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Effect of planting density and nitrogen fertilization on grain yield of hybrid maize

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Abstract
Korean maize yields have stagnated near 5.3 t ha^{-1} for a decade, even as newer hybrids with higher genetic yield ceilings enter the market. One common explanation is that farmers plant too few seeds per hectare and under-fertilise with nitrogen. This research tested that idea by growing hybrid maize (cv. Kwangpyeongok) at four planting densities (55,000, 65,000, 75,000, and 85,000 plants ha^{-1}) crossed with three nitrogen rates (120, 180, 240 kg N ha^{-1}) in a split-plot design at two locations — Daejeon and Jeju — during 2023. Grain yield peaked at 75,000 plants ha^{-1} and 180 kg N ha^{-1} (9.42 t ha^{-1} at Daejeon; 8.87 t ha^{-1} at Jeju). Pushing density to 85,000 plants ha^{-1} lowered yield by 4-7%, while 240 kg N gave no meaningful gain over 180 kg. These results suggest that moderate density increases paired with 180 kg N ha^{-1} can lift Korean maize productivity without raising input costs.

Keywords: Planting density, nitrogen fertilization, hybrid maize, grain yield, plant population, nitrogen rate, crop management, Korean agriculture, Kwangpyeongok, split-plot experiment.

Introduction
Low planting density wastes incoming radiation. Maize is a C4 crop that converts sunlight into dry matter more efficiently than most cereals, but only when the canopy closes early enough to intercept nearly all photosynthetically active radiation by silking [3]. At 55,000 plants ha^{-1}, canopy closure may not occur until well after V12, leaving weeks of radiation underused. Raising the population brings the canopy together sooner, but it also intensifies below-ground competition for water and nitrogen [4].
That is where nitrogen rate comes in. Higher populations need more total N to maintain the same per-plant supply. If N is limiting, dense stands produce small, barren ears that drag down per-hectare yield rather than lifting it [5]. The practical question is whether the density-N interaction observed in US and Chinese Corn Belt conditions also holds on the volcanic soils of Jeju and the alluvial lowlands around Daejeon — two contrasting environments that together represent a good cross-section of Korean maize land.

Field Experimental Design
Trials were established at two sites: the Chungnam Agricultural University farm, Daejeon (36°22′N, 127°21′E; 68 m elevation, alluvial silty clay loam, pH 6.3) and the Jeju College research station (33°27′N, 126°34′E; 290 m elevation, volcanic Andosol, pH 5.8). A split-plot design was used with planting density as the main plot (four levels: 55, 65, 75, 85 thousand plants ha^{-1}) and nitrogen rate as the subplot (120, 180, 240 kg N ha^{-1}), replicated three times at each location. Individual plots measured 6 m × 4.2 m. The hybrid Kwangpyeongok (115-day maturity) was sown on 25 April 2023 at both sites.

Crop Growth Stage Documentation
Emergence occurred 8-10 DAS at Daejeon and 10-12 DAS at Jeju (cooler). V6 was reached 32-35 DAS; topdress N was applied at this stage. Tasseling began 58-62 DAS and silking followed 2-4 days later. Physiological maturity (black layer) was recorded 112-118 DAS depending on site and density. Higher densities delayed silking by 1-2 days, consistent with shading-mediated slower ear development [6].

Material and Methods

Material

Nitrogen was applied as urea (46% N), with 40% broadcast at sowing and 60% side-dressed at V6. Basal phosphorus (60 kg P_2O_5 ha^{-1} as fused superphosphate) and potassium (60 kg K_2O ha^{-1} as KCl) were applied uniformly at sowing. Planting was done by hand-dibbling at the target inter-row and intra-row spacing to achieve the desired population. Irrigation was supplementary, applied by sprinkler only during prolonged dry spells (>10 consecutive rainless days) at Jeju; Daejeon relied on rainfall.

Methods

Five consecutive plants were tagged per plot for growth measurements: plant height, ear height, stem diameter at the second internode, and leaf area index (LAI) at silking. Grain yield was harvested from the net plot area (4.8 m × 2.8 m), adjusted to 14% moisture. Yield components — ears per plant, kernel rows per ear, kernels per row, and 1000-kernel weight — were recorded. Nitrogen use efficiency (NUE) was calculated as grain yield per unit of N applied. Data were analysed as a combined split-plot ANOVA over locations using SAS 9.4 [7], with means separated by Duncan's multiple range test at $p = 0.05$.

Results

Table 1: Grain yield (t ha^{-1}) of hybrid maize as influenced by planting density and nitrogen rate at two Korean locations

Density ($\times 10^3$)	Daejeon 120N	Daejeon 180N	Daejeon 240N	Jeju 120N	Jeju 180N	Jeju 240N	Overall Mean
55	7.14	7.89	8.03	6.58	7.32	7.41	7.39
65	7.86	8.67	8.84	7.21	8.14	8.27	8.17
75	8.41	9.42	9.51	7.84	8.87	8.94	8.83
85	8.12	9.07	9.18	7.43	8.48	8.61	8.48

LSD (0.05): Density = 0.36; N rate = 0.28; Density × N = 0.52; Location × Density = 0.41

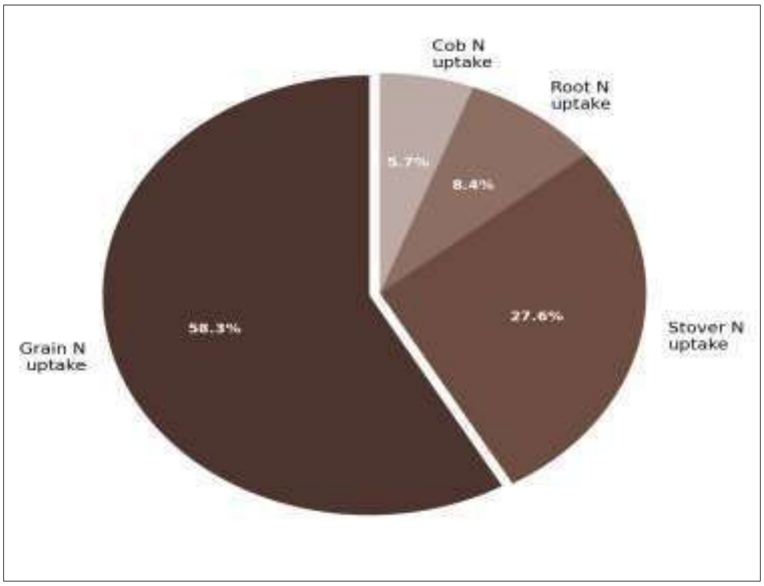

Fig 1: Partitioning of total nitrogen uptake among grain, stover, root, and cob fractions in hybrid maize (pooled across densities and N rates)

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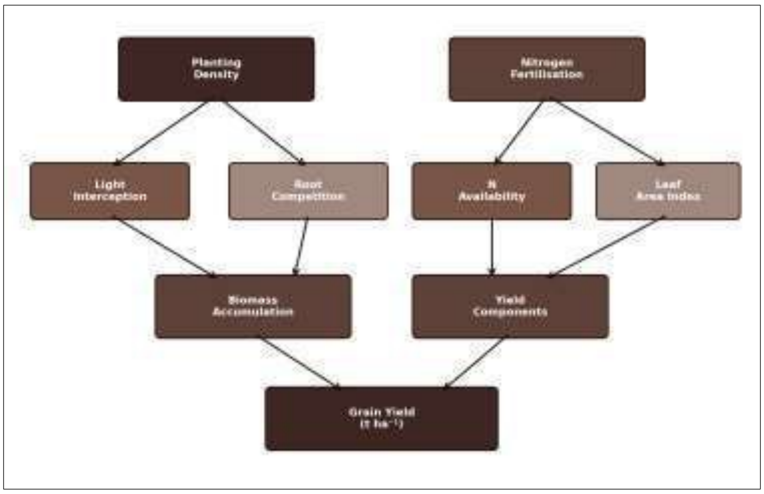

Fig 2: Conceptual pathway showing how planting density and nitrogen fertilization interact to determine grain yield through intermediate growth and yield components.

Comprehensive Interpretation
The 75,000 plants ha^{-1} × 180 kg N ha^{-1} combination produced the best yield at both sites. Going from 55k to 75k plants lifted yield by 17-20% at the 180 N rate because more plants intercepted more light and set more ears per unit area. But at 85k, yield dipped by 4-7% as increased barrenness (0.92 ears per plant vs 1.04 at 75k) and lighter kernels (278 g vs 312 g per 1000) offset the extra population. The jump from 180 to 240 kg N produced only 1-2% additional yield and lowered NUE from 49.3 to 37.1 kg grain per kg N.

Discussion
The density optimum near 75,000 plants ha^{-1} agrees with results from Ciampitti and Vyn [8], who showed that modern temperate hybrids tolerate crowding better than older cultivars but still hit diminishing returns above 80,000 plants ha^{-1}. The 85k density probably crossed the threshold where intra-plant competition for assimilates delays silk emergence relative to pollen shed, increasing the anthesis-silking interval and reducing kernel set [9].

The flat yield response from 180 to 240 kg N suggests that 180 kg N ha^{-1} was already meeting crop demand at these densities. The Jeju Andosol, with its high allophane content, immobilises some applied N in organo-mineral complexes, which may explain the slightly lower yields there despite adequate fertilisation [10]. Daejeon's alluvial soil released more mineralised N from its higher organic-matter reserve, giving an additional background supply.

For Korean farmers currently planting at 55-60k, raising density to 75k and applying 180 kg N ha^{-1} offers a realistic path to 9+ t ha^{-1} yields. The additional seed cost is trivial, and the N rate is actually below the 200 kg ha^{-1} many farmers already apply.

Conclusion
Planting density of 75,000 plants ha^{-1} with 180 kg N ha^{-1} maximised hybrid maize grain yield at both Daejeon (9.42 t ha^{-1}) and Jeju (8.87 t ha^{-1}). Higher density (85k) and higher nitrogen (240 kg) did not improve yield and reduced nitrogen use efficiency. Moderate increases in planting population, combined with judicious nitrogen management, can close the productivity gap in Korean maize farming without additional input cost.

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