COMPARATIVE N AND DRY MATTER DYNAMICS IN CORN EARS, STEMS, AND LEAVES DURING THE CRITICAL PERIOD AFTER EARLY AND LATE-SPLIT SIDEDRESS N

Sarah M. Mueller and Tony J. Vyn
Agronomy Department, Purdue University, West Lafayette, IN
smuelle@purdue.edu, tvyn@purdue.edu

ABSTRACT

There is currently great interest in the possible agronomic and environmental benefits of split N applications that include a late vegetative sidedress timing. The objective of this study was to determine the impact of N rate and timing of N application on the accumulation of N and dry matter in the ears, stems, and leaves of corn during the critical period (encompassing the period two weeks before to two weeks after silking) in order to understand the differing sensitivity to N stress in these three plant organs. To test this, in 2015 a four-hybrid experiment was conducted using 6 N rates where N was either applied in a single early sidedress application or split with the last 40 lbs delayed until V12. Treatment N rates included 0, 140, 140+40 (180S), 180, 180+40 (220S), and 220 lbs N acre^{-1}. Averaged across 4 hybrids, ear N concentrations started at 7.2% (average of all non-zero N rates) 2 weeks before silking and declined rapidly to 1.4% 2 weeks after silking. Preliminary data indicated that ear N concentrations during the critical period were similar across N rates, suggesting high ear N conservation even under stress. Ear growth rate was maintained across all but the 0 N rate. Ear N accumulation rate peaked during the week after R1 when the 180S, 220, and 220S continue to accumulate N at a higher rate than the other N treatments. The leaves continued to accumulate both N and dry matter throughout the critical period. The stems, however, continued to gain dry matter but decreased in N content indicating N remobilization was already occurring. These first-year findings indicate that, during the critical period, the stem is the most sensitive indicator to N stress because it is the first to decline in N content in response to moderately-low N conditions. Late-split N application appeared to delay stem N remobilization (presumably because of increased plant N status) but had no impact on ear or leaf N concentration during the critical period.

INTRODUCTION

N fertilizer is the largest annual expense in mid-west corn production (Foreman, 2014). Due to both economic and environmental pressures, it is of upmost importance to increase the efficiency with which N fertilizers are applied and managed. Traditionally, for practical management reasons such as greater labor availability, lower fertilizer prices, and fewer competing essential field operations (e.g. planting), the majority of N fertilizer has been applied either pre-planting or during very early vegetative growth. However, rapid N accumulation by the growing crop does not occur until V6-R1, maximizing near the time of silk emergence (Ciampitti et al., 2013a). Once applied to the soil, N is exposed to losses from denitrification, leaching, volatilization, and – if not injected - surface run-off (Raun and Johnson, 1999). These risks of N loss are exacerbated by the disconnect between N fertilizer application and rapid crop N uptake (Dinnes et al., 2002). One potential avenue for decreasing N fertilizer losses is by improving the synchrony of crop N demand and field N applications, i.e. late-season N applications (Shanahan et al., 2008). Although the idea of strategically applying N during late vegetative growth is not entirely new, the recent increase in availability of high-clearance equipment capable of applying N fertilizers has increased the practicality of N applications during the late-vegetative growth stages.

The complexity of the dynamic relationships between N timing, soil, and the growing corn crop has been amply illustrated in the mixed results on the benefits of various N timing strategies in prior research reports. While Scharf et al. (2002) found no evidence of decreased grain yield when N sidedress was delayed until V11, they also concluded that applications at the time of V12-V16 incurred about a 3% yield reduction when compared to applications prior to V12. Similarly, Walsh et al. (2012) found a yield loss in 6 out of 9 sites when side-dress was delayed until V10-VT. However, in both studies, these yield losses were found when no N was applied pre-plant or at planting, and the researchers concluded that the decreased yields were a result of N stress of such severity that it's negative effects could not be reversed by the late N application. (Walsh et al., 2012) also concluded that when an N application was split between pre-plant and V10 side-dress, there was no yield loss from the late V10 sidedress. Although there is limited research dealing with sidedress applications later than V8, the conclusion that yields are maintained (or not significantly decreased) with split N applications has also been found by other researchers (Miller et al., 1975; Randall et al., 1997, 2003; Gehl et al., 2005; Kovács, 2013).

To further complement this potential N management strategy, there is also evidence that modern corn hybrids accumulate more total N after silking (Ciampitti and Vyn, 2012; Chen et al., 2015; Mueller and Vyn, 2016) and in some cases as much as 30% of the total N is taken up during the grain filling period (Ciampitti et al., 2013a). Late season N applications may be one way to take advantage of this shift in crop physiology. In a recent synthesis review of all published literature that reports both R1 and R6 whole-plant N accumulation, Mueller and Vyn (2016) found that grain N in hybrids released prior to 1991 was proportionally more likely to arise from remobilized N, and hybrids released after 1991 were more likely to use a greater proportion of N taken up during the grain filling period to meet grain N demand. Increased post-silking N accumulation has been associated with increased leaf longevity (stay green) because root N uptake is better able to meet plant N needs and therefore remobilization from the vegetative tissue is delayed (Rajcan and Tollenaar, 1999; Mi et al., 2003; He et al., 2004; Pommel et al., 2006; Ciampitti and Vyn, 2011; Ciampitti et al., 2013b). Maintenance of leaf N status, and therefore photosynthesis, has been credited as a key factor in the increase in corn grain yield over time (Fakorede and Mock, 1980; Duvick, 1984; Ma and Dwyer, 1998). The synthesis of all of this is modern hybrids are more likely to be accumulate and respond to increased soil mineral N availability due to supplemental, late-season N applications.

The primary objective of this research was to increase our understanding of how supplemental, late season N applications impact the N uptake and partitioning to the stems, leaves, and ears during the critical period.

MATERIALS AND METHODS

Experimental Design and Measurements

This experiment was carried out at the Pinney-Purdue Agriculture Center near Wanatah, IN on a sandy-loam soil. The rain-fed plots were arranged in a split-plot design with 6 N rates as the main plot and 4 hybrids as the sub-plot. There were 6 replications. The previous crop was soybeans and tillage consisted of fall chisel plowing and spring secondary tillage. Plots were 6 rows wide (30 in rows) and 90 feet long. The N rates are outlined in Table 1. Starter was applied as 12 gal/acre of 19-17-0 placed two inches to the side and two inches below the soil surface from the planting row. Both V3 and V12 N applications were applied using 28% UAN. The V3 sidedress was coulter injected. The V12 sidedress was surface banded with the use of a high clearance Hagie applicator and 360 Yield Center Y-Drops. Stratego fungicide was aerial applied near the tasseling stage.

All hybrids used were from DuPont Pioneer. Hybrids included were (year of release): 3394 (1991), 3335 (1995), 1498CHR (2012), 1360HR (2014). All hybrids were of similar relative maturity. The seeding rate was 34,000 plants/acre. In this report all data will be presented as the average of all 4 hybrids.

Table 1. 2015 N rate and timing treatments.

Treatment Name	Sidedress Timing	N Applied as Starter	N Applied at V3	N Applied at V12	Total Applied N
			- - -(lbs acre^{-1}) - - -		
0	--	25	--	--	25
140	V3	25	115	--	140
180	V3	25	155	--	180
180S	V3 + V12	25	115	40	180
220	V3	25	195	--	220
220S	V3 + V12	25	155	40	220

Intensive plant biomass harvests were taken during the critical period in order to better understand how N rate and timing impact N uptake and N allocation dynamics when kernel establishment occurs. Whole-plant biomass was taken two weeks before R1 (-2), at R1, and 2 weeks after R1 (+2). Samples were partitioned into leaves, stems, ears, and ear leaves. In addition, only ears were sampled one week before R1 (-1) and one week after R1 (+1). All ears were separated from the husks. Husks were analyzed with the leaves at the -2, R1, +2 biomass harvests. All samples were dried to a constant weight at 140°F. Samples were then weighed and ground to 1 mm. Plant tissue N concentration analysis was conducted by DuPont Pioneer (Johnston, IA). Whole-plant biomass zones were consisted of 10 consecutive plants pre-selected shortly after emergence.

Statistical Analysis

Statistical analysis was conducted using SAS 9.3 (SAS Institute Inc., 2012). An analysis of variance was performed using PROC MIXED with hybrid, N rate and the interaction of hybrid x N rate considered fixed factors (block and the interaction of block x N rate were considered random factors). Critical difference determinations were based on Fisher's least significant difference (LSD) at the level of $\alpha = 0.05$.

RESULTS AND DISCUSISON

Ear N and Dry Matter Dynamics

During the critical period, N concentration was highly conserved in the developing ears (Figure 1). Two weeks before R1 (-2) ear N concentrations for non-zero N plots was 7.2% while the 0N treatment averaged 6.5%. These concentrations declined rapidly, due to dilution accompanying ear growth, reaching 2.7% (non-zero rates) and 2.4% (0N) by R1 and further decreasing to 1.4% (average of all N rates, N rates not significantly different) by two weeks after silking (+2). As would be expected, the ear growth rate (lbs dry matter acre^{-1} day^{-1}) during the critical period had the inverse pattern of the ear N concentrations. Ear growth rate did not differ significantly between N rates until after R1 when the 0N rate slowed markedly in comparison to all other treatments. In the second week after silking, ear growth rate for 0N was only 178 lbs dry matter acre^{-1} day^{-1} compared to 288 lbs dry matter acre^{-1} day^{-1} in the non-0N treatments.

Ear N accumulation rate (lbs N acre^{-1} day^{-1}) was significantly impacted by N rate and timing at the peak of ear N accumulation in the week following R1 (Figure 2). In the week before R1, the 0N was significantly lower than all other N treatments and 180S was significantly lower than 180. In the week following R1 there was a quantitative separation with 220, 220S, and 180S maintaining higher ear N accumulation rates compared to the single applications of 180 and 140 lbs N acre^{-1}. However, only the 180S and 140 means were significantly different from each other (0N was significantly lower than all other treatments).

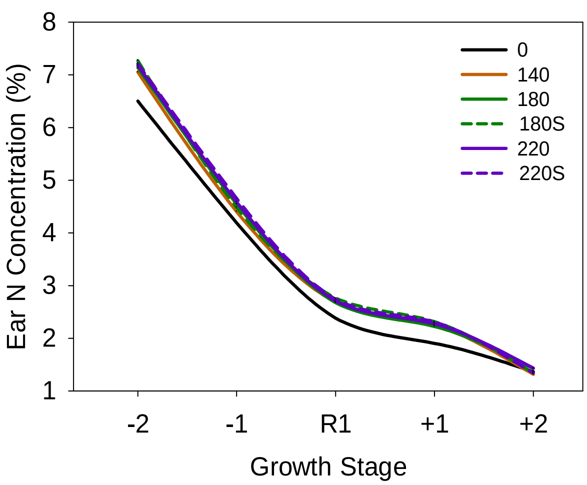

Figure 1. Change in ear N concentration (%) during the critical period as affected by N rate.

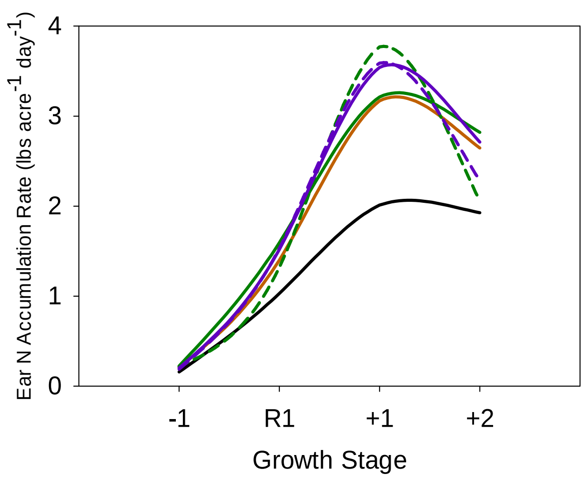

Figure 2. Change in ear N accumulation rate (lbs acre^{-1} day^{-1}) during the critical period as affected by N rate.

Stem and Leaf N and Dry Matter Dynamics

Leaf dry matter increased rapidly until R1, after which dry matter accumulation plateaued. At -2 there was no significant difference in leaf dry weight among the N rates, but the 0N achieved a slower dry matter accumulation rate and therefore fell behind in dry weight at both the R1 and +2 stages. Leaf N accumulation pattern was similar to dry matter. All treatments continued to gain leaf N prior to R1 and then remained relatively stable in the two weeks following silking. At all three sampling times the 0N was significantly lower than all other treatments. At +2 the 220S was significantly higher than 140, 180S, and 220 N rates due to continued N accumulation.

Stem dry weight also increased dramatically from -2 to R1, but then became stagnant from R1 to +2 (Figure 3). However, in contrast with the leaf N accumulation, stem N began to decrease markedly in the two weeks following R1 (Figure 4). This decline in stem N reserves indicates early on-set of stem N remobilization, presumably to the developing ear. Remobilization was much more pronounced in the 0, 140, and 180 treatments where stem N declined by 25%, 26%, and 22% from R1 to +2, respectively. The highest N rate and split N treatments maintained higher stem N status only losing 10%, 11%, and 9% of the stem N for the N rates of 180S, 220, and 220S, respectively, during the same 2-week period. Throughout the critical period, stem N content was significantly affected by N rate and timing (Table 2). The split and highest N rates (180S, 220S, and 220) remobilized the least amount of stem N. This may indicate that concurrent N uptake was better able to keep up with ear N demand under these N treatments.

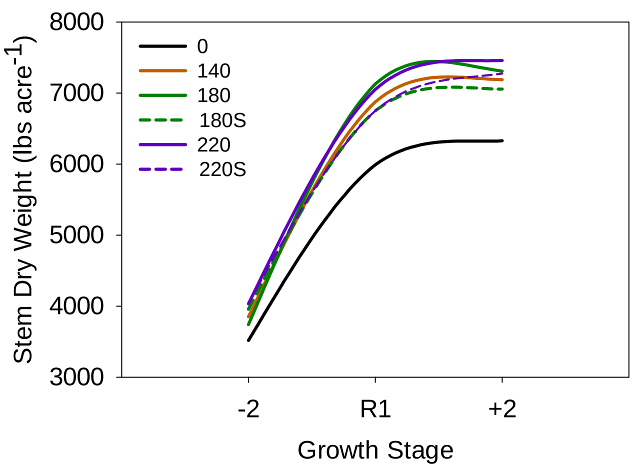

Figure 3. Change in stem dry weight (lbs acre^{-1}) during the critical period as affected by N rate.

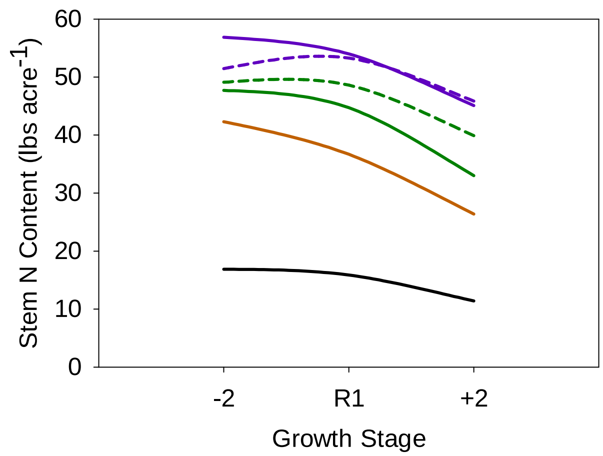

Figure 4. Change in stem N content (lbs acre^{-1}) during the critical period as affected by N rate.

Table 2. Impact of N treatment on stem N accumulation (lbs N acre^{-1}) 2 weeks before silking (-2), at silking (R1), and 2 weeks after silking (+2) in 2015. Values represent the average of 4 hybrids. Treatment means with different letters indicate significantly different LSMeans

N Rate	-2		R1		+2	
0	17.1	d	16.1	d	11.5	d
140	42.8	c	37.1	c	26.7	c
180	48.2	bc	45.2	b	33.4	b
180S	49.7	abc	49.1	ab	40.3	a
220	57.5	a	54.6	a	45.6	a
220S	52.0	ab	53.9	a	46.4	a

SUMMARY

There is currently much interest in the potential to increase grain yields and recovery of N fertilizers through more intensive N management strategies, such as late vegetative N applications. In order to better understand how supplemental, late season N applications impact these end-of-season outcomes, it is critical to study how they affect both dry matter and N partitioning during the critical period. Preliminary results from this study indicate that it is unlikely that N management will impact ear N concentrations; however, we observed higher ear N accumulation rates during peak uptake (the week following R1) following late-season split N treatments.

Because new N uptake during grain filling is not sufficient to meet the demands of the developing ear, accumulation and remobilization of N in the vegetative plant organs is of key interest. We demonstrated that in the two weeks prior to silking, leaves continue to increase in N content and then plateau after R1. In contrast, stems have already reached maximum N content prior to the onset of the critical period, and remobilization begins to occur quickly following pollination, with the least remobilization occurring in those treatments that have the highest soil N availability during this period. These results suggest that leaf N is maintained in order to retain leaf chlorophyll and continue active photosynthesis, while stem N is used first to ear N demands. The stem also appears to be the most sensitive indicator of plant N status because it is the first to decline in N content under low and moderately-low N conditions. The application of N during the late vegetative growth stages did appear to delay stem N remobilization (presumably because of increased plant N status); however, it did not have an impact on ear or leaf N concentration during the critical period.

ACKNOWLEDGMENTS

This study was made possible through grant support from DuPont Pioneer, the 4R Nutrient Stewardship Research Fund, and the Indiana Corn Marketing Council. Data from this experiment in 2016 is currently being analyzed.

REFERENCES

Chen, K., S.V. Kumudini, M. Tollenaar, and T.J. Vyn. 2015. Plant biomass and nitrogen partitioning changes between silking and maturity in newer versus older maize hybrids. F. Crop. Res. 183: 315–328.

Ciampitti, I.A., J.J. Camberato, S.T. Murrell, and T.J. Vyn. 2013a. Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: I. Macronutrients. Agron. J. 105(3): 783.

Ciampitti, I.A., S.T. Murrell, J.J. Camberato, M. Tuinstra, Y. Xia, P. Friedemann, and T.J. Vyn. 2013b. Physiological dynamics of maize nitrogen uptake and partitioning in response to plant density and nitrogen stress factors: II. Reproductive phase. Crop Sci. 53: 2588–2602.

Ciampitti, I.A., and T.J. Vyn. 2011. A comprehensive study of plant density consequences on nitrogen uptake dynamics of maize plants from vegetative to reproductive stages. F. Crop. Res. 121: 2–18.

Ciampitti, I.A., and T.J. Vyn. 2012. Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. F. Crop. Res. 133: 48–67.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, and J.L. Hatfield. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils. Agron. J.

94(1): 153–171.
Duvick, D.N. 1984. Genetic contributions to yield gains of U.S. hybrid maize, 1930 to 1980. *In* Genetic contributions to yield gains of five major crop plants. Madison, WI, USA.
Fakorede, M.A.B., and J.J. Mock. 1980. Growth analaysis of maize variety hybrids obtained from two recurrent selection programmes for grain yield. New Phytol. 85: 393–408.
Foreman, L. 2014. Characteristics and production costs of U.S. corn farms, including organic, 2010.
Gehl, R.J., J.P. Schmidt, L.R. Stone, A.J. Schlegel, and G.A. Clark. 2005. In situ measurements of nitrate leaching implicate poor nitrogen and irrigation management on sandy soils. J. Environ. Qual. 34(6): 2243–2254.
He, P., W. Zhou, and J. Jin. 2004. Carbon and nitrogen metabolism related to grain formation in two different senescent types of maize. J. Plant Nutr. 27(2): 295–311.
Kovács, P. 2013. Systems evaluation of shallow anhydrous ammonia placements, rates, and timing on maize plant uniformity, yield, and N use efficiency.
Ma, B.L., and L.M. Dwyer. 1998. Nitrogen uptake and use of two contrasting maize hybrids differing in leaf senescence. Plant Soil 199: 283–291.
Mi, G., J. Liu, F. Chen, F. Zhang, Z. Cui, and X. Liu. 2003. Nitrogen uptake and remobilization in maize hybrids differing in leaf senescence. J. Plant Nutr. 26(1): 237–247.
Miller, J.F., J. Kavanaugh, and G.W. Thomas. 1975. Time of N application and yields of corn in wet, alluvial soils. Agron. J. 67(3): 401.
Mueller, S.M., and T.J. Vyn. 2016. Maize plant resilience to N stress and post-silking N capacity changes over time: A review. Front. Plant Sci. 7: 1–14.
Pommel, B., A. Gallais, M. Coque, I. Quilleré, B. Hirel, J.L. Prioul, B. Andrieu, and M. Floriot. 2006. Carbon and nitrogen allocation and grain filling in three maize hybrids differing in leaf senescence. Eur. J. Agron. 24(3): 203–211.
Rajcan, I., and M. Tollenaar. 1999. Source : sink ratio and leaf senescence in maize: II. Nitrogen metabolism during grain filling. F. Crop. Res. 60: 255–265.
Randall, G.W., T.K. Irgavarapu, and B.R. Bock. 1997. Nitrogen application methods and timing for corn after soybean in a ridge-tillage system. J. Prod. Agric. 10(2): 300–307.
Randall, G.W., J.A. Vetsch, and J.R. Huffman. 2003. Corn production as affected by time and rate of manure application and nitrapyrin. Agron J. 95: 1213–1219.
Raun, W.R., and G.V. Johnson. 1999. Improving nitrogen use rfficiency for cereal production. 91(3): 357–363.
Scharf, P.C., W.J. Wiebold, and J.A. Lory. 2002. Corn yield response to nitrogen fertilizer timing and deficiency level. Agron. J. 94: 435–441.
Shanahan, J.F., N.R. Kitchen, W.R. Raun, and J.S. Schepers. 2008. Responsive in-season nitrogen management for cereals. Comput. Electron. Agric. 61(1): 51–62.
Walsh, O., W. Raun, A. Klatt, and J. Solie. 2012. Effect of delayed nitrogen fertilization on maize (Zea mays, L.) grain yields and nitrogen use efficiency. J. Plant Nutr. 35(4): 538–555.

PROCEEDINGS OF THE

46th
NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 32

November 2-3, 2016
Holiday Inn Airport
Des Moines, IA

PROGRAM CHAIR:

Dorivar Ruiz Diaz
Kansas State University
Manhattan, KS 66506
(785) 532-7213
ruizdiaz@ksu.edu

PUBLISHED BY:

International Plant Nutrition Institute
2301 Research Park Way, Suite 126
Brookings, SD 57006
(605) 692-6280
Web page**: www.IPNI.net**

ON-LINE PROCEEDINGS:

http://extension.agron.iastate.edu/NCE/