Effects of Row Spacing Configuration on Nitrogen Uptake, Utilization, and Yield of Summer Maize (Postprint)

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Abstract

To determine the suitable row spacing configuration for mechanized production in the summer maize production region of southern Huang-Huai, field experiments were conducted simultaneously at two experimental sites in Fangcheng County and Huixian County, Henan Province, during 2012–2013. Three maize hybrids representing different plant height types—tall-stalk 'XY335', medium-stalk 'ZD958', and short-stalk '512-4'—were used as experimental materials. Two planting densities (low: 60,000 plants · hm 2; high: 75,000 plants · hm 2) and five row spacing configurations (50 cm, 60 cm, 70 cm, 80 cm uniform row spacing, and 80 cm+40 cm wide-narrow row spacing) were established to investigate the effects of different plant-type maize varieties on nitrogen uptake and utilization efficiency and yield under varying density and row spacing conditions. The results demonstrated that under low-density planting conditions, both tall-stalk 'XY335' and short-stalk '512-4' exhibited obvious yield advantages with the 60 cm uniform row spacing treatment; medium-stalk 'ZD958' achieved the highest yield with 60 cm and 70 cm uniform row spacing in Huixian and Fangcheng, respectively. Under high-density planting conditions, both tall-stalk 'XY335' and medium-stalk 'ZD958' achieved the highest yield with the 60 cm uniform row spacing treatment; whereas short-stalk '512-4' showed obvious yield advantages with 50 cm uniform row spacing, though the difference was not significant compared with the 60 cm uniform row spacing treatment. Plant nitrogen accumulation exhibited a trend of initially increasing then decreasing with expanding row spacing, with relatively greater nitrogen accumulation at 60 cm uniform row spacing, which was significantly higher than the 80 cm uniform row spacing and 80 cm+40 cm wide-narrow row spacing treatments under low density, but showed no significant difference among row spacing treatments under high density. Different varieties exhibited differential responses in plant nitrogen accumulation to row spacing: tall-stalk varieties showed no significant differences among row spacings; medium-stalk varieties had the lowest accumulation at 80 cm uniform row spacing, which differed significantly from other row spacing treatments; short-stalk varieties had the highest nitrogen accumulation at 50 cm and 60 cm uniform row spacing, which differed significantly from other row spacings. Under both density planting conditions, grain nitrogen accumulation and nitrogen harvest index both initially increased then decreased with expanding row spacing, reaching maximum values at the 60 cm uniform row spacing treatment, and both were significantly higher than other row spacing treatments. Partial factor productivity of nitrogen fertilizer exhibited a trend of initially increasing then decreasing with expanding row spacing, with higher values at the 60 cm uniform row spacing treatment, though the difference was not significant compared with other row spacing treatments under low density, but was significant compared with the 80 cm uniform row spacing treatment under high density. Compared with other row spacing treatments, the 60 cm uniform row spacing treatment demonstrated relatively higher nitrogen uptake and utilization efficiency and yield, could better coordinate the relationship between soil and plant nitrogen uptake and utilization in maize, and accommodate different plant height types of maize varieties to achieve high yield within a certain density range, and thus could be promoted as a unified row spacing configuration for summer maize in the southern Huang-Huai region.

Full Text

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Abstract

To identify optimal row spacing configurations for mechanized summer maize production in the southern Huanghuai region, field experiments were conducted at two locations (Fangcheng and Huixian) in Henan Province during 2012–2013. Three maize hybrids representing different plant height types—tall 'Xianyu 335' (XY335), medium 'Zhengdan 958' (ZD958), and dwarf '512-4' —were evaluated under two planting densities (low: 60,000 plants · hm ^{2}; high: 75,000 plants · hm ^{2}) and five row spacing configurations (50 cm, 60 cm, 70 cm, 80 cm uniform spacing, and 80 cm+40 cm wide-narrow spacing). The study examined how plant type, density, and row spacing affected nitrogen (N) uptake efficiency, utilization, and grain yield.

Under low-density conditions, both the tall XY335 and dwarf 512-4 achieved superior yields with 60 cm uniform row spacing, while medium-height ZD958 performed best with 60 cm spacing in Huixian and 70 cm in Fangcheng. At high density, XY335 and ZD958 both produced maximum yields with 60 cm spacing, whereas 512-4 showed yield advantages with 50 cm spacing, though not significantly different from 60 cm. Plant N accumulation initially increased then decreased with expanding row spacing, peaking at 60 cm. Under low density, 60 cm spacing produced significantly higher N accumulation than 80 cm and wide-narrow configurations, while differences were non-significant at high density. Varietal responses differed: tall varieties showed no significant differences across spacings; medium varieties had lowest accumulation at 80 cm; and dwarf varieties achieved highest accumulation at 50–60 cm.

Across both densities, grain N accumulation and N harvest index followed similar patterns, reaching maxima at 60 cm and significantly exceeding other treatments. Partial factor productivity of N fertilizer (PPNF) also peaked at 60 cm, with significant differences from 80 cm at high density but not at low density. Overall, 60 cm uniform row spacing provided relatively high N utilization efficiency and yield, effectively coordinating soil-plant N relations and accommodating different plant height types across a range of densities. This configuration is recommended as a unified row spacing for mechanized summer maize production in the southern Huanghuai region.

Keywords: Summer maize; Plant height; Variety; Row spacing; Plant density; Nitrogen uptake and utilization; Grain yield

Introduction

The rapid development of agricultural mechanization has created an urgent need for standardized maize planting configurations to improve harvest efficiency and reduce production costs. In the Huanghuai maize region, inconsistent row spacing has led to decreased mechanical harvesting efficiency and lower economic returns. The United States experience with 76 cm as the standard row spacing offers valuable insights for China' s mechanized maize production. While optimal row spacing is influenced by plant architecture, cultivation patterns, and ecological conditions, arbitrary adjustments based on local conditions substantially reduce mechanical operational efficiency. Moreover, altered spatial arrangements significantly affect maize N uptake and utilization.

Previous research has extensively examined row spacing effects on N efficiency, but typically in conjunction with fertilization and irrigation practices. Few studies have investigated how different plant types respond to row spacing under field conditions regarding N uptake and utilization. This study addresses this gap by evaluating three plant height types across two densities and five row spacings in the southern Huanghuai region, aiming to identify a row spacing that balances high yield with efficient resource use.

Increasing planting density represents an effective yield enhancement strategy, but excessive density causes mutual shading, premature senescence, lodging, and ultimately yield reduction. At fixed densities, appropriate row spacing adjustment can optimize above- and below-ground resource distribution, mitigating adverse effects of high density on population growth and yield. Row spacing modification significantly affects water and fertilizer utilization, particularly N fertilizer efficiency. Research indicates that narrow row spacing increases soil nitrate residue compared to wide spacing, and enhances plant N uptake and utilization efficiency under consistent fertilization. Wide-narrow row planting also improves fertilizer benefit and utilization efficiency compared to uniform spacing.

Future maize production trends emphasize dwarf stature, density tolerance, stress resistance, mechanization adaptability, and resource efficiency. This study systematically evaluates row spacing configurations for different plant height types to provide theoretical support for unified row spacing adoption.

1.1 Experimental Sites

Field experiments were conducted from 2012–2013 at two locations in Henan Province: Fangcheng (33°19 N, 112°89 E) and Huixian (35°45 N, 113°77 E). The Fangcheng site had lime concretion black soil with 12.8 $g \cdot kg^{1}$ organic matter, 0.97 $mg \cdot kg^{1}$ total N, 10.2 $mg \cdot kg^{1}$ available P, and 186.3 $mg \cdot kg^{1}$ available K in the 0–20 cm layer. The Huixian site had fluvo-aquic soil with 10.5 $mg \cdot kg^{1}$ organic matter, 0.83 $mg \cdot kg^{1}$ total N, 13.3 $mg \cdot kg^{1}$ available P, and 177.4 $mg \cdot kg^{1}$ available K.

During June–September, Fangcheng recorded average temperatures of 25.88°C (2012) and 26.38°C (2013) with precipitation of 463.7 mm and 358.3 mm, respectively. Huixian recorded 25.5°C (2012) and 26.63°C (2013) with 315.4 mm and 304.9 mm precipitation.

1.3 Experimental Design

A three-factor split-plot design was employed with three plant height varieties as main plots, five row spacing configurations (50 cm, 60 cm, 70 cm, 80 cm uniform, and 80 cm+40 cm wide-narrow) as subplots, and two planting densities (60,000 and 75,000 plants $\cdot hm^{2}$) as sub-subplots, totaling 30 treatments. Each plot consisted of six rows, 6 m long, with three replications.

Sowing occurred on June 10 in Fangcheng both years, and on June 12 (2012) and June 15 (2013) in Huixian, with harvest in late September. Fertilizer application rates were 240 $kg \cdot hm^{2}$ N, 120 $kg \cdot hm^{2}$ P O , and 150 $kg \cdot hm^{2}$ K O. Phosphorus and potassium were applied as basal fertilizers, while nitrogen was split equally at the 5-leaf and 9-leaf stages. Other field management followed standard high-yield practices.

1.4.1 Soil NO -N Content Determination

At maize maturity, when no effective precipitation or irrigation had occurred for at least two weeks, soil samples were collected from three points per plot at two positions: mid-row and 25 cm from the plant base (mid-narrow row for wide-narrow spacing). Samples were taken at 0–20 cm and 20–40 cm depths using a soil auger. Soil water content was measured, and NO -N content was determined using flow injection analysis.

1.4.2 Plant Nutrient Determination

At maturity, three representative plants per plot were harvested and separated into stems (with sheaths), leaves, grain, and other parts. After oven-drying to constant weight, samples were weighed, ground, and sieved. Nitrogen content was determined by the Kjeldahl method. Plant N accumulation and partial factor productivity of N fertilizer (PPNF) were calculated following Jiang et al. [8] and Lü et al. [20]:

$$\text{N accumulation } (\text{kg} \cdot \text{hm}^{\ 2}) = \text{N content } (\%) \times \text{biomass} \tag{1}$$

$$\text{N harvest index (NHI)} = \frac{\text{grain N accumulation}}{\text{aboveground total N}} \tag{2}$$

$$\text{PPNF } (\text{kg} \cdot \text{kg}^{\ 1}) = \frac{\text{grain yield}}{\text{N application rate}} \tag{3}$$

1.4.3 Yield Measurement

At maturity, all ears from the middle two rows of each plot were harvested, threshed, and weighed. Grain yield was calculated at 14% moisture content.

1.5 Statistical Analysis

Yield data were collected from both Fangcheng and Huixian, while other data were from Huixian only. Data were analyzed using DPS 14.5 for significance testing (LSD method) and SigmaPlot 12.5 for figure preparation.

2.1 Effects of Row Spacing on Maize Yield

Averaged across years and locations, tall XY335 yielded 4.70% more than medium ZD958 (non-significant) and 7.74% more than dwarf 512-4 (significant). Across all varieties, high density increased yield by 8.27% compared to low density (significant). Multi-ANOVA revealed highly significant differences in yield among varieties, densities, and row spacings .

For tall XY335 at low density, 60 cm spacing produced the highest yield in Fangcheng both years (significantly different from wide-narrow spacing in 2013). In Huixian, 60 cm was optimal in 2012 (significantly different from all except 70 cm), while wide-narrow spacing was highest in 2013 (non-significant). At high density, 60 cm spacing was superior at both sites both years, with significant differences from 80 cm and wide-narrow treatments.

For medium ZD958 at low density, 70 cm spacing was optimal in Fangcheng (significantly different from 80 cm and wide-narrow), while 60 cm was best in Huixian (significantly different from 50 cm in 2012 and 80 cm in 2013). At high density, 60 cm was optimal in Huixian both years (significantly different from 80 cm), while Fangcheng showed 60 cm (2012) and 50 cm (2013) as highest, with respective significant differences.

For dwarf 512-4 at low density, 60 cm spacing was superior at both sites both years, showing various significant differences. At high density, 50 cm was optimal in Fangcheng (significantly different from wide-narrow), while 60 cm was best in Huixian (significantly different from 80 cm and wide-narrow in 2012, and from 80 cm in 2013).

2.2 Effects of Row Spacing on Soil NO -N Content

In Huixian, soil NO -N content at mid-row decreased gradually with expanding row spacing (except wide-narrow) . Across varieties and years at low density in the 0–20 cm layer, 50 cm, 60 cm, 70 cm, and wide-narrow treatments showed no significant differences among themselves but were all significantly different from 80 cm spacing. At high density in both soil layers, 50 cm and 60 cm spacings were not significantly different from each other but were significantly different from 70 cm, 80 cm, and wide-narrow treatments.

Soil NO -N content 25 cm from plants showed similar trends, decreasing with row spacing expansion (except wide-narrow). At low density in the 0–20 cm layer, 50 cm and 60 cm spacings were not significantly different but both differed significantly from 80 cm. At high density, 50 cm differed significantly from all other spacings, which were not significantly different among themselves. In the 20–40 cm layer, both densities showed no significant difference between 50 cm and 60 cm, but both differed significantly from other spacings.

2.3.1 Effects of Row Spacing on Plant N Accumulation

Plant N accumulation per plant at maturity was 8.24% higher at high density than low density (significant). Across varieties and years, 60 cm spacing produced the highest accumulation at both densities, significantly exceeding 80 cm and wide-narrow treatments at low density.

Tall XY335 showed no significant differences among row spacings. Medium ZD958 at low density showed no significant differences in 2012, but in 2013, 60 cm differed significantly from 80 cm. At high density, 50 cm, 60 cm, and 70 cm were not significantly different in 2012 but all exceeded 80 cm and wide-narrow; in 2013, 60 cm differed significantly from 80 cm. Dwarf 512-4 at low density showed 60 cm not significantly different from 50 cm but significantly higher than other spacings both years. At high density, 60 cm was highest in 2012 (significantly different from wide-narrow) and 2013 (non-significant).

Multi-ANOVA indicated significant differences in plant N accumulation among varieties, row spacings, and densities .

2.3.2 Effects of Row Spacing on Grain N Accumulation

Grain N accumulation at maturity was 3.7% higher at high density than low density (non-significant). Across varieties and years, 60 cm spacing produced the highest accumulation at both densities, significantly exceeding other treatments. Averaged across years, 60 cm exceeded 50 cm, 70 cm, 80 cm, and wide-narrow by 9.8%, 17.0%, 21.1%, and 16.4% at low density, and by 8.2%, 14.4%, 26.0%, and 17.2% at high density.

2.3.3 Effects of Row Spacing on N Harvest Index

N harvest index averaged 5.18% higher at low density than high density (significant). Across varieties and years, 60 cm spacing was highest at both densities, significantly exceeding other spacings. At low density, 60 cm exceeded 50 cm, 70 cm, 80 cm, and wide-narrow by 8.0%, 12.5%, 19.1%, and 11.0%; at high density, the differences were 6.5%, 11.6%, 20.3%, and 13.2%, respectively.

2.3.4 Effects of Row Spacing on Partial Factor Productivity of N Fertilizer

PPNF was 7.79% higher at high density than low density (significant). Across varieties and years, 60 cm spacing produced the highest values. At low density, differences among spacings were non-significant. At high density, 60 cm differed significantly from 80 cm but not from other spacings.

2.4 Correlation Analysis Among Row Spacing, Yield, and N Utilization

Correlation analysis revealed significant positive relationships between grain yield and plant N accumulation, grain N accumulation, and N harvest index, but negative correlations with mid-row soil NO -N content. Row spacing showed significant negative correlations with N harvest index and soil NO -N content. These results indicate that wide row spacing reduces N utilization efficiency compared to narrow spacing, and that appropriate row spacing reduction enhances N uptake efficiency and increases population yield across plant height types and densities.

3 Discussion and Conclusion

The development of maize mechanization necessitates unified row spacing to improve production efficiency. Proper row spacing configuration optimizes canopy structure and increases yield under fixed densities. While current production still relies primarily on tall and medium-height varieties like XY335 and ZD958, future trends favor dwarf, density-tolerant, lodging-resistant cultivars adapted to mechanization and efficient resource use. This study demonstrates that different plant height types respond distinctively to density and row spacing.

Soil NO -N, the directly absorbable N form, significantly affects fertilizer efficiency. NO -N moves with soil water, and at fixed density, wider row spacing increases soil evaporation, reduces water content, and diminishes nitrate retention. Our results showing decreased soil NO -N with expanding row spacing align with previous findings, confirming that moderate row spacing reduction improves N fertilizer utilization. However, excessively narrow spacing impairs aboveground light and heat resource distribution, reducing photosynthetic efficiency.

Plant N accumulation responses to row spacing varied by plant type: tall varieties were insensitive, medium varieties accumulated less N at wide spacing, and dwarf varieties accumulated more at narrow spacing. This suggests that row spacing reduction benefits N uptake in medium and dwarf varieties.

Our study evaluated three plant height types and two densities to assess unified row spacing feasibility from both high-yield and resource-efficiency perspectives. Results showed that within 50–70 cm spacing, N utilization efficiency and yield varied non-significantly across varieties and densities, but the excessively wide 80 cm spacing exceeded maize' s self-regulation capacity, significantly reducing both parameters.

Enhanced aboveground N accumulation and utilization promotes yield formation. Row spacing configuration affects N uptake, with narrow spacing significantly increasing plant N accumulation under low N conditions, thereby promoting population yield. Our results demonstrate that 80 cm and wide-narrow treatments had the lowest N accumulation. PPNF is a crucial indicator for fertilizer efficiency, while NHI reflects N translocation to grain. Previous studies show wide spacing reduces N recovery and utilization efficiency compared to narrow spacing, which improves NHI, utilization efficiency, translocation efficiency, and population yield. Our findings confirm that 50–70 cm narrow spacing increased N translocation to grain with less residual N in other organs, producing more grain per unit N.

The lower soil NO -N content at 70–80 cm spacing was not solely due to increased crop uptake but likely involved leaching losses, as NO -N moves downward with water. Our 0–40 cm soil data warrant further investigation of deeper soil layers.

Appropriate row spacing improves soil nutrient distribution and physicochemical properties, promoting plant growth and nutrient utilization to increase yield. Our results demonstrate that suitable row spacing significantly affects the soil nutrient environment, and moderate row spacing reduction enhances aboveground nutrient accumulation and utilization while increasing yield. The 60 cm uniform row spacing configuration provided high N utilization efficiency and yield advantages across plant height types and densities, effectively coordinating soil-plant N relations. This configuration is recommended for widespread adoption in mechanized summer maize production in the southern Huanghuai region.

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