Plant Population Influences on Maize Physiological Responses to Nitrogen Application

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I. Introduction

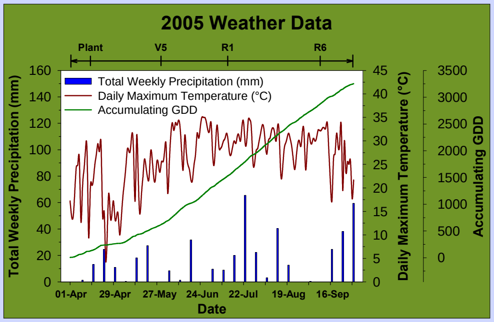
Background:

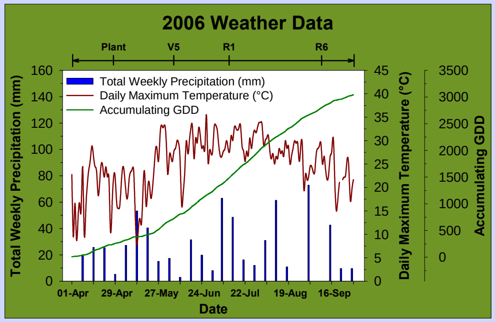
Past genetic improvements in maize (*Zea mays* L.) have led to the creation of modern hybrids that are increasingly tolerant to a variety of stresses, and most notably, high plant populations (Tokatlidis and Koutroubas, 2004). Private- and public-sector breeding efforts have also produced hybrids that are generally more nitrogen (N) efficient (i.e. grain yield per unit N applied) than their older counterparts (Tollenaar and Wu, 1999). However, even when density-tolerant hybrids and N applications are employed, high plant populations can adversely affect overall grain yield due to increased plant-to-plant variability for grain yield and other morpho-physiological traits in addition to a higher incidence of barrenness (Tokatlidis and Koutroubas, 2004; Maddonni and Otegui, 2006). Increased plant-to-plant variability reduces per-unit-area maize grain yield due to unequal resource (e.g. mineral N, soil moisture, and solar radiation) availability per plant. The creation and maintenance of stand uniformity is therefore essential for high productivity levels. The application of N fertilizer is one method by which per-plant resource availability can be improved at high plant populations, thus reducing intraspecific competition and resulting plant-to-plant variability.

Poster Hypotheses:

1) Mineral N availability is more essential for optimizing maize growth and development at high plant populations than at low plant populations.
2) With greater N rates at high plant densities, per-unit-area maize grain yield increases due to decreased per-plant grain yield variability, greater kernel number, reduced silking delays, improved biomass (i.e. source) production, and both delayed and reduced leaf senescence during the grain-filling period.

III. Weather Data





II. Materials and Methods

Experimental Setup:

- Years: 2005-2006
- Location: Purdue University Agronomy Center for Research and Education (ACRE); West Lafayette, IN (40° 28′ N Lat.)
- Soil-type: Chalmers silty clay loam (4% Organic Matter)
- Layout:
  - Split-plot Design
  - Four Blocks
  - 6 Rows Plot^{-1}
- Per-Plant Sampling Area:
  - Rows 3 and 4
  - 4 m Row^{-1}
- Tillage: Fall Strip-tillage
- Starter Fertilizer: 9-18-9 at 150 L ha^{-1}
- Hybrid: Pioneer 31G68

Treatments:

- Plant Population (whole unit):
  - 54,000 plants ha^{-1}
  - 79,000 plants ha^{-1}
  - 104,000 plants ha^{-1}
- N (UAN) Rate (sub unit):
  - 0 kg N ha^{-1}
  - 170 kg N ha^{-1} (V3)
  - 340 kg N ha^{-1} (V3, V5)

Special Note:

- For this poster, only a subset of the previously mentioned per-plant measurements was analyzed. Although results presented here are for only two years and a single hybrid, this experiment involved four years of data (2004-2007) with two hybrids each year; hybrids were the first split, plant population the second split, and N rate the third split in all these tests.

Per-Plant Measurements (Partial List) (≈ 4,000 plants yr^{-1}):

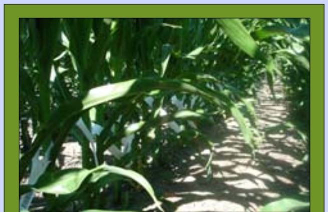
- Emergence Date (GDD Post-planting)
- Plant Spacing (cm)
- Plant Height (cm) [V5, V15, R6]
- 6th Internode Stalk Diameter (mm) [V15, R3, R6]
- Leaf Chlorophyll Content/SPAD [V15 (12th Leaf); R1, R3, R5 (Earleaf)]
- Leaf Area Index (LAI) (R1) (2006) (Valentinuz and Tollenaar, 2006)
- Earleaf Position (V-Stage Location)
- Total Leaf Number
- Anthesis (2006) and Silking (2005, 2006) Date (Number of Days Post-planting)
- Vegetative Biomass (R6) and Harvest Index (HI) (2006)
- Total Kernel Number
- Total Grain Weight (g)
- Grain Moisture Content (%)

Measurement of V5 plant height on individual plants with use of a bar-coded height stick and a Symbol® personal data assistant.

Statistical Analyses:

- Analysis of variance (ANOVA) was performed using SAS® PROC GLM or PROC MIXED for balanced or unbalanced data, respectively.
- The whole-unit error was pooled with the sub-unit error.
- A combined year analysis (2005-2006) was performed, with all year × treatment interactions pooled.
- When treatment effects were significant, least significant difference (LSD) mean separation tests and least-squares mean (LS-mean) separation tests (t-test) were performed for balanced and unbalanced data, respectively.

Measurement of R3 stalk diameter at the 6th internode on individual plants with use of a digital caliper and a Visor® personal data assistant.



Use of bar-coded tags and stakes for the monitoring of individual plant growth and development in a per-plant sampling area.

IV. Results

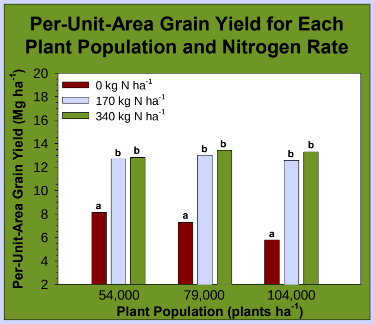


Figure 1:

Per-unit-area grain yield (GY_A) was determined by machine harvest of 4 m by 30.5 m or 27.5 m plots in 2005 and 2006, respectively. Means with different letters indicate statistically significant differences at $P \leq 0.05$ within each plant population. The plant population × N-rate interaction was significant at $P \leq 0.05$ ($P = 0.013$).

Key Results:

1. GY_A increased within each plant population with an initial application of 170 kg N ha^{-1}.
2. No increase in GY_A resulted from a second 170 kg N ha^{-1} application at each plant density.
3. GY_A decreased dramatically with increasing plant population for the 0 kg N ha^{-1} rate.
4. The lowest GY_A was present for the 104,000 plants ha^{-1}, 0 kg N ha^{-1} treatment combination.

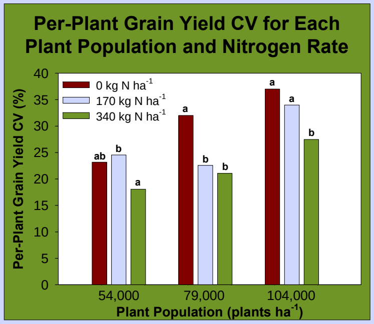


Figure 2:

CV represents the coefficient of variation. Means with different letters indicate statistically significant differences at $P \leq 0.05$ within each plant population. The plant population × N-rate interaction was significant at $P \leq 0.10$ ($P = 0.089$).

Key Results:

1. Per-plant grain yield variability (GY_{CV}) generally increased with increasing plant population regardless of N rate.
2. An initial N application of 170 kg ha^{-1} decreased GY_{CV} at 79,000 plants ha^{-1} but not at 104,000 plants ha^{-1}.
3. Although a second N application of 170 kg ha^{-1} did not increase GY_A (Figure 1) at the highest plant density, it did result in a significant decrease in GY_{CV}.
4. The treatment combination of 104,000 plants ha^{-1}, 0 kg N ha^{-1} had the highest GY_{CV}, while the treatment combination of 54,000 plants ha^{-1}, 340 kg N ha^{-1} had the lowest GY_{CV}.

IV. Results (cont.)

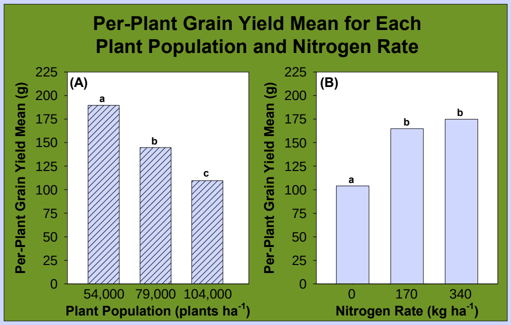


Figure 3 (A-B):

Means are averaged across the other treatment. Means with different letters indicate statistically significant differences at $P \leq 0.05$. The plant population × N-rate interaction was not significant at $P \leq 0.10$.

Key Results:

1. Per-plant grain yield (GY_P) decreased with increasing plant population regardless of N rate (A).
2. The first application of 170 kg N ha^{-1} significantly increased GY_P regardless of plant population (B).
3. A second application of 170 kg N ha^{-1} had no significant effect on GY_P regardless of plant population (B).

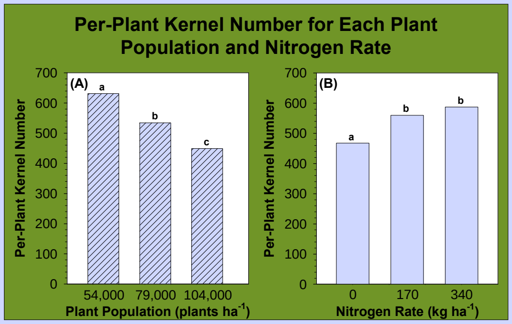


Figure 4 (A-B):

Means are averaged across the other treatment. Means with different letters indicate statistically significant differences at $P \leq 0.05$. The plant population × N-rate interaction was not significant at $P \leq 0.10$.

Key Results:

1. Per-plant kernel number (KN_P) decreased with increasing plant population regardless of N rate (A).
2. As with GY_P, the first application of 170 kg N ha^{-1} significantly increased KN_P regardless of plant population (B).
3. As with GY_P, a second application of 170 kg N ha^{-1} had no significant effect on KN_P regardless of plant population (B).

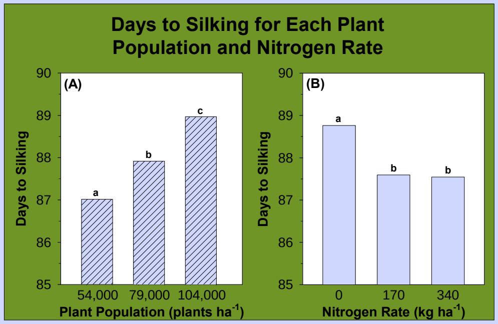


Figure 5 (A-B):

Days to silking (DY_{SI}) represents the number of days from planting until silk emergence. Means are averaged across the other treatment. Means with different letters indicate statistically significant differences at $P \leq 0.05$. The plant population × N-rate interaction was not significant at $P \leq 0.10$.

Key Results:

1. DY_{SI} increased with increasing plant population regardless of N rate (A).
2. The first application of 170 kg N ha^{-1} significantly decreased DY_{SI} regardless of plant population (B).
3. A second application of 170 kg N ha^{-1} had no significant effect on DY_{SI} regardless of plant population (B).

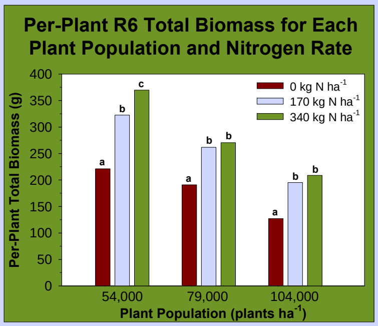


Figure 6:

Means with different letters indicate statistically significant differences at $P \leq 0.05$ within each plant population. The plant population × N-rate interaction was significant at $P \leq 0.10$ ($P = 0.081$). Data is from 2006 only.

Key Results:

1. A single application of 170 kg N ha^{-1} significantly increased per-plant R6 total biomass (TB_P) at each plant density.
2. A second application of 170 kg N ha^{-1} increased TB_P at only the lowest plant population.
3. For each N rate, increases in plant population resulted in decreases in TB_P.
4. The highest TB_P occurred for the 54,000 plants ha^{-1}, 340 kg N ha^{-1} treatment combination, while the lowest TB_P was present for the 104,000 plants ha^{-1}, 0 kg N ha^{-1} treatment combination.

IV. Results (cont.)

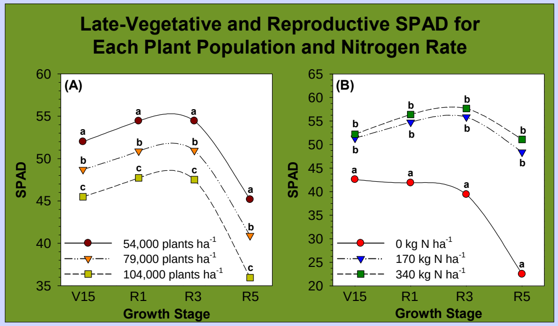


Figure 7 (A-B):

Means are averaged across the other treatment. Means with different letters indicate statistically significant differences at $P \leq 0.05$ within each growth stage. The plant population × N-rate interaction was not significant at $P \leq 0.10$.

Key Results:

1. SPAD values were generally reduced with increasing plant population (A) and decreasing N rate (B) for each growth stage.
2. For all three plant populations, SPAD values appeared to increase from V15 to R1, peak between R1 and R3, and decrease from R3 to R5.
3. Values for SPAD at V15, R1, R3, and R5 did not differ for the 170 kg N ha^{-1} and 340 kg N ha^{-1} application rates.
4. The contribution of an initial N application of 170 kg ha^{-1} significantly improved both apparent leaf N content and "stay-green" for all three plant populations in a similar fashion.

V. Conclusions

1. The availability of N was more critical for maintaining per-unit-area grain yield (GY_A) (Figure 1) at higher plant populations than at lower plant populations.
2. When N was least available (104,000 plants ha^{-1}, 0 kg N ha^{-1}), GY_A (Figure 1) was lowest and per-plant grain yield variability (GY_{CV}) (Figure 2) was highest, indicating intense intraspecific competition for available N.
3. A lack of increase in GY_A (Figure 1) and per-plant grain yield (GY_P) (Figure 3B) from a second application of 170 kg N ha^{-1} suggests that other resources (e.g. solar radiation and soil moisture) may have been more limiting than mineral N after the initial side-dress application.
4. At the highest plant population, a lack of N application reduced per-plant R6 total biomass (TB_P) (Figure 6) and per-plant kernel number (KN_P) (Figure 4B) and increased days to silking (DY_{SI}) (Figure 5B). Decreased TB_P and KN_P and increased DY_{SI} and GY_{CV} (Figure 2) are expected responses to reduced resource availability in maize (Maddonni and Otegui, 2004; Borrás et al., 2007).
5. Limitations in available N as a result of high plant densities and low N rates reduced apparent foliar N concentrations and induced early leaf senescence (Figures 7A-B), potentially decreasing per-plant photosynthetic rates and, incidentally, TB_P accumulation (Figure 6) (Tollenaar and Lee, 2006). These physiological responses likely induced source limitations during the grain-filling period that resultantly restricted both GY_A (Figure 1) and GY_P (Figure 3A-B).
6. **Summary:** Mineral N availability was more essential for optimizing maize growth and development at high plant populations than at low plant populations. With greater N rates at high plant densities, GY_A (Figure 1) increased due to decreased GY_{CV} (Figure 2), greater KN_P (Figure 4A-B), a potentially reduced anthesis-silking interval (ASI) (evident from fewer DY_{SI}) (Figure 5A-B), improved TB_P (Figure 6), and both delayed and reduced apparent leaf senescence during the grain-filling period (Figure 7). This is the first study to confirm the importance of adequate N availability for reducing per-plant variability resulting from intraspecific competition at high plant densities.

VI. Literature Cited

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