Effect of Late Nitrogen Fertilization on Grain Yield and Grain Filling in Corn

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Summary
For decades, yield improvement in corn has been accompanied by an increase in plant nitrogen (N) uptake. Modern hybrids are absorbing more N during reproductive stages, while delaying N remobilization to the grain for later in the growing season. To evaluate the effect of late-season N applications in distinct corn genotypes, grain yield and grain filling parameters were evaluated in field experiments under early and late N regimes during 2017 and 2018 growing seasons. Hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and contrasting N application scenarios (including a zero-N control) were evaluated at the Kansas State University Ashland Bottoms Research Farm, Manhattan, KS. Results showed that under N stress conditions, the absence of N fertilization in corn significantly reduced yields, by affecting both grain number (GN) and grain weight (GW). Regarding genotypes, a positive trend was found between the year of release of the hybrid and yields, with greater yields for the modern hybrid (i.e., 206 bu/a for P1197). No significant effects were found between N applied at silking or 2 weeks after R1 for the 2017 field study; comparably, no impact of including an additional application at V12 was detected during 2018. In respect to the grain filling process, N fertilization significantly increased the grain filling duration (GFD) and grain filling rate (GFR). Still, evaluations across altered source-sink ratios are needed in order to investigate whether differential responses to late-season N are determined by variations in the availability of assimilate.

Introduction
In corn, a strong connection was documented between plant N demand and final grain yield (Ciampitti and Vyn, 2013). Studies have shown that yield improvement across decades was accompanied by an increase in plant N uptake, as modern hybrids absorb more N during reproductive stages (Ciampitti and Vyn, 2012; Haegele et al., 2013)—while delaying N remobilization to the grain until later in the growing season. Current hybrids accumulate approximately 35–40% total N after silking (Ning, 2017). Still, evaluation on a range of N management practices is necessary to understand the optimal approach to improve yields and fertilizer use efficiency in corn.

Current N fertilization strategies in corn are still characterized by a weak synchrony with plant N uptake during the growing season. In the United States, it is estimated that producers apply only 25% of total N after planting (Cassman et al., 2002), generally expected to be placed at early growth stages. Additionally, environmental concerns due to the risk of pollutant N losses from denitrification, leaching, volatilization, and surface run-off have recently placed N management under scrutiny (Raun and Johnson, 1999; Cassman et al., 2003). As a result, using late N fertilization is a method to synchronize the N supply and demand in the system, and potentially increase fertilizer recovery efficiency. However, studies are required to assess the effects of late season N on grain yield and its numerical components. This research study was implemented to evaluate yield and grain filling N responses to different late-N fertilization strategies among hybrids released during different decades.

Procedures

A two-year field study was conducted at the Kansas State University Ashland Bottoms Research Farm, Manhattan, KS, during 2017 and 2018 (39°08' N, 96°37' W). At 6-in. soil depth, the soil pH was 5.9, soil organic matter was 1.34%, there was 50 ppm of phosphorus (Mehlich), and there was 158 ppm of potassium. Table 1 presents climatic data for the 2017 and 2018 growing seasons.

In 2017, two field experiments (one under irrigation and one rainfed) were arranged in a split-plot design with two factors evaluated, genotype with three levels in the main plot, and fertilizer N rate with three levels in the sub-plot. For genotype, three Pioneer hybrids with different release years (3394, 1990s; P1151, 2000s; and P1197, 2016) and three contrasting N scenarios (zero N, N at flowering, and N at two weeks after flowering) were tested. The study was planted on May 5, 2017, in plots of four rows, 30 in. apart and were 10-ft wide × 70-ft long. For the two fertilized treatments, an initial 50 lb/a was added at planting, and a second application was added at V6 growth stage (50 lb/a and 100 lb/a for rainfed and irrigated, respectively). Depending on the treatment, the last application (22 lb/a and 44 lb/a for rainfed and irrigated, respectively) was performed at silking (R1, Ritchie et al., 1997) or two weeks after R1. Total fertilizer N rate applied for the treatments receiving N was 122 lb/a for the rainfed and 194 lb/a for the irrigated condition.

In 2018, one irrigated location was managed as a split-plot with factorial subplot, where hybrids were assigned to whole plots. Subplots were combinations of levels of N and source-sink treatment factors + a zero-N negative control. The study was planted on April 25, 2018, with similar plot sizes and layout as 2017. For genotypes, two Pioneer hybrids were evaluated (3394 and P1197). For N, two fertilization approaches were tested with the same final N rate of 194 lb/a: 1) early N, split in two applications (50% planting and 50% V6); and 2) late N, split in three applications (50% planting, 20% V6, and 30% V12). Four levels of source-sink ratio were included with: 1) control with normal pollination; 2) reduced sink, with partially restricted pollination; 3) reduced source, with partial defoliation; and 4) reduced both sink and source, combination of treatment 2 and 3. Reduced sink treatments were achieved using a bag to cover the entire ear when the silks were 1-in. long (Rajcan and Tollenaar, 1999). Partial defoliation was accomplished by removing, between two or three weeks after silking, the four topmost leaves. Lastly, a zero N (no N applied) treatment with normal pollination was added as a negative control. Experimental areas were kept free of weeds, pests, and diseases during the growing season.

The measurements for both years included soil N levels (nitrate + ammonium), plant stand counts, leaf area index ((LAI) Plant Canopy Analyzer LAI 2200), shoot biomass at silking and physiological maturity, yield determination by combine harvest equipment, and yield components (grain number, seed weight, and harvest index). Grain filling was measured since R2 growth stage, collecting one ear per plot every three to four days (2017) or per week (2018) from each treatment combination, until harvest. Ten kernels from the central portion of the ear were sampled to track changes in kernel dry weight and water volume during the entire period.

Results

Grain Yield and Numerical Components

For 2017 and all treatment combinations, GN and GW were both positively correlated with final grain yield ($R^2 = 0.58$ and $R^2 = 0.43$, respectively) in agreement with other previous studies (Andrade et al., 1996) (Figure 1A and B). For 2018, grain number was mostly related to final yield. No overall relationship was found for GW in the 2018 study, where the artificial modification of both grain number and weight, by impeding pollination or reducing foliage, was reflected in a notorious variability of the results.

In order to confirm the relationship between crop condition at the beginning of grain filling (silking) and final grain weight, its correlation with total biomass at R1 and leaf area index (LAI) at R1 was tested for 2017 and 2018 (Figure 2A and B, respectively). In addition, these parameters were also tested at R3 with the aim of detecting any differences between the two fertilized treatments; however, no differences were found between them (data not shown).

2017 Experiment

Table 2 summarizes average yields and yield components for fertilizer N rate levels (N) and corn hybrids (H) evaluated during 2017. There was a significant interaction between N and water condition (WC) for final grain yields. A single level effect of H was observed in yields ($P \leq 0.05$). A positive trend was found between the year of release of the hybrid and yields, from 177 bu/a for 3394 (early 1990s) to 206 bu/a for P1197 (modern). As expected, fertilized treatments differed from the zero N treatment (with a more prominent effect under irrigated conditions – explaining the WC × N interaction), while there were no significant differences in average yields between late-N treatments.

Regarding yield components, significant differences between N levels and genotypes were found for grain number (GN) ($P \leq 0.001$ and $P \leq 0.05$, respectively), and between N treatments for grain weight (GW) ($P \leq 0.001$). Overall, final GW did not differ between genotypes, reflecting that yield variations among H were primarily driven by the number of grains per ear defined around silking. However, GN and GW were both affected by the absence of N fertilization, suggesting that GW reductions could have a considerable effect on yields, particularly in N stressed environments.

2018 Experiment

For 2018, yield components were consistently affected by source-sink (S) treatments (Table 3). As for the focus of this report on H and N effects, no significant differences were observed among treatments for yields and grain number. Only a minor interaction was apparent between N and H for final grain weight. Interestingly, final grain yields did not differ between early and late N treatments, signifying that an additional application of N was not beneficial for increasing yields under the 2018 conditions. Further evaluations and comparisons on source-sink treatments still need to be performed.

Grain Filling Rate and Duration

Grain filling dynamics were evaluated in terms of duration of the grain filling period (GFD) and rate of dry matter accumulation (GFR) using a bi-linear model. Additionally, grain filling period was considered as divided by two phases, a lag phase and a linear grain filling phase. The lag phase represents a period of active cell division (Borras and Westgate, 2006) when potential kernel size is defined. Lag phase duration (LPD) was calculated in the applied bi-linear model as the period from silking to the intersection of the curve with the x-axis, representing initial linear grain fill. There were no differences in duration of lag phase across N treatments or hybrids across experiments (data not shown). This indicates that variations in GFD (especially during 2017 experiment, Table 2) were primary driven by changes in linear grain filling or effective grain fill, which is considered as the period between end of lag and final GW (black layer formation).

Moreover, all N conditions evaluated in this study, reached final GW (black layer formation) at a similar moisture content [estimated means = 35.7% (2017) and 35.2% (2018)], indicating that the model of grain filling on a water-concentration basis (WC, %) was not affected by changes in the rate or timing of N. Another aspect that requires further investigation is the grain maximum water content (MWC) that was achieved across N management strategies, considering that MWC is an indicator of potential grain volume and, therefore, grain size.

2017 Experiment

Increments in GW were both related to changes in GFD and in the GFR for N treatments in 2017 (Table 2). The effect of N supply in GFR was dissimilar between genotypes, reflecting a significant genotype and environment interaction response N × H (Table 2, $P < 0.05$). The three genotypes displayed a positive response with N fertilization, while no significant effect was observed as triggered by late N applied.

2018 Experiment

For 2018, and averaged over the levels of source-sink, no differences between early and late N supply were identified for grain filling parameters (Table 3). Differential responses can be expected from late-season N, determined by variations in N uptake partitioning during reproductive stages.

Conclusions

In N stressed conditions, the absence of fertilization in corn significantly reduced grain yields, by affecting both GN and GW. Regarding genotypes, a positive trend was found between the year of release of the hybrid and yields, with higher yields for the modern hybrid (i.e., 206 bu/a for P1197). Regarding the grain filling process, N fertilization significantly increased GFD and GFR; however, no differences in grain filling parameters were observed between early and late N applications.

Even though split applications until early reproductive stages differed from the zero N control treatment, no significant effects were found between N applied at silking or 2 weeks after R1 for any of the analyzed parameters in the 2017 field study. Similarly, in the 2018 study no significant effect of including an additional application at V12 was observed, when compared against a more typical approach of split N at planting + at V6. Further studies are needed in order to unravel reproductive N uptake dynamics and partitions to better understand N impact during the grain filling process in corn.

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Table 1. Monthly values for daily solar radiation, temperature, and total precipitation for the 2017 and 2018 growing seasons. Source: Kansas Mesonet, 2019

	2017					2018				
	May	Jun	Jul	Aug	Sep	May	Jun	Jul	Aug	Sep
Solar radiation (MJ m^{-2} day^{-1})	25.2	27.3	26.5	23.0	18.5	23.7	26.4	24.5	21.8	16.5
Mean temperature (°F)	65.8	75.4	80.4	72.1	72.0	72.1	79.7	78.6	76.6	69.6
Precipitation (inches)	3.74	2.82	1.33	6.09	0.81	3.28	2.15	2.86	6.65	5.02

Table 2. Analysis of variance and means for yield (15.5% moisture), grain number, grain weight, grain filling rate, and duration for three nitrogen (N) levels and three hybrids (H) under two water conditions (WC, irrigated and rainfed) for the 2017 experiment

Factor	Yields	GN	GW	GFR	GFD
	bu/a	grains/m^2	mg/grain	mg/GDUs grain	GDUs
0 (zero) N	119 b	2927 b	217 b	0.31 b	1146 b
N at flowering	234 a	4017 a	273 a	0.33 a	1219 a
N 2 weeks after flowering	223 a	4195 a	279 a	0.34 a	1207 ab
3394	177 b	3285 b	254 a	0.34 a	1158 b
P1151	194 ab	4021 a	251 a	0.32 a	1181 ab
P1197	206 a	3833 ab	263 a	0.32 a	1232 a
Sources of variation					
Hybrid	*	*	Ns	+	*
Nitrogen	***	***	***	**	*
WC × H	Ns	Ns	Ns	Ns	Ns
WC × N	*	+	Ns	Ns	+
H × N	Ns	Ns	*	*	Ns
WC × H × N	Ns	Ns	Ns	Ns	Ns

Different letters indicate significant differences at $P \leq 0.05$.
+ Significant at $P \leq 0.1$; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.
Ns = non-significant.
GN = grain number. GW = grain weight. GFR = grain filling rate. GFD = grain filling duration. GDUs = growing degree units.

Table 3. Analysis of variance and means for yield (15.5% moisture), grain number, grain weight, grain filling rate, and duration for two nitrogen (N) levels†, two hybrids (H), and four source-sink (S) treatments for 2018 experiment

Factor	Yields	GN	GW	GFR	GFD
	bu/a	grains/m^2	mg/grain	mg/GDUs grain	GDUs
Early N	169 a	2652 a	274 a	0.35 a	1126 a
Late N	169 a	2572 a	283 a	0.36 a	1142 a
3394	161 a	2328 a	283 a	0.35 a	1140 a
P1197	177 a	2896 a	274 a	0.36 a	1129 a
Sources of variation					
Source-sink	Ns	***	***	**	*
Hybrid	Ns	Ns	Ns	Ns	Ns
Nitrogen	Ns	Ns	Ns	Ns	Ns
S × H	Ns	+	+	Ns	Ns
S × N	Ns	Ns	Ns	Ns	Ns
H × N	Ns	Ns	+	Ns	Ns
S × H × N	Ns	+	Ns	Ns	Ns

Different letters indicate significant differences at $P \leq 0.05$.
+ Significant at $P \leq 0.1$; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.
Ns = non-significant.
GN = grain number. GW = grain weight. GFR = grain filling rate. GFD = grain filling duration. GDUs = growing degree units.
†For interpretation of the results, negative control (zero N + control source-sink) was excluded from the analysis.

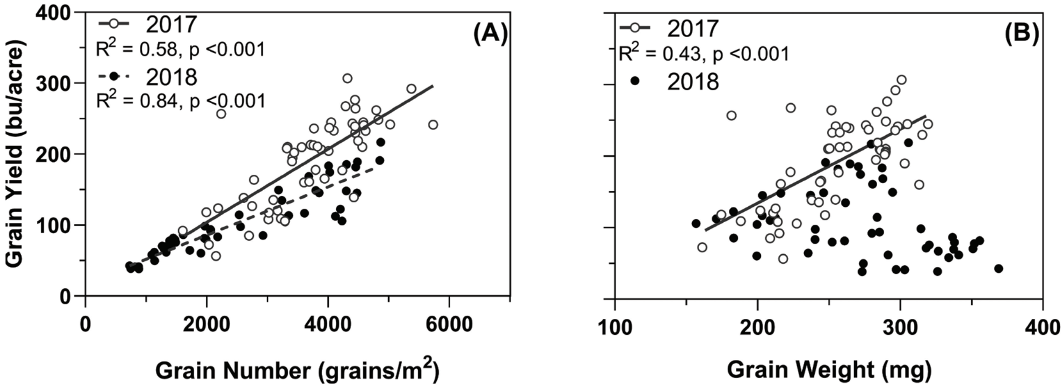

Figure 1. Relationship between final grain yield and grain number (A) and grain weight (B), for data from 2017 (open symbols) and 2018 (closed symbols) field experiments.

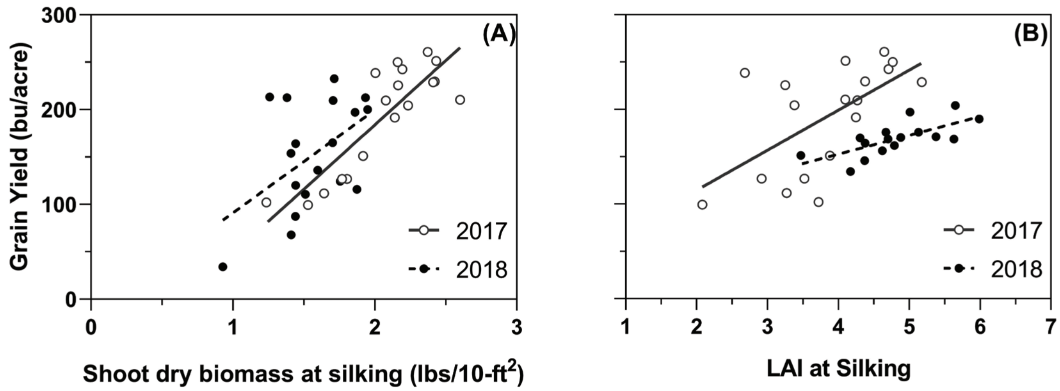

Figure 2. Relationship between final grain yield and shoot dry biomass (A) and leaf area index (B) at silking, for data from 2017 (open symbols) and 2018 (closed symbols) field experiments.