Supplemental late-vegetative N applications for high-yield corn: Agronomic, economic and environmental implications with modern versus older hybrids.

Tony J. Vyn, Agronomy Department, Purdue University

Introduction:

Modern corn hybrids have a "functional stay green" capacity whereby their leaves not only stay green longer during the grain filling period, but also maintain their photosynthetic capacity until much later in the grain filling period (Tollenaar and Lee, 2011). Modern hybrids also yield more than hybrids of earlier decades because of their improved stress tolerance to plant density and other stress factors (whether pest-related factors or abiotic challenges). Therefore, one of the major corn management questions of our time is whether corn hybrids take up more of their total plant N during the reproductive period (i.e. beginning at the R1 stage as defined by Abendroth et al., 2011) and, if they do, whether modern hybrids are more responsive to intentionally very late-vegetative stage N fertilizer applications.

The recent review of all known research that actually measured whole-plant N uptake, grain yield, and plant density at both R1 and R6 stages of development came to the conclusion that corn hybrids from 1991 to 2011 took up more of their total N during the grain filling period than hybrids from before 1990 (Ciampitti and Vyn, 2012). The follow-up to that study (Ciampitti and Vyn, 2013a) concluded that about 56% of all grain N at maturity is coming from new plant N uptake after the R1 stage. In the most detailed study ever published of the interaction of hybrids, plant densities and N rates on corn nutrient uptake, our research group concluded that at least 30% of the total N uptake at maturity occurred after the R1 stage (Figure 1; Ciampitti et al., 2013). Although, in the latter case, the two relatively modern hybrids (Mycogen 2T789 and Mycogen 2 M750) didn't vary that much from each other, there was considerable evidence that both N rates as well as plant density itself can influence both the amounts and the proportion of total corn plant N uptake that occurs after flowering.

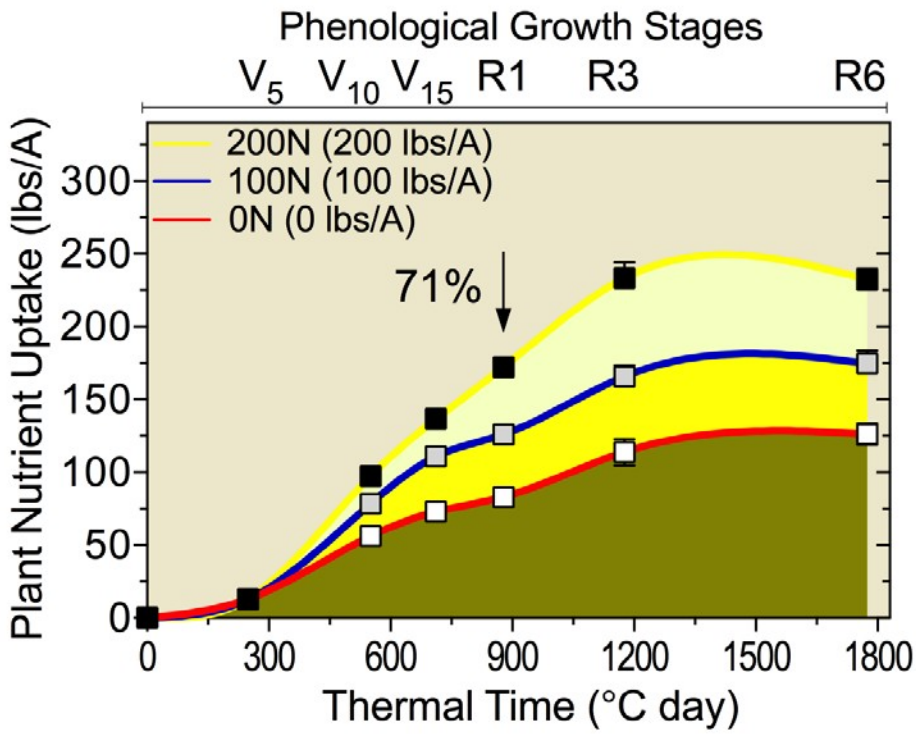

Figure 1. Plant nitrogen uptake at distinct corn growth stages in response to three N rates applied as side-dressed UAN at about the V5 stage in 2010 and 2011 (mean of 2 locations and 2 hybrids at a plant density of 32,000 plants per acre). Source: Ciampitti et al., 2013a

An even more recent study by our Cropping Systems Research group has confirmed the different plant N uptake capabilities and the different timing of that N uptake in an old hybrid (Dekalb XL72AA from 1975, one of the very popular B73 x MO17 crosses) grown side-by-side with two modern transgenic hybrids from 2005 (Table 1) under optimum management. Thus far, we have learned that these modern hybrids accumulate much more N in the post-flowering period. The two modern hybrids averaged 90 vs. 61 pounds N/acre, or ~30 pounds N/acre more, after flowering than the 1975 hybrid. Newer hybrids took up more total N as well as proportionately more N (37.5% vs. 30% of total N accumulated at maturity) in the grain fill period (Table 1).

Table 1. Effects of two “modern” hybrids (2005) versus a common older hybrid (1975) on corn grain yield, total N uptake, post-flowering stage N uptake, and N internal efficiency (NIE) when N rate = 200 pounds N/acre (mean of 3 plant populations from 22,000 to 42,000/acre and 3 site-years in NW + NC Indiana in 2012-2013). ***Data Source: K. Chen (Ph.D. Student) & T.J. Vyn***

Hybrid (commercial release year)	Grain Yield (bushels/acre)	Total Plant N Uptake (pounds/ac)	Post-silk emergence Plant N Uptake (% of final total uptake)	NIE (Grain Weight per Pound of Plant N)
DKC61-69VT3 (2005)	226	240	37	53
DKC61-72RR (2005)	225	244	38	52
DKC XL72AA (1975)	189	203	30	52

Modern hybrids are not necessarily superior to older hybrids in taking up plant N in the vegetative stages; in fact, they sometimes take up less N prior to silking. But modern hybrids continue to take up N longer in the grain filling period, and they have a much higher efficiency of making grain with the N that is accumulated in the aboveground parts of corn plants. Note the considerably higher NIE with both 2005 hybrids versus the 1975 hybrid in Table 1, for example. These preliminary results in Table 1 are part of an ongoing study that involves more hybrids and a second, lower N rate. The study is financed by both Monsanto and by the Indiana Corn Marketing Council in order to improve publically available crop growth models (e.g. new AgMaize model) and how they can more accurately predict the capability of modern hybrids to respond to climate change and nutrient input factors. That study complements considerations that are important to future improvements in 4R Nutrient Stewardship.

In the past few years, Pioneer agronomists have posed the question about whether modern hybrids would be more likely to be responsive to very late-vegetative stage N applications. The interest within DuPont Pioneer is partially because farmer David Hula (the winner of recent National Corn Yield Contests) intentionally adds supplemental N to his very high yield corn just prior to tassel appearance, and partially because of the recognition that recent higher yielding and "stay-green" hybrids with superior insect protection might benefit more from adding a low rate of N near the beginning of the critical period (about 10 days prior to silk emergence) than hybrids of 20 years ago. The imagined benefits from such late-stage N applications are that it will increase ear N concentrations at the early stages when kernel number establishment is so dependent on the overall ear N concentration as well as the ear N concentration. Our recent portrayal of the very high N concentrations and the very swift decline over time in the ear N concentrations (Ciampitti et al., 2013b) has highlighted the fundamental importance of trying to increase and maintain higher ear shoot N concentrations in the very early stages of grain fill in order to have the highest possible combination of kernel number/plant and kernel weight.

Because of their interest in late-season N application, Pioneer DuPont has agreed to partially fund a project that would help to support a new graduate student in the Cropping Systems program at Purdue University for a 3-year period. They will be providing me with $35,000 per year for a 3-year period starting in March of 2014. They will also be providing me with seed of two older hybrids that were of huge commercial importance in the early- to mid-1990's to compare with two newer hybrids that are higher yielding. All four hybrids will be of approximately comparable maturity (112-114 CRM hybrids). But the high costs for plant analyses in a study of this magnitude, and the relevance of the results to Eastern Corn Belt farmers who are clients of other seed companies mean that obtaining the support of other funding agencies is very important. Because what we intend to learn is pertinent not only to the specific hybrids, but in general terms to current elite hybrids versus those of 20 years ago, I believe that all producers and crop consultants in the Eastern Corn Belt will benefit from the results of this study.

We know that part of the positive response of modern corn hybrids to higher N rates is that total plant and grain uptake of other nutrients like P and Zn also increase (Ciampitti and Vyn, 2013b). Although we acknowledge that we should also study the response of high-yield corn to late-vegetative application of other nutrients like Mn and Zn that can have sometimes surprisingly high post-flowering uptakes, such a study would be prohibitively expensive to do across a range of hybrid eras. We also want to study the place of new technologies like the commercial high-clearance nutrient applicators that can inject N between the rows (Figure 2). Such technologies were not available a decade ago, and these new tools provide growers with new opportunities to shift some of their N fertilizer applications to a later time frame.

Figure 2. Late application of coulter-injected N between corn rows about the V12 stage near Wanatah, IN. Photo courtesy of Dr. J. Camberato (Purdue University).

Perhaps one of the more difficult negative environmental consequences to monitor with corn production systems is that of management consequences on greenhouse gas emissions (Synder et al., 2009). Our cropping systems group at Purdue University has also done extensive work on monitoring greenhouse gases in corn production systems over the last 10 years. Recently, much of our focus has been on nitrous oxide (N_2O) emissions in high yield corn systems in on-farm locations (Omonode et al., 2013) and in detailed research studies involving alternate tillage and rotation systems (Omonode et al., 2010; Burzaco et al., 2013). We fully recognize the susceptibility of N losses to the atmosphere as N fertilizer rates increase, and that the potential for that loss is much higher in the rainfed Eastern Corn Belt than it would be in irrigated systems in the Western Corn Belt (Omonode and Vyn, 2014). Part of the N_2O gas mitigation can occur when nitrification inhibitors are co-applied with N sources and with enhanced efficiency N fertilizers (Burzaco et al., 2013; Halvorson et al., 2013; Omonode and Vyn, 2014).

Late-vegetative N applications are potentially even more vulnerable to losses of N_2O to the atmosphere than normal pre-plant or early side-dress N applications. Environmental critics of on-farm N fertilizer practices in North American will be especially critical of these perceived "extra" N applications. The industry needs to assemble data on greenhouse gas emissions associated with such late-vegetative N applications, and demonstrate how both corn yield enhancement and atmospheric improvements can occur simultaneously before such systems can be broadly recommended.

The largest single pathway to reduce N_2O losses to the atmosphere is to increase the N uptake by corn plants itself, and to put the focus on enhancing crop yield and total plant N uptake while minimizing N_2O emissions (Burzaco et al., 2014; Van Groenigen et al., 2010). Thus the whole concept of "yield-scaled N_2O emissions" has been enthusiastically embraced as a realistic risk benefit approach that puts N_2O emissions into perspective of the N loss risk per tonne of grain yield that is so essential to meet society's demand for food, feed, fiber and fuel. We have used that concept in our recent paper on the implications of pre-plant versus side-dress N timing, N rates and nitrification inhibitors on emissions during the growing season. The more common split N applications (pre-plant or pre-emerge followed by side-dress N) should have even more potential to reduce N_2O emissions, but no research has looked at N_2O emissions and whole-plant corn plant N uptake when the split N approach intentionally involves small quantities of N applied at V12 to V15. The possible yield benefits of late-vegetative N applications to yield in modern hybrids needs to be considered in light of the potential N losses (including emissions).

Primary Objectives:

1. To determine the extent to which modern hybrids are likely to be more yield-responsive to late-vegetative N applications than hybrids of 20 years ago, and the physiological reasons for those differences if, indeed, modern hybrids are more responsive.
2. To evaluate the opportunity for split N applications involving an intentionally late-vegetative N application to reduce season-long and cumulative N_2O emissions relative to a single early side-dress N application strategy.
3. To use a partial budget approach to determine the economic implications of late-season N applications (whether supplemental N is applied, or whether a normally recommended N rate is side-dress applied both early and late) in high-yield corn production systems relative to a single-time, side-dress N application.

Methodology:

We propose to conduct two field experiments per year from 2014 to 2016 in NW Indiana on sandy loam soils with high yield potential, and in a typical corn-soybean rotation. The first of those experiments will be more intensive, rain-fed, and with smaller plots than the second location, which will involve very large field strip type plots with fewer treatments (in irrigated and non-irrigated production systems). We will conduct detailed measurements of soil properties, corn physiology, and greenhouse gas emissions during the season as well as the corn yield response to the intended treatments. This holistic approach will enable us to simultaneously address the agronomic, environmental and economic issues that surround the question of late- vegetative stage N application in modern production systems.

A. Small-plot Study in a Split-plot design with 5 replications (2014-2016):

Main N Treatments:

1. Zero N control
2. 140 pounds N/acre applied at V4-V5
3. 180 pounds N/acre applied at V4-V5
4. 220 pounds N/acre applied at V4-V5
5. 140 pounds N/acre applied at V4-V5 plus 40 pounds N applied at V12-V14
6. 180 pounds N/acre applied at V4-V5 plus 40 pounds N applied at V12-V14

Hybrid Sub-Treatments:

1. Pioneer 3394 (1991)
2. Pioneer 3335 (1995)
3. Pioneer 1498HR (2012)
4. Pioneer 1360HR (2014)

The proposed total N rates are slightly below and somewhat above the currently recommended Agronomic Optimum N Rates for this region of Indiana (Camberato et al., 2014). All N fertilizer used in the study would be UAN (28%N). We can already apply the 28% at the early side-dress stage very accurately with our own applicator, but we will rely on hiring a custom high-clearance unit for the late-vegetative stage UAN application (a unit similar to that depicted in Figure 2). Our goal is to inject the late-season N into the soil to a depth of 2-3” using coulters since we want to insure that the additional N becomes available quickly to the corn plants during their time of high N uptake requirements (e.g. 4 to 5 pounds N per acre per day or even more). Individual plots will be at least 6 rows wide (30” rows) and 75’ long.

Proposed Measurements in Small Plot Study:

Corn plant measurements will largely follow the intensive approach we have used in previous studies so that we can answer the “why” as well as the “what” questions surrounding corn response to N in different management situations (Burzaco et al., 2014; Ciampitti et al., 2013a,b). Key measurements include final plant population (compared to the seeding rate of 35,000 plants/acre), time to anthesis and silk emergence, total/component plant biomass and N uptake at both R1 and R6, ear shoot N status at weekly intervals before and after R1 stage, leaf area index at multiple growth stages, leaf SPAD at multiple times during the grain-fill period, kernel number and kernel weight at R6, incidence of barren plants at R6, grain yield, grain moisture and grain nutrient concentrations at R6, and both grain and nutrient harvest index.

Greenhouse gas measurements will involve the accepted protocols that we have used in earlier studies (Omonode et al., 2013; Burzaco et al., 2013). Essentially our focus will be on determining cumulative N_2O losses during the growing season. We intend to sample at weekly intervals during the bulk of the growing season at all N rates, but at bi-weekly intervals during the first month following the two side-dress application times (V4-V5 and V12-V14).

Soil measurements will mainly focus on soil nitrate and ammonium concentration testing to depths of 30 or 60 cm at V4-V5 prior to side-dress N application, at V12-15, at R1 and again at R6 (physiological maturity). We are interested in knowing the possible extra residual N in the soil profile with late-season application at the 2 N rates versus the other single-timing N application treatments. All soil and plant samples will be analyzed at the commercial A&L Laboratories in Fort Wayne, IN. Standard soil pH, P, K, Ca, and Mg sampling will be done in each replication. We will also attempt to measure soil moisture status during the season at multiple depths (see earlier notes).

Weather variables will be measured, and we will attempt to also monitor soil temperature and volumetric soil moisture on a continuous basis in selected plots. In 2012 and 2013, we have successfully used the Deere "Field Connect" probe system to monitor soil moisture levels every 30 minutes during the growing season at depths of 10, 20, 30, 50 and 100cm. This approach is expensive (at approximately $1500 per rented probe per season), but it is very helpful in explaining soil N losses and hybrid rooting pattern differences during the season.

B. Large-scale Field Studies:

Starting in April of 2015, we will conduct parallel large-field studies in both irrigated and non-irrigated corn production systems. These experiments will be conducted in both 2015 and 2016, and hopefully at multiple locations in Indiana and in Kansas (the latter in collaboration with Dr. Ignacio Ciampitti). The intention will be to use two hybrids and 4 N rate treatments at each location (based on Main Treatment numbers 3 to 6 above), and to utilize at least 3 reps per location of randomized field-length strips. The 2 hybrids used in these large-scale studies will be different than those proposed in the small-plot trial, but will be selected for their yield potential and possibly for their unique N uptake strategies (e.g. elite and high-yield hybrids recognized as varying in N use efficiency and/or water use efficiency). We plan to conduct at least 4 such trials per year in 2015 and 2016 in both Kansas and Indiana, though the actual amount will depend on funding and resources. The measurements will be similar to those proposed above for the small plot study (i.e. soil, plant and greenhouse gas data will be collected) but at a lower intensity.

Economic Implications:

We also propose to use a partial budgeting approach in the final year of the project to estimate the relative profitability of the various N management approaches. The graduate student that is involved in this project (Sarah Mueller) is a December, 2013 “Distinguished” graduate of Agricultural Economics at Purdue University. She also took a minor in Agronomy, and has enthusiastically embraced the agronomy concentration option for her MS degree. We may incorporate an Agricultural Economics faculty on her committee to provide further oversight on the relative economic aspects of (a) splitting the currently recommended N rate (180 pounds N acre) for the corn-soybean rotation in this region of Indiana into 140 (early) plus 40 (late) versus a single application at V4-V%, (b) applying a supplemental application of 40 pounds at a late stage (i.e. 40 pounds N late in addition to the 180 early N rate) relative to the 180 and 220 pound/acre N rate single-time applications.

Collaborations and Industry Involvement:

We will be consulting regularly with certified crop advisors, farmers and agricultural companies in carrying out this project, and in communication of the results from this project. As an example, I am Co-Chair as well as a regular speaker at the annual 2-day CCA Conference in mid-December in Indianapolis (attended by 770-800 individuals in 2012-2013). I also speak regularly at other major crop conferences in surrounding states. This past year, I spoke at crop and soil conferences in Iowa, Illinois, Ohio, Tennessee, Michigan and Indiana. I have also collaborated with the Indiana Corn Marketing Council and the National Corn Growers’ Association on N_2O emissions from various tillage, N rate and N inhibitor management strategy combinations. These environmental aspects of N fertilizer use continue to be of importance to corn farmers and to society, and there is still much to learn to continue to improve the 4R recommendations in light of major changes in genetics, weather and nutrient application technologies.

Dupont Pioneer are committing $35,000/year to this project for 2014-2016, and that money will be used to pay for undergraduate student labor (about $6,000 per year), for greenhouse gas sample collection and Gas Chromatography laboratory analyses (about $20,000 per growing season), for some of the total expected costs of soil fertility sampling for nitrate-N and ammonium-N at multiple depths and times between V4 and R6 growth stages (estimated at $3,000 per growing season) and for corn plant sample drying, grinding and nutrient analyses costs beyond those requested of the 4R Nutrient Stewardship program (estimated at an additional $6,000 per year). DuPont Pioneer will also contribute free corn seed to the project.

Other seed and fertilizer companies will also be approached to help support and “grow” this project. Another major step forward in the overall nature of this project is to investigate late-vegetative application of other nutrients. For example, we know from our recent work that up to 30% of the Mn and 50% of the Zn and Fe that is accumulated by corn plants over the growing season is actually taken up after silk emergence (Ciampitti and Vyn, 2013b). We also know that crop removal per unit yield of certain nutrients may increase substantially at very high corn yield levels (Ciampitti et al., 2014). In fact, there are going to be genetic, environment and management situations where the old standard nutrient removal approaches (i.e. constant removal per bushel regardless of yield level) may underestimate the actual removal. So we will continue to explore micro-nutrient timing, placement and product approaches that may help meet the other essential nutrient needs of high yield corn via late-season strategies. Over the years, my systems research program has benefited from supplemental financial support by various fertilizer companies including The Mosaic Company, PotashCorp, Yara International, etc.

Since a major emphasis of this project is on understanding the influence of current corn genetics on the timing and amounts of late-season nutrient uptake, I will continue to consult with seed companies beyond just Pioneer alone. My current research work on the physiology of nitrogen use efficiency gains with modern hybrids (i.e. relative to one or more older hybrids) involves funding support from both Monsanto and DowAgroSciences. However, that work is limited to a very traditional approach to the timing of N application itself. So there is a desperate need to study new timing approaches to N timing and placement (and later with other nutrients) that help to meet the yield potential of modern hybrids in a – hopefully - more sustainable manner.

Outreach Activities:

We intend to communicate the results, and 4R management implications of the project, in oral and poster presentations at the CCA, ASA and NCEI Soil Fertility conferences as well as in appropriate Purdue Extension field days. We will be happy to make presentations at the 4R Fund Review meetings when our schedules permit. We also intend to publish our results in refereed journals (like Agronomy Journal, Crop Management, Crop Science, etc.) and in various trade publications and Purdue University Extension Newsletters (like the Pest & Crop Newsletter). All results will be posted annually on a Purdue website for access, and we will invite IPNI staff and other potential sponsors to plot tours.

All outreach activities discussing late-season N applications will weave in essential aspects of the 4R Nutrient Stewardship Strategy that are so important to achieving both productivity and environmental gains with late-season N application because there are some risks involved (especially in rainfed production systems). Thus our group will continue to emphasize the timing, rate and placement aspects that are essential to achieving improved nutrient uptake and minimizing losses to the atmosphere.

Project Management:

I will manage the entire project, but I will be capably assisted by technicians and graduate students with considerable experience in farm/plot equipment operation, field/lab research instrumentation, plant/soil sampling, and statistical analyses. Our cropping systems group has been highly effective in training graduate students that are sought after in both industry and academic research and Extension positions all across the United States. I will serve as the Major Advisor to Sarah Mueller, and we will invite the appropriate faculty to join her committee. Our cropping systems research group has a reputation for publishing high-quality results rather promptly so that they will reach a broad audience.

I will continue to pursue other complementary funds from industries and grower associations to expand this project to involve nutrients other than nitrogen alone, and to involve multi-state locations. I intend to work closely with Dr. Ignacio Ciampitti at Kansas State University if we can together find additional funding.

References:

Burzaco, J. P., D.R. Smith, and T.J. Vyn. (2013a). Nitrous oxide emissions in Midwest US maize production vary widely with band-injected N fertilizer rates, timing and nitrapyrin presence. Environmental Research Letters, 8: 1-11.

Burzaco, J. P., I. A. Ciampitti, and T. J. Vyn, (2014). Nitrapyrin impacts on maize yield and nitrogen use efficiency with spring-applied nitrogen: Field studies vs. meta-analysis comparison. Agronomy Journal, 105(6), 1-8.

Camberato, J., R.L. Nielsen, and B. Joern. 2014. Nitrogen management guidelines for corn in Indiana. Applied Crop Research Update (January 8, 2014). URL: http://www.agry.purdue.edu/ext/corn/news/timeless/NitrogenMgmt.html

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. Field Crops Res. 133: 48-67. http://www.sciencedirect.com/science/article/pii/S0378429012001013

Ciampitti, I. A., and T. J. Vyn. (2013a). Grain nitrogen sources over time in maize: A review. Crop Science, 53(2), 366-377. http://doi:10.2135/cropsci2012.07.0439

Ciampitti, I. A., and T. J. Vyn, (2013b). Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: II Calcium, magnesium, and micronutrients. Agronomy Journal, 105(6), 1645-1657.

Ciampitti, I.A. and T.J. Vyn, 2014. Nutrient sufficiency concepts for modern corn hybrids: Impacts of management practices and yield levels. Crop Management (in press).

Ciamptti, 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: 1. Macronutrients. Agronomy Journal, 105(3), 783-795.

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 Science, 53(6), 2588-2602. http://doi:10.2135/cropsci2013.01.0041

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 Science, 53(6), 2588-2602. http://doi:10.2135/cropsci2013.01.0041

Halvorson, A.D., C.S. Snyder, A.D. Blaylock, and S.J. Del Grosso. 2013. Enhanced-efficiency nitrogen fertilizers: Potential role in nitrous oxide emission mitigation. Agron. J. 105:1-8.

Omonode, R.A., D.R. Smith, A. Gál, and T.J. Vyn. 2011a. Nitrous oxide fluxes in corn following three decades of tillage and rotation treatments. Soil Sci. Soc. Am. J. 75: 152-163.

Omonode, R.A., T.J. Vyn, D.R. Smith, R. Grant and C. Johnston. 2011b. Reducing nitrous oxide emissions from Indiana cornfields: Evaluation of tillage and N fertilizer best management approaches. A project report submitted to the Indiana Corn Marketing Council.

Omonode, R.A., and T.J. Vyn. 2013. Nitrification kinetics and nitrous oxide emissions when nitrapyrin is coapplied with urea–ammonium nitrate. Agron. J. 105:1475–1486.

Omonode, R.A., and T. J. Vyn. 2014. Nitrification inhibitor and enhanced-efficiency fertilizer's potential to delay nitrification and reduce nitrous oxide emissions in North America: A synthesis. Submitted for Review.

Snyder C.S., T.W. Bruulsema, T.L. Jensen, and P.E. Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems and Environment 133:247–266.

Tollenaar, M., and E.A. Lee. 2011. Strategies for enhancing grain yield in maize. Plant Breeding Reviews 34: 37-82.

Van Groenigen, J.W., G.L. Velthof, O. Oenema, K.J. van Groenigen, and C. van Kessel. 2010. Towards an agronomic assessment of N_2O emissions: a case study for arable crops. Eur. J. Soil Sci.

Project Time Line and Milestones Summary:

Month	2014	2015	2016	2017
January		Lab analyses, statistics and presentations		Lab analyses, statistics and presentations
February		Report preparation and presentations	Report and manuscript preparation	Final report and manuscript preparation and presentations
March		Annual report submission and grant application	Annual report submission, Extension updates, and new grant application	Final report submission and manuscript submission; Extension publication and data base submission
April/May	Plant corn	Plant corn	Plant corn	
May/June	Apply early N and take crop/soil measurements	Apply early N and take crop/soil measurements	Apply early N and take crop/soil measurements	
June/July	Apply late N and take Crop/Soil measurements	Apply late N and take Crop/Soil measurements	Apply late N and take Crop/Soil Measurements	
July	R1 stage intensive measurements	R1 stage intensive measurements	R1 stage intensive measurements	
August	Crop/Soil Measurements	Crop/Soil Measurements	Crop/Soil Measurements	
September	Sample processing	Sample processing	Sample processing	
October	Harvest and crop/soil measurements	Harvest and crop/soil Measurements	Harvest and crop/soil	
November	Sample processing	Sample processing	Sample processing	
December	Lab analyses, Statistics and Presentations	Lab analyses, Statistics and Presentations	Lab analyses, Statistics and Presentations	

List of Deliverables:

1. Complete data set from the project will be provided to the 4R Fund Database. The anticipated data set from this project will include all plant, soil and greenhouse gas concentration variables measured on the experiments associated with the project plus the accompanying procedures, climate conditions, and timeframes that are appropriate background methodology information for the dataset.
2. Annual progress reports by March 31 of 2015 and 2016, plus a final report by March 31 of 2017.
3. Presentations at 4R Fund Review Meetings (as often as schedules permit but presumably at least annually?).
4. Submission of two or more manuscripts for review in refereed journals such as the Agronomy Journal, Soil Science Society of America Journal, Crop Management, and Field Crops Research. Two manuscripts will be submitted prior to March of 2017 and more may be submitted later in 2017.
5. Copies of all refereed publications and Extension publications from the Cropping Systems research group that deal with the specific topic of late-vegetative stage nutrient applications, and the general topic of reproductive-stage nutrient uptake by modern corn hybrids in various management and environment situations.
6. Interactions and visits with IPNI directors and fertilizer industry agronomists about this project either hosted at Purdue University, or in other venues as appropriate.
7. Continued search for supplementary funding from other groups to expand the project to more locations and to involve more nutrients other than nitrogen.
8. Copy of the MS thesis by Sarah Mueller that will be based on this project.
9. Copies of the appropriate Power Point slide sets from Extension presentations based on this project.