-seeded on May 25 after barley (Hordeum vulgare L.) harvest at a planting density of 7.5 × 10 plants · hm ^{2} with 76 cm row spacing in an equal-row configuration. Phosphorus and potassium fertilizers were applied at rates of P O 112.5 kg · hm ^{2} and K O 225 kg · hm ^{2}, respectively, with 50% applied at seedling stage and 50% at flowering-boll stage. Other field management practices followed standard procedures.

1.2 Sampling and Measurements

1.2.1 Biomass and Nutrient Accumulation At initial flowering, peak flowering, and boll-opening stages, five representative cotton plants were sampled per plot with three replications. Plants were separated into roots, stems, branches, leaves, and reproductive organs (buds and bolls), then oven-dried at 105°C for 30 minutes and at 80°C to constant weight for biomass determination. The biomass distribution ratio to reproductive organs was calculated. At boll-opening stage, plant samples were ground and analyzed for total nitrogen content using the Kjeldahl method. Nitrogen accumulation and the nitrogen distribution ratio to reproductive organs were calculated using the following formulas:

- Biomass distribution ratio of reproductive organs (%) = (Reproductive organ biomass × 100) / Total biomass
- Nitrogen distribution ratio of reproductive organs (%) = (Reproductive organ nitrogen accumulation × 100) / Total nitrogen accumulation

1.2.2 Yield At boll-opening stage, boll number was surveyed in 20 consecutive plants per plot, and 30 normally opened bolls were harvested to determine boll weight and lint percentage for yield calculation.

1.3 Nitrogen Use Efficiency

Nitrogen use efficiency indices were calculated as follows:

- Apparent nitrogen recovery efficiency (ANRE, %) = [(Nitrogen accumulation in fertilized plot − Nitrogen accumulation in unfertilized plot) × 100] / Nitrogen application rate
- Agronomic nitrogen efficiency (ANE, kg · kg ¹) = (Lint yield in fertilized plot − Lint yield in unfertilized plot) / Nitrogen application rate
- Nitrogen production efficiency (NPE, kg · kg ¹) = Lint yield per unit area / Nitrogen accumulation in plants at maturity

1.4 Statistical Analysis

Data processing and graphing were performed using Microsoft Excel, and statistical analysis was conducted using SPSS 11.0 software.

Results

2.1 Effects of Nitrogen Management on Lint Yield and Components

As shown in , nitrogen rate significantly affected lint yield and yield components. In 2013, lint yield increased with nitrogen rate, though differences between N3 and N4 were not significant. Among yield components, boll number showed similar trends to lint yield; boll weight was lower at N0 and N1 levels; and lint percentage generally decreased with increasing nitrogen rate. In 2014, the highest lint yields were observed at N4 and N2, with yield component trends similar to 2013. Across both years, application frequency significantly affected lint yield, boll number, and lint percentage, but not boll weight. Lint yield and boll number were significantly higher under T2 than T1, while lint percentage was higher under T1 than T2.

Furthermore, significant interactive effects between nitrogen rate and application frequency were observed for lint yield, boll number, and boll weight. In both years, the highest lint yields occurred under N2T2 and N4T2 treatments. Boll number was highest under N2T2, N3T2, and N4T2, while boll weight was highest under N2T2, N3T1, N4T1, and N4T2.

2.2 Effects of Nitrogen Management on Biomass Accumulation and Distribution

As shown in , both nitrogen rate and application frequency significantly affected cotton biomass accumulation. Biomass at all growth stages increased with nitrogen rate. At initial flowering, biomass was higher under T1 than T2, while at peak boll and boll-opening stages, the opposite was observed. The biomass distribution ratio to reproductive organs decreased with increasing nitrogen rate but increased with application frequency. Significant interactive effects were found for biomass and reproductive organ distribution ratio. At boll-opening stage, biomass was highest under N4T2, while the reproductive organ distribution ratio was highest under N0, with consistent trends across both years.

2.3 Effects of Nitrogen Management on Nitrogen Accumulation and Utilization

As shown in , nitrogen rate and application frequency significantly affected nitrogen accumulation and its distribution to reproductive organs. Nitrogen accumulation increased significantly with both higher nitrogen rates and more frequent applications. The nitrogen distribution ratio to reproductive organs showed no significant differences among N0–N2 treatments in 2013 and N0–N1 in 2014, but decreased significantly with higher nitrogen rates thereafter, while increasing significantly with more frequent applications. Significant interactive effects were observed, with nitrogen accumulation highest under N4T2 in both years. The reproductive organ nitrogen distribution ratio was highest under N1T2 and N2T2 in 2013 and under N1T2 in 2014.

Apparent nitrogen recovery efficiency (ANRE) and agronomic nitrogen efficiency (ANE) decreased with increasing nitrogen rate but increased significantly with application frequency. Nitrogen production efficiency (NPE) was higher at N1, decreasing with higher nitrogen rates and with more frequent applications. Interactive effects revealed that ANRE and ANE were highest under N1T2, followed by N2T2, in both years. In 2013, NPE was higher under N1T1 and N2T1, while in 2014 it was higher under N1T1 and N1T2.

2.4 Relationships Between Biomass, Yield, and Nitrogen Accumulation and Utilization

Correlation analysis revealed that cotton biomass and lint yield were extremely significantly positively correlated with nitrogen accumulation but not significantly correlated with the nitrogen distribution ratio to reproductive organs (Table 4). This indicates that yield and biomass formation are based on nitrogen accumulation rather than nitrogen distribution patterns. The reproductive organ biomass distribution ratio was significantly negatively correlated with nitrogen accumulation but extremely significantly positively correlated with the reproductive organ nitrogen distribution ratio, suggesting that nitrogen and biomass distribution patterns are consistent. Biomass showed no significant correlation with ANRE and ANE but was significantly negatively correlated with NPE, indicating that high biomass does not favor improved NPE. The reproductive organ biomass distribution ratio was extremely significantly positively correlated with ANRE, ANE, and NPE, demonstrating that a high reproductive organ biomass distribution ratio benefits nitrogen use efficiency. No significant correlations were found between yield and nitrogen use efficiency indices, indicating that high nitrogen use efficiency and high yield are not necessarily achieved simultaneously.

Discussion

3.1 Effects of Nitrogen Management on Cotton Yield and Biomass

Rational nitrogen application is crucial for regulating crop yield. Generally, cotton yield increases with nitrogen rate at low levels but plateaus after reaching a certain threshold, with excessive nitrogen potentially reducing yield. In this study, high lint yields were achieved at nitrogen rates of 150–300 kg(N) · hm ^{2} in 2013 and 150 kg(N) · hm ^{2} in 2014 under two-split applications, likely due to favorable soil fertility conditions. Traditional transplanted cotton production typically requires nitrogen rates above 337.5 kg(N) · hm ^{2} applied in 4–5 splits. Compared with conventional practices, the current approach reduces nitrogen input by 50% and application frequency by 2–3 times, benefiting cost-effectiveness and environmental protection.

Biomass accumulation forms the basis of crop yield. Wang et al. reported that both excessive and insufficient nitrogen affect biomass. In this study, cotton biomass increased with nitrogen rate, while the reproductive organ biomass distribution ratio showed the opposite trend. Higher reproductive organ biomass distribution ratios at nitrogen rates of 0–75 kg(N) · hm ^{2} suggest that under low nitrogen conditions, vegetative growth is suppressed and photosynthates are preferentially allocated to organs with strong sink capacity. The decreasing reproductive organ distribution ratio with increasing nitrogen rate indicates that higher nitrogen promotes vegetative growth, potentially causing imbalance between vegetative and reproductive growth at later stages. Application frequency also significantly affected biomass, with one-time application promoting rapid vegetative establishment before initial flowering, while two-time application resulted in higher final biomass accumulation and better coordination between vegetative and reproductive growth.

3.2 Effects of Nitrogen Management on Nitrogen Accumulation and Utilization

Biomass accumulation is based on nutrient absorption, and nitrogen management affected nitrogen accumulation and distribution in synchrony with biomass in this study. When nitrogen rates exceeded 75 kg(N) · hm ^{2}, nitrogen use efficiency decreased with increasing rate, indicating that excessive nitrogen is detrimental to efficiency improvement. Compared with one-time application, two-time application increased ANRE and ANE, suggesting that split application better facilitates nitrogen accumulation and yield increase. Interactive effects demonstrated that nitrogen use efficiency was highest at nitrogen rates of 75-150 kg(N) · hm ^{2} with two applications.

3.3 Relationships Between Biomass, Yield, and Nitrogen Accumulation and Utilization

Correlation analysis has shown that nitrogen accumulation is fundamental to biomass and yield formation. In this study, nitrogen accumulation at 75 kg(N) · hm ^{2} was substantially lower than other treatments, resulting in significantly reduced biomass and yield. However, at excessive nitrogen rates such as 300 kg(N) · hm ^{2}, nitrogen accumulation and biomass were significantly higher than at 150 kg(N) · hm ^{2}, but yield differences were not significant, possibly due to delayed maturity associated with excessive nitrogen application. Thus, both too low and too high nitrogen rates are detrimental to yield formation. Under the experimental conditions, nitrogen rates above 150 kg(N) · hm ^{2} not only failed to increase lint yield but also reduced nitrogen use efficiency.

Further analysis revealed no significant correlation between nitrogen use efficiency and yield, indicating that appropriate nitrogen management strategies can achieve both high yield and improved nitrogen use efficiency. Nitrogen management influences nitrogen accumulation and distribution, thereby affecting biomass and yield. Under two-split application, lint yield did not increase significantly when nitrogen rates exceeded 150 kg(N) · hm ^{2}, while nitrogen use efficiency was higher at 75-150 kg(N) · hm ^{2} and decreased thereafter. For example, at 150 kg(N) · hm ^{2}, ANRE and ANE were 17.5% and 3.6 kg · kg ^{1} higher (2013) and 18.5% and 3.0 kg · kg ^{1} higher (2014) than at 300 kg(N) · hm ^{2}, respectively. Therefore, applying nitrogen at 150 kg(N) · hm ^{2} in two splits (seedling and flowering-boll stages) represents the optimal nitrogen management strategy for early-maturing cotton after barley harvest under the experimental conditions.

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Note: Figure translations are in progress. See original paper for figures.