International Plant Nutrition Institute
Final Project Report

Grantee Name: Harold M. van Es	
Project Title: Beta-testing the Adapt-N tool in on-farm strip trials	
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Project overview

Corn production accounts for the largest share of crop land area in the US and is the largest consumer of nitrogen (N) fertilizers. Routine application of N fertilizer in excess of crop demand has led to well-documented environmental problems and social costs. Current N rate recommendation tools are highly generalized over space and time and therefore do not allow for precision N management through adaptive and site-specific approaches. Adapt-N is a computational tool that combines soil, crop and management information with near-real-time weather data to estimate optimum N application rates for corn. We evaluated this precision nutrient management tool during four growing seasons (2011 through 2014) with 113 on-farm strip trials in Iowa and New York. Each trial included yield results from replicated field-scale plots involving two sidedress N rate treatments: Adapt-N-estimated and Grower-selected (conventional). Adapt-N rates were on average 53 and 31 kg ha^{-1} lower than Grower rates for NY and IA, respectively (-34% overall), with no statistically significant difference in yields. On average, Adapt-N rates increased grower profits by \$65 ha^{-1} and reduced simulated environmental N losses by 28 kg ha^{-1} (38%). Profits from Adapt-N rates were noticeably higher under wet early-season conditions when higher N rate recommendations than the Grower rates prevented yield losses from N deficiencies. In conclusion, Adapt-N recommendations resulted in both increased growers profits and decreased environmental N losses by accounting for variable site and weather conditions.

For this project we were to implement six strip trials in Central and Western New York, involving Grower and Adapt-N recommended nitrogen rates. We accomplished this through collaborating with Cayuga County Cooperative Extension Field Crops Specialist Keith Severson (3 trials), Western New York Crop Management Association Executive Consultant David DeGolyer (6 trials) and two Cornell Ag research stations (6 trials) for the 2014 and 2015 seasons. Altogether we had 8 strip trials in the 2015 season. Out of these, one had to be declared lost because of excessive rainfall during the late spring. Two more trials had cover crops and therefore are not presented at this time while we wait for the development of the cover crop module in the Adapt-N tool. Of the 5 trials that we could analyze at this time, the Adapt-N treatment increased profits by 114 $ ha^{-1} over the Grower treatment on average, while reducing 59 kg ha^{-1} of applied N. We have included a summary of the 2015 results in the following pages.

Successes

- Successfully completed many on-farm trials.
- Results are very positive, and provide direction for improvement. Adapt-N performs well when used correctly.
- Been able to reach more than target number of professionals on the use and benefit of the Adapt-N approach. Have achieved considerable exposure in other parts of the country, especially the mid-west.
- We have been able to complete training sessions and reach many professionals.

Obstacles

- Extended winters and wet springs may have effected some of the trials as corn struggled to get started. Some yields were affected in some cases.
- The strip trials indicated that farmers require more guidance on the use of the tool, especially as it relates to yield estimates. The tool performed very well when the yield goals were well estimated.

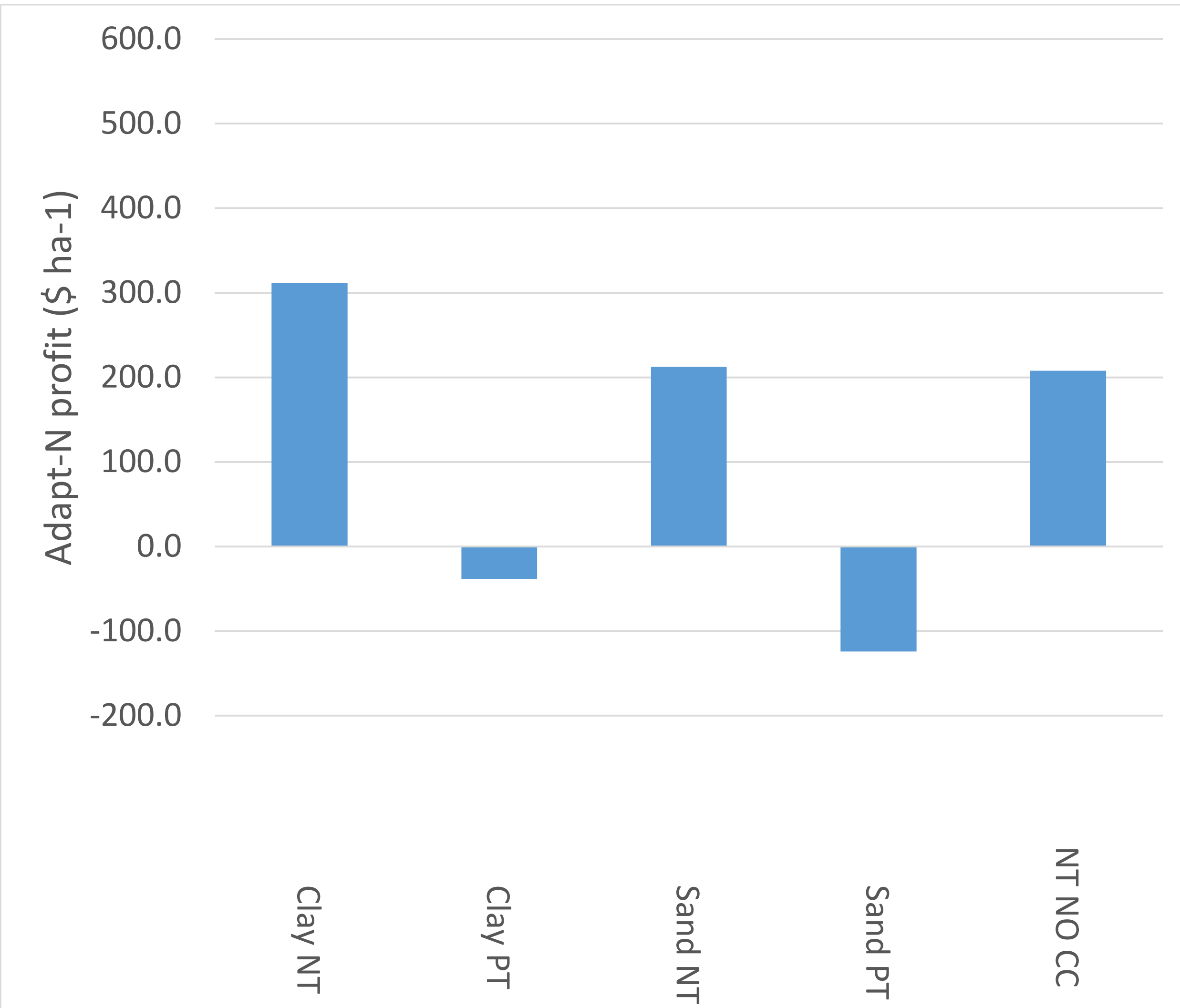
The results of this work and related previous work have been written up and are shared in this final report:

Summary of strip trials

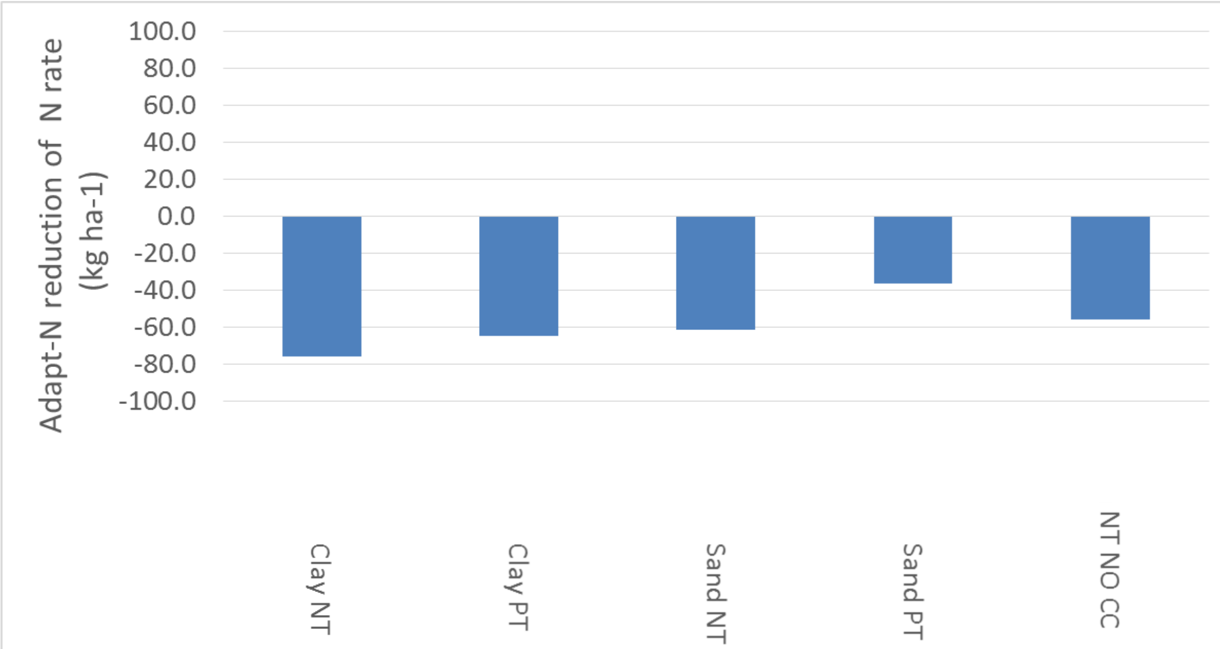
The 2015 season was a challenging one, with above average rainfall and many instances of flooding and saturated conditions that led to stand loss, especially in fields with bad drainage. In addition, in anticipation of the availability of a cover crops module in Adapt-N we had set up two trials with cover crops. However the integration of the cover crop module into the Adapt-N interface has been delayed. Fortunately the cover crop trials can and will be used in the near future to validate the cover crops model once it becomes available.

Altogether we had 8 strip trials in the 2015 season. Out of these, one had to be declared lost because of excessive rainfall during the late spring. Two more trials had cover crops and therefore are not presented at this time (see above). The results of the remaining five strip trials are presented below. On average, the Adapt-N treatment increased profits by 114 \$ ha^{-1} over the Grower treatment, while reducing 59 kg ha^{-1} of applied N.

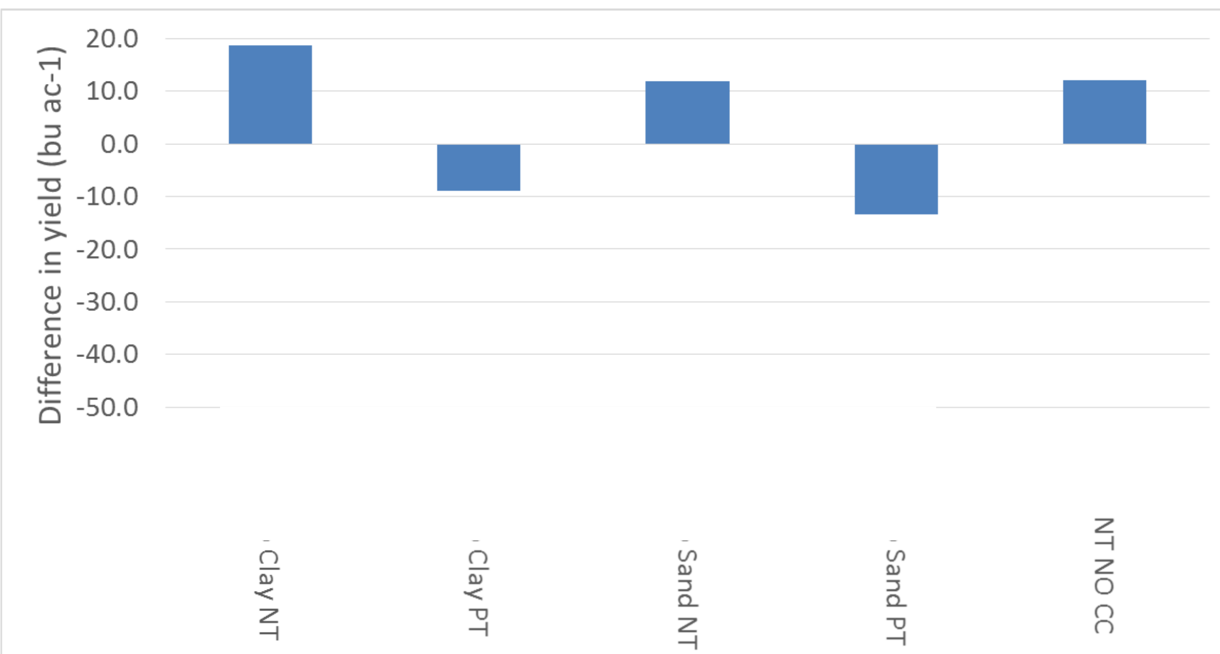
Difference in profit (average profit of 114 \$ ha^{-1})



Difference in N rate: (Adapt-N reduced on average 59 kg ha^{-1}.



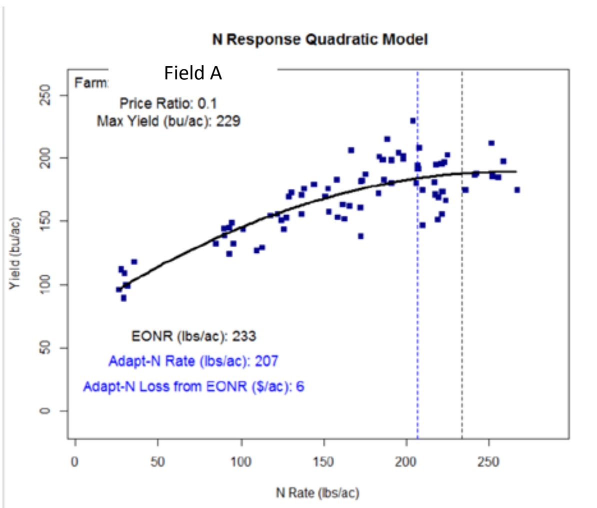
Difference in yield: Adapt-N increased on average 252 kg ha^{-1}.



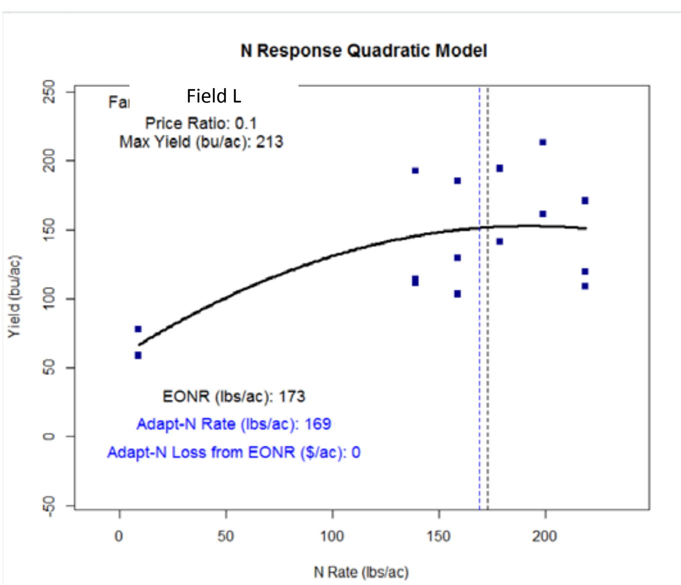
Summary of multi N rate trials

We had 4 multi N rates trials in the 2015 season, in 2 of these trials cover crops were incorporated and the data will be used to validate the cover crops module once it is completed. For the trials which had no cover crops Adapt-N did very well, with a mean loss from the EONR (Economic Optimum N rate) of $3. These results are very satisfying in light of the extreme wet season we had. The response curves of these trials are presented below, with the calculated EONR value plotted in black, while Adapt-N rate is plotted in blue.

Field A – Adapt-N $6 loss from EONR

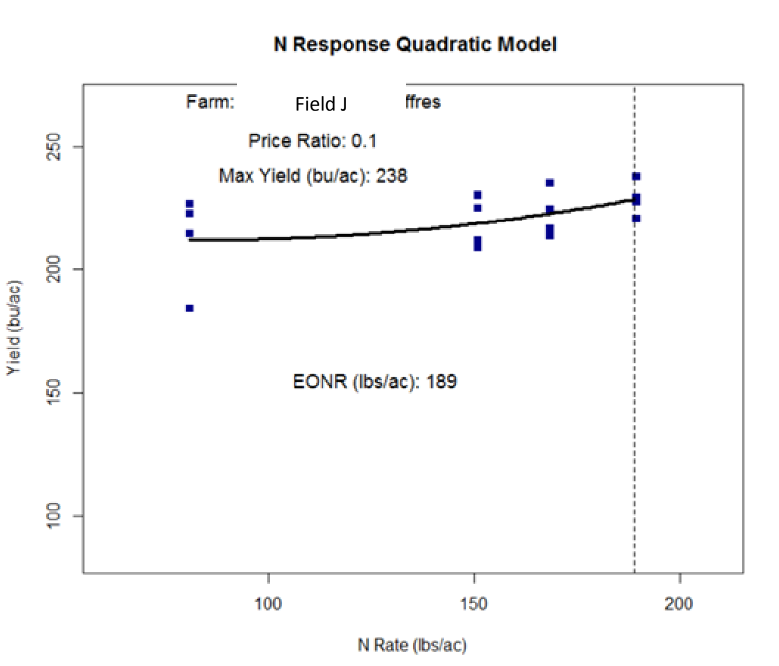


L Field – Adapt-N $0 loss from EONR

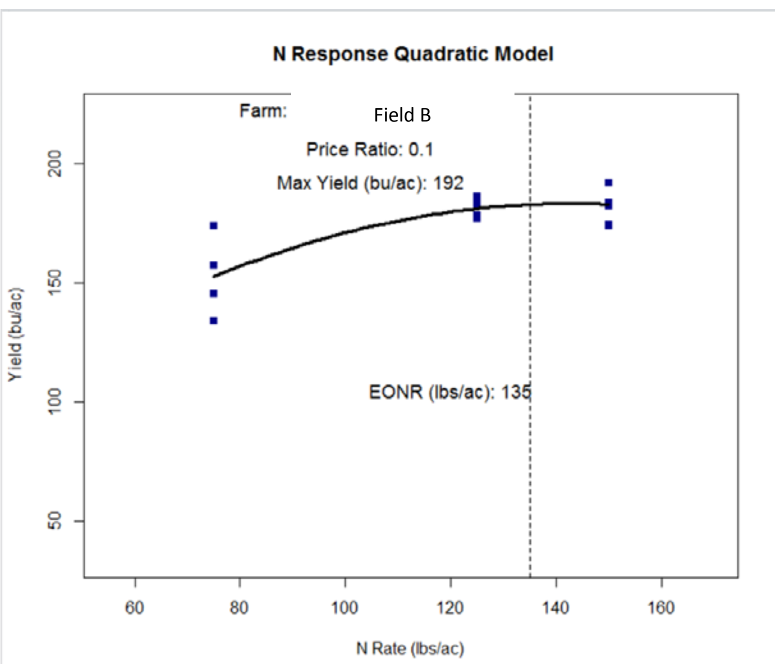


The response curves bellow are for the cover crops trials. Interestingly, in one of these trials (Field J) the cover crops had a very large impact on N availability, leading to relatively flat response curve and a large yield achieved for low sidedress rates. These are promising results which will be explored further in the next few months.

Field J –



Field B – Adapt-N



Adapt-N Outperforms Grower-Selected Nitrogen Rates in Northeast and Midwest USA Strip Trials

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Abstract

Maize (*Zea Mays* L.) production accounts for the largest share of crop land area in the US and is the largest consumer of nitrogen (N) fertilizers. Routine application of N fertilizer in excess of crop demand has led to well-documented environmental problems and social costs. Current N rate recommendation tools are highly generalized over space and time and therefore do not allow for precision N management through adaptive and site-specific approaches. Adapt-N is a computational tool that combines soil, crop and management information with near-real-time weather data to estimate optimum N application rates for maize. We evaluated this precision nutrient management tool during four growing seasons (2011 through 2014) with 113 on-farm strip trials in Iowa and New York. Each trial included yield results from replicated field-scale plots involving two sidedress N rate treatments: Adapt-N-estimated and Grower-selected (conventional). Adapt-N rates were on average 53 and 31 kg ha^{-1} lower than Grower rates for NY and IA, respectively (-34% overall), with no statistically significant difference in yields. On average, Adapt-N rates increased grower profits by \$65 ha^{-1} and reduced simulated environmental N losses by 28 kg ha^{-1} (38%). Profits from Adapt-N rates were noticeably higher under wet early-season conditions when higher N rate recommendations than the Grower rates prevented yield losses from N deficiencies. In conclusion, Adapt-N recommendations resulted in both increased growers profits and decreased environmental N losses by accounting for variable site and weather conditions.

Abbreviations: EONR - Economically Optimum Nitrogen Rate; NRE - Nitrogen Recovery Efficiency; PNM - Precision Nitrogen Management; SOM - Soil Organic Matter; SSURGO – Soil Survey Geographic Database.

Introduction

Global consumption of N-based fertilizers has risen substantially in the last few decades and is expected to continue to increase (Galloway et al., 2004; Erisman et al., 2008). Application of N fertilizer use in excess of crop demand can have an adverse, well documented effect on the environment (Vitousek et al., 1997; Gruber and Galloway, 2008). Nitrogen losses through leaching (Andraski et al., 2000; van Es et al., 2002) and runoff (David et al., 2010) affect groundwater aquifers (Böhlke, 2002; Gu et al., 2013) and aquatic biota in downstream streams and estuaries (Carpenter et al., 1998; Diaz and Rosenberg, 2008). Nitrogen losses through denitrification can result in increased emissions of nitrous oxide (N_2O; McSwiney and Robertson, 2005), a potent greenhouse gas for which agriculture is the main anthropogenic source (Smith et al., 2008). Altogether, increased anthropogenic N fluxes into the environment have a significant economic cost for society (Dodds et al., 2009; Sutton et al., 2011) which is largely externalized from the production economics, i.e., farmers and retailers have limited economic incentives to reduce environmental N losses unless they can be coupled to higher profits.

Maize [*Zea* mays L.] accounts for 27% of the US crop land area (USDA NASS, 2015a) and receives on average the highest N rate among major field crops (157 kg ha-1; USDA-ERS, 2015a). Maize N management in the US is often relatively inefficient, with N Recovery Efficiency (NRE, the proportion of applied N taken up by the crop) estimated at 37% (Cassman et al., 2002), but can be as high as 67% for split N applications on irrigated maize (Wortmann et al., 2011). One of the factors leading to excess agricultural N application is that soil N is spatially and temporally variable (Scharf et al., 2005; Kitchen et al., 2010; van Es et al., 2007b). Therefore, defining a location-specific economically optimum N rate (EONR, the N rate at which further increase in N is no longer economical) is challenging. The EONR is affected by multiple resource and production-related factors, including the timing and rate of precipitation events during the early growing season (van Es et al., 2007b; Tremblay et al., 2012), the timing of N application (Dinnes et al., 2002), N mineralization from soil organic matter (SOM), carry-over N from previous cropping seasons (Mulvaney et al., 2001; Ferguson et al., 2002), soil texture (Shahandeh et al., 2005), crop rotations (Stanger and Lauer, 2008) and topographic position affecting soil moisture availability (Schmidt et al., 2007; Zhu et al., 2015) and organic carbon (Pennock, 2005). Considering the difficulty of estimating EONR for any location and growing season and the relatively low N fertilizer cost relative to grain, many farmers use application rates in excess of the EONR for their field to ensure that the crop yield is not limited by N (Scharf et al., 2005; Shanahan et al., 2008). Providing farmers with better tools to estimate the EONR in the early- to mid-growing season when management interventions are still feasible (Scharf et al., 2011) will allow them to manage N applications in a more sustainable and economically beneficial way.

The Adapt-N tool (Melkonian et al., 2008) is an adaptive in-season N recommendation tool used to optimize a split application nutrient management approach. This approach (i.e. starter plus sidedress) generally improves NRE and reduces environmental N losses over large pre-plant applications (van Es et al., 2006). The Adapt-N tool is currently calibrated for use on about 95% of the US maize production area. It is offered in a cloud-based environment and is accessible through any internet-connected device that supports a web browser. The basis of the Adapt-N tool is a dynamic, deterministic simulation model that represents relevant soil and crop processes of maize production systems to generate more field-specific recommendations, and incorporates real-time weather information, as well as local soil and crop management factors.

The objectives of this study are: (i) to evaluate the performance of the Adapt-N tool compared to the Grower conventional practices in multiple seasons of strip trial field experiments; and (ii) to compare the associated simulated environmental N fluxes resulting from Adapt-N and Grower-selected applications.

Methods

The Adapt-N tool

Adapt-N was a publicly-available tool through <name withheld> University at the onset of this study, but was licensed and commercialized in 2014 (<name withheld>). The tool is based on the Precision Nitrogen Management (PNM) model (Melkonian et al., 2002, 2005, 2008), which in turn is an integrated combination of the LEACHN model (Hutson and Wagenet, 2003), and a maize N uptake, growth and yield model (Sinclair and Muchow, 1995). In the PNM model the soil profile is discretized into 20 layers of 50 mm each, which serve as the basis for the soil water flux and nutrient transformations modeling domain. An important feature of Adapt-N is its dynamic access to gridded high-resolution (4x4 km) weather data (precipitation, max-min temperature and solar radiation), which allows for field-specific and timely adjustments. The high resolution weather database is derived from routines using the US National Oceanic & Atmospheric Administration's Rapid Update Cycle weather model (temperature) and operational Doppler radars (precipitation). For both, observed weather station data are used to correct such estimates and generate spatially interpolated grids (DeGaetano and Belcher, 2007; DeGaetano and Wilks, 2009). Soils information used in Adapt-N is based on NRCS SSURGO datasets (http://soildatamart.nrcs.usda.gov/). The Adapt-N tool combines various user inputs (Table 1) with soil and weather data to dynamically simulate early-season crop and soil N dynamics and estimate soil N supply and crop uptake. The model was tested by Sogbedji et al. (2006) and Melkonian et al. (2010), and showed low prediction errors.

The tool is highly flexible in terms of N management options with inputs for fall, spring or split applications of fertilizer-N and a range of manure types and compositions, as well as accounting for N inputs from rotation crops (soybean [*Glycine max* (L.) Merr.], sod, etc.). Both the manure and sod inputs have a three year look-back period depending on location. Users can input various formulations of inorganic N fertilizers and select from a range of enhanced efficiency N products. One of the key user inputs is the site-specific attainable yield, based on long-term yield records.

The Adapt-N tool generates N recommendations based on a mass balance approach according to:

$$N_{rec} = N_{\exp\_yld} - N_{crop\_now} - N_{soil\_now} - N_{rot\_credit} - N_{fut\_gain-loss} - N_{profit\_risk} \qquad [1]$$

Where N_{rec} is the N rate recommendation (kg ha^{-1}); N_{exp_yld} is the crop N content needed to achieve the expected yield; N_{crop_now} and N_{soil_now} are the N content in the crop and soil as calculated by the PNM model for the current simulation date; N_{rot_credit} is the (partial) N credit from crop rotation (e.g. soybean); $N_{fut\_gain-loss}$ is a probabilistic estimate of future N gains minus losses until the end of the growing season, based on model simulations with historical rainfall distribution functions; and N_{profit_risk} is an economic adjustment factor that integrates corrections for fertilizer and grain prices, as well as a stochastic assessment of the relative profit risk of under-fertilization vs. over-fertilization. The Adapt-N tool also offers estimates of uncertainty around the recommended rate and provides tabular and graphical outputs that provide additional diagnostic information on simulated nitrogen dynamics.

The start date for model simulations in the Adapt-N tool is either January 1st of the simulation year or the fall of the previous year (in the case of fall manure or fertilizer applications). The soil profile is initialized with ammonium and nitrate contents that are typical for post-season conditions.

Validation methodology

The Adapt-N tool was validated using 113 paired field strip trials conducted in New York and Iowa during the 2011- 2014 growing seasons (Fig. 1). The locations of these trials were based on Growers willingness to participate in the research. Strip sizes varied from field to field, depending on field dimension, soil texture distribution, and collaborator preference. A minority (24%) of the trials had two replications, while the rest had three to seven replications. All replications were implemented using spatially-balanced complete block designs (van Es et al., 2007a) by the growers in collaboration with private crop consultants or university extension staff following prescribed experimental protocols. Nitrogen pre-plant applications rates were identical within each trial treatments, but varied among trials according to collaborator preference. For most of the trials (70%) composite soil samples were taken from each field and the soil texture was determined using the rapid soil texture analysis method (Kettler et al. 2001). Percentage of organic matter was determined by Loss-on-Ignition (Nelson and Sommers, 1996). In the case where field soil samples were not available, data on soil texture and SOM percentage were based on the SSURGO database and Grower records. The validation sites covered a wide range of soil texture classes and organic matter contents, although most of the trials were conducted on the more ubiquitous loam or silt loam soils (Fig. 2). More data regarding the trials are listed in Tables S1-S2. In each trial, the treatments were defined by the amount of N applied at sidedress, where the rates were: (i) the Adapt-N recommendation at the date of sidedress and (ii) a rate independently selected by the Grower, representing conventional practice. Yields were measured by calibrated yield monitor or in a few cases by hand harvest of at least 15 m of maize row in each plot. Following harvest, the treatments in each trial were compared based on the cost of N application and yield revenue using an estimate of partial profit:

$$\Delta P = (Y_A - Y_G) \times P_M - (N_A - N_G) \times P_N - P_{SD} \quad [2]$$

where ΔP is the partial profit (\$ ha^{-1}); Y_A and Y_G are the Adapt-N and Grower yields (kg ha^{-1}), respectively, corrected to 15.5% moisture content; N_A and N_G are the total N applied (kg ha^{-1}) in the Adapt-N and Grower treatments, respectively, and P_{SD} is a credit (\$20 ha^{-1}) accounting for operational savings if sidedress was avoided in either the Adapt-N or the Grower treatment. P_M and P_N are the mean US price for maize and N fertilizer during the years 2007-2013, equal to \$0.195 kg^{-1} (USDA NASS, 2015b) and \$1.098 kg^{-1} (USDA ERS, 2015), respectively. Fertilizer cost was calculated as the mean price of urea-ammonium nitrate (30% N) and anhydrous ammonia (82% N), adjusted to their elemental N concentrations. If the crop grown in the trial was silage (13% of all trials), the yield was converted to grain yield using a factor of 8.14, assuming a harvest index of 0.55 and moisture content of 15.5% and 65% for grain and silage, respectively. Treatment comparisons were not made for individual trials due to the low statistical power associated with two treatments and modest replication. Instead, mean values for each trial were used for an aggregate analysis of all trials or large subsets (IA and NY), with replicates considered as sampling error. This offers a very robust analysis of this extensive dataset. A paired t-test analysis was applied to test for significance (α=0.05) in the difference in profits and yields between Adapt-N and Grower rates.

Estimating environmental fluxes

The Adapt-N tool simulates leaching losses from the bottom of the root zone and gaseous losses to the atmosphere due to denitrification and ammonia volatilization. Both leaching and gaseous losses are simulated deterministically in the PNM model based on soil water dynamics and the rate equations of N transformations that are modified by temperature and water conditions (Sogbedji et al., 2006). Nitrogen losses were simulated from January 1st (or fall application date, if applicable) until Dec 31st. While substantial N losses are possible before the sidedress date (especially for the case of large pre-plant applications), in this analysis these losses would be the same for both the Adapt-N and the Grower treatments. Therefore in order to directly compare the environmental fluxes resulting from Adapt-N and Grower sidedress N applications, only the environmental fluxes that occurred after the application of sidedress N are reported.

Results and discussion

Nitrogen rates and profit analysis

The sidedress rates for trials with a history of manure application were generally lower for both the Adapt-N and Grower treatments (Fig. 3). For 17 (51%) of the manured trials, Adapt-N estimated that the applied manure and any applied starter N was sufficient to supply crop N needs, recommending zero sidedress. In 82% of all 113 trials the Adapt-N tool recommended lower N application than the respective Grower rate, with an average reduction of 45 kg ha^{-1} (34%; Table 2). While the mean N rates applied at sidedress by the Grower differed substantially between the NY and IA trials (159 and 82 kg ha^{-1} , respectively), the Adapt-N tool showed similar efficiency in reducing these rates (34% and 37%, respectively). These reduced rates resulted in an increased profit in 73% of trials, and an average increase of \$65 ha^{-1} over the Grower rate (Fig. 4) when all trials were considered. Paired t-tests indicate that the average yield was arithmetically slightly higher for Adapt-N, but not significantly different from the Grower rates (p=0.24 and p=0.96 for NY and IA, respectively), while the profit is significantly higher (p=1.9E-7 and p=0.03 for NY and IA, respectively).

Effect of seasonal rainfall on N rates recommendation

In seasons with dry or average spring rainfall conditions (i.e., 2011, 2012 and 2014) the Adapt-N treatment had on average 55 kg ha^{-1} lower N rates than the Grower treatment, a reduction of 39%. These reduced rates suggest that the Grower rate in those years was generally in excess of crop N requirements as the Adapt-N rates were sufficient to obtain similar yields. This resulted in an average profit increase of $48 ha^{-1} using Adapt-N in these years (Fig. 4).

The ability of the Adapt-N tool to adjust sidedress N rates to account for early season weather was demonstrated for the 2013 season in New York and Iowa. For the NY 2013 trials, heavy rainfall events occurred shortly following crop planting, when large amounts of mineralized N and early applied N were susceptible to losses. Adapt-N accounted for these weather effects and recommended higher N sidedress rates in 72% of the trials compared to the Grower-selected rates (an average increase of 22 kg ha^{-1}). This is illustrated in Figure 5, using data from Trial 24 (S1). Similar to a third of the trials in the NY 2013 season, this Grower chose to rely solely on large pre-plant application (197 kg ha^{-1}) to supply crop N requirements. A series of heavy rainfall events following planting (Figure 5a) led to large simulated N losses and the soil to become mostly depleted of available N by the middle of the growing season (Figure 5b). In the absence of an additional sidedress application, the deficit in soil N led to a low seasonal crop N uptake of 89 kg ha^{-1} (Figure 5b). In contrast, Adapt-N recommend an additional sidedress N application of 67 kg ha^{-1}, which replenished soil N deficits and led to a 99% increase in the simulated seasonal crop N uptake and an increase of 2605 kg ha^{-1} (42 bu ac^{-1}) in measured yield compared to the Grower. Overall, higher rates were recommended by Adapt-N for the 2013 NY trials (Table 2).

These results demonstrate that an adaptive N management approach that accounts for weather effects can be highly profitable, especially during years with high early-season precipitation.

In Iowa, however, 2013 Adapt-N rates were higher than Grower-chosen rates in only 29% of trials, despite the wet spring conditions. This is attributed to (a) the choice of all participating Growers in IA to manage N in a starter + sidedress approach with lower potential for early-season losses; and (b) an earlier occurrence of extreme rainfall events in IA in 2013 compared with the NY trials, when less of the potentially available N from organic matter had mineralized. Therefore, the average Adapt-N recommendation in IA for 2013, though higher than in the 2011 and 2012 trial years, was still 20 kg ha^{-1} (22%) lower than the Grower rate. Considering that the N rates applied by growers tend to include some "insurance N" to account for possible losses during the growing season (Dobermann and Cassman, 2004), these results demonstrate that the N rates applied by growers in the IA trials were modestly excessive even in a year (2013) with a very wet spring.

Environmental Losses

For all trials in both states, simulated combined leaching and gaseous losses were on average reduced by 28 kg ha^{-1} (38%) for the Adapt-N recommended rates compared to the Grower-selected rates (Fig 6a,b; Table 3). The simulated total N losses for the IA trials were on average 58% lower than for the NY trials, presumably due to lower applied N rates and different climate and soil conditions. The partition of total N losses between leaching and gaseous N loss pathways also differed between the states, with leaching losses consisting of 61% of total losses in NY, and only 32% for the IA simulated losses. The difference in leaching losses could in part be attributed to a soil texture effect - the NY sites generally have higher sand contents and lower clay contents (Table 3), and generally deeper rooting depths for IA soils (Table S1).

The average simulated leaching losses of 40 and 25 kg ha^{-1} (Figs. 6a and 7a, Table 3) for the Grower and Adapt-N trials, respectively, are comparable to measured leaching losses for other Midwestern maize trials reported in the literature (Kaspar et al., 2007; Qi et al., 2011, 2012; Malone et al., 2014). Adapt-N rates resulted in an average reduction of 14 kg ha^{-1} (36%) in simulated leaching losses compared to the Grower rates, and were consistently higher for the NY trials compared to the IA trials, despite high variability among locations and seasons: 22 kg ha^{-1} (39%) in New York and 0.3 kg ha^{-1} (3%) in Iowa. This can be attributed to several characteristics of the IA sites, including (i) higher denitrification losses relative to leaching due to generally finer soil textures (Table 3), (ii) greater rooting depths causing more water and N uptake in the lower profile (Table S1), and (iii) a higher participation rate of growers who already used highly optimized N application timing of low starter rates followed by sidedress, resulting in a modest difference in sidedress rate of 31 kg ha^{-1} between the Grower and Adapt-N.

Simulated gaseous losses (Fig. 6b and 7b) were similarly lower for the Adapt-N compared to the Grower treatment (average reduction of 13.5 kg ha^{-1}; 39%). The 2011 and 2012 seasons for the NY trials resulted in >50% reductions in simulated gaseous losses when using Adapt-N vs. Grower rates. Again, benefits were generally greater in NY than IA, although the reduction in gaseous losses in IA were greater (18%) than the reduction in leaching losses (3%).

Conclusions

This study presents the economic and environmental benefits of applying a dynamic simulation tool (Adapt-N) to generate in-season N rate recommendations in Iowa and New York across a large number of site-years representing a broad range of weather conditions, soil textures and management practices. The Adapt-N recommendations were generally lower than the Grower regular practice, and on average achieved higher profits while reducing environmental losses, thereby demonstrating the value of this adaptive N management approach for maize.

The potential benefits of the use of a dynamic simulation tool like Adapt-N were likely underestimated in this study as the participants represented a progressive group who already optimize N timing and placement decisions with sidedress applications. On average, only 32% of US Maize growers apply in-season N applications as part of their N management practices (USDA-ERS, 2015b). The economic and environmental benefits of Adapt-N could further increase as it stimulates better N application timing with the fraction of farmers who still use high rates of pre-plant (esp. fall) nitrogen applications. Overall, we conclude that adoption of simulation-based adaptive N management tools such as Adapt-N can help reduce the environmental costs of N fertilization while increasing economic benefits to growers.

Acknowledgments

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Figure 1. (A) Map of the U.S. with New York and Iowa outlined, and the locations (in green) of the Adapt-N strip trials in Iowa (B) and New York (C).

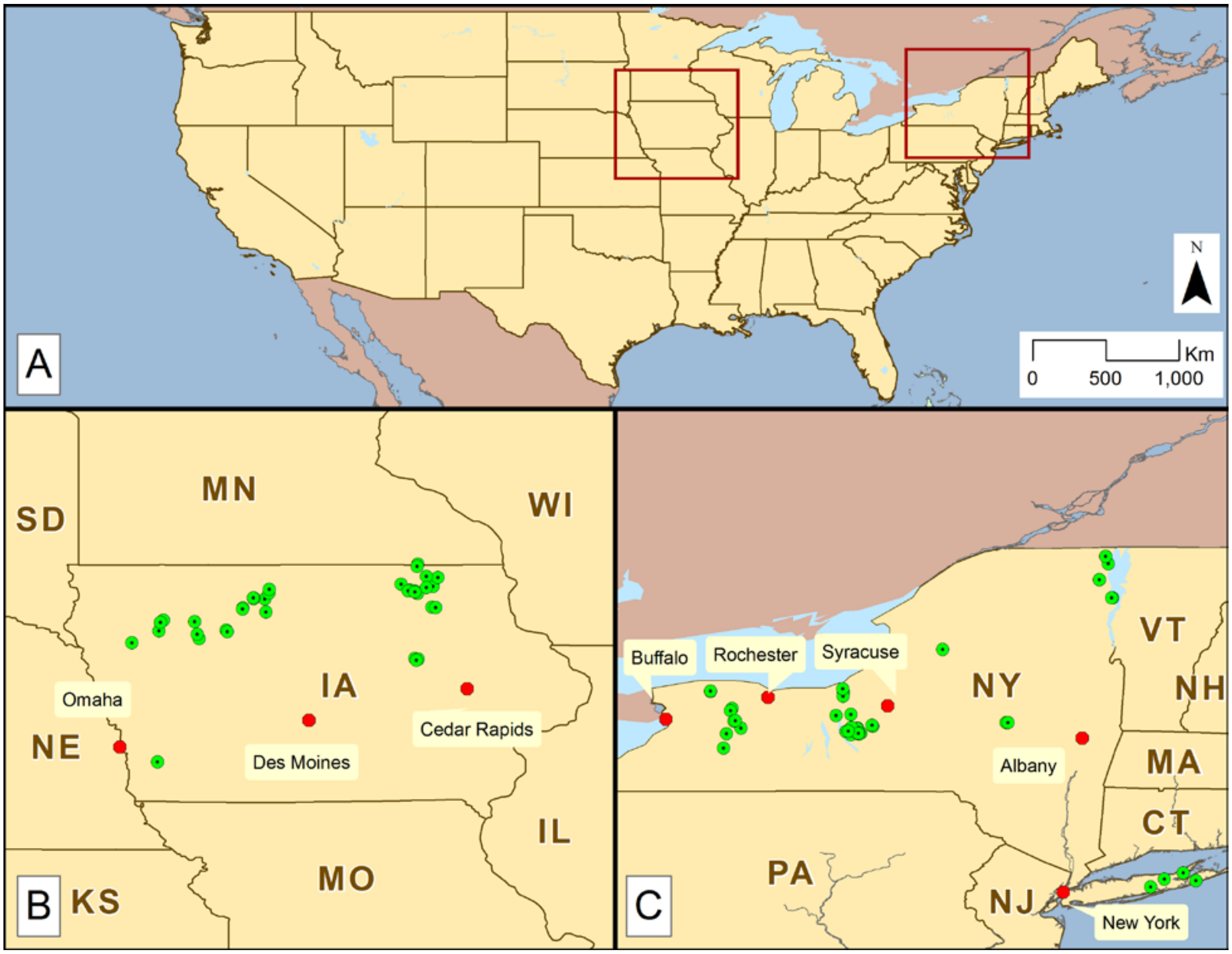


Figure 2. Soil texture and organic matter percentage of the trials used to validate the Adapt-N tool (produced using the “soil texture” R software package (Moeys et al., 2015)).

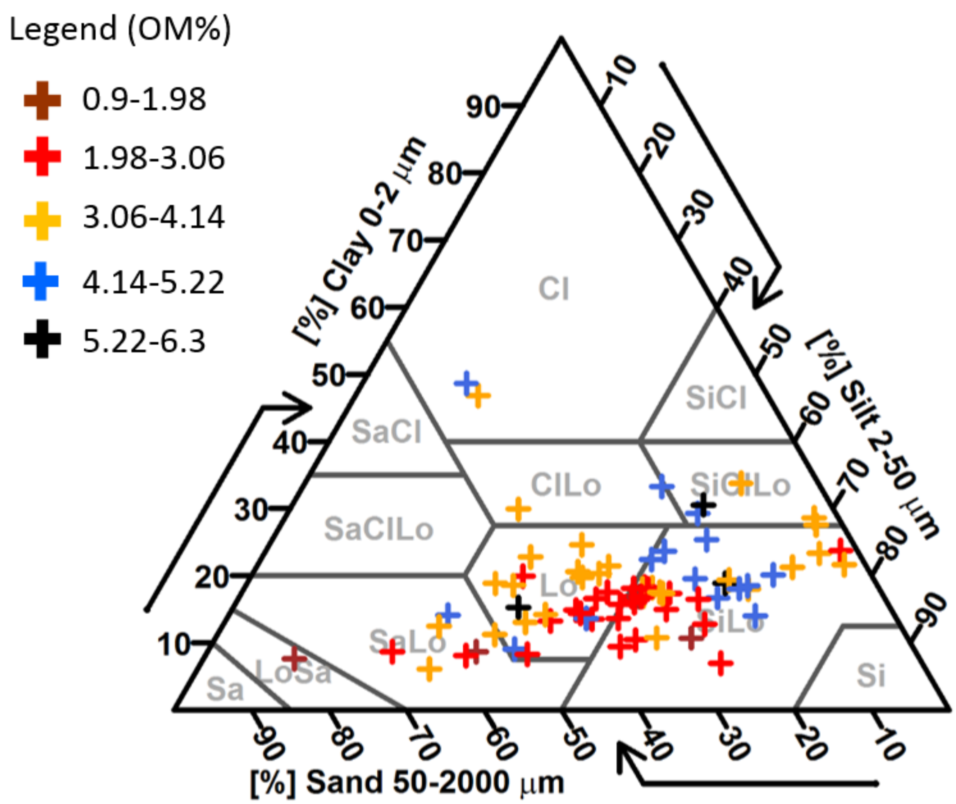


Figure 3. The Grower and Adapt-N sidedress rates for the NY (a) and IA (b) experimental trials. Sites with manure application in the three years prior to the trial are marked in red.

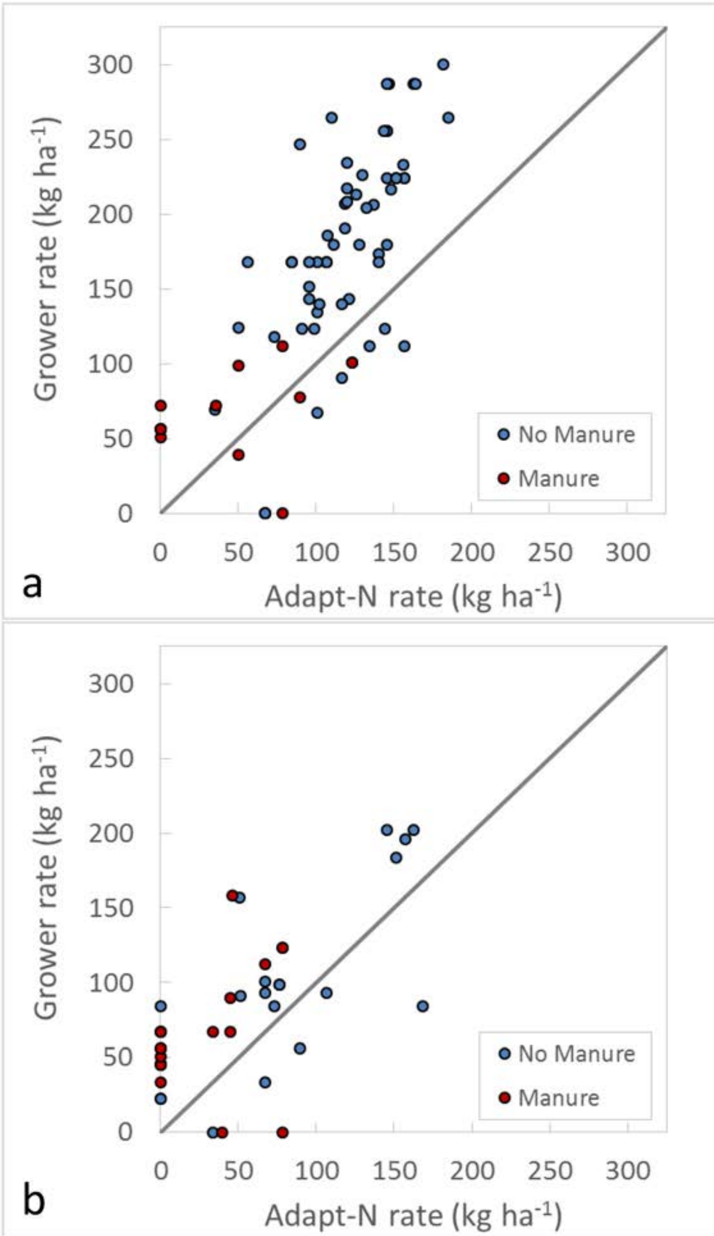


Figure 4. Partial profit analysis of the 113 trials used to validate the Adapt-N tool.

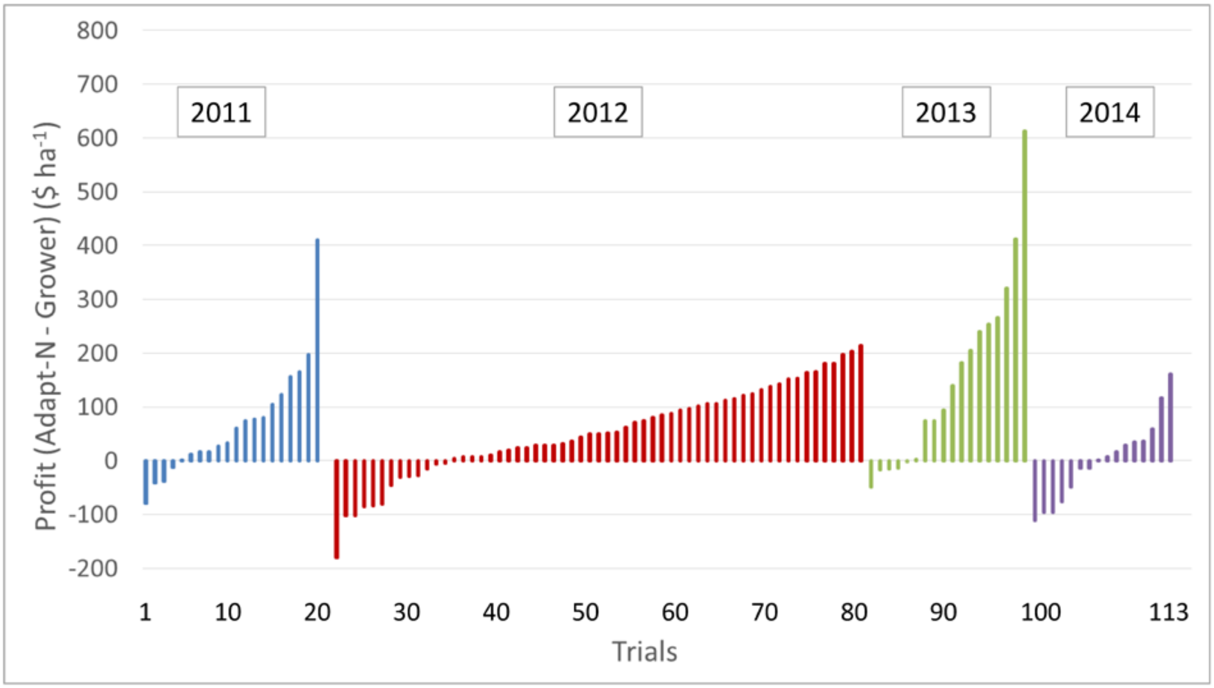


Figure 5. The effect of weather conditions on soil N availability, demonstrated using data from 2013 season NY trial number 24. In both Adapt-N and the Grower treatments 197 kg ha^{-1} was applied with planting. (a) Daily precipitation from January 1st to October 1st; (b) Simulated soil N availability and crop N uptake for the case of the Grower; (c) Simulated soil N availability and crop N uptake for the case of Adapt-N. The solid red line represents the preplant N application date, while the dashed red line represents the sidedress date

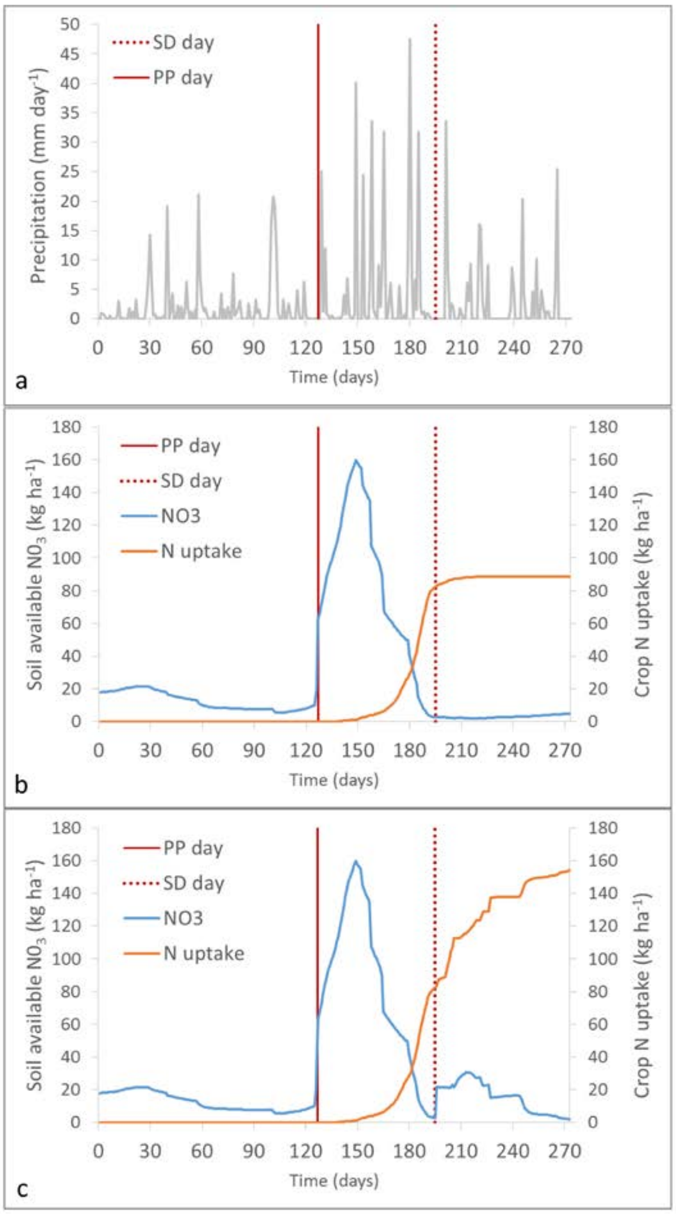


Figure 6. Adapt-N and Grower simulated leaching (a) and gaseous (b) losses.

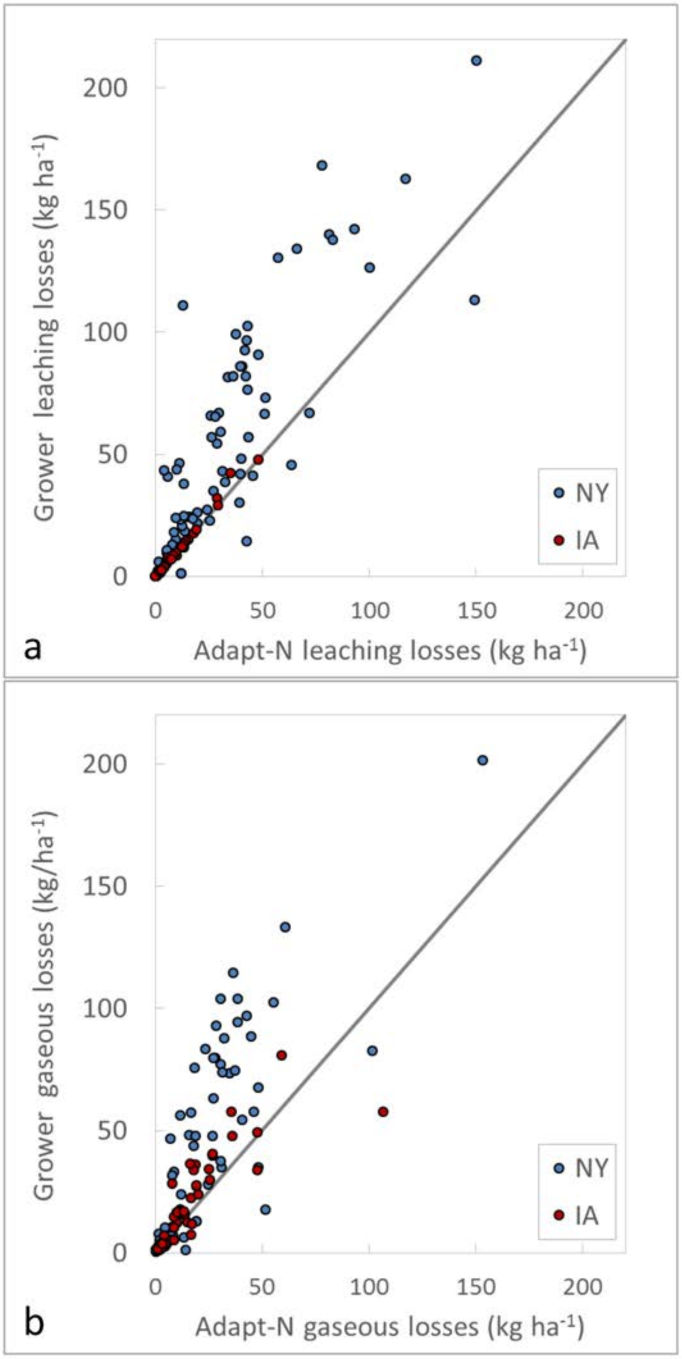
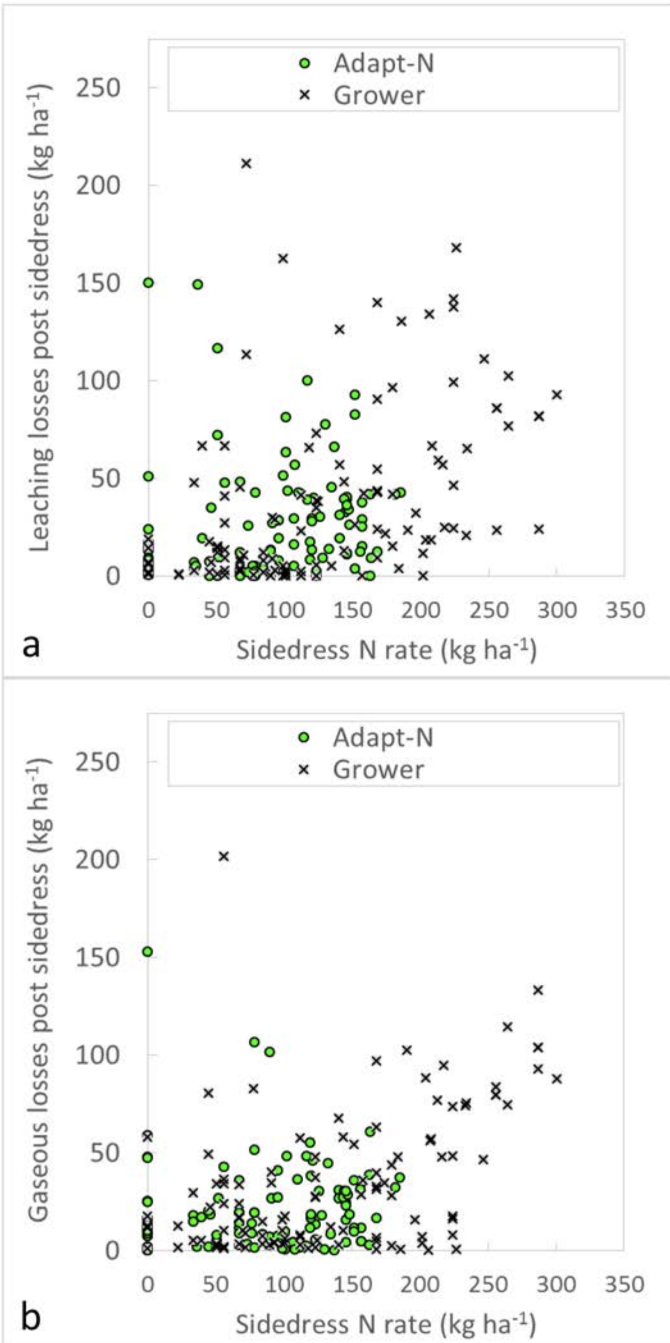


Figure 7. Relationship between N applied at sidedress and simulated post-sidedress leaching losses (a) and gaseous losses (b).



Tables

Table 1. Summary of inputs for Adapt-N tool. Default values are available for some inputs.

Feature	Approach
Simulation time scale	Daily time-step. Historical climate data for post-date estimates
Optimum N rate estimation	Mass balance: deterministic (pre) and stochastic (post) with grain-fertilizer price ratio and risk factors
Weather inputs	Near-real time: Solar radiation; max-min temperature; precipitation
Soil inputs	Soil type or series related to NRCS database properties; rooting depth; slope; SOC; artificial drainage
Crop inputs	Cultivar; maturity class; population; expected yield
Management inputs	Tillage (texture, time, residue level); irrigation (amount, date); manure applications (type, N & solid contents, rate, timing, incorporation method); previous crop characteristics
N Fertilizer inputs	Multiple: Type, rate, time of application, placement depth; fertilizer price; enhance efficiency compounds.
Graphical outputs	N contributions and uptake; N losses (total, NO_3 leaching and gaseous); N content dynamics; crop development; weather inputs; site-specific fertilizer maps (advanced)
Other	Web accessible; option for automatic daily updates by email or text message; batch data upload capability. Available for 95% of US corn acres.

Table 2. Yield and Profit results of the Adapt-N strip trial evaluation. N rates presented for the Adapt-N and the Grower plots are for the sidedress rate and not the total applied N rate at the trial. The average Adapt-N rate is followed by its spatial CV(%). The difference in N rate is followed by the percentage reduction from the Grower treatment. (A-G) Diff. indicates the difference between Adapt-N and the Grower treatments.

Year	n	Rainfall May-June	Grower N rate	Adapt-N rate	(A-G) N rate diff.	Grower Yield	Adapt-N yield	(A-G) Yield diff.	(A-G) Profit diff.
		mm	kg ha^{-1}			Mg ha^{-1}			\$ ha^{-1}
New York									
2011	11	229	133	71 (46%)	-62 (46%)	8.2	8.1	-0.1	82.8
2012	42	168	187	113 (43%)	-74 (40%	11.9	11.8	-0.1	61.6
2013	11	267	80	102 (47%)	+22 (28%)	10.8	12.1	1.3	227.3
2014	9	206	154	115 (12%)	-40 (26%)	11.7	11.6	-0.2	13.4
Mean	73	217	159	106 (43%)	-53.4 (34%)	10.65	10.9	0.2	96.3
Iowa									
2011	9	269	54	36 (149%)	-18.8 (35%)	12.2	12.1	-0.1	52.9
2012	17	155	75	44 (118%)	-30.9 (41%)	9.5	9.5	0.0	35.4
2013	7	358	91	70 (32%)	-20.1 (22%)	11.0	11.0	0.0	39.9
2014	7	351	126	71 (83%)	-55.3 (44%)	10.8	10.4	-0.4	-16.5
Mean	40	283	82	52 (97%)	-30.4 (37%)	11.0	10.8	0.3	25.5
Grand mean	113	250	131	86 (63%)	-45(34.3%)	10.8	10.9	0.1	65.1

Table 3. Simulated leaching and gaseous losses for Adapt-N and Grower-selected N rates. The clay and sand percentages represent the mean value of the trials in each season. (A-G) Diff. indicates the difference between Adapt-N and the Grower treatments.

Year	Grower leaching losses (kg ha^{-1})	Adapt-N leaching losses (kg ha^{-1})	(A-G) Leaching diff. (kg ha^{-1}) (%)	Grower gaseous losses (kg ha^{-1})	Adapt-N gaseous losses (kg ha^{-1})	(A-G) Gaseous diff. (kg ha^{-1}) (%)	Clay %	Sand %
				New York				
2011	59.0	29.2	-29.8 (50%)	20.0	8.5	-11.5 (58%)	14.2	45.8
2012	69.2	41.3	-27.9 (40%)	57.4	27.9	-29.5 (51%)	15.8	35.7
2013	28.5	28.5	0 (0%)	14.1	17.6	+3.5 (25%)	15.5	37.3
2014	27.2	15.6	-11.6 (43%)	22.5	15.6	-6.9 (31%)	22.7	36.2
Mean	56.4	34.4	-22.0 (39%)	40.9	21.9	-19.0 (46%)	16.4	37.5
				Iowa				
2011	13.0	12.9	-0.1 (1%)	17.3	15.6	-1.7 (10%)	21.8	17.6
2012	3.3	3.2	-0.1 (1%)	26.0	24.4	-1.6 (6%)	21.4	33.8
2013	8.4	8.5	+0.1 (1%)	24.2	15.9	-8.3 (34%)	24.7	21.8
2014	17.7	16.2	-1.5 (8%)	15.8	10.0	-5.8 (37%)	20.2	34.6
Mean	8.9	8.6	-0.3 (3%)	22	18	-4.0 (18%)	21.9	28.2
Grand mean	39.6	25.3	-14.3 (36%)	34.2	20.7	-13.5 (39%)	18.3	34.2

Comparing dynamic and static mass-balance N-recommendation approaches for the state of NY

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Maize (*Zea Mays* L.) is a major crop accounting for 27% of US cropland area [*USDA_NASS*, 2015a]. Maize plants have a C4 photosynthetic pathway, making them naturally efficient in turning cumulative N input into biomass production [*Sage and Pearcy*, 1987], and at the US they receive on average the largest N input of all major US crops (157 kg ha^{-1};[*USDA_ERS*, 2015]). The application of N to Maize fields is often in excess of crop actual N needs, resulting in environmental problems such as nitrate leaching into groundwater and streams [*Fenn et al.*, 1998; *David et al.*, 2010; *Cameron et al.*, 2013], and emissions of N2O gasses into the atmosphere [*Millar et al.*, 2010].

Soil N availability varies in time and space [*van Es et al.*, 2007a], and is effected, among others, by soil type and texture [*St Luce et al.*, 2011], N availability from previous crops [*Gentry et al.*, 2001, 2013], organic amendments such as manure applications [*Eghball et al.*, 2004; *Woli et al.*, 2015], and weather effects which drive N losses and consequently soil N availability [*Kahabka et al.*, 2004; *Kay et al.*, 2006; *Xie et al.*, 2013; *Deen et al.*, 2015]. To address this variability and to aid Growers in maximizing their profits by applying the Economically Optimum N Rate (EONR), several N recommendation methods for Maize were developed over the years. These methods include proximal sensing of crop N deficits [*Scharf et al.*, 2011; *Schmidt et al.*, 2011]; in-season soil testing, e.g. the Pre-Sidedress Nitrogen Test [*Magdoff et al.*, 1984]; simulation tools, such as the QUEFTS model [*Janssen et al.*, 1990] which was recently applied in Asia (e.g. [*Pampolino et al.*, 2012; *Xu et al.*, 2014] or models which are calibrated for the US such as the Adapt-N tool [*van Es et al.*, 2007a; *Melkonian et al.*, 2008]; the Maximum Return To N [*Sawyer et al.*, 2006], an empirical approach widely promoted for the US Midwest which relays on multi-years and multi-site N response trials; and Stanford-type mass balance approaches [*Stanford*, 1973], such as the Cornell N calculator (CNC, [*Ketterings et al.*, 2003]) which is promoted for the state of NY.

Stanford-type mass balance approaches are driven by the crop yield potential, internal cycling of N within the specific soil type and the efficiency of N uptake by the crop (Equation 1, [Stanford 1973[).

$$N_f = (1.2Y - E_p KN_p - E_{rm} N_{rm})/E_f \qquad [1]$$

Where N_f is crop requirements (lbs ac^{-1}); Y is the yield potential (bu ac^{-1}), which is multiplied by 1.2 assuming 50 lbs for a dry weight of one bushel of corn and the ratio of 1 of grain to stover; KN_p is the fraction of organic matter available to be mineralized with the efficiency factor of E_p; N_{rm} is the amount of residual mineral N at the root zone with the efficiency factor E_{rm}; and E_f is the fraction of N_f recovered by the crop, effected by application rate, timing of application and other factors such as soil properties [*Stanford*, 1973]. The Stanford-type mass balance approach is potentially appealing as it allows site-specific N recommendation depending on soil and crop N availability, and its relative simplicity makes it easy to implement in the field. However, this approach has a few issues: (a) it has some success in predicting the attainable yield, but it often fail in predicting the EONR (van-Es, 2007); (b) Similar to other widespread N recommendation approaches such as the Maximum Return to Nitrogen (MRTN) approach for the Midwest or the Corn Nitrogen Calculator (CNC) approach for the Northeast, the Stanford-type approach is static by nature, neglecting the effect of weather on soil N dynamics and availability within the growing season. Recommendations for a particular location are fixed from year to year, disregarding the direct control of weather on mineralization rates or environmental N losses. Stanford himself stated that “A limitation of the foregoing approach is that it largely ignores the dynamic nature of the water-soil-plant-nitrogen system” [*Stanford*, 1973].

Adapt-N [*Melkonian et al.*, 2008] is a web-based commercial N recommendation tool for maize (Adapt-N.com). It is driven by a mass balance approach, which in contrast to the static approach of Stanford (1973), employs a dynamic approach to the mass balance equation. High resolution weather data (4X4 km^2) serve in near real-time as input to a simulation model, which in turn updates the soil and crop N availability in the mass balance equation on a daily basis, creating a fully dynamic approach for estimating the crop N requirements. This approach therefore offers a more elaborative and dynamic treatment of the mass balance equation. This study evaluates whether accounting for weather effects and site-specific conditions improves N recommendation rates and their deviation from the EONR compared to a static N recommendation approach. We compare Adapt-N, representing the dynamic approach for N recommendation, and the Cornell Corn N Calculator [*Ketterings et al.*, 2003], a static Stanford-type N recommendation tool, with the specific three objectives:

a) To compare the efficiency of these two tools in estimating measured EONR rate;

b) To compare the sidedress N recommendation rates of the Adapt-N and the CNC tools; and

c) To compare the simulated environmental losses resulting from these recommended N rates.

Methods

Methodological approach

This analysis assumes a split N management approach for both tools (i.e. starter + sidedress). While the Adapt-N tool was developed as a sidedress N recommendation tool, the CNC tool generates a total N recommendation for the field conditions regardless of nutrient management approach. Therefore for the case of the CNC tool, if the grower in the experiment opted to apply some of the N rate as a starter or pre-plant, this rate was subtracted from the total N recommendation and the rest was used as sidedress recommendation. For the case of Adapt-N, these early applied N rates were included in the simulations used to generate the sidedress recommendations.

The Cornell Corn N Calculator

The CNC tool was downloaded from http://nmsp.cals.cornell.edu/software/calculators.html. Generating a recommendation required several user inputs regarding the soil type and manure applications (if applicable). The CNC tool allows the yield potential to be extracted from the tool's own database (i.e. the default potential yield) or to be entered manually by the user. For this analysis we have used the CNC to generate N recommendations using both the default yield potential and for a yield potential supplied by the Grower of each field, based on historical yield records. The CNC tool generates N recommendation according to Equation (2):

$$N_{required} = (YP_{corngrain} * 1.2 - N_{soil} - N_{sod}) / (f_{eff}/100) \qquad [2]$$

Where $N_{required}$ is the N recommendation; $YP_{corngrain}$ is the yield potential (bu ac $^{-1}$, 85% dry matter); N_{soil} is a soil-specific credit accounting for future mineralization of soil organic matter; N_{sod} is a credit accounting for soil N availability from various types of plowed-down sods, and f_{eff} is a nitrogen uptake efficiency factor that depends on soil type and drainage. When the default CNC yield potential is used the yield depends on soil type and drainage. A factor of 20 lbs ac $^{-1}$ is added to the $N_{required}$ value for the case of no-till soil management.

The Adapt-N tool

For a detailed description of the Adapt-N tool the reader is referred to [*Melkonian et al.*, 2008; *Sela et al.*, 2016]. Adapt-N is an in-season sidedress N recommendation tool, designed to optimize split N application where the bulk of N is applied at sidedress. It is currently calibrated for use on 95% of the US maize production area and is offered in a cloud-based environment, making it accessible through any internet-connected device that supports a web browser. The tool has a dynamic access to gridded high-resolution (4x4 km) near-real-time weather data derived from routines using the US National Oceanic & Atmospheric Administration's Rapid Update Cycle weather model and operational Doppler radars. For both, observed weather station data are used to correct estimates and generate spatially interpolated grids [*DeGaetano and Belcher*, 2007; *DeGaetano and Wilks*, 2009]. The tool requires user input such as soil texture or series, percentage of organic matter, yield potential, crop variety, data on previous crops, manure or pre-plant N applications (if applicable), and the field tillage practice. The engine of the Adapt-N tool is the Precision Nitrogen Management (PNM) model [*Melkonian et al.*, 2005], a biogeochemical model which solves soil water and N fluxes, crop N uptake and crop growth on a daily time step. Adapt-N generates N recommendations according to a mass balance equation which is solved on a daily basis (Equation 3):

$$N_{rec} = N_{\exp\_yld} - N_{crop\_now} - N_{soil\_now} - N_{rot\_credit} - N_{fut\_gain-loss} - N_{profit\_risk} \qquad [3]$$

Where N_{rec} is the N rate recommendation (kg ha^{-1}); N_{exp_yld} is the crop N content needed to achieve the expected (potential) yield; N_{crop_now} and N_{soil_now} are the N content in the crop and soil as calculated by the PNM model for the current simulation date; N_{rot_credit} is the (partial) N credit from crop rotation (e.g. soybean); $N_{fut\_gain-loss}$ is a probabilistic estimate of future N gains minus losses until the end of the growing season, based on model simulations with historical rainfall distribution functions; and N_{profit_risk} is an economic adjustment factor that integrates corrections for fertilizer and grain prices, as well as a stochastic assessment of the relative profit risk of under-fertilization vs. over-fertilization.

Field data used for the analysis

A dataset of 16 trials conducted between the years 2011-2015 was used for the analysis. The location of these trials and the data characterizing them is presented in Figures (1, 2) and Table (1). In each of these trials multiple N rate applications were applied, allowing to calculate the respective EONR of each trial (Table 1). A quadratic function was used to fit the data from the multiple N rates experiments and to calculate the EONR using a code written in R, assuming a price of $1.098 kg-1 and $0.195 kg-1 for N fertilizer and Maize yield. This price correspond to the mean US price for maize and N fertilizer during the years 2007-2013 [*USDA_ERS*, 2015; *USDA_NASS*, 2015b]. Following, the respective economic losses from this optimal rate resulting from the Adapt-N and the CNC rates were calculated. If a recommendation rate was higher than the EONR, the loss was calculated as the difference between the EONR and the recommended rate, multiplied by the price fertilizer. Half of the trials had 3 N rates applied (usually a zero, an intermediate and high value of N), and the rest had 5 or 6 N rates. Trials where the calculated EONR was equal to the highest N rate applied in the experiment were removed from the analysis. While the majority of the trials had 3-4 replications for each rate, due to field conditions and the collaborating Grower preferences, a few trials had only two replication for each rate. The replications in all the field experiments were implemented using spatially-balanced complete block designs [*van Es et al.*, 2007b]. For 81% of the field trials composite soil samples were collected at the field and the soil texture and organic matter percentage were determined using the rapid soil texture method [*Kettler et al.*, 2001] and by Loss-on-Ignition [*Nelson and Sommers*, 1996], respectively. For the remaining 19% of the fields data regarding the soil texture and organic percentage were obtained from the Grower's records. Both the CNC and the Adapt-N tools mass balance approach is driven by the potential yield, and a good estimation of it is vital to allow accurate N rate recommendations. Therefore to eliminate the cases of user-input errors associated with underestimation of the actual potential yield for each field, in three cases (19%) where the achieved yield in the experiment was more than 20 bu ac^{-1} (1.25 Mg ha^{-1}) higher than the potential yield supplied by the grower, the potential yield estimate was corrected and set as (achieved yield – 20 bu ac^{-1}). Notice that this correction does not fit in hindsight the potential yield to the achieved one, but instead leaves a 20 bu ac^{-1} difference accounting for common Grower's estimation errors.

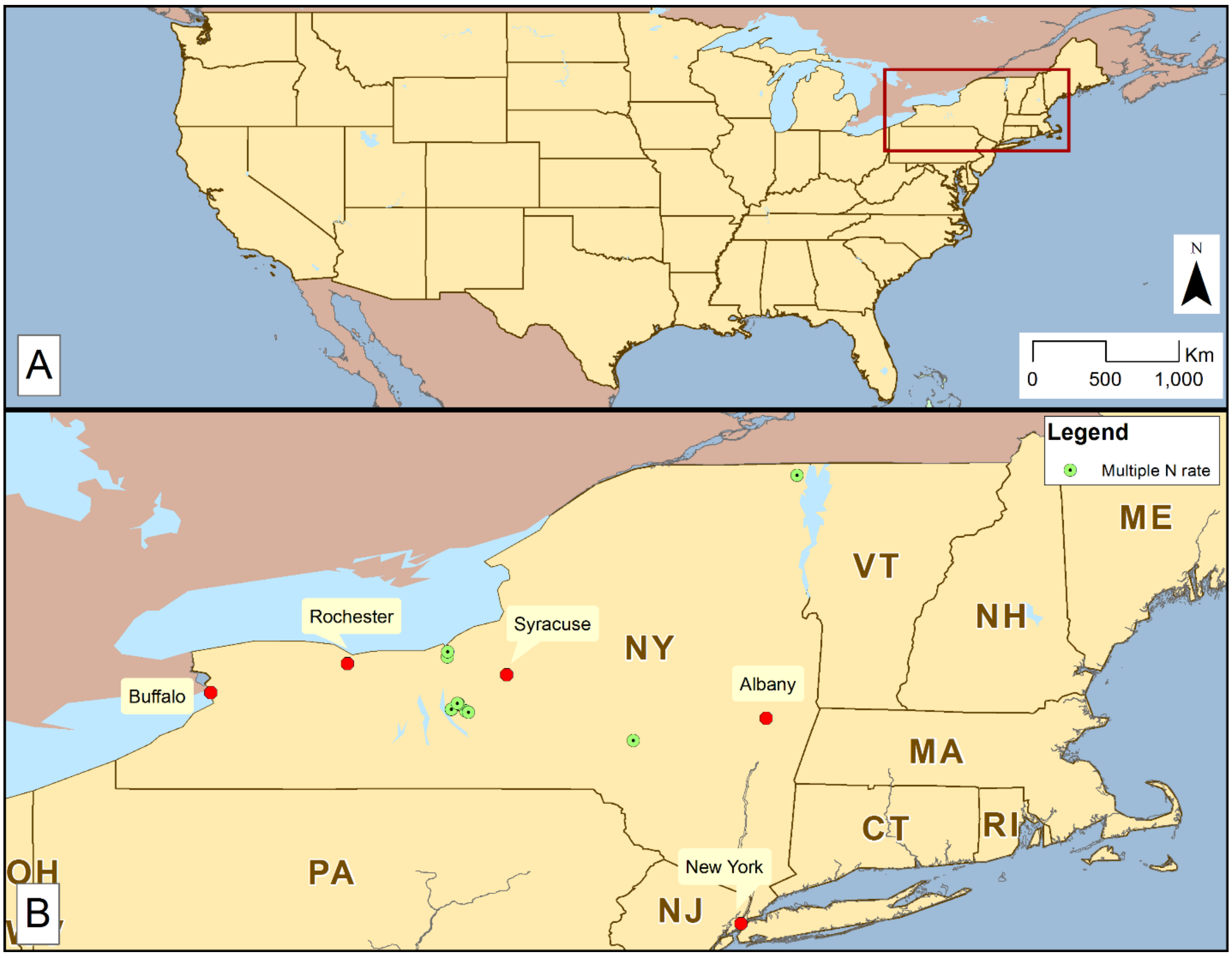

Figure 1. Location (marked green) of the multiple N rate trials used for the analysis (b) in the state of NY (a).

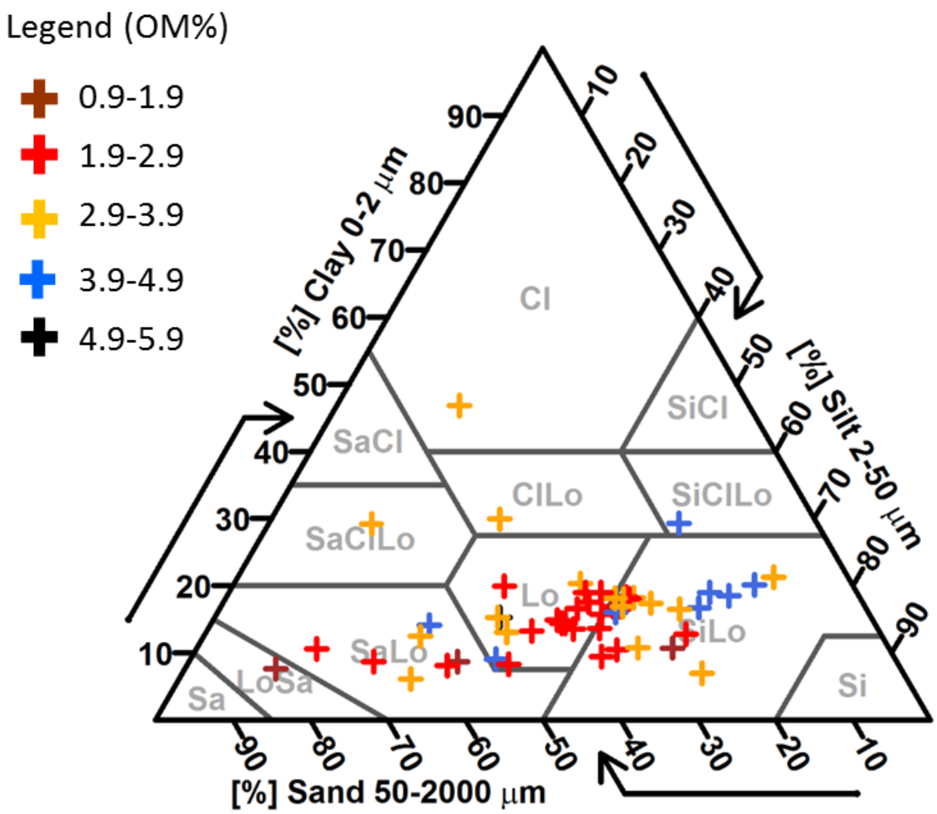

Figure 2. Soil texture and organic matter percentage of the trials used in the analysis (produced using the “soil texture” R software package [*Moeys et al.*, 2015]).

Table 1 – Information regarding the multi-rate trials used for the economic analysis. The reported range of rates reflect the total N rate used in the experiment, including the starter application. Depth indicates the depth of sidedress incorporation.

						Sidedress information					
Site	Year	County	Soil series or class	OM %	Tillage€	# of rates	Range of rates (kg ha-1)	# of reps	SD date	Form‡	Depth (cm)
1	2011		Silt Loam	3	ST	3	28-196	2	16/6	UAN	8
2	2011		Silt Loam	3	CT(50)	3	28-196	2	16/6	UAN	8
3	2012		Silt Loam	2.5	CT(50)	3	27-251	4	26/6	UAN	8
4	2012		Silt Loam	4.1	ST	3	25-235	2,3	15/6	UAN	8
5	2012		Silt Loam	3	ST	3	25-258	2,3	22/6	AA	23
6	2012		Silt Loam	4.4	ST	3	25-260	2,3	21/6	AA	23
7	2012		Silt Loam	3.8	ST	3	25-232	2,3	16/6	AA	23
8	2013		Silt Loam	2.4	CT(50)	3	27-251	2	7/7	UAN	8
9	2014		Williamson	3	ST	6	61-212	3	20/6	UAN	8
10	2014		Hogansburg	2.9	ST	5	38-206*	4	18/7	UAN	8
11	2014		Malone	3.7	CT(25)	5	38-206*	4	18/7	UAN	8
12	2014		Loam	2.3	ST	5	75-176	3	30/6	UAN	8
13	2014		Lansing	2.7	ST	5	154-266	3	27/6	UAN	8
14	2014		Silt Loam	3.7	CT(50)	6	40-320	4	1/7	AS	8
15	2015		Sodus	3	CT(25)	6	10-235	2,3	10/6	UAN	8
16	2015		Honeoye	3.4	ST	6	25-282	4	17/6	AA	23

€ CT = Conservation tillage (%residue); ST = Spring Tillage; ‡UAN = Urea Ammonium Nitrate; AA = Anhydrous Ammonia; AS = Ammonium Sulfate. * These trials had a 28,050 L ha $^{-1}$ dairy manure application the fall previous to the experiment, with ammonium and organic N concentrations of 0.003 and 0.006 kg L^{-1}, respectively.

Estimation of environmental fluxes

Leaching losses from the bottom of the root zone and gaseous losses to the atmosphere due to denitrification and ammonia volatilization are simulated by the PNM model, and reported by the Adapt-N tool, based on soil water dynamics and rate equations of N transformations [*Sogbedji et al.*, 2006]. The trials used for the analysis had different N management approaches according to the collaborator preferences, such as preplant N or manure applications in different quantities. While these management decisions might have led to high simulated N losses prior to sidedress time, these losses would have been the same for the Adapt-N and the CNC tools. Therefore, to compare the environmental losses resulting from the Adapt-N or the CNC sidedress recommendations, only the environmental fluxes that occurred after the application of sidedress N and until the end of the season (Dec 31st) are reported.

Results and discussion

Comparison of potential yields and N recommendation rates

Figure (3) presents a comparison between the potential yields supplied for each field by the Grower and or derived by the soil type by the CNC. The potential yields supplied by the CNC tool were substantially lower than the Grower's own estimates, 8.2 Mg ha^{-1} compared with 12.1 Mg ha^{-1}, reflecting an average reduction of 3.9 Mg ha^{-1} (62 bu ac^{-1}, 32%). This difference between the CNC and the Grower-estimated potential yields was found statistically significant when subjected to a paired t-test ($p<0.0001$, $\alpha=0.05$). Incidentally, the Grower-estimated potential yield averaged 12.1 Mg ha^{-1} while the achieved average yield was 11.9 Mg ha^{-1}. Therefore, Grower-estimated potential yields were generally close to the actually achieved yields at the end of the season, and the lower potential yields supplied by the CNC tool might represent an outdated potential yield estimate.

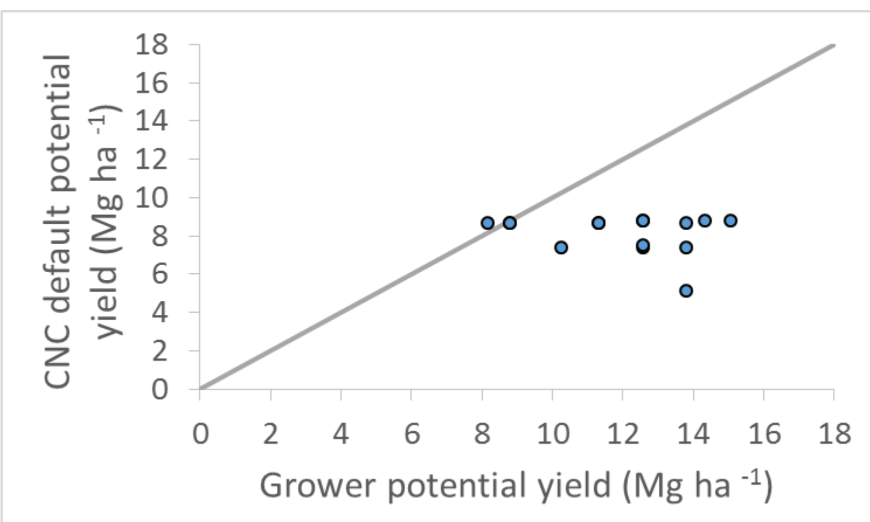

Figure 3. Comparison between the potential yields for each field trial as estimated by either the Grower or extracted from the CNC tool.

Figure (4a,b) presents the sidedress recommendations of the Adapt-N and CNC tools. The average recommendation rate for Adapt-N, which is driven by the Grower-estimated potential yield, was 158 kg ha^{-1} and 45 kg ha^{-1} for the non-manured and manured trials (respectively). The choice of the potential yield was found to have a strong effect on the N rates recommend by the CNC. Using the Grower-estimated potential yield (Figure 4a), the CNC recommend on average 239 kg ha^{-1} and 131 kg ha^{-1} for the non-manured and manured trials (respectively), a substantial increase of 81 kg ha^{-1} (51%) and 86 kg ha^{-1} (191%) over the Adapt-N rate. Using the CNC default potential yield (Figure 4b), the CNC recommended on average 109 kg ha^{-1} for the non-manured trials (a 49 kg ha^{-1}, 31% decrease over the respective Adapt-N rate). For the manured trials the CNC tool recommendation remained higher than Adapt-N's recommendation, with 90 kg ha^{-1} (100% increase). However, as these sidedress N recommendation result from a possibly outdated potential yield, these rates could be insufficient in fulfilling the crop actual needs.

Economic analysis

Figure (5) and Table (2) present a comparison between the total N recommendations of the CNC and Adapt-N tools and the calculated EONR for each trial. The default potential yield supplied by the CNC tool leads to under estimation of the EONR rate (Figure 5a), with an average rate of 135 kg ha^{-1} compared with a 178 kg ha^{-1} for the EONR and a calculated Root Mean Square Error (RMSE) of 62 kg ha^{-1}. These low recommendations further lead to an average loss from the EONR of 96 \$ ha^{-1}. Conversely, when the CNC tool was supplied with a Grower-estimated potential yield, the CNC recommendations were found to overestimate the EONR (Figure 5b), with an average rate of 257 kg ha^{-1} and a calculated RMSE of 96 kg ha^{-1}. These high N rates reflects an average excess of 79 kg ha^{-1} of N over the EONR, and lead to an average loss from the EONR of 83 \$ ha^{-1}.

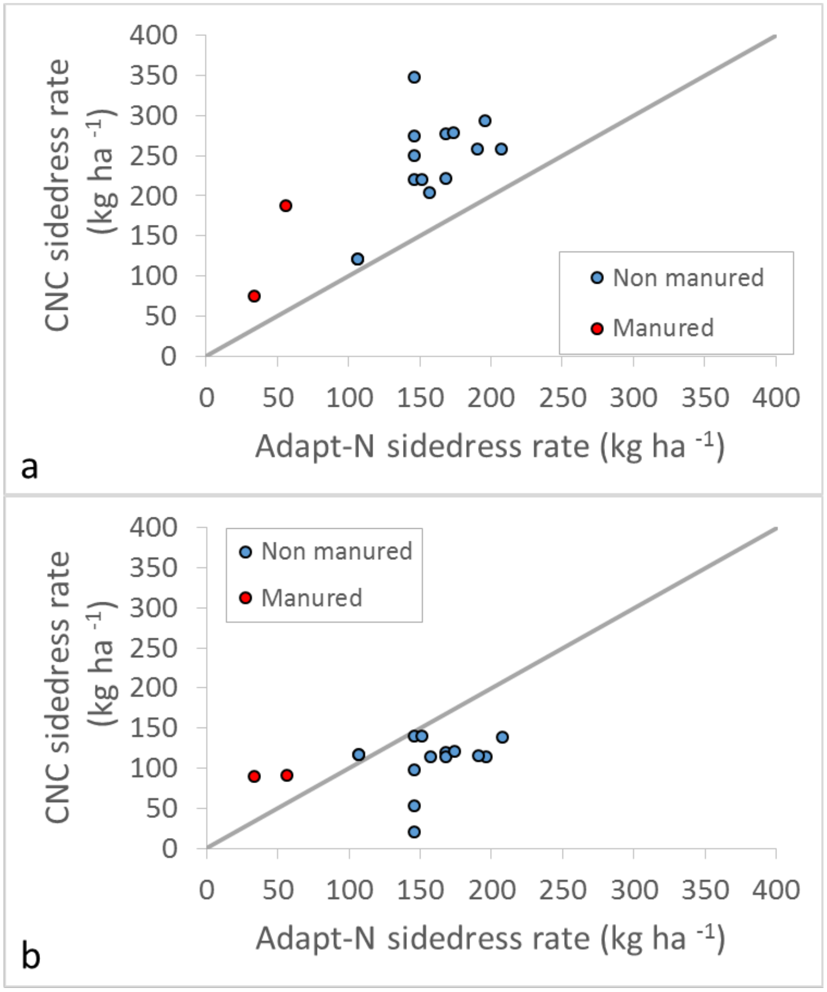

Figure 4. Comparison of sidedress N rates between the Adapt-N and CNC tools. The CNC rate is calculated using the default potential yield (a) and a potential yield supplied by the Grower (b).

Figure (5c) presents the relation between the Adapt-N rates, which is driven by the Grower-estimated potential yield, and the EONR. Adapt-N was found to successfully account for the different production environments and weather effects, and accurately predicts the EONR with an average N rate of 172 kg ha^{-1}, a bit short of the 178 kg ha^{-1} calculated value of the EONR (a calculated RMSE of 31 kg ha^{-1}.). Consequently, the average loss from the EONR was 19 \$ ha^{-1}, a significant improvement over the losses from the CNC rates. These results demonstrate that

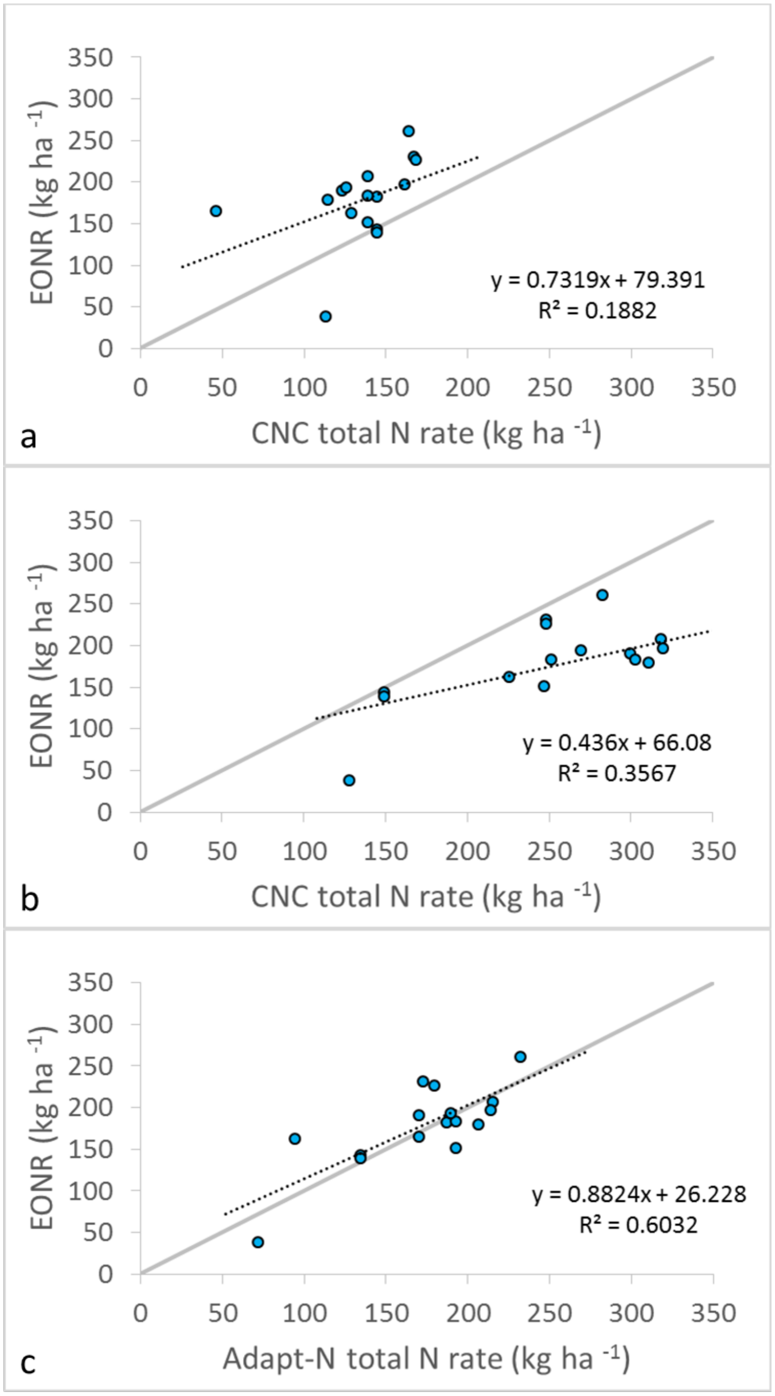

Figure 5. Comparison between the EONR and (a) CNC recommendations based on the tool default potential yields, (b) CNC recommendations based on the Grower potential yields, and (c) Adapt-N recommended rates.

Table 2– Information regarding sidedress recommendations, the calculated EONR for each trial and the respective losses of the Adapt-N and CNC recommendation rates.

Site	year	EONR rate (kg ha-1)	Adapt-N rate (kg ha-1)	Adapt-N loss from EONR ($ ha^{-1})	CNC rate (kg ha-1) DY	CNC loss from EONR ($ ha^{-1}) DY	CNC rate (kg ha-1) GY	CNC loss from EONR ($ ha^{-1}) GY
1	2011	143	135	5	145	0	149	2
2	2011	139	135	0	145	0	149	2
3	2012	231	173	67	167	82	248	5
4	2012	191	170	20	123	217	299	120
5	2012	183	187	0	145	35	303	132
6	2012	165	170	0	46	255	372	229
7	2012	207	215	0	139	84	318	122
8	2013	226	179	59	168	91	248	12
9	2014	179	206	30	114	371	311	145
10	2014	38	72	22	113	67	128	86
11	2014	163	94	35	129	7	225	69
12	2014	151	193	46	139	10	247	105
13	2014	184	182	0	139	44	229	42
14	2014	197	214	5	161	17	319	135
15	2015	184	189	0	126	99	269	94
16	2015	261	232	5	164	161	282	25
	Grand mean	178	172	19	135	96	257	83

DY and GY for the CNC rates and losses from the EONR indicate the CNC default potential yield and Grower potential yield, respectively.

accounting for in-season weather effects and site specific conditions is important and improves the prediction of the EONR.

The effect of N recommendations on environmental N losses

Figure (6) and Table (3) present the simulated environmental losses which occurred following the application of the Adapt-N and CNC sidedress rates. For both tools the simulated leaching losses accounted for 56% of all losses, reflecting the medium texture type which dominates the field sites (mean Sand and Clay texture fractions of 37% and 7%, respectively). Adapt-N rates reduced on average 29 kg ha^{-1} of simulated leaching losses (Figure 6a, 53% reduction) and 23.7 kg ha^{-1} of simulated gaseous losses (Figure 6b, 54% reduction). These results suggest substantial environmental benefits from using a tool like Adapt-N to generate sidedress N recommendations. Figure (6c) presents the relation between total environmental N losses occurring post sidedress and the sidedress rate. In agreement with field observation [*McSwiney and Robertson*, 2005; *Lawlor et al.*, 2008; *HOBEN et al.*, 2011], an exponential relationship emerges between sidedress application amount and the simulated N losses. Therefore the generally excessive N recommendations of the CNC tool have the potential to cause high environmental N losses, with every additional 1 kg ha^{-1} of N to the CNC mean sidedress rate generates 0.7 kg ha^{-1} of N losses. Conversely, for the mean N sidedress rate of the Adapt-N tool, every additional 1 kg ha^{-1} generates 0.3 kg ha^{-1} of N losses. These results imply a very low efficiency for the high amount of N recommended by the CNC tool which on average, is mostly lost to the environment.

Conclusions

This study presents a comparison between two N recommendation tools for maize cropping: CNC, which uses a static Stanford-type approach, and Adapt-N, which uses a dynamic simulation-based approach. Adapt-N recommendations were found to be superior the CNC ones in term of profitability and reconstructing the experimental EONR under the different production environments. The default potential yield estimates supplied by the CNC tool were found to be unrealistically low compared with both the grower-estimates potential yields and the actual achieved yields in the experimental sites. However, forcing the CNC tool with grower-estimated potential yields resulted in a substantial overestimation of the EONR and increased environmental losses. Our results suggest that adoption of adaptive N recommendation tools over static ones for the state of New York can increase the farmers profit while reducing environmental N losses.

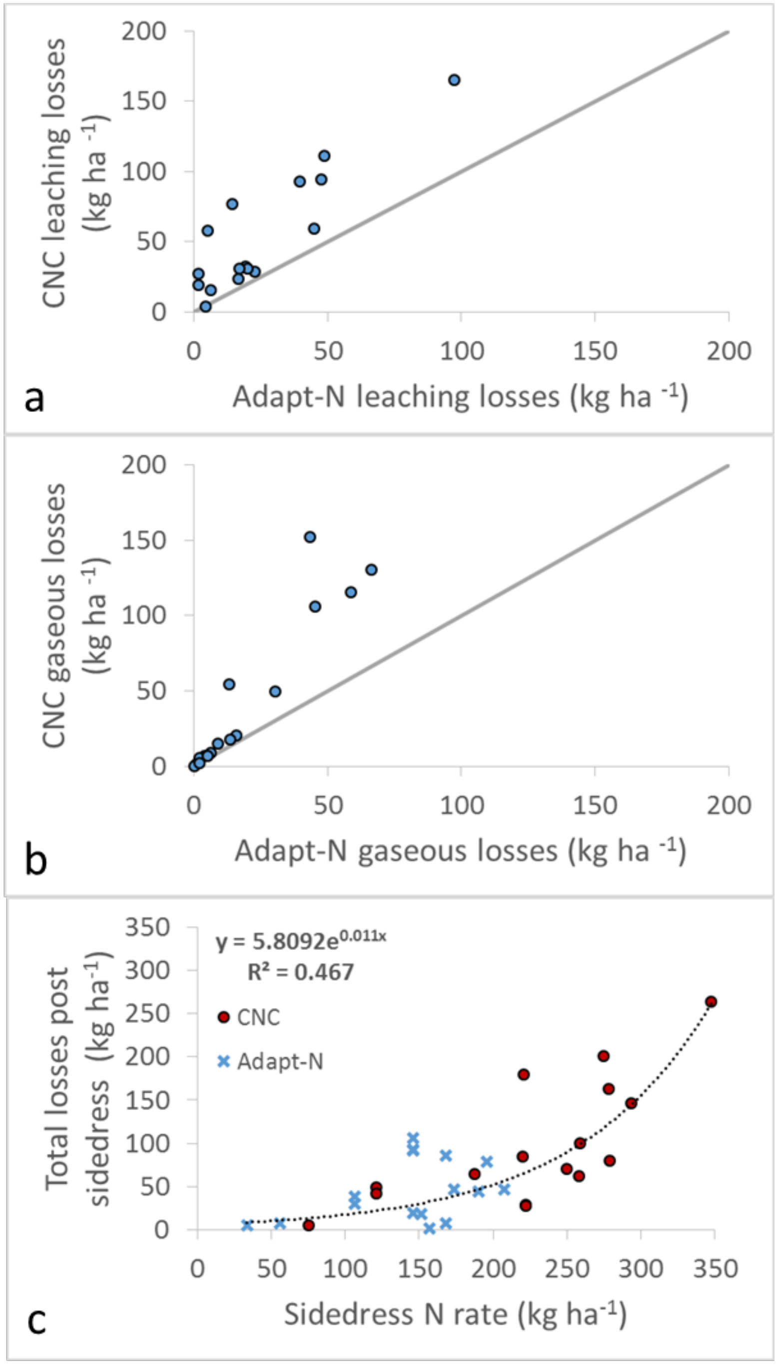
CNC leaching losses (kg ha -1)
Adapt-N leaching losses (kg ha -1)
a
CNC gaseous losses (kg ha -1)
Adapt-N gaseous losses (kg ha -1)
b
y = 5.8092e0.011x
R² = 0.467
CNC
Adapt-N
Total losses post sidedress (kg ha-1)
Sidedress N rate (kg ha-1)
c

Figure 6. Comparison between the Adapt-N and the CNC simulated leaching (a) and gaseous (b) losses. Panel (c) presents the relations ship between the total simulated losses post sidedress and the sidedress rate for the two tools.

Table 3– Information regarding simulated environmental losses in each trial for the Adapt-N and CNC tools. The reported losses for the CNC tool are for the Grower-estimated potential yield.

Site	year	CNC leaching losses (kg ha-1)	Adapt-N leaching losses (kg ha-1)	(A-CNC) Leaching diff. (kg ha-1) (%)	CNC gaseous losses (kg ha-1)	Adapt-N gaseous losses (kg ha-1)	(A-CNC) Gaseous diff. (kg ha-1) (%)
1	2011	28.9	22.9	-6.1	20.2	15.7	-4.5
2	2011	23.4	16.5	-7.0	17.8	13.5	-4.4
3	2012	165.3	97.4	-67.9	14.8	9.0	-5.8
4	2012	31.9	19.2	-12.8	130.7	66.3	-64.5
5	2012	111.0	48.8	-62.2	152.5	43.2	-109.3
6	2012	94.2	47.5	-46.6	106.3	45.4	-60.9
7	2012	30.7	20.2	-10.5	115.7	58.7	-56.9
8	2013	76.9	14.2	-62.7	7.2	3.9	-3.3
9	2014	15.2	6.1	-9.2	54.6	13.2	-41.4
10	2014	4.1	4.1	0.0	1.2	0.7	-0.6
11	2014	58.2	5.0	-53.1	5.7	1.9	-3.8
12	2014	19.5	1.6	-17.9	8.9	6.1	-2.8
13	2014	27.5	1.8	-25.7	0.2	0.2	0.0
14	2014	30.8	16.8	-14.0	49.5	30.2	-19.4
15	2015	92.6	39.5	-53.1	6.8	5.0	-1.8
16	2015	59.4	44.7	-14.7	2.5	2.1	-0.3
	Grand mean	54.4	25.4	-29.0	43.4	19.7	-23.7

Acknowledgments

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Appendix A

Selected articles by project team during project period:

What's Cropping Up? 9/2015: Corn Stalk Nitrate Test Show Low Accuracy for Evaluating Corn Deficiencies and Excesses By L. Fennell, B. Moebius-Clune, A. Ristow, and H. van Es

What's Cropping Up? 11/2015: Comparing Static and Adaptive N Rate Tools for Corn Production. By L. Fennell, S. Sela, A. Ristow, H. van Es, and S. Gomes.

What's Cropping Up? 11/2015: Adapt-N Recommendations Reduce Environmental Losses. By L. Fennell, S. Sela, A. Ristow, B. Moebius-Clune, D. Moebius-Clune, B. Schindelbeck, H. van Es, and S. Gomes.

What's Cropping Up? 10/2014: Adapt-N Boosts Profits and Cuts N Losses in Three Years of On-Farm Trials in New York and Iowa. By B. Moebius-Clune, M. Ball, H. van Es, and J. Melkonian

What's Cropping Up? 6/2014: Adapt-N Responds to Weather, Increases Grower Profits in 2013 Strip Trials. By B. Moebius-Clune, M. Ball, H. van Es, and J. Melkonian.

Selected case studies by project team to date:

What's Cropping Up? 2/2015: Farmers with Diverse Nitrogen Management Practices Find Value in the Adapt-N Tool in Iowa. By M. Ball, B. Moebius-Clune, S. Gomes, A. Ristow, and H. van Es

What's Cropping Up? 6/2014: New York Farm Delves Deeper with Adapt-N. By By M. Ball, B. Moebius-Clune, H. van Es, J. Melkonian, K. Severson.

Selected popular press articles to date:

Marketwired.com, March 10, 2015. Top Precision Ag Companies Partner to Confront Nitrogen Challenges in Agriculture.

Lancaster Farming, February 28, 2015. Prepping for Planting? Focus on Practices that Pay.

Sustainable America, February 17, 2015. A New Fix for the Nitrogen Problem. *New technology helps farmers grow more with less impact on the environment*.

Article on the Environmental Defense Fund Website, January 20, 2015: https://www.edf.org/blog/2015/01/20/4-reasons-fertilizer-pollution-may-soon-be-thing-past

The Cornell Chronicle, January 9, 2015. Movin' on up: Startup "graduates" from McGovern incubator.

The Packer, October 23, 2014. Wal-Mart adds detail to sustainability plans.

Communications of the ACM, October 14, 2014. Agriculture is becoming a 'Model Citizen'.

Walmart Blog, October 13, 2014. Sustainable Farming with True Affordability in Mind.

Boston Globe, October 7, 2014. Walmart touts food initiative's green benefits.

Walmart Sustainability Milestone Meeting, October 6, 2014. Adapt-N mentioned in webcast of Walmart company leaders discussing their environmental sustainability efforts.

The Guardian, August 20, 2014. New technology helps farmer conserve fertilizer and protect their crops.

Prairie Farmer, April 1, 2014. Adapt-N gives real-time nitrogen answers.

Corn Stalk Nitrate Test Shows Low Accuracy for Evaluating Corn Deficiencies and Excesses

September 17, 2015

Lindsay Fennell, Bianca Moebius-Clune, Aaron Ristow, and Harold van Es
Soil and Crop Sciences Section – School of Integrative Plant Science, Cornell University

A high percentage of corn fields may receive substantially more N fertilizer than is economically optimum, for which there are no obvious visual signs. Conversely, fields deficient in N have obvious visual cues, such as stunted growth and yellowing leaves. The Corn Stalk Nitrate Test (CSNT) has been used for two decades by farmers and consultants as an end-of-season tool for evaluating field-specific corn N management practices. More recently, it has been strongly promoted as a tool for producers to aid in fertilizing to maximum profits by determining whether the crop has received deficient, adequate, or excessive amounts of nitrogen, and has been endorsed by many as part of an adaptive management approach. However, we submit that the promotion of CSNTs should be reconsidered based on the existing evidence of its imprecision.

The Test and Its Utility

The basis of the test is that corn plants that received excessive nitrogen to attain maximum yields have high nitrate levels in the lower stalks at the end of the season. Conversely, plants suffering from nitrogen deficiency remove (translocate) more N from the lower corn stalks during the grain-filling period (Blackmer & Mallarino, 1996). Universities and grower associations suggest the following interpretations of the test:

- Low (less than 250 ppm nitrate-N, in some states 450 or 750): high probability that the crop was N deficient.
- Optimal (generally between 250 and 2000 ppm nitrate-N, in some states also including a “marginal” range when below 750): high probability that yields were not limited by N, and no apparent excess.
- Excess (>2000 ppm nitrate-N): high probability that N uptake exceeded plant needs.

The CSNT’s post-mortem evaluation is supposedly useful to growers for deciding future N management. With multiple year assessments, protocols state that appropriate consideration should be given for weather conditions, and fertilization rates should be increased for fields that usually test in the low range and decreased when CSNTs are in the excess range.

Following this logic, continued use of the test would allow growers to fine-tune adjustments toward optimal rates. In this, we need to consider the accuracy of the CSNT, notably its ability to detect (i) N deficiencies and (ii) excessive N applications. It has been reported in journal articles and fact sheets that yield adequacy is often observed with CSNT values in the “low” range, which indicates that the test is a weak indicator of N deficiency (What’s Cropping Up? Vol.22 No.3). An Iowa report based on a large data set of N rate trials (Sawyer, 2010) indicated that 15% of CSNT values in the “low” range were false positives, while of cases with field-verified N deficits, 30% of CSNT results were false negatives. In addition, a Maryland study involving 10 experiments (Forrestal et al., 2012) found about one third of “low” CSNT values to be false positives for deficiencies. In other words, adequate fertilizer was applied when the CSNT reported N deficiency.

For accurately detecting N excesses, earlier research from New York suggests that fields with excessive N applications may still show low or optimum CSNT values (What’s Cropping UP? Vol.21 No.3) and that site differences affect CSNT values more than excess or deficient fertilizer rates (Katsvairo et al., 2003). The aforementioned Iowa report (Sawyer, 2010) also indicated that 33% of cases with field-verified excess N applications were not identified through the test. The Maryland study found as much as half of the CSNT results to be false negative for excessive nitrogen.

As part of research on the Adapt-N tool (http://www.adapt-n.com/), we conducted strip trials from 2011-to-2014 (including 14 multiple year assessment trials) that provided the opportunity for us to evaluate whether the CSNT is an effective tool for adaptive nitrogen management in corn production.

Methods

Ninety-one replicated strip trials on commercial and research farms were conducted for four growing seasons (2011-2014) throughout New York (49 trials) and northern Iowa (42 trials). They involved two rates of N, a “high” rate and a “low” rate, which resulted in field-scale strips with N rate differences ranging from 10 to 140 lbs/ac. The rates were set by applying a conventional “Grower” rate or using the Adapt-N tool to make an adaptive N recommendation. In most cases the Grower rate was higher. Trials had 3 to 8 replications for each treatment (except for 13 trials that with only single strip yield measures but replicated CSNT values). Trials were distributed across both states under a wide range of weather conditions, and involved grain and silage corn, with and without manure application, and rotations of corn after corn and corn after soybean (Tables 1, 2, & 3).

Table 1. Assessment of CSNT performance, based on 2011 strip trial results involving two fertilizer rates. CSNT values less than 250 ppm (low) are presumed to indicate N deficiencies and values greater than 2000 ppm (high) are presumed to indicate excess N.

Field Trial	Harvest	Manure	After Soy	Low-High N fertilizer difference (lbs/ac)	Effective yield diffference (bu/ac equiv) [a]	Effective excess N applied for High Rate (lbs/ac) [b]	CSNT for Low N Treatment	CSNT for High N Treatment	CSNT Correct for diagnosing demonstrated deficiency?	CSNT correct for diagnosing demonstrated excess?
NY3	grain	no	yes	-82	-22	54	424	6250	NO	YES [c]
NY4	grain	no	no	-140	0	140	784	1776		NO [c]
NY5	silage	yes	no	-15	0	15	6893	6364		YES
NY6	grain	yes	no	-30	0	30	156	169		NO
NY7	silage	yes	no	-50	0	50	279	1357		NO
NY8	grain	no	no	-43	-8	33	465	829	NO	NO
NY9	grain	no	no	-66	0	66	109	469		NO
NY11	grain	no	no	-31	0	31	757	953		NO
NY12	grain	no	no	-40	-29	3	102	39	YES	NO
NY18	grain	no	yes	-115	-7	106	172	747	YES	NO
NY21	silage	yes	no	-43	0	43	917	1233		NO
NY22	grain	no	yes	-123	-13	107	98	2054	YES	YES
NY24	grain	no	no	-52	-12	37	153	1103	YES	NO
**NY25	silage	no	no	-34	0	34	47	65		NO
**NY26	silage	no	no	-21	0	21	192	208		NO
**NY27	grain	no	no	-75	0	75	1	71		NO
**NY28	grain	no	no	-75	0	75	1	1		NO
IA1	grain	no	yes	-50	-6	42	2650	4830	NO	YES
IA4	grain	yes	yes	-30	-6	23	848	429	NO	NO
IA5	grain	no	no	-30	0	30	36	1450		NO
IA6	grain	no	yes	-18	-5	11	2070	3000	NO	YES
IA8	grain	yes	yes	-50	-15	32	498	102	NO	NO
IA9	grain	no	yes	-45	0	45	277	392		NO
IA10	grain	yes	no	-40	-7	31	258	180	NO	NO
IA11	grain	yes	yes	-50	0	50	113	1410		NO
IA12	grain	no	no	-55	-17	34	99	102	YES	NO
IA13	grain	yes	yes	-35	0	35	3170	6590		YES
IA15	grain	no	yes	-41	0	41	1270	1685		NO
IA18	grain	yes	yes	-60	0	60	1049	1345		NO
IA19	grain	no	yes	-60	-6	52	293	2530	NO	YES
IA20	grain	no	yes	-60	-6	52	476	2727	NO	YES
IA21	grain	yes	yes	-20	-9	9	431	466	NO	NO
IA22	grain	yes	yes	-20	-15	1	917	1134	NO	NO
IA23	grain	no	no	-30	0	30	1763	2325		YES
IA24	grain	no	no	-75	-41	24	197	1595	YES	NO

a. To allow for comparisons between trials, grain equivalents for silage were calculated as 8.14 bu grain/T silage, by using a harvest index of 0.55.

b. Where no yield loss was found (p>0.7 or measured yield grain), effective yield difference was set to zero, and effective excess N was set to fertilizer applied in excess of the lower N rate, either Adapt-N or Grower rate. Where yield lost or there is a greater than 40% chance that yield was lost, effective yield difference was set equal to measured yield loss, and, by accounting for a conservative 1.25lb N per bu corn, the effective excess N was adjusted downward.

c. Cells color coded green mark correctly identified deficiencies or excesses. Cells color coded red and "NO" signify excess of 30lb of N or greater not diagnosed as excess by the CSNT. White cells coded as "NO" indicate incorrect diagnosis with N excesses or deficiencies less than 30 lbs/ac.

d. The low or high treatment used to diagnose demonstrated deficiency or excess depended on which rate, Adapt-N or Grower, was higher or lower

e. Deficiency was determined when there was an effective yield difference >0

f. **Multi-year Assessment Trials

Table 2. Assessment of CSNT performance, based on 2012 strip trial results involving two fertilizer rates. CSNT values less than 250 ppm (low) are presumed to indicate N deficiencies and values greater than 2000 ppm (high) are presumed to indicate excess N.

Field Trial	Harvest	Manure	After Soy	Low- High fertilizer difference (lbs/ac)	Effective yield diffference (bu/ac equiv) [a]	Effective excess N applied for High Rate (lbs/ac) [b]	CSNT for Low Treatment	CSNT for High Treatment	CSNT Correct for diagnosing demonstrated deficiency?	CSNT correct for diagnosing demonstrated excess?
NY1	grain	no	no	-60	0	60	3155	4401		YES [c]
NY2	grain	no	no	-71	-8	60	2723	2251	NO	YES
NY3	grain	no	no	-70	0	70	1253	2072		YES
NY4	grain	no	yes	-30	-9	19	276	268	NO	NO [c]
NY7	grain	no	no	-25	0	25	483	876		NO
NY8	grain	no	yes	-30	-6	23	784	481	NO	NO
NY12	grain	no	yes	-100	0	100	169	20		NO
NY13	grain	no	no	-60	0	60	354	821		NO
NY14	silage	yes	no	-10	0	10	5467	7374		YES
NY15	silage	yes	no	-11	0	11	6819	7638		YES
**NY17	silage	no	no	-29	-7	20	30	213	YES	NO
**NY18	silage	no	no	-23	-6	15	173	487	YES	NO
**NY19	grain	no	no	-65	-21	38	306	86	YES	NO
**NY20a	grain	no	no	-65	-10	52	273	143	YES	NO
**NY20b	grain	no	no	-65	0	65	273	143		NO
**NY20c	grain	no	no	-65	-15	46	273	143	YES	NO
NY21	grain	no	no	-20	0	20	130	52		NO
NY22	grain	no	yes	-23	-6	16	54	64	YES	NO
NY24	grain	yes	no	-32	0	32	114	350		NO
NY26	grain	no	yes	-34	-6	27	159	231	YES	NO
NY27	grain	yes	no	-50	-35	6	0	0	YES	NO
NY28	grain	yes	no	-45	0	45	17	36		NO
NY29	grain	no	no	-40	0	40	23	518		NO
IA59	grain	yes	yes	-40	-7	31	1169	2209	NO	YES
IA60	grain	yes	no	-40	0	40	5893	6760		YES
IA61	grain	yes	no	-38	0	38	6645	7910		YES
IA62	grain	no	yes	-63	-15	45	84	203	YES	NO
IA63	grain	yes	yes	-40	-6	32	888	3445	NO	YES
IA64	grain	yes	yes	-40	-6	32	87	616	YES	NO
IA65	grain	no	yes	-30	0	30	2283	2223		YES
IA66	grain	yes	no	-30	0	30	1136	772		NO
IA67	grain	yes	yes	-20	0	20	503	499		NO
IA68	grain	yes	yes	-20	0	20	1426	1277		NO
IA69	grain	no	yes	-20	0	20	308	489		NO
IA70	grain	no	yes	-20	0	20	505	1338		NO
IA71	grain	yes	yes	-40	0	40	3073	4440		YES
IA73	grain	yes	no	-70	0	70	2027	2700		YES
IA76	grain	no	no	-95	0	95	1883	4326		YES
IA77	grain	yes	no	-45	0	45	4333	3850		YES
IA78	grain	yes	yes	-50	0	50	6358	6035		YES
IA79	grain	yes	no	-35	0	35	1236	1367		NO
IA83	grain	no	no	-39	0	39	1700	3008		YES

a. To allow for comparisons between trials, grain equivalents for silage were calculated as 8.14 bu grain/T silage, by using a harvest index of 0.55.

b. Where no yield loss was found (p>0.7 or measured yield grain), effective yield difference was set to zero, and effective excess N was set to fertilizer applied in excess of the lower N rate, either Adapt-N or Grower rate. Where yield lost or there is a greater than 40% chance that yield was lost, effective yield difference was set equal to measured yield loss, and, by accounting for a conservative 1.25lb N per bu corn, the effective excess N was adjusted downward.

c. Cells color coded green mark correctly identified deficiencies or excesses. Cells color coded red and "NO" signify excess of 30lb of N or greater not diagnosed as excess by the CSNT. White cells coded as "NO" indicate incorrect diagnosis with N excesses or deficiencies less than 30 lbs/ac.

d. The low or high treatment used to diagnose demonstrated deficiency or excess depended on which rate, Adapt-N or Grower, was higher or lower

e. Deficiency was determined when there was an effective yield difference >0

f. **Multi-year Assessment Trials

Table 3. Assessment of CSNT performance, based on 2013 and 2014 strip trial results involving two fertilizer rates. CSNT values less than 250 ppm (low) are presumed to indicate N deficiencies and values greater than 2000 ppm (high) are presumed to indicate excess N.

Year	Field Trial	Harvest	Manure	After Soy	Low-High fertilizer difference (lbs/ac)	Effective yield diffference (bu/ac equiv) a	Effective excess N applied for High Rate (lbs/ac) b	CSNT for Low Treatment	CSNT for High Treatment	CSNT Correct for diagnosing demonstrated deficiency?	CSNT correct for diagnosing demonstrated excess?
2013	**NY7	grain	N	N	-60	-9	49	509	830	NO	NO c
2013	**NY8	grain	N	N	-60	-12	46	1258	748	NO	NO
2013	IA58	grain	Y	Y	-40	-6	32	60	69	YES	NO
2013	IA59	grain	Y	Y	-30	0	30	116	276		NO
2013	IA61	grain	N	Y	-23	0	12	145	37		NO
2013	IA62	grain	N	Y	-12	0	12	50	36		NO
2013	IA63	grain	N	Y	-30	0	30	68	1080		NO
2014	NY1	grain	N	N	-55	-6	47	501	800	NO	NO
2014	NY5	grain	N	Y	-30	0	30	3735	3270		YES c
2014	NY6	grain	N	N	-30	0	30	3552	6020		YES
2014	NY7	grain	N	Y	-50	-13	34	645	814	NO	NO
2014	NY13	grain	N	N	-15	0	15	1400	3575		YES
2014	**NY20	silage	N	N	-68	0	78	147	371		NO
2014	**NY21	silage	N	N	-71	0	61	234	483	YES	NO

a. To allow for comparisons between trials, grain equivalents for silage were calculated as 8.14 bu grain/T silage, by using a harvest index of 0.55.
b. Where no yield loss was found (p>0.7 or measured yield grain), effective yield difference was set to zero, and effective excess N was set to fertilizer applied in excess of the lower N rate, either Adapt-N or Grower rate. Where yield lost or there is a greater than 40% chance that yield was lost, effective yield difference was set equal to measured yield loss, and, by accounting for a conservative 1.25lb N per bu corn, the effective excess N was adjusted downward.
c. Cells color coded green mark correctly identified deficiencies or excesses. Cells color coded red and "NO" signify excess of 30lb of N or greater not diagnosed as excess by the CSNT. White cells coded as "NO" indicate incorrect diagnosis with N excesses or deficiencies less than 30 lbs/ac.
d. The low or high treatment used to diagnose demonstrated deficiency or excess depended on which rate, Adapt-N or Grower, was higher or lower
e. Deficiency was determined when there was an effective yield difference >0
f. **Multi-Year Assessment Trials

To allow for comparison across all trials, silage yield values were converted to grain equivalents (8.14 bu grain per ton silage, using a harvest index of 0.55). The yield results from a majority of the trials showed unambiguous over-fertilization associated with the higher N rate (same yields for both rates). In these cases, where there was no further yield gain with added N (within 5 bu/ac), the "effective yield difference" was set to zero. If there was a yield difference higher than 5 bu/ac the "effective yield difference" was set to the difference between the high and low rates. Where there was unambiguous over-fertilization with the higher N rates, the amount of "effective excess N applied" was set to the N rate difference between treatments (Tables 1-3).

In some cases the low rate provided insufficient N (reduced yields), and the optimum N level appeared to be between the high and low rates. In these cases, the amount of effective excess N applied was estimated by subtracting a conservative 1.25 lb N from the N rate difference between the treatments per bushel of yield lost due to the lower rate.

Fifteen corn stalk sections, sampled from each replicate strip, were dried, ground, and analyzed for nitrate content, according to published protocols. Means for each treatment are presented in Tables 1-3. The utility of the CSNT was then assessed by evaluating the relationship between N rates, test values, and yield losses, and determining whether it accurately diagnosed field-demonstrated deficient or excessive N levels.

Results

First, we evaluated whether CSNT values for the higher N rates were in fact higher than those for the lower N rates,which is an indicator of the precision to varying N levels. Overall, the CSNT values were higher for the low N rate in 31% of cases in NY and 26% of cases in IA, suggesting that in a significant number of cases the test was unable to reflect the actual N rate differences and results were presumably obscured by high variability .

Next, we evaluated the relationship between yield loss and CSNT values. Figures 1 (NY) and 2 (IA) show the relationship between yield loss and CSNT results for the four growing seasons (2013 and 2014 were combined due to lower trial numbers). Given the categorical interpretation of CSNT results, we can identify four types of erroneous results from the CSNT):

- In many cases without yield loss CSNT values were below the 250 ppm “low” threshold, indicating **frequent false positives for N deficiencies**: The tool often identified deficiencies when in fact there were none.
- Many cases with yield losses were associated with CSNT values greater than 250 ppm, indicating **frequent false negatives for deficiencies:** The tool often did not identify deficiencies when fertilizer N levels were in fact deficient.
- In a few cases high CSNT values (>2000 ppm) were not associated with excess N rates. I.e., **infrequent false positives for N excess:** When the test indicated excess N, it was generally correct.
- In many cases with excess N rates the CSNT did not show high values (>2000 ppm). **e., frequent false negatives for N excess:** The tool often did not identify excesses when fertilizer N levels were in fact excessive.

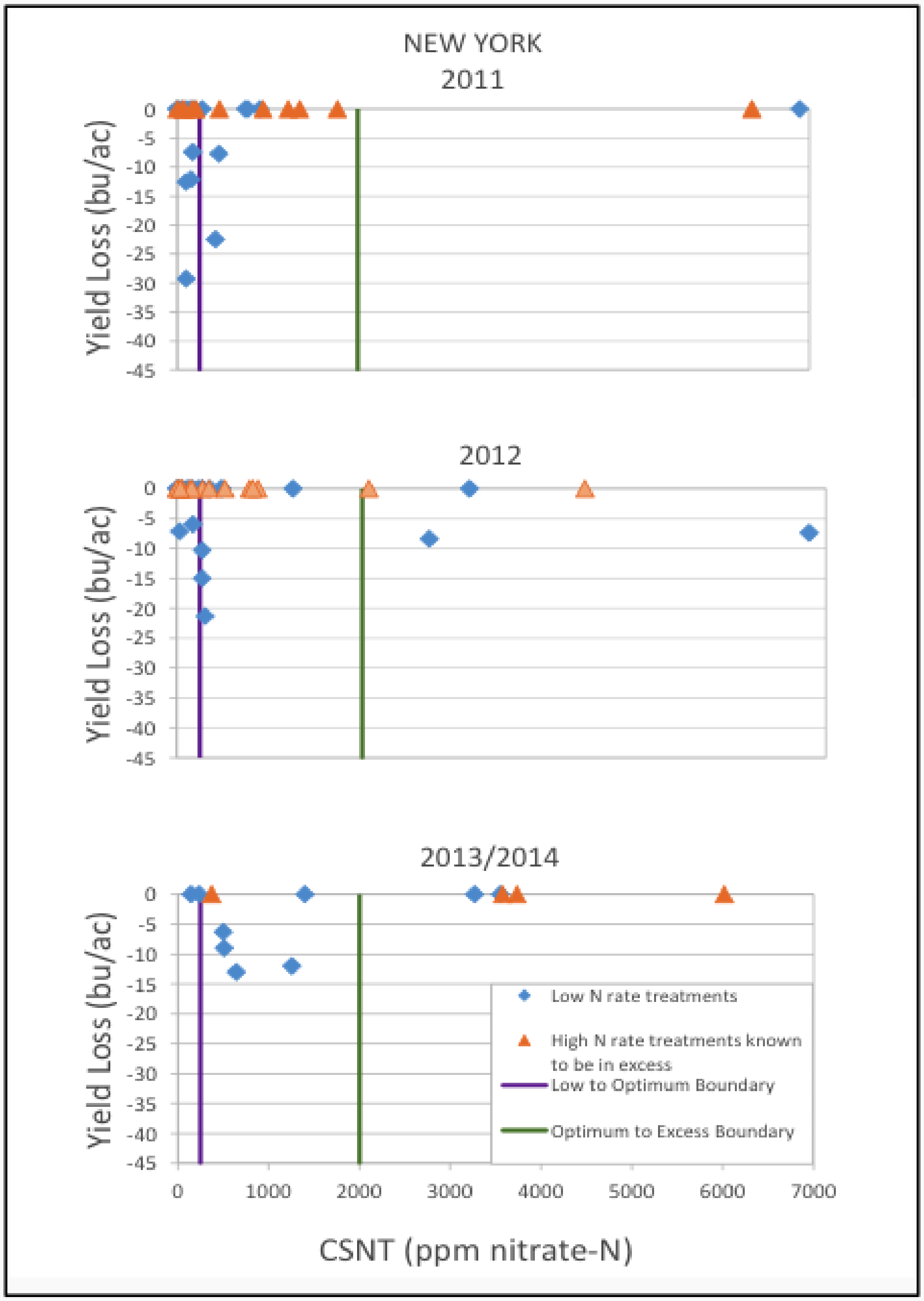

Figure 1. New York 2011-2014 yield losses and CSNT values from the lower rate treatments in all trials, and for higher rate treatments in those trials where excess was unambiguous (no further yield gain with further added N). Orange triangle symbols with CSNT values less than 2000 ppm are false negatives for excess N. Blue diamond symbols with CSNT values greater than 250 are false negatives for N deficiencies. All symbols that show CSNT values less than 250 but no yield losses (top left of graph) are false positives for N deficiencies.

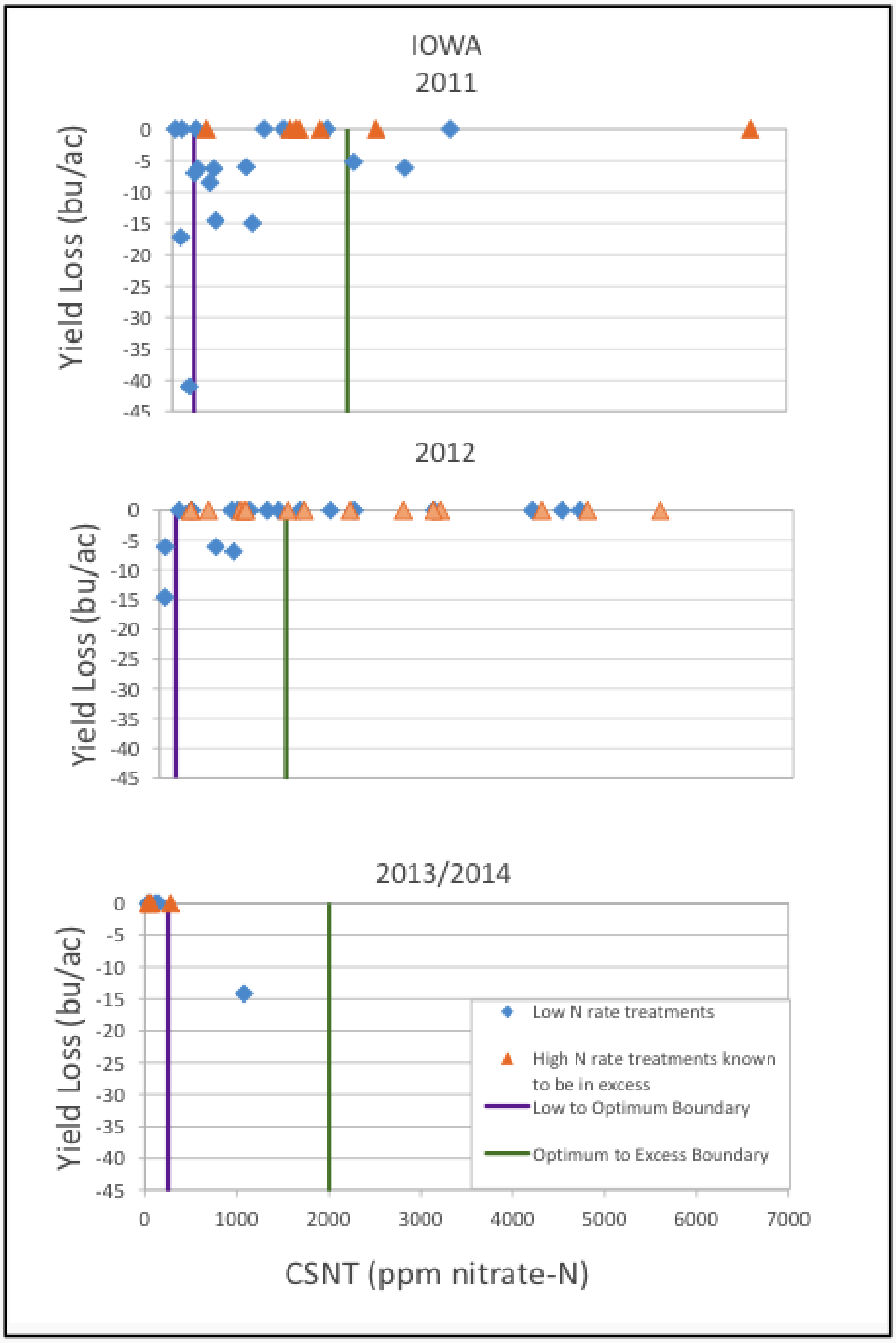

Figure 2. Iowa 2011-2014 yield losses and CSNT values from the lower rate treatments in all trials, and for higher rate treatments in those trials where excess was unambiguous (no further yield gain with further added N). Orange triangle symbols with CSNT values less than 2000 ppm are false negatives for excess N. Blue diamond symbols with CSNT values greater than 250 are false negatives for N deficiencies. All symbols that show CSNT values less than 250 but no yield losses (top left of graph) are false positives for N deficiencies.

Summarized results (Table 4) show that when CSNT values greater than 2000 ppm were measured ("excessive"), a high probability existed that indeed excess N was applied – only 6% (NY) and 8% (IA) false positives. This is the only criterion by which the test performs well. However, excessive N rates (no yield losses) can result in a wide range of CSNT values and we found that more than half of the fields with proven excess N application of greater than 30 lbs/ac (65% for NY AND 53% for IA) did not show CSNT values greater than 2000 ppm. I.e., the test failed to detect excess N rates in the majority of cases. Similarly, the CSNT generally performs very poorly when trying to detect deficiencies, with failure rates typically above 50% for both false positives and false negatives.

N Status	Concern	New York	Iowa
Deficiency	False positive	71% (n=31)	67% (n=16)
	False negative	24% (n=21)	69% (n=16)
Excess	False positive	6% (n=17)	8% (n=25)
	False negative (>30 lbs N/ac excess)	65% (n=49)	53% (n=38)

Table 4. 2011-2014 New York and Iowa trials, showing the proportion of CSNT values that correctly or incorrectly identified field-demonstrated deficiency or excess status.

Conclusions

We conclude from these 91 strip trials over four years that the test has very limited ability to support management decisions. The poor utility for detection of N deficiencies was well known from the literature, although not recognized by many. Our results confirm this. The primary question therefore was whether the test can effectively detect *excessive* N applications. The answer appears to be a strong “no”. Although “excessive” CSNT values were reliably associated with over-fertilized plots (only 6-8% false positives), the test failed to identify over-fertilized crops (30 up to 140 lbs/ac) in about two-thirds of the cases in NY and half the cases in Iowa. I.e., a majority of the excessive N cases were not identified by the test. Since the test’s primary utility is related to determining excessive N rates, it appears to perform weakly in serving its main purpose.

An additional concern is that end-of-season evaluations of the current growing season have limited value for the predictability of N needs in future growing seasons. Research has demonstrated (summarized by van Es et al., 2007) that weather conditions during the early growing season greatly affect N losses and are a critical factor in determining optimum N rates. This implies that CSNT results from one growing season have limited value for predicting N needs for the next year when the weather may be very different. Overall, we conclude that the CSNT is not an effective tool for use in field-specific adaptive N management, primarily because it fails to identify the majority of cases with excessive or deficient N levels.

Acknowledgements

This work was supported by grants from the New York Farm Viability Institute, the USDA-NRCS Conservation Innovation Grants Program, the Northern New York Agricultural Development Program, and the International Plant Nutrition Institute. We are grateful for the cooperation in field activities from Bob Schindelbeck, Keith Severson, Kevin Ganoe, Sandra Menasha, and Anita Deming of Cornell Cooperative Extension, from Dave DeGolyer, Dave Shearing and other staff at the Western NY Crop Management Association, from Eric Bever and Mike Contessa at Champlain Valley Agronomics, and from Shannon Gomes, Hal Tucker, Michael McNeil and Frank Moore in Iowa, as well as the many farmers who implemented these trials.

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Comparing Static and Adaptive Nitrogen Rate Tools for Corn Production

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Determining the optimum nitrogen rate for corn production has been an elusive goal for many years, despite its economic significance to farmers and the concerns about environmental impacts. Several tools are available to provide nitrogen rate recommendations for corn growers, and many producers and retailers often wonder how these different recommendation systems compare. These approaches can be categorized as (i) static and (ii) adaptive. Static tools offer generalized recommendations that do not consider seasonal conditions of weather and soil/crop management, while adaptive approaches account for the variable and site-specific nature of soil N dynamics. Using strip trial data from four years of research on commercial farms we compare the recommendations from conventional static approaches in New York (Cornell Nutrient Calculator; CNC) and Iowa (Maximum Return to Nitrogen; MRTN) with the adaptive Adapt-N approach to explore the differences in recommended rates. The strip trials involved only Grower rates vs. Adapt-N rates as treatments, and we consequently cannot make direct conclusions on yield and profitability relative to CNC and MRTN. Therefore, in this article we focus on simply comparing the N rate recommendations from the three different tools.

The Tools

Cornell Nutrient Calculator: The Cornell Nutrient Calculator is a static approach that includes a basic mass balance calculation of N demand (yield-driven crop uptake) and N supply (soil organic matter, manure, previous crops, etc.), combined with efficiency factors. The CNC estimates can be derived from a spreadsheet downloaded from http://nmsp.cals.cornell.edu/software/calculators.html. The CNC nitrogen recommendation for corn is calculated as follows (Ketterings et al., 2003):

$$N_{Required} = (YP_{corngrain} * 1.2 - N_{soil} - N_{sod})/(\frac{f_{eff}}{100})$$

Where $N_{Required}$ is the total amount of N (lbs N/acre) from any source required for optimum crop production. $YP_{corngrain}$ is the yield potential of corn grain in bushels (85% dry matter) per acre. N_{soil} and N_{sod} are the amounts of N (lbs N/acre) expected to be released from mineralization of soil organic matter and a plowed-down sod, respectively, and f_{eff} is a nitrogen uptake efficiency factor that depends on soil type and drainage. $YP_{corngrain}$, N_{soil}, *and* f_{eff} are available from tabular values based on soil type that are incorporated into the spreadsheet. $YP_{corngrain}$ can also be entered as a default value or based on field yield history. Manure contributions from up to three years past can be incorporated into the recommendations.

MRTN: The Maximum Return to N (MRTN) method is also a static approach which is based on the average economically optimum nitrogen rate (EONR) from multi-site and multi-year field trial data and is promoted in most Midwestern US states (Sawyer et al., 2006). In Iowa, MRTN recommendations are highly generalized into a single state-wide recommendation for either corn-after-corn or corn-after-soybean with adjustments only for the relative prices for grain and fertilizer. However, Deen et al. (2015) found that variations in seasonal weather were three times more impactful on EONR than price ratio fluctuations. MRTN recommendations can be determined using an online calculator (http://extension.agron.iastate.edu/soilfertility/nrate.aspx).

Adapt-N: The Adapt-N tool employs simulation models and biophysical data to combine soil, crop and management information with near-real-time weather data to estimate optimum N application rates for corn. Although it was developed at Cornell University it has recently been licensed for commercial use (adapt-N.com). It is currently calibrated for use on about 95% of the US corn production area and is flexible in terms of nutrient management options with inputs for applications of fertilizer or manure from different sources (dairy, swine, poultry), or rotation crops (sod, soybean, etc.). One of the key user inputs is the site-specific attainable yield, based on long-term yield records.

Adapt-N generates adaptive N recommendations based on a dynamic mass balance approach according to the following equation:

$$N_{rec} = N_{exp\_yld} - N_{crop\_now} - N_{soil\_now} - N_{rot\_credit} - N_{fut\_gain-loss} - N_{profit\_risk}$$

Where N_{rec} is the N rate recommendation; N_{exp_yld} is the crop N content needed to achieve the expected yield. The expected yield is based on producer provided historic field data; N_{crop_now} and N_{soil_now} are the N content in the crop and soil as calculated by the model for the current simulation date; $N_{fut\_gain-loss}$ is a probabilistic estimate of future N gains minus losses until the end of the growing season, based on model simulations with historical rainfall distribution functions; and N_{profit_risk} is an economic adjustment factor that integrates corrections for fertilizerand grain prices, as well as the relative profit risk of under-fertilization vs. over-fertilization.

Adapt-N vs. Cornell N Calculator and MRTN rates

Adapt-N was used in 115 paired field strip trials with three or four nitrogen fertilizer replications conducted mostly on commercial farms (two university research farms were involved) in New York and Iowa during the 2011-through-2014 growing seasons (cf. Fennell et al., 2015; this issue). Although the experimental design of the study compares N rates for Adapt-N and Grower-selected treatments (which represented conventional practices), we also had an opportunity to compare the adaptive approach of the Adapt-N tool to the respective rates recommended by the CNC and the MRTN methods. Note: Each growing season did not necessarily involve the same fields and management practices, like manure application. The pre-plant or starter fertilizer rates varied and averaged 76 and 56 lbs/ac for the NY and IA trials, respectively.

The CNC estimate included two rates: (i) based on the default yield potentials in the CNC software (which were universally much lower) and (ii) based on expected yield values for the field supplied by the grower, i.e. “realistic” field-specific expected yield. N credits from manure application were directly accounted for in the CNC software.

For the MRTN approach, the rate was adjusted to account for manure credits calculated using the Iowa State University manure management guidelines (PM-1811), which assumes N use efficiency of 100% and 35% for swine and dairy manure, respectively. If the sum of the calculated credits for a trial exceeded the MRTN rate, a zero MRTN rate was assigned.

Results

In contrast to the static N recommendation approach, Adapt-N recommended N rates varied substantially from field to field and among growing seasons (Table 1 and 2). Since the strip trials involved an Adapt-N and a Grower-selected rate, they allow us to make conclusions on the performance of these two approaches. In short, results showed that in 83% of all 115 strip trials, Adapt-N recommended a lower N application than the respective Grower-defined rate and these reduced rates resulted in an increased profit in 73% of trials, with an average increase of $29/ac over the Grower rate (Sela et al., in review; Moebius-Clune et al., 2014).

Table 1. 2011-2014 New York research trial summary of the Cornell Nutrient Calculator (CNC) total N recommendations using default yields and the realistic (field-measured) expected yields (EY); Adapt-N recommendations are based on model estimates using realistic estimated yields while Grower recommendations are based on their current practice.

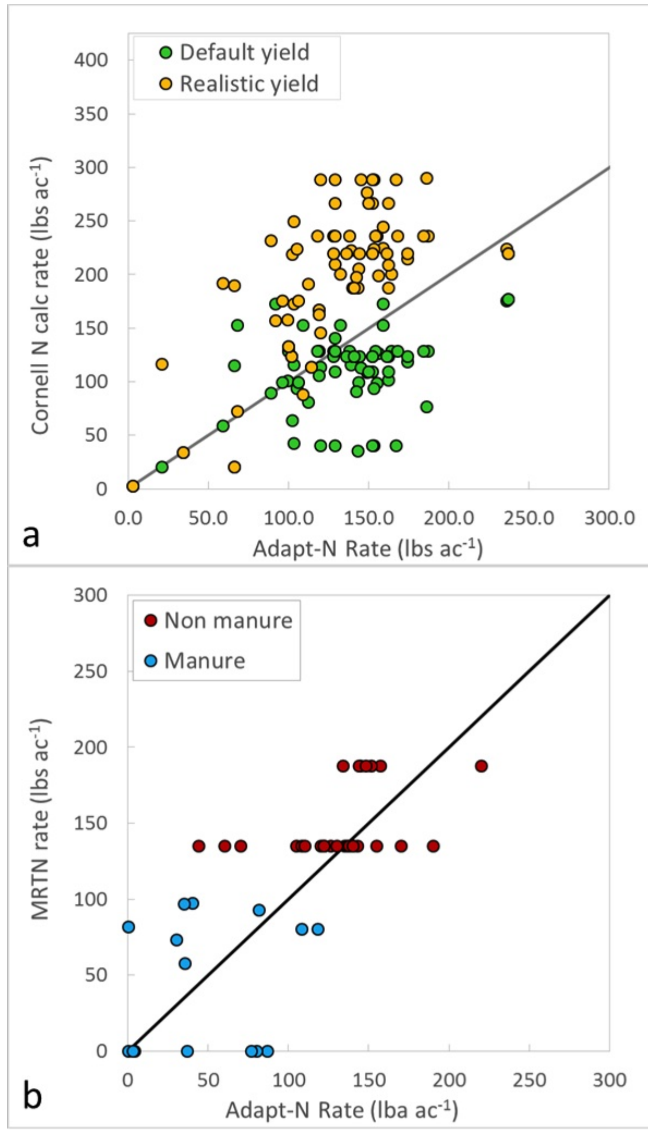
		Expected Yields			Recommendations (Total fertilizer N)				
Year	n	CNC default	CNC realistic	Diff.	CNC w/ default EY	CNC w/ realistic EY	Diff.	Adapt-N realistic	Grower practice
		------------ bu/ac ------------			-------------------------- lbs/ac -------------------------				
2011	11	132	155	23	110	134	24	101	156
2012	42	130	186	56	106	219	113	130	196
2013	11	127	188	61	116	215	99	166	147
2014	9	128	183	54	104	196	92	137	172
Average	**73**	**129**	**178**	**49**	**109**	**191**	**82**	**134**	**168**

Table 2. 2011-2014 Iowa research trial summary of MRTN recommendations; Adapt-N recommendations are based on model estimates from the Adapt-N tool using realistic estimated yields, while Grower recommendations are based on conventional practice dependent on field history.

		Recommendations (Total fertilizer N)					
		MRTN		Adapt-N		Grower	
Year	n	Manure	Non manure	Manure	Non manure	Manure	Non manure
		---------------------------- lbs/ac			------------------------------------		
2011	9	44	156	30	156	53	168
2012	17	36	151	39	123	64	153
2013	9	78	135	86	140	122	151
2014	7	0	153	87	118	187	159
Average	**42**	**40**	**149**	**60**	**134**	**107**	**157**

CNC vs. Adapt-N: The CNC method accounts for several variables, including past manure applications and soil types, which, as previously mentioned, are reflected in a different rate for each trial. One issue with the current CNC approach is the selection option for the yield potential (*YP*), based either on default values or "realistic" yield estimates from historic field-measurements. The CNC default expected yields were on average 49 bu/ac lower than the realistic expected yields (Table 1). Incidentally, New York grower-estimated realistic yields averaged 178 bu/ac, which was generally close to the actual achieved yields at the end of the season, 173 bu/ac on average. The resulting CNC N rate recommendations were highly sensitive to these yield estimates: rates based on realistic yields averaged 82 lbs/ac higher than those based on the default expected yields (191 and 109 lbs/ac, respectively).

Adapt-N recommended rates fell in between those extremes at 134 lbs/ac. (Table 1, Fig. 1a). I.e., the CNC rates calculated using the realistic estimated yields were on average 57 lbs/ac higher than the Adapt-N rates. Based on the results of the comparison of Adapt-N with Grower-selected rates (which were generally excessive but still 23 lbs/ac lower than the CNC rates with realistic yields; Table 1), we infer that the CNC recommendations with realistic expected yields are generally too high. Conversely, using the less-realistic default yields appears to result in overall better N rate recommendations, but still too low in wetter seasons (esp. 2013).



MRTN vs. Adapt-N: The MRTN rates for the Iowa trials were fixed at 188 lbs/ac and 133 lbs/ac for corn-after-corn and corn-after soybean rotations, respectively for the non-manured sites (Fig 1b), while the Adapt-N rates showed a wide range from about 40 to 220 lbs/ac, primarily depending on soil type, organic matter contents and weather conditions. On average the Adapt-N rates for non-manured sites were 15 lbs/ac lower than the respective MRTN rates (134 vs.149 lbs/ac; Table 2).

The Iowa manured sites showed a wide range of fertilizer recommendations for both Adapt-N and MRTN (Fig 1b). On average, the recommended fertilizer rates for Adapt-N were 20 lbs/ac higher than MRTN, with differences especially pronounced in cases involving fall swine manure applications where the Iowa State University calculations assume 100% N contribution for the following growing season, often resulting in very low N fertilizer recommendations. The Grower practice averaged higher than both the MRTN rates and Adapt-N rates, especially for manured fields (67 and 47 lbs/ac higher than MRTN and Adapt-N, respectively). In all, MRTN rates are similar on average to Adapt-N rates, but the former is lower with manure applications and higher without manure. Adapt-N rates varied more based on location-specific conditions.

Conclusions

The static N recommendation tools are more generalized compared to adaptive tools like Adapt-N, and do not allow for precision N management specific to each production environment (field, season, management). The 115 strip trials offered an opportunity to make comparisons of Adapt-N with Cornell N Calculator (New York) and MRTN (Iowa) N rate recommendations under real-farm conditions, but did not enable direct analysis of their relative yield and profitability performance.

We conclude that the main issue with the CNC recommendations is the large discrepancy between the N recommendations using the default yield potentials and those based on realistic yield potentials. When using the latter, the yield expectations are more correct but the recommended rates are much higher than the Adapt-N rates and appear to be excessive in most cases. Conversely, recommendations based on default yields average below Adapt-N rates and appear to be too conservative in wetter years. The default yield values appear to be about 40-50 bu/ac below current yields, which have in recent decades increased due to improved crop genetics and management. Updating the default yield values appears logical, but would result in excessive N recommendations in most years.

MRTN recommended rates were on average similar to Adapt-N rates, but they were lower with manure applications and higher without manure. In the non-manure cases, MRTN rates were principally higher in some years (2012; 2014). Adapt-N rates varied more based on location-specific conditions, which is important for preventing excesses and deficiencies and reducing environmental impacts.

In all, we conclude that *on average* the static (CNC and MRTN) and adaptive (Adapt-N) approaches resulted in similar N rate recommendations, but they vary considerably depending on growing season weather, soils, management practices and yield assumptions.

Acknowledgements

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Adapt-N Recommendations Reduce Environmental Losses

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Soil nitrogen is spatially and temporally variable and it can be challenging for farmers to determine a location-specific optimum N rate, often leading to excess (insurance) applications. Corn N management is therefore relatively inefficient, with N recovery (the proportion of applied N taken up by the crop) often being less than 50%. The nitrogen that is lost through leaching and runoff has a massive negative effect on groundwater aquifers and aquatic biota in streams and estuaries downstream. The Chesapeake Bay and Gulf of Mexico are notable concerns and ambitious nutrient reduction goals have been established. Another major concern is the gaseous nitrogen loss that can result in high emissions of nitrous oxide (N_2O), a potent greenhouse gas for which agriculture is the main anthropogenic source.

These increased N fluxes into the environment have significant economic and environmental costs. There are a number of approaches to reduce such N losses, including reduced N applications, cover cropping, buffer strips, etc. Arguably the most important one is the better estimation of the optimum N rate so that excess N applications can be avoided.

Adapt-N and Strip Trials

The optimum N rate depends on numerous factors including the timing and amounts of early season precipitation, previous organic and inorganic N applications, soil organic matter, carry-over N from previous cropping seasons, soil texture, rotations, etc. Adapt-N is a simulation tool that combines such location-specific soil, crop and management information with date-specific weather data to estimate optimum N application rates for corn. It thereby allows for precision N management specific to each production environment (field, season, management). The tool was developed at Cornell University and has been licensed for commercial use (adapt-N.com).

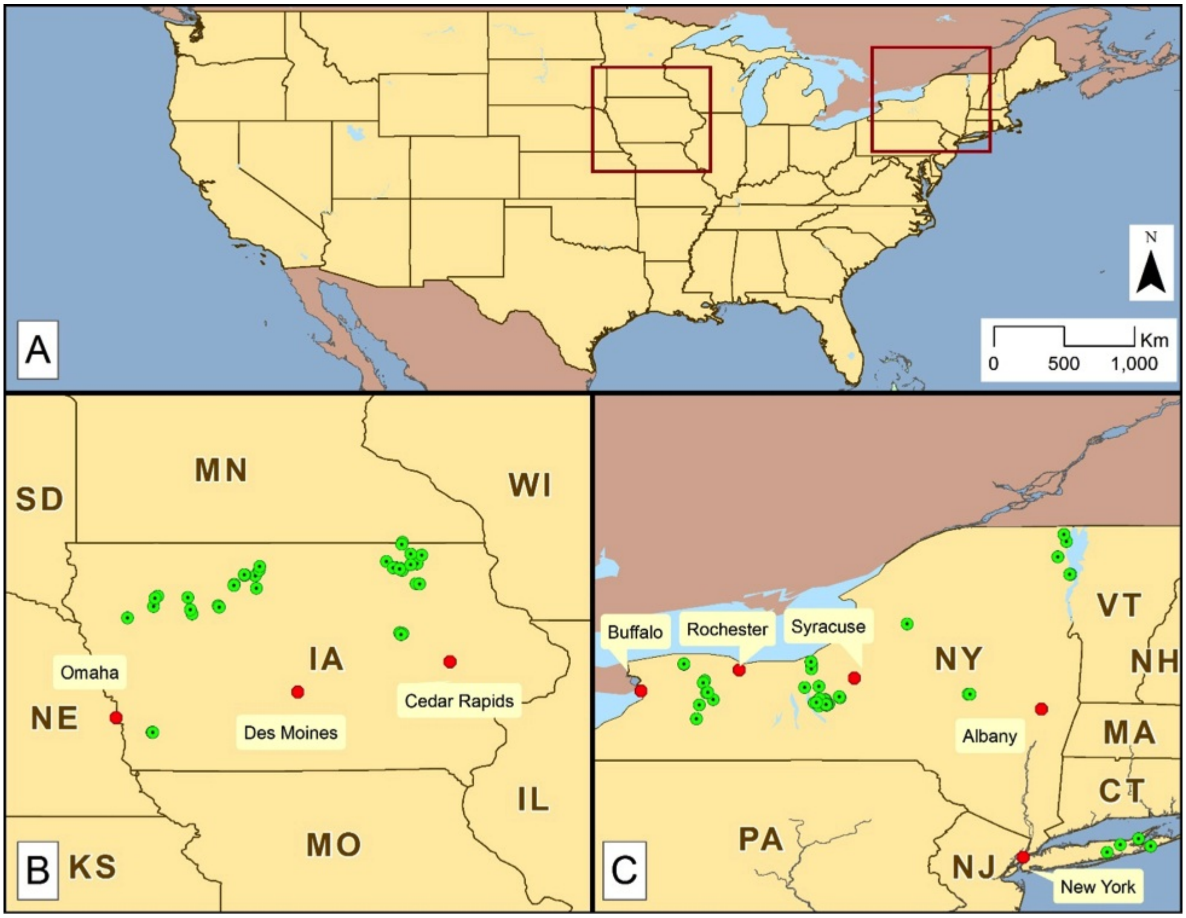
The Adapt-N tool also has environmental utility as it simulates leaching losses from the bottom of the root zone and gaseous losses into the atmosphere due to denitrification and ammonia volatilization. Both leaching and gaseous losses are simulated based on soil water dynamics and the use of N loss equations that are modified by temperature and water conditions.

The Adapt-N tool was used in 115 paired field strip trials with two to seven replications conducted mostly on commercial farms (two university research farms were involved) in New York and Iowa during the 2011 through 2014 growing seasons (Fig. 1). Trials were distributed across both states under a wide range of weather conditions, and involved grain and silage corn, with and without manure application, and rotations of corn after corn and corn after soybean. The pre-plant or starter fertilizer rates averaged 76 and 56 lbs/ac for the NY and IA trials, respectively. In each trial, the treatments were defined by the amount of N applied at sidedress, where the rates were:

(i) the Adapt-N recommendation for the date of sidedress, and

(ii) a Grower-selected rate, which typically represented their conventional practice.

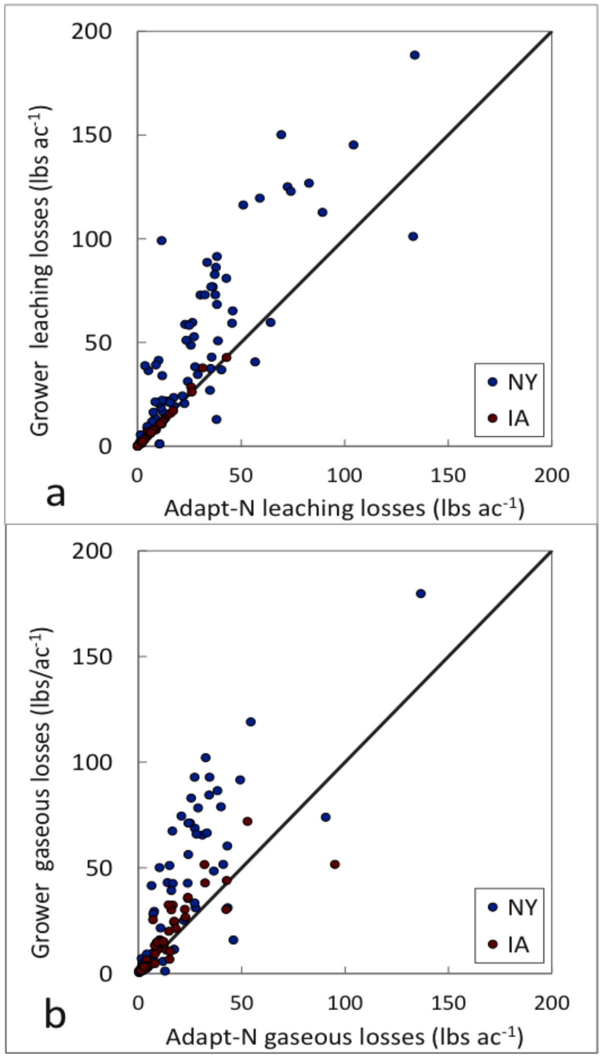
We determined corn yields and associated profit differences for the two treatments. In order to directly compare the environmental fluxes resulting from Adapt-N and Grower sidedress N applications, we ran full season simulations (up to December 31st) for all 115 trials and estimated the environmental fluxes that occurred after the application of sidedress N.



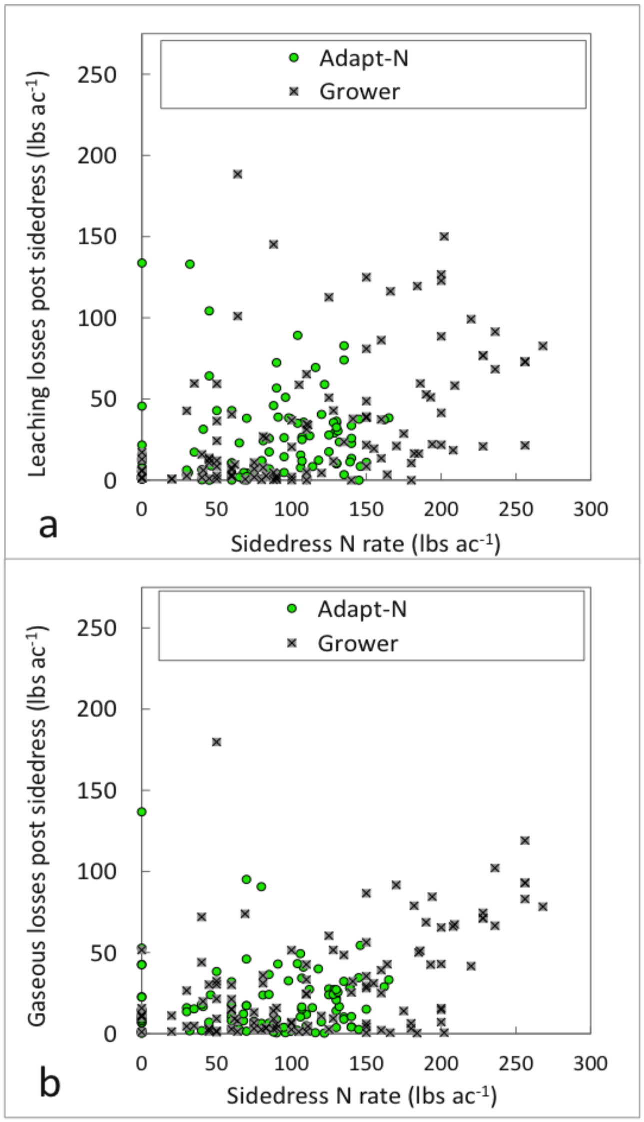
Results

Complete results for this study are presented in Sela et al. (in review). We measured clear agronomic benefits from the precision approach of the Adapt-N tool over the Grower treatment: N rates were on average reduced by 40 lbs/ac (34%), while average yields were actually 2 bu/ac higher. This resulted in $26/ac higher profits on average over all 115 strip trials.

For all trials in both states, simulated total N losses (leaching and gaseous combined) were on average reduced by 24.9 lbs/ac (38%) for the Adapt-N recommended rates compared to the Grower-selected rates (Fig 2), in line with the lower applied N rates. Simulated total N losses for the Iowa trials were on average somewhat lower than for the New York trials, presumably due to different climate and soil conditions.



Leaching losses: The average simulated leaching losses of 35.3 and 22.6 lbs/ac (Figs. 2a and 3a) for the Grower and Adapt-N treatments, respectively, are comparable to measured leaching losses from other experiments in the literature. Adapt-N rates resulted in an average reduction of 19.6 lbs/ac (39%) in New York and .3 lbs/ac (3%) in Iowa in simulated leaching losses compared to the Grower rates, and reductions were consistently higher for the New York trials. This can be attributed to several characteristics of the New York sites, including (i) generally wetter climate with much pre- and post-season precipitation, (ii) lower denitrification losses relative to leaching due to generally coarser soil textures, and (iii) shallower rooting depths causing less water and N uptake in the lower soil profile. Simulations were terminated on December 31 of each year, so are underestimates of actual benefits in both states, as further N leaching may still have occurred during spring and winter prior to the next growing season.



Gaseous losses: Simulated gaseous losses (Figs. 2b and 3b) were also lower for the Adapt-N compared to the Grower treatment (average reduction of 12.9 lbs/ac; 39%). The 2011 and 2012 seasons for the New York trials resulted in >50% reductions in simulated gaseous losses when using Adapt-N vs. Grower rates. Again, benefits were generally greater in New York than Iowa, although the relative reduction in gaseous losses in Iowa were greater (18%) than the reduction in leaching losses (3%).

Conclusions

The results of this study show environmental gains from using Adapt-N's precision management approach to estimating in-season N rates across a robust number of fields, soil types and weather conditions in Iowa and New York. In all, the Adapt-N recommended N rates adapted effectively to the varying field and weather conditions, were generally lower than the Grower's regular N rate, and achieved both economic and environmental benefits. Although the benefits varied by year, state and site, the overall environmental losses were reduced by 24.9 lbs/ac (more in NY than IA) through the use of this precision management approach. This implies a reduction of 38% in the post-application N losses. In all, use of Adapt-N can significantly contribute to nitrogen reduction goals. A final note: The potential benefits of its use are likely underestimated in this study, especially for IA, as the participants already represented a progressive group of growers who optimize their own N timing and placement decisions with sidedress applications, while many Midwestern growers still apply most of their nitrogen in the fall or at planting.

Acknowledgements

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Adapt-N Boosts Profits and Cuts N Losses in Three Years of On-Farm Trials in New York and Iowa

October 2, 2014

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Adapt-N is an on-line tool that provides location-specific, weather-adjusted nitrogen (N) recommendations for corn. At sidedress time, critical early-season weather that strongly influences actual N needs is incorporated into the recommendation. To accomplish this, the tool uses 1) a simulation model that was developed and calibrated through field research over several decades, 2) high resolution 2.5 x 2.5 mile daily temperature and precipitation information, and 3) soil and crop management information entered via a web interface on any internet-capable device. Adapt-N's cloud-based environment (central data server, high security, and accessibility through desktop, laptop and mobile devices, future embedding in other farm software) offers a user-friendly experience.

We conducted a total of 104 strip trials in 2011, 2012, and 2013 in New York and Iowa (Figure 1) to beta test Adapt-N for its ability to improve recommendations for corn N need at sidedress time. Yield data and simulated losses across trials show that the Adapt-N tool significantly increased grower profits, while decreasing N inputs and environmental losses, as summarized in this article. In 2014, Adapt-N was commercialized through a public-private partnership between Cornell University and Agronomic Technology Corporation (ATC, see http://www.adapt-n.com/). The partnership aims to sustain and broaden the tool's availability, customer service, usability, and integration with existing farm management technologies, while allowing for continued research and development at Cornell University.

Methods

We completed 67 replicated strip trials in New York (14 in 2011; 42 in 2012; 11 in 2013) and 37 trials in Iowa (9 in 2011; 19 in 2012; 9 in 2013) on commercial and research farms throughout each state (Figure 1. One 2012 trial in Minnesota is included with the Iowa trials).

Figure 1. Map of 2011-2013 trial locations (map courtesy of batchgeo.com)

Sidedress treatments involved at least two rates of nitrogen, a conventional "Grower-N" rate based on current grower practice (G) and an "Adapt-N" recommended rate (A). An Adapt-N simulation was run for each field just prior to sidedressing to determine the optimum weather-adjusted N rate.

2011-2013 Adapt-N Trial Results					
Average Change due to Adapt-N use (Adapt-N - Grower-N)	By State		By N rate change		Grand Mean
	NY trials n=67	IA trials n=37	N decrease (A<G) n=87	N increase (A>G) n=17	n=104
Total N fertilizer applied (lb/ac)	-52	-29	-60	38	-44
Simulated N leaching loss (lb/ac)*	-11	-1	-10	3	-8
Simulated N total loss (lb/ac)*	-36	-4	-34	16	-26
Yield (bu/ac equivalent)	2	0	-2	17	1
Profit ($/ac)	$37	$17	$23	$65	$30

Table 1. Agronomic, economic and environmental assessment of model performance in 2012. Values are average differences resulting from Adapt-N use (Adapt-N minus Grower-N treatment) such that a negative number shows a decrease due to Adapt-N, a positive number shows an increase due to Adapt-N. *Simulated N leaching losses and N total losses do not include 2011 IA trials – data not available.

Yields were measured by weigh wagon, yield monitor, or in a few cases by representative sampling (two 20 ft x 2 row sections per strip). Partial profit differences between the Adapt-N and Grower-N practices were estimated using prices of $0.50/lb N, $5/bu grain, $50/T silage, and $8/ac operational savings if sidedress was avoided in either the Adapt-N or Grower treatment. Yields were used as measured, regardless of statistical significance, since the statistical power to detect treatment effects for a single experiment is inherently low.

Total N losses to the environment (atmosphere and water) and N leaching losses were simulated by Adapt-N for each N treatment, through the end of each growing season. End dates for N loss simulation were October 30, 2011 (NY trials only), December 15, 2012, and December 31, 2013. More detailed descriptions of each year's methods and results were provided in previous WCU articles (Moebius-Clune et al., 2012, 2013, and 2014).

Agronomic and Economic Comparison

Adapt-N rates resulted in average N input reductions of 52 lbs/ac in NY, 29 lbs/ac in IA, and 44 lbs/ac overall (Table 1). Profit gains from the use of Adapt-N were considerable. Profits increased in 81% of all NY trials, in 70% of all IA trials, and in 77% overall when growers followed Adapt-N recommendations (Figure 2). Profit gains of $30/ac on average ($37/ac in NY, $17/ac in IA) were obtained most frequently due to reductions in N inputs, without significant yield loss: +1 bu/ac on average across all trials. Most collaborating growers were already using progressive N management including sidedressing, so that benefits achieved in these trials can be considered to be a conservative estimate of potential benefits of using Adapt-N. Benefits will be higher for growers who currently use few N best management practices.

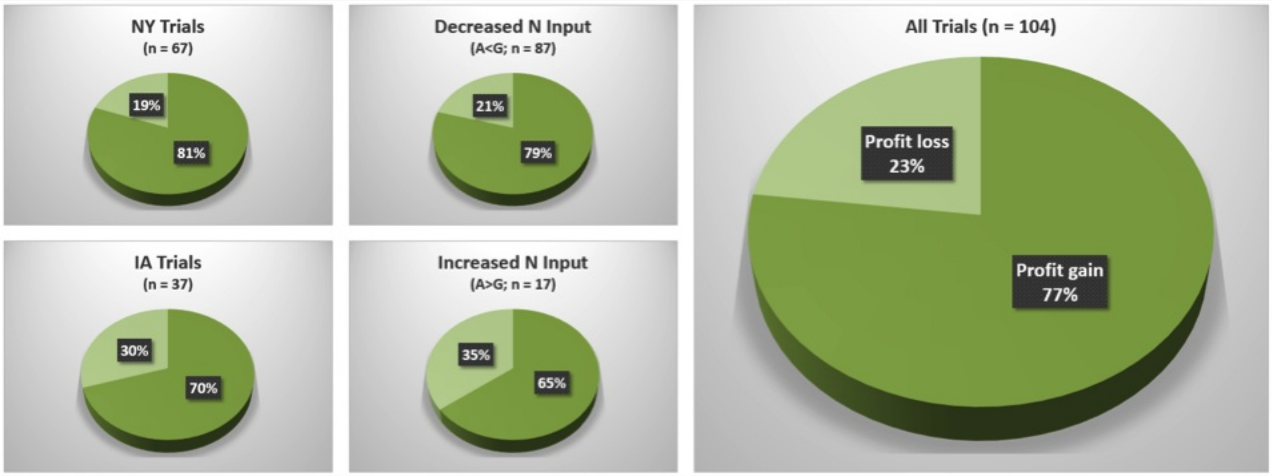

Figure 2. Proportion of trials with profit gains (dark green) or losses (light green) as a result of using the Adapt-N recommendation compared to current grower N management in 2011-2013 trials. With appropriate use of the most up-to-date version of Adapt-N, success rates can be further improved.

Decreased N rates: Adapt-N recommended a lower N rate than grower practice in 84% of trials, by 60 lbs/ac on average (Table 1). Such recommendations occurred after a normal or dry spring, when N from spring mineralization or early fertilizer applications remains available to the crop. Yield losses were generally minor, averaging -2 bu/ac across trials with N reductions, and leading to profit gains in 79% of cases – on average $23/ac (Table 1, Figures 2 and 3). This implies that a grower is about four times more likely to achieve increased profit from a reduced Adapt-N rate than from their current higher rate. This statistic includes all trials over three years, although model improvements have been made each year based on trial information, such that actual probabilities of increased profit with reduced N inputs are likely further improved for future years.

Increased N rates: Even larger profit gains of $65/ac on average were achieved when Adapt-N recommended increasing N inputs over the grower's current practice in 16% of trials. Consequent average yield increases of 17 bu/ac across these trials were achieved for an average additional 38lb/ac fertilizer application (Table 1). Such higher recommendations occurred primarily in 2013 ($94/ac profit on average in NY 2013 trials), and in select locations in other years, after a wet spring. Needs for additional N were correctly identified in 65% of these cases, resulting in significant yield and profit increases. In 35% of cases, on the other hand, the additional N was not needed. In almost all of these cases, unpredictable post-sidedress drought decreased yield potential below the expected yield that was used for the recommendation at the time the sidedress rate decision had to be made (Moebius-Clune et al., 2013).

Profit loss when under-fertilizing (from reduced yields) is generally larger than when over-fertilizing (from unnecessary fertilizer application). Thus lower recommendations to account for potential future yield-limiting events cannot be justified for economical sidedress recommendations. By contrast, pre-sidedress weather events affecting yield potential and N availability are known, and Adapt-N can effectively manage this risk. Therefore, the chances of over-recommending N inputs are somewhat higher than those of under-recommending, further decreasing risk of profit loss. For illustration, overall, profit gains greater than $50/ac occurred in 29 cases, while losses greater than $50/ac were determined in only 2 cases (Figure 3).

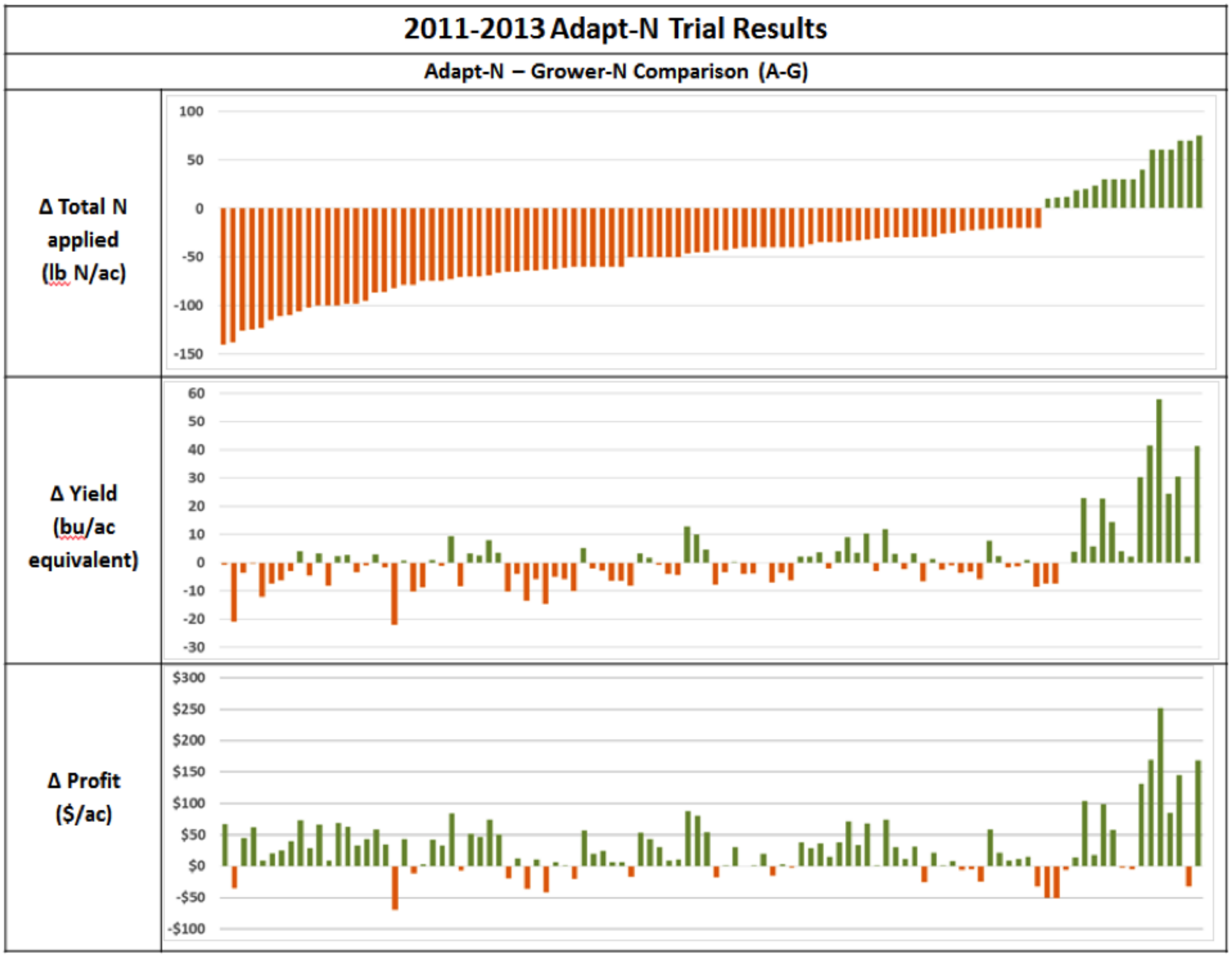

Figure 3. Results from each trial (n = 104) are vertically aligned. Bars show difference between Adapt-N and Grower treatments (A-G) such that negative numbers (orange) show decrease due to Adapt-N, and positive numbers (green) show increase due to Adapt-N.

Environmental Benefits

Adapt-N reduced N rates in 84% of cases, by 60 lbs N/ac on average, resulting in simulated reductions in total N losses to the environment by the end of the growing season of 34 lbs/ac, and leaching losses by 10 lbs N/ac (Table 1). Further losses of residual excess N generally occur over the winter and spring months when crop uptake ceases, soil water is recharged, and saturation or near-saturation occur, particularly in the Northeast. Thus the simulated reductions are a low estimate of actual environmental loss reductions, which are likely closer to the difference in applied N. In 16% of trials, where Adapt-N increased N rates, by 38 lbs/ac on average, total N losses increased on average by only 16 lbs/ac, and leaching losses by 3 lbs/ac. Further over-winter losses in these cases are lower, because much of the additional applied N was taken up by the crop to produce the increased yield, and thus would not be lost.

Lessons for Expert Use of Adapt-N from three years in the field

Growers can decrease risk of N deficiency, environmental losses, and yield losses, and increase profit margins. To optimize Adapt-N use, we recommend the following:

- Plan to apply the majority of fertilizer nitrogen at sidedress time instead of prior to or at planting. If manure is applied prior to planting or when enhanced efficiency products are used, aim for conservative rates.
- Monitor the field's N status and account for early season weather impacts on N availability by using Adapt-N's daily updates.

- Supply input information on soil and crop management that is representative of each management unit (e.g. test soil and manure based on representative samples, keep good records of operations, estimate expected yield as the second-highest out of 5 years of accurate yield information). For each management unit, measure soil organic matter at least every 3 years, ideally to a 12" depth.
- If appropriate, adapt input information at the time of sidedressing to account for seasonal influences, such as decreased yield potentials or shallow rooting depths from extreme wet conditions.
- Use the most recent Adapt-N recommendation available on sidedress day. Apply sidedress N between V6 and V12, depending on N and equipment availability. Generally, later sidedressing with high-clearance applicators allows for more accurate recommendations. Variable rate applicators can be used to adjust Adapt-N simulations for management units in fields.
- Use Adapt-N scenario simulations after the growing season to learn more about how weather and management influence N availability.
- In the long term, manage for healthy soils and use Adapt-N to account for N contributions from high organic matter levels and deep root zones.

Conclusions

Three consecutive growing seasons involving 104 on-farm strip trials demonstrate that Adapt-N is an effective tool for N management in corn systems, with average profit gains of at least $30/ac. With model improvements and increased expert use of the tool, we estimate that profit gains over current grower practices can be expected in at least four out of five cases. Adapt-N generally correctly identified cases when either decreased or increased N was needed to maintain yields. The tool also provides a strong incentive to shift N applications to sidedress time when weather impacts can be accounted for in the model. By using Adapt-N, growers can contribute to solving persistent problems with greenhouse gas emissions, groundwater pollution, and hypoxia in our estuaries, while increasing profits in both wet and dry years.

For more information: Recorded webinars, a manual, and other Adapt-N training materials are available at http://adapt-n.cals.cornell.edu/. The Adapt-N tool is accessible through any device with internet access, now from the team's commercial partner, Agronomic Technology Corporation, at http://www.adapt-n.com/ (cost is about $1-3/ac, depending on area covered). Adapt-N users can elect to receive email and/or cell phone alerts providing daily updates on N recommendations and soil N and water status for each management unit in Adapt-N.

Acknowledgements: This work was supported by funding from the NY Farm Viability Institute, the USDA-NRCS Conservation Innovation Program, the International Plant Nutrition Institute, McKnight Foundation, Walton Family Foundation, USDA-NIFA, MGT Envirotec, and USDA-SARE. We are grateful for the cooperation in field activities from Keith Severson, Kevin Ganoe, Sandra Menasha, Joe Lawrence, Anita Deming, Harry Fefee, Kitty O'Neil, Mike Hunter, and Brent Buchanan of Cornell Cooperative Extension, Bob Schindelbeck of the Cornell Section of Soil and Crop Sciences, Mike Davis at the Willsboro Research Farm, Dave DeGolyer, Dave Shearing and Jason Post at Western NY Crop Management Association, Eric Bever and Mike Contessa at Champlain Valley Agronomics, Eric Young at Miner Institute, and Peg Cook at Cook's Consulting in New York, and from Shannon Gomes, Hal Tucker, Michael McNeil, and Frank Moore at MGT Envirotec. We also are thankful for the cooperation of the many farmers who implemented these trials on their farms.

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Moebius-Clune, B., H. van Es, and J. Melkonian. 2012. Adapt-N Increased Grower Profits and Decreased Environmental N Losses in 2011 Strip Trials. What's Cropping Up? 22.

Adapt-N Responds to Weather, Increases Grower Profits in 2013 Strip Trials

June 2, 2014

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Adapt-N is an on-line tool for weather-adjusted precision nitrogen management in corn that has been available to growers in the Northeast and several Midwestern states since 2010 (http://adapt-n.cals.cornell.edu). In 2013, with an uncharacteristically wet spring, the tool successfully adapted N recommendations to account for early-season N dynamics, and further demonstrated its ability to improve farmer profits.

Background

Nitrogen dynamics in corn production are strongly influenced by weather, particularly early-season precipitation. In Northeastern and Midwestern US climates, N mineralizes from soil organic matter earlier than a corn crop is able to take it up. In a dry or normal spring, most of such early-mineralized soil N remains available to a corn crop (Figure 1a), so that growers can reduce N inputs without yield loss as demonstrated in 2011-2012 (Moebius-Clune et al., 2013a).

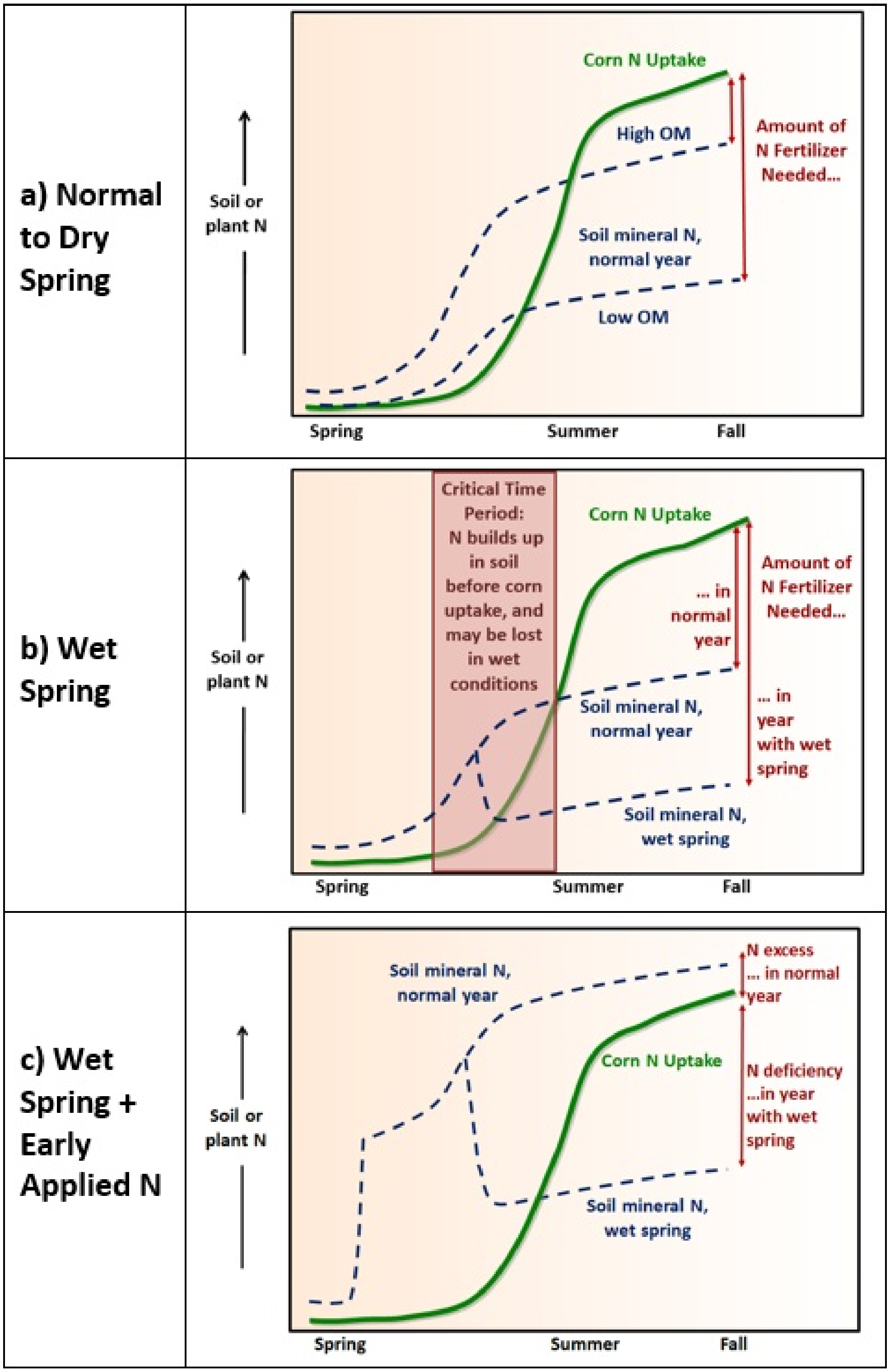

Figure 1. Early-season N dynamics in corn systems. a) N in organic matter (OM) begins mineralizing before corn is ready to take it up, and contributes significant amounts of nitrogen for crop uptake in normal to dry years. b) In a wet spring, early-mineralized N is easily lost during this critical time period, leading to later-season N shortages if not accounted for with additional sidedressed N. c) Applying N fertilizer or manure early increases the risk of large losses.

However, many growers apply the bulk of their nitrogen inputs before or at corn planting. This means not only that they lose the opportunity to reduce inputs in-season after a dry spring, but that they face significant risk of profit loss due to wet weather. Significant N loss of both early-mineralized and early-applied soil N occur during wet spring weather (Figure 1b and c). N rates must then be adjusted in-season when these losses can be accounted for, in order to maintain corn yield potential.

Adapt-N provides such site-specific in-season N sidedress recommendations. It uses a well-calibrated computer model and information on soil and crop management, along with real-time, high-resolution weather data, to account for a location's conditions. It also provides insights on soil nitrogen status, gains and losses, and crop growth stage through simulation outputs.

The tool's accuracy and precision have been evaluated through on-farm trials and improved in response to performance and user feedback (Moebius-Clune et al., 2013a, 2013b, 2013c, 2012). The wet spring encountered in much of the Adapt-N user area in 2013 provided the first chance to test the tool for extreme wet conditions. A summary article for all three years of testing provides averages for 104 trials over 3 years of testing in NY and IA. In this article, we examine Adapt-N's performance in 2013 New York and Iowa strip trials, guided by the following questions:

1. Do Adapt-N simulations of N losses in wet-spring conditions lead to weather-adaptive N recommendations that are agronomically and economically beneficial to farmers?

2. How do the model's recommendations affect environmental N losses in a wet season?

Methods

We completed 20 replicated strip trials on commercial and research farms, 11 in New York and 9 in Iowa during the 2013 growing season. Trials were conducted in grain and silage corn, in varied tillage systems, with and without manure application, with previous crops of corn or soybean (Table 1). Most participants applied small amounts of starter or preplant N, with the majority of total grower rates applied at sidedress. Sidedress treatments involved at least two rates of nitrogen, a "Grower-N" rate based on current grower practice, and an "Adapt-N" rate based on a simulation run just prior to sidedressing.

Growers in IA and NY implemented field-scale strips with 2 to 7 (usually 4) replications per treatment. In several trials (23-25, 27, 61, 62) treatment replicates were reported as composite harvest values due to time and equipment constraints.

Yields were measured by weigh wagon, yield monitor, or in a few cases by representative sampling (two 20 ft x 2 row sections per strip). Partial profit differences between the Adapt-N recommended and Grower-N management practices were estimated through a per-acre partial profit calculation:

Profit = [Adapt-N yield – Grower-N yield] * crop price – [Adapt-N rate – Grower-N rate] * price of N + Sidedress operation savings/loss

Yields were used as measured, regardless of statistical significance, since the statistical power to detect treatment effects is inherently low for whole-field strip trials, but averaging across many trials provides good statistical power for assessing Adapt-N performance. Prices of $0.50/lb N, $5.00/bu grain, $50/T silage were used. (Prices varied across implementation areas, but generally were close to a 10:1 price ratio). Operational costs of sidedressing

State	Trial ID	Harvest	Manure	Prior crop
NY	7	grain	no	grain corn
NY	9	grain	no	soy
NY	12	grain	no	soy
NY	15	grain	no	soy
NY	18	grain	no	grain corn
NY	23	grain	no	soy
NY	24	grain	no	soy
NY	25	grain	no	soy
NY	5	silage	no	silage corn
NY	22	silage	2013	silage corn
NY	27	silage	2013	silage corn
IA	57	grain	2012	soy
IA	58	grain	2012	soy
IA	59	grain	2012	soy
IA	61	grain	no	soy
IA	62	grain	no	soy
IA	63	grain	no	soy
IA	64a	grain	no	soy
IA	65a	grain	no	soy
IA	65b	grain	no	soy

Table 1. Background information on 2013 on-farm strip trials implemented in NY and IA to compare current Grower N application rates with rates recommended by the Adapt-N tool.

($8/ac) were accounted for where only one of the treatments was sidedressed. Agronomic, economic, and simulated environmental outcomes of these trials were used to assess Adapt-N performance.

Results

Agronomic and economic comparisons between Grower-N and Adapt-N treatments for each trial are provided for NY and IA trials in Figure 2, and as averages for agronomic, economic, and environmental performance in Table 2.

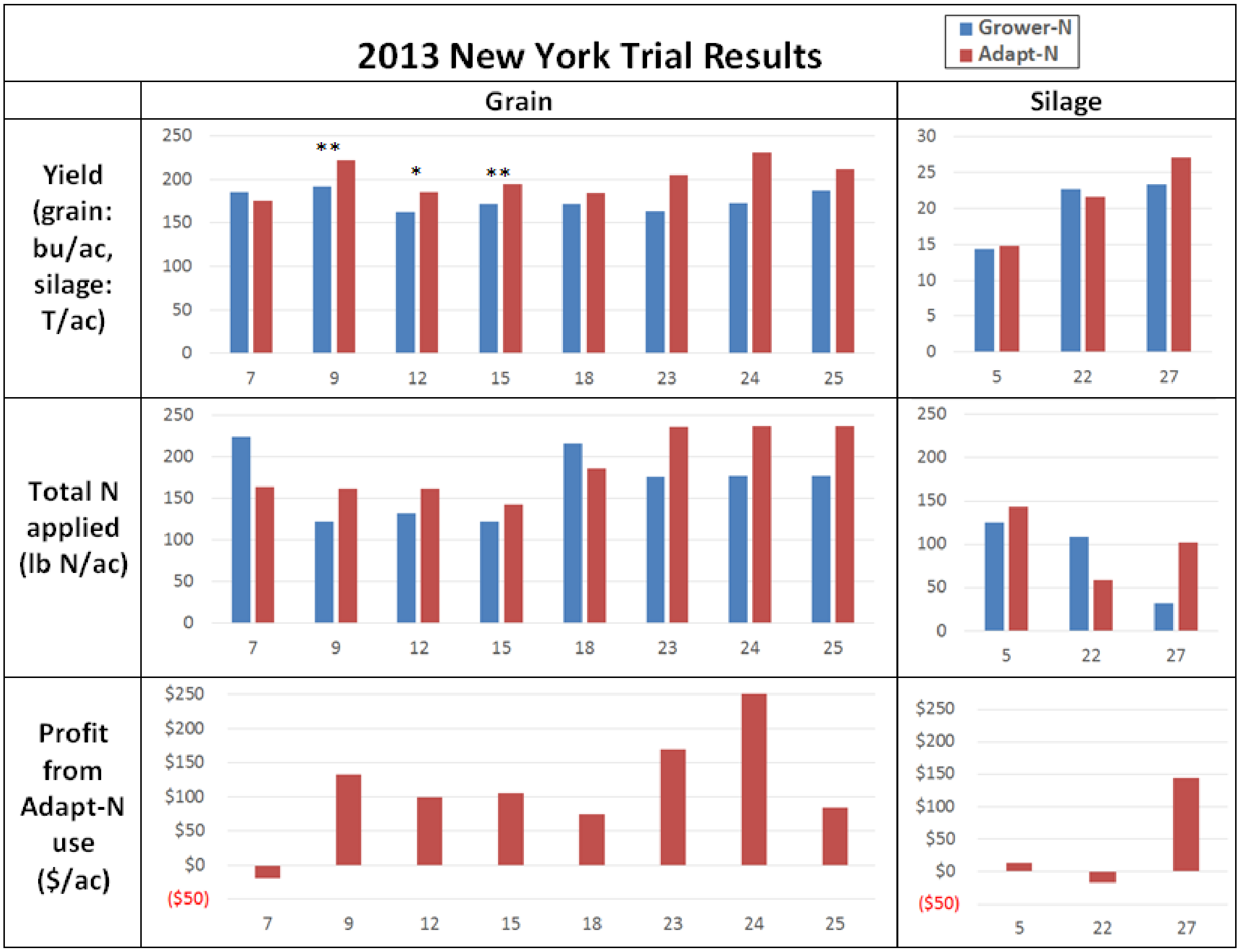

Figure 2. Yield and fertilizer use from Grower-N vs. Adapt-N treatments in a) NY and b) IA trials. N rates represent total N in lbs/acre applied as inorganic fertilizer in 2013. Partial profit gain (positive) or loss (negative) from using the Adapt-N recommendation, relative to grower's current practices. (Yields statistically different at *$p < 0.05$ or **$p < 0.01$)

In 2013, in contrast to previous years, Adapt-N rates were higher than Grower-chosen sidedress rates in 73% of NY trials, because the most extreme rainfall occurred primarily after corn planting, in June and early July, when large amounts of mineralized N and early applied N were vulnerable to losses. In Iowa, however, Adapt-N rates were higher than Grower-chosen rates in only 22% of trials, despite the wet spring, because the most extreme rainfall occurred in May and early June, followed by fairly dry conditions in some of the user area. At that time, relatively less of the potentially available N from organic matter had mineralized. The largest losses thus occurred where corn was planted early and preplant N fertilization was high (up to 110lb/ac, trial 63), prior to extreme rainfall. This was only the case in a small number of trials.

2013 Trial Results					
Average Change due to Adapt-N use (Adapt-N - Grower-N)	NY grain	NY silage	All NY trials	All IA trials	Grand Mean for NY and IA
	n=8	n=3	n=11	n=9	n=20
Total N fertilizer applied (lb/ac)	23	13	20	-19	0
Yield (grain: bu/ac; silage: T/ac; combined: bu/ac grain equiv)	25	1	21	1	11
Profit ($/ac)	$112	$47	$94	$12	$53
Simulated N leaching loss (lb/ac)	3	-1	2	0	1
Simulated N total loss (lb/ac)	11	0	8	-9	0

Table 2. Agronomic and economic assessment of model performance in 2013. Values are average differences resulting from Adapt-N use (Adapt-N minus Grower-N treatment), such that a negative number indicates a decrease due to Adapt-N, a positive number indicates an increase due to Adapt-N. Profit calculations assume $5.00/bu grain, $50/T silage, $0.50/lb N, and $8/ac operational savings if sidedress was avoided. Silage yields are reported as grain equivalent (1T silage = 8.14 bu grain)

Those who sidedressed the majority of their N in June were able to avoid the extreme losses. Averaging all 20 trials conducted in NY and IA in 2013, total fertilizer applied and environmental losses did not change, while yield increased by +11 bu/ac, and profits increased by $53/ac.

NY trials. Adapt-N recommended increased sidedress rates over the grower's normal practice in 8 out of 11 NY trials. The difference between Adapt-N recommendations and grower practice (A-G) averaged +20 lbN/ac (-60 to +70 lb N/ac). Yield increased on average by +21 bu/ac (-10 to +58 bu/ac; silage reported as grain equivalent: 1 T silage = 8.14 bu grain). In all cases where Adapt-N recommended a fertilizer increase, higher rates resulted in increased yields and profits. Overall, profits from Adapt-N recommendations increased in 9 out of 11 trials (82%), ranging from -$20 to +$252/ac with an average increase of $94/ac.

Despite significant fertilizer increases, simulated total losses of N over the season (through 12/31/2013) averaged only 8 lb N/ac higher in Adapt-N versus Grower strips (Table 2). Post sidedress losses occur if sidedress N is applied before the crop is large enough to prevent wet soil conditions through high transpiration rates, or if excess N remains at the end of the season. Most of the additional fertilizer recommended by Adapt-N was taken up by the crop after sidedressing, while N applications and losses were reduced in 3 of the trials. In two trials where profit losses did occur, we suspect that the combination of inadequately drained, compacted, poorly aggregated soils and heavy rains caused higher losses than simulated by the model.

Success stories from two growers in particular can be highlighted. Grower Arnold Richardson, working with Keith Severson of CCE Cayuga County, saw significant profit gains of over $100/ac on average from Adapt-N use this year (see Case Study in this volume, http://blogs.cornell.edu/whatscroppingup/?p=759). Dave DeGolyer of Western NY Crop Management Association established several trials of rescue N applications in July with growers Donn and Chad Branton (23-25, Fig 2). The Brantons' standard N management places nearly all N fertilizer in a deep slot with stabilizer at planting. However, this year demonstrated that such fertilizer is vulnerable to losses during heavy rains despite stabilizer. Adapt-N indicated that more N was needed, even though enough would have been available in a normal year (Fig 1c). By sidedressing an additional 60 lb N/ac, the Brantons saw increases of 25, 42, and 58 bu/ac in three trials and profit gains of approximately $79, $164, and $246/ac due to avoided yield loss. The Brantons have decreased their preplant N applications this spring, and plan to use Adapt-N-informed sidedress rates provided by WNYCMA.

IA trials. Despite the wet spring, Adapt-N recommended fertilizer rate reductions from grower's normal practice in 7 out of 9 IA trials, in part because most participating IA growers were planning to apply the majority of their N at sidedress. The difference between Adapt-N recommendations and grower practice (A-G) ranged from -40 to +30 lbN/ac with an average change of -19 lb N/ac. Yield changes due to Adapt-N use ranged from -4 to +14 bu/ac with an average of +1 bu/ac. Profits increased on average by $12/ac, ranging from -$6 to +$57/ac, with increases due to Adapt-N in 3 trials, no change ($0 to $1/ac) in 3 trials, and decreases in 3 trials. Simulated total N losses over the season (through 12/31/2013) were lower in Adapt-N versus Grower strips (-9 lb N/ac on average). Similarly to NY results, small profit losses in a few trials with reductions in N rates are likely due to the extreme wet conditions for which the model had not yet been field tested. Improvements in model handling of drainage have been in progress for the 2014 version of Adapt-N. Overall, the fact that Adapt-N was able to decrease N inputs even after such a wet spring without significant yield loss in these 6 trials (-1 bu/ac on average) indicates that Adapt-N accounted for losses successfully, and can inform much more significant N input reductions in Iowa during more normal or dry years, as demonstrated by our 2011 and 2012 trials, when growers plan on sidedressing. It should also be noted that predominant practice of IA growers at this time is to apply N in the fall or spring prior to planting. Such growers would have seen results most like trial 63 in IA, and trials 23-25 in NY (Figure 2), where additional N was needed to make up for rain-induced losses, with increased profits above $50/ac likely.

b)

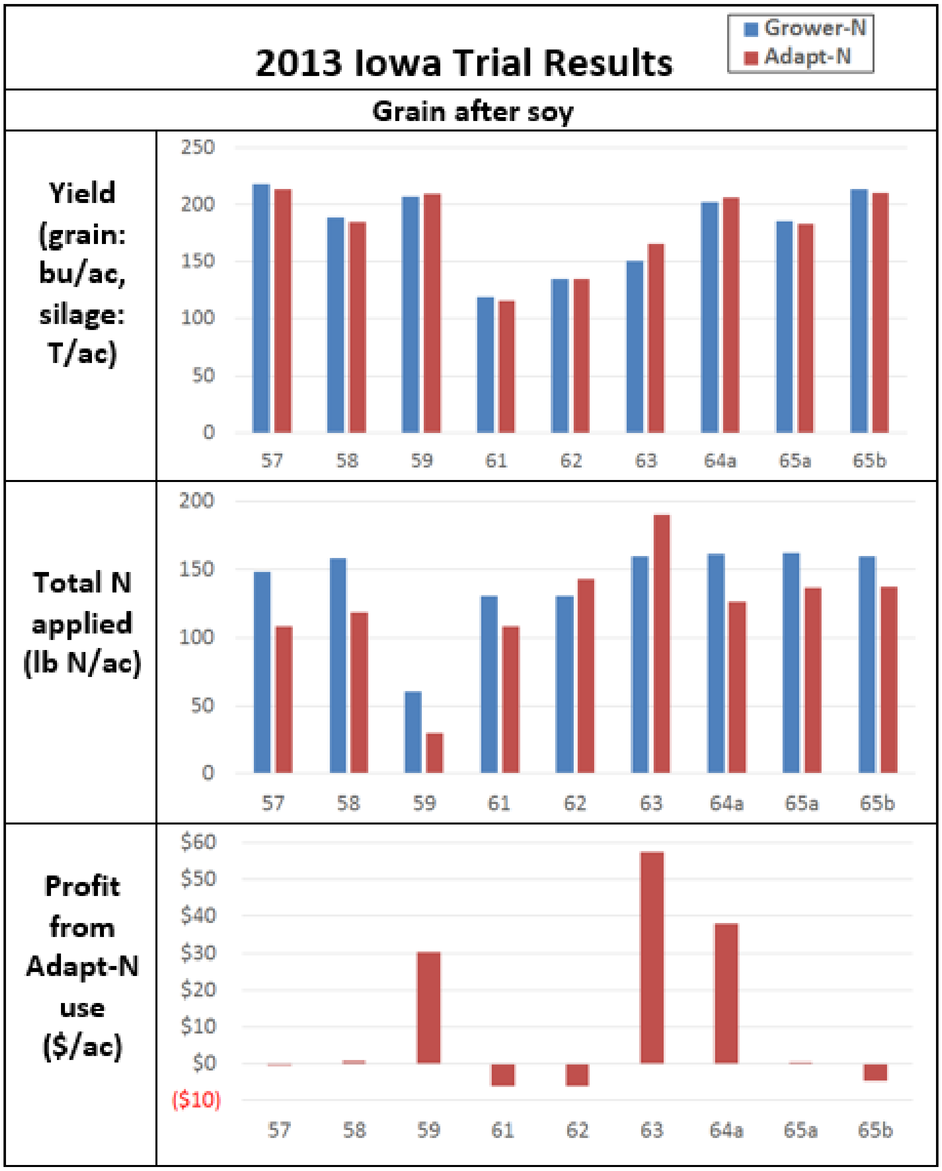

Figure 2b

Conclusions

2013 on-farm testing in NY and IA further demonstrated the monetary and environmental value of using Adapt-N's weather-adjusted recommendations.

Key Take Home Points:

- Environmental losses due to Adapt-N recommendations in 20 trials, on average, did not increase over grower practice in the wet 2013 season.
- Yields increased by 11 bu/ac on average (21 bu/ac in NY, 1 bu/ac in IA).
- Profits increased by $53/ac ($94/ac in NY, $12/ac in IA).
- In 75% of trials Adapt-N increased or maintained profits compared to grower practice. The model's ability to handle the impacts of poor drainage has been further improved for 2014.

- 2013 results demonstrate the value of site-specific, adaptive recommendations provided by Adapt-N. The tool's site-specific recommendations successfully identified opportunities for N input reductions where possible, and N input increases where agronomically necessary to maintain yield potential following a wet spring.
- Results, especially in IA, conservatively estimate possible profit gains in a wet year, because most collaborating growers sidedress the majority of their N. Profit were highest when compared to more common grower practices of large or total preplant applications.
- This third year of on-farm testing further confirms the significant advantages growers have when they apply the majority of their N at sidedress time, when economically optimum N rates can be better estimated.

For more information: An in-depth 2014 training webinar on Adapt-N, manual, and further information are available at http://adapt-n.cals.cornell.edu/. The Adapt-N tool can be used from any device with internet access, and as of the 2014 sidedress season is offered through a public-private partnership between Cornell University and Agronomic Technology Corporation for a fee ($1-3/ac, depending on area covered). Users can sign up for an account at http://www.adapt-n.com/products/, and can elect to receive email and/or cell phone alerts providing daily updates on N recommendations and soil N and water status for each management unit being simulated in Adapt-N.

Acknowledgements: This work was supported by funding from the NY Farm Viability Institute, the USDA-NRCS Conservation Innovation Program, the International Plant Nutrition Institute, McKnight Foundation, and MGT Envirotec. We are grateful for the cooperation in 2013 field activities from Keith Severson, Joe Lawrence, Anita Deming, Harry Fefee, Kitty O'Neil, Mike Hunter, and Brent Buchanan of Cornell Cooperative Extension, Bob Schindelbeck of the Cornell Department of Crop and Soil Sciences, Mike Davis at the Willsboro Research Farm, Dave DeGolyer, Dave Shearing and Jason Post at Western NY Crop Management Association, Eric Bever and Mike Contessa at Champlain Valley Agronomics, Eric Young at Miner Institute, and Peg Cook at Cook's Consulting in New York, and from Shannon Gomes, Hal Tucker, and Frank Moore at MGT Envirotec. We also are thankful for the cooperation of the many farmers who implemented these trials on their farms.

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Farmers with Diverse Nitrogen Management Practices Find Value in the Adapt-N Tool in Iowa

February 5, 2015

Margaret Ball[1], Bianca Moebius-Clune[2], Shannon Gomes[3], Aaron Ristow[1], Harold van Es[1], Soil and Crop Sciences, Cornell University[1], NRCS Soil Health Division[2], Cedar Basin Crop Consulting[3]

Shannon Gomes, owner of Cedar Basin Crop Consulting, provides services for 25 farmers in Northeast Iowa. Gomes, with his 28 years of consulting experience and a Master's degree from Iowa State University, has extensive knowledge of Iowa soils and a particular interest in precision management. He emphasizes a scientific approach in his work, advising clients and helping them run trials to assess the many available tools and products on their farms.

Gomes has long been searching for a better way to monitor nitrogen (N) availability and provide precise N recommendations. He's tried "all the different nitrogen management tools," with varying results, but has never been satisfied. When he stumbled upon Adapt-N in 2009, he found what he had been looking for: a real-time, location-specific adaptive N recommendation model that accounts for weather, management practices, and field variability. Since then, Gomes' expertise and enthusiasm have been essential in field-testing Adapt-N over three seasons and introducing the tool to Iowa. He now models all his clients' corn acres in Adapt-N, using it as both a starting point for his N recommendations, and a teaching tool for understanding complex N dynamics. We spoke with Gomes, his colleague Frank Moore, and two farmer clients—Nick Meier and Ken Humpal—to learn how they are using Adapt-N.

Shannon Gomes provides consulting services to 25 farmers in Northeast Iowa and has been using the Adapt-N tool.

The Farmers

Nick Meier

Nick farms 1200 acres on a corn-soy rotation for grain and seed production. Typical of most farmers in Iowa, he used to apply all his nitrogen in the fall, but now puts on half (80 lb/ac) in the fall, another 30 lb/ac with pre-emergence herbicide, and the remainder (about 50 lb/ac) as an early sidedress application around the V2 stage. Adapt-N simulations of each field, run by Gomes, allow Nick to adjust this final sidedress application based on the spring's weather conditions and other field-specific factors.

Nick has completed three Adapt-N field trials. In 2012, Adapt-N recommended that he skip sidedressing altogether. There was no yield penalty, and he saved $34/ac on fertilizer and operational costs. Though waiting until sidedress sometimes makes Nick nervous, he appreciates the reduced risk of losses, and is still pushing his N applications later, as much as his comfort level will allow. In 2013, the tool warned that much of the fall-applied N had been lost to rain, and Nick should adjust his sidedress rate upward by 30 lb/ac. The higher rate yielded 14 more bu/ac and +$57/ac profit.

Ken Humpal

Ken raises dairy and beef cattle, corn (grain and silage), soy, and alfalfa on 1700 acres. Like Nick Meier, he used to apply all nitrogen in the fall, but now puts about 50% of the season's N on as spring pre-plant (anhydrous ammonia) and the rest as sidedress. On sandier ground, he'll skip the pre-plant altogether and wait for sidedress, because leaching risks are higher.

Ken used late spring soil nitrate tests (PSNT) in the past to determine N rates, adjusting for alfalfa and soybean credits. Now, Ken uses Adapt-N recommendations for all his acres, with minor adjustments. The tool helps account for variation in his fields due to OM content (3-5%), previous crop (corn, soy, alfalfa, or cereal rye cover crop), manure history, and soil type influences. It also helps him track the retention or loss of nitrogen from manure applications, for purposes of nutrient management planning and regulation compliance. Ken completed one Adapt-N field trial in 2011. In this instance, the tool recommended he apply 30 lb N/ac above his usual practice, and the higher rate was justified by a 6 bu/ac higher yield and +$13/ac profit.

Frank Moore

Frank is a consultant colleague of Gomes and a farmer himself. He grows corn and soy on 2000 acres, and develops nutrient management plans for his clients through Three Rivers Ag Consulting. Unlike many Iowa farmers, Frank does not apply N in the fall or at planting but rather applies only 30 lb N/ac with pre-emergence herbicide. The rest of the season's N is added at sidedress, using Adapt-N-recommended rates. His sidedressing equipment can be driven in corn up to about 18" tall without damaging it, even at this stage. It takes Frank about 5 days to sidedress 1000 acres of corn, but he's never been rained out. Sidedressing does cost slightly more for the extra trip, Frank says, but it is worth the minimized risk of N losses, and the ability to reduce total N applied in dry years.

Before Adapt-N, Frank applied all N with his pre-emergence herbicide. This system "works about 3 out of 5 years", he says, but not when you have excessive rain. Using Adapt-N hasn't greatly changed Moore's N rates overall, but it has helped him shift more N from spring to sidedress, and adjust for weather. He applied less than normal across his farm in 2012, and more in the wet season of 2013. In addition, Frank completed six trials of Adapt-N on his fields and on average, Adapt-N reduced N rates by 22 lb/ac resulting in insignificant yield and profit changes. Frank says the biggest savings from his N program have come in extreme circumstances. In 2013, when spring weather prevented planting in many fields, Moore estimates he saved $35,000 by avoiding putting N on early!

Using Adapt-N

"When you compare [Adapt-N] to other tools… nothing even comes close," says Gomes, "and I've used all of them!" In a normal weather year, Gomes and his farmers observe that Adapt-N recommends N rates similar to what they would use otherwise. However, the tool is particularly useful in accounting for contrasting weather scenarios. For instance, in the very dry 2012 versus the very wet 2013 springs, Adapt-N helped Gomes "stay ahead of the curve" – recognizing and correcting N shortage in a field before the crop showed signs of deficiency. Adapt-N has allowed growers to reduce N applications by 29 lb/ac on average with no yield penalty, resulting in average savings of $17/ac.

The tool is convenient—it achieves field- and sub-field-level precision without the large sampling effort associated with in-season field-measurements. Before using Adapt-N, Gomes based N recommendations on PSNT samples from a few thousand acres per year. Although many samples can be taken, it's hard to be sure they are representative. When it rained after sampling, he had to go out and re-sample, or assume that test results were no longer useful. Gomes and Ken Humpal agree they can now monitor soil N availability through Adapt-N – its previous-day high resolution precipitation data gives the closest thing to real-time N measurements, and doesn't require in-season waiting on the results of lab tests. "I think [Adapt-N] is the thing!" Ken says. Within 24 hours of a rainfall event "you *know* what you've got out there."

The model provides graphs of available soil N, N uptake and losses, rainfall, temperature, and other factors that are extremely useful as teaching tools, understanding recommendations, and for scenario testing through retrospective runs. For example, from the wet season of 2013 we can see Adapt-N's "what-if" N timing simulations comparing standard management, Nick Meier's actual management, and the Adapt-N recommendation (Figure 1; sidebox). This can help a farmer re-examine previous N management programs, and consider the effects of new programs before actually putting them into practice. "The most powerful part of the interface is the graphs," says Gomes. "You can sit down with a farmer and show them what's really happening."

Learning through Adapt-N "What-If" Scenario Testing

Adapt-N can simulate "what-if" scenarios, comparing season-long effects of N application timing and other management practices. Figure 1 shows three Adapt-N simulations run retrospectively on Nick Meier's 2013 trial field in eastern Iowa. The soil is Kenyon loam, 3.7% OM, with no manure history, and 2012 crop was soybean. If Nick had applied all N in fall (his historical practice, and that of the majority of farmers in his region), large spring losses would have limited crop N uptake and yield (left column). Nick's current practice, splitting N between fall, spring, and sidedress (middle), reduced losses and increased crop N uptake relative to the fall-applied scenario. If he had applied nitrogen only in the spring and at sidedress (right), N losses would have been further reduced, and less total fertilizer would have been needed for an equivalent yield. Crop nitrogen that's not provided by fertilizer comes from the mineralization of soil organic matter.

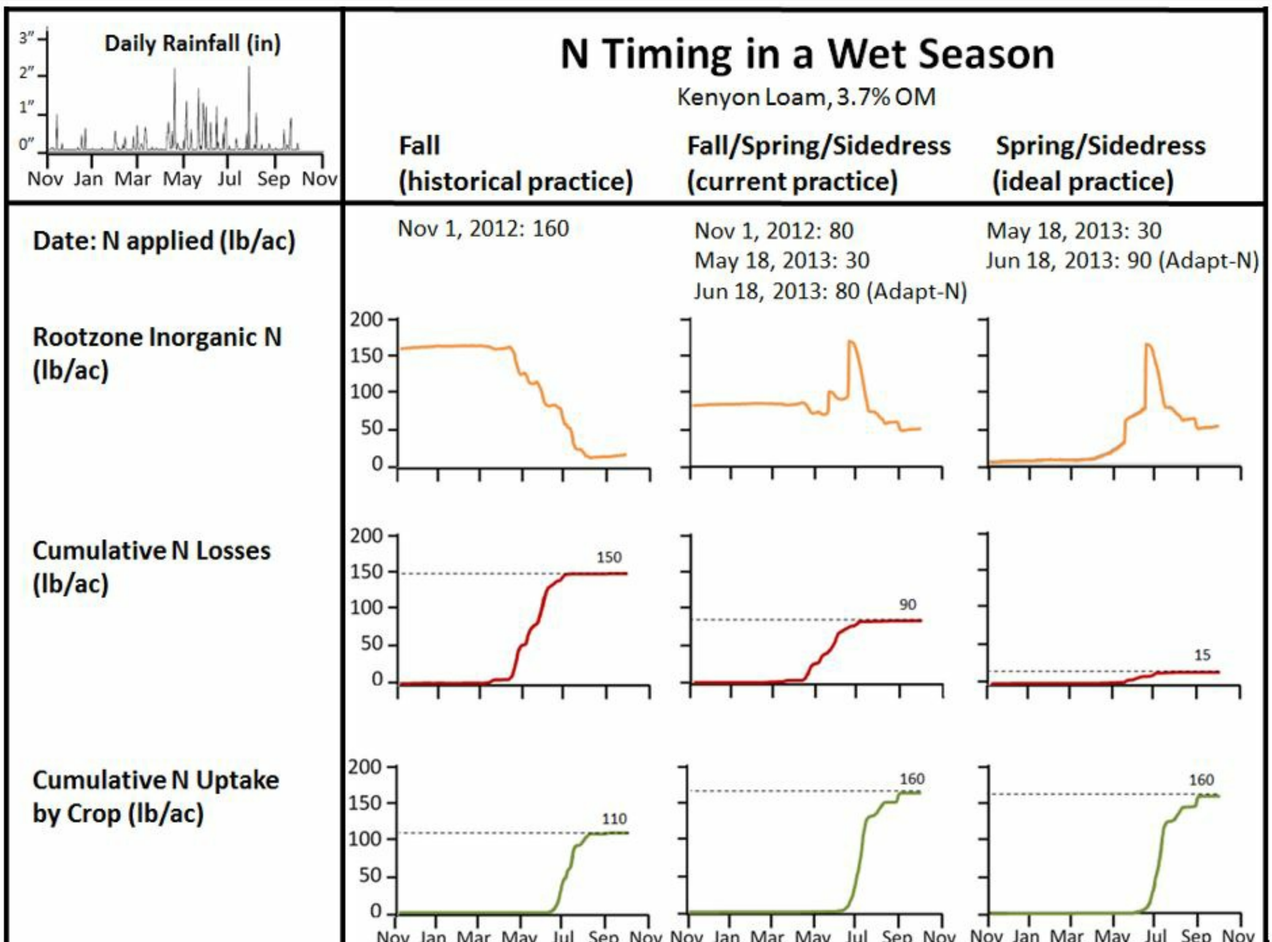


Figure 1. Adapt-N "what-if" simulation of three N timing practices (fall only; fall/spring/sidedress; and spring/sidedress) in a wet season. Adapt-N recommendations in this simulation would have minimize N losses and required less total N for an equivalent yield.

Future Directions

Gomes is proud that he has persuaded most of his clients to move away from fall N application—a project he's been working on for quite a while. Now that he uses Adapt-N for recommendations on all client acres, he is able to offer even more incentive to plan on sidedressing, using more precise rates adjusted in season.

Shifting toward sidedress is not without its concerns. Nick and Ken worry about getting rained out and missing the critical window to fertilize, or damaging young corn. Ken remains confident however that sidedressing risks and costs are justified by the additional savings he found during three years of field trials. “I’m excited about Adapt-N,” he says “it’s just a matter of fitting it into the system…” Frank Moore has found great benefit in sidedressing, and risks of rain-out or damage to corn have not caused him problems in his many years using this system. As high-clearance equipment, RTK/GPS, and variable rate technology are becoming more common among growers and custom applicators, the incentives for sidedressing are starting to clearly outweigh the challenges.

What is on Shannon Gomes’ mind for the future? He is strongly interested in soil health testing and helping his clients improve their soil management. Soil health and nitrogen management are closely connected (Figure 2), and Gomes is looking at cover crop and tillage system impacts on soil health and nitrogen dynamics. This way, his farmers can reap the benefits from improved soil health through increased yields and higher N availability, as estimated by Adapt-N.

Figure 2. Weather and soil health properties interact to influence soil N dynamics. Such field-scale differences influence physical and biological factors that drive N mineralization and losses as shown in the aerial view of Ken Humpal’s farm.

New York Farm Delves Deeper with Adapt-N

June 2, 2014

Margaret Ball, Bianca Moebius-Clune, Harold van Es, Jeff Melkonian, Department of Crop and Soil Sciences, Keith Severson, Cayuga County Cooperative Extension, **Cornell University**

Arnold Richardson has had his eye on Adapt-N since 2009, when the tool for weather-adapted sidedress nitrogen recommendations first became available. Of a self-described "competitive nature," the Red Creek, NY farmer is constantly seeking and testing new strategies that can improve his farm system and boost yields and profits. After several years of watching the development of Adapt-N and its success in early on-farm trials, Richardson conducted strip trials of the Cornell nitrogen management tool in three fields in 2013. All three trials increased his yield and profit, and of course, got him thinking about what improvements to make next.

The Richardson Farm crew (left to right): Arnold, Eric, and Ryan Richardson and Nick Humphrey.

Richardson and sons grow grain corn and soybean on 1000 acres near the border of Cayuga and Wayne counties. The mix of rich river bottom loams and stony clay drumlins in their fields requires flexibility and ingenuity in management. The team has significantly changed management practices since inheriting the farm several decades ago. They switched from continuous corn to a corn-soybean rotation, which gave an immediate 20 bu/ac yield bump on corn, says Arnold. They've also experimented with various primary tillage tools, switching from moldboard to chisel plow in 1983, then testing strip till, aerator, and most recently "vertical tillage" tools over several years to see what works best in their system. Most recently, the farm's experiments have included increased seeding rates and a review of their nitrogen management practices.

The Richardsons have long taken a weather-conscious approach to nitrogen management decisions, applying most N as sidedress to better match the timing of crop uptake. "That's the best time," says Arnold. "The corn is making big decisions about its future at the 5 – 8 collar stage. We try to help it make good decisions… We've got to keep the corn happy all the way through." They follow a general rule of 1 lb N per 1 bushel expected yield, adjusting for N use efficiency and soybean credits, for an average of around 150 lb N per acre per year over the whole farm. Understanding that weather influences N dynamics, the Richardsons even split their N into earlier and later sidedress applications on sandier fields, to minimize the risk of leaching losses with rain. They ran a few Adapt-N simulations in previous years, usually coming up with recommendations that were lower than or similar to their own rates. However, they had not adjusted their total N rates based on weather until they tested Adapt-N in the field last year.

Keith Severson of Cayuga County Cooperative Extension guided the Richardsons in establishing three Adapt-N strip trials in 2013. The trials were conducted in corn grain following soybean, on Williamson and Ontario silt loams with 2.6% to 3.8% organic matter. All trials received 22 lb N/ac in starter, following the farm's normal practice. The third trial also received an extra 50 lb N/ac in May, because Richardson wanted to test a practice more similar to that of his neighbors, who apply more of their nitrogen early. Two treatments, replicated four times, were implemented in late June to compare Adapt-N-recommended and Grower-chosen sidedress rates. Due to the unusually wet spring, N leaching and denitrification losses (simulated by Adapt-N) were high. Adapt-N thus recommended sidedress rates 20, 30, and 40 lb/N higher than Richardson's chosen rates. Yields increased significantly with the higher N rates in all three trials, with gains of 23 to 30 bu/ac. At Richardson's actual prices ($0.75/lb N and $5.00/bu corn), this translates to profit gains of $91/ac to $122/ac from the use of Adapt-N. Total yields in the trial strips ranged from 162 to 222 bu/ac. As well as implementing the trials, Richardson also followed Adapt-N recommendations on the rest of the farm's acres, "which resulted in a larger N bill than originally planned, but with a pleasing result yield wise," he says. One Adapt-N trial plot earned the farm fourth place in the Finger Lakes section of New York State Corn and Soybean Growers' Association 2013 Yield Contest, at 232 bu/ac.

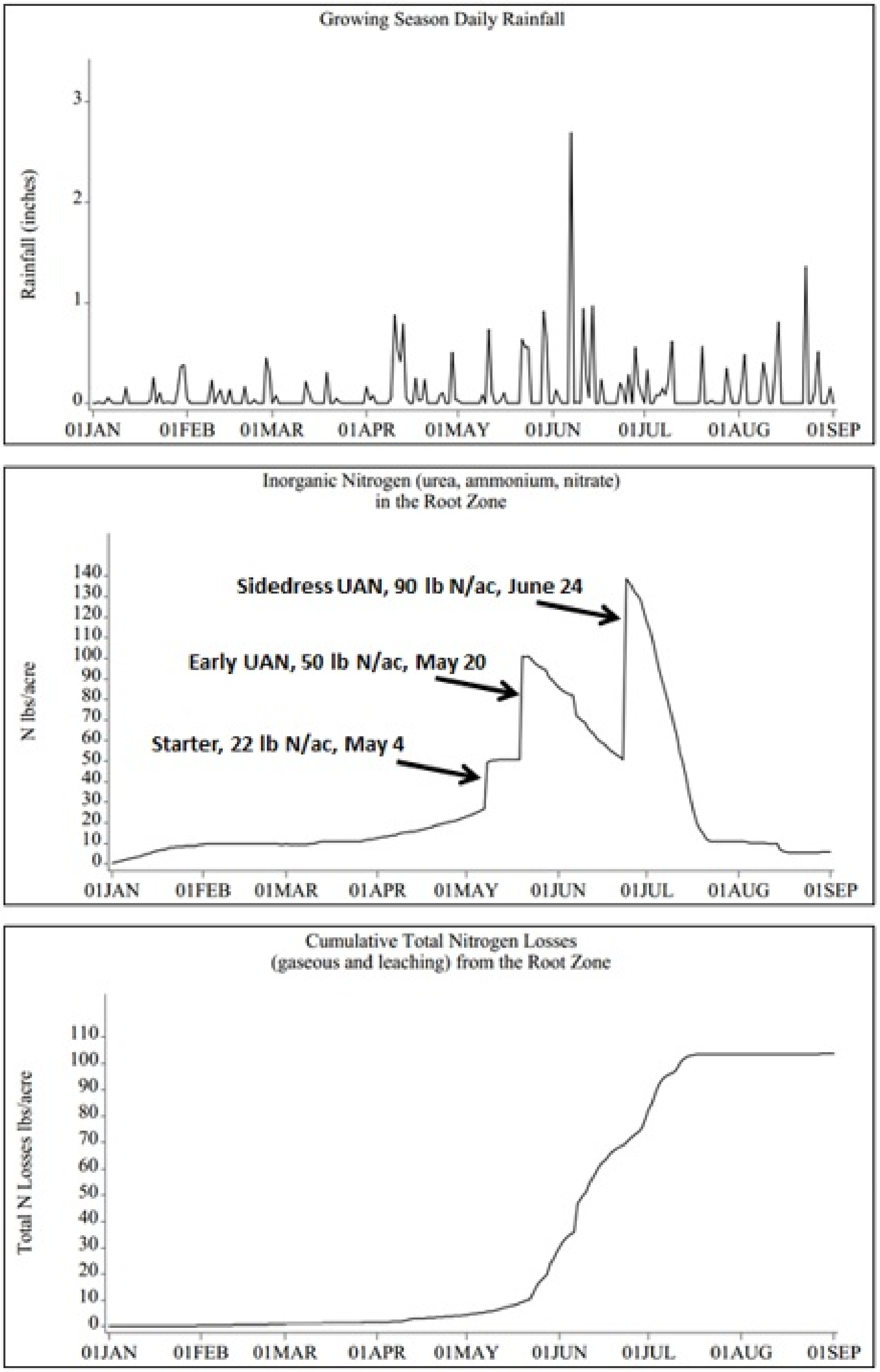
Richardson Farm 2013 Trial Results

Trial ID	Total N applied (lb/ac)			Yield (bu/ac)			Profit ($/ac)**	p ***
	Adapt-N	Grower	A - G*	Adapt-N	Grower	A - G*	A - G*	
9	162	122	+ 40	222	192	+ 30	+ $122	0.007
12	162	132	+ 30	185	162	+ 23	+ $91	0.05
15	142	122	+ 20	194	171	+ 23	+ $99	0.0001

Yield and profit increases with Adapt-N recommended rates
* Difference of Adapt-N minus Grower. Positive number shows increased N applied due to Adapt-N
** Profit calculation using farm's actual prices ($0.75/lb N and $5.00/bu corn)
*** p values below 0.05 are statistically significant (real) yield differences

Richardson's experience was typical of Adapt-N trials in New York last season. In 8 out of 11 NY **2013 trials**, Adapt-N increased N rates over grower practice. Across all trials, growers saw their yields increase by an average of 21 bu/ac with Adapt-N rates 20 lb/ac higher than grower-chosen rates, resulting in profit gains of $94/ac (10:1 price ratio, silage reported as grain equivalent). Adapt-N was able to adjust N rates upward by using site-specific high resolution climate data to simulate the year's unusually wet spring conditions, and the resulting large leaching and denitrification losses of early-applied fertilizer and early-mineralized organic N. By contrast, in the more normal springs of 2011-2012, Adapt-N simulations were able to correctly identify higher N availability from the same sources. In 56 trials in these years, New York growers gained $31/ac on average by cutting back on 66 lb/ac of unnecessary N applications.

While yield and profit gains are a convincing incentive for the Richardsons to continue to use Adapt-N, the value of Adapt-N runs deeper than just financial on the Richardson farm. Arnold and sons were struck by the tool's graphs of soil N availability and rainfall, which clearly showed the farm's weather-related early N losses. Arnold has also "gotten into these what-if scenarios quite a bit," regularly using his Adapt-N account to play with different management schemes and retrospective simulations.



Graphic output from Adapt-N, showing rainfall, root-zone inorganic nitrogen, and cumulative N losses in one of Richardson's trials. The large early-season losses are typical of a wet spring.

The biggest lesson in Arnold's eyes, however, has come from three Cornell Soil Health Test samples that the Richardsons submitted as part of their Adapt-N trials. The farm's chemical analysis scores were perfect due to years of careful soil test-based management, but new biological and physical measures like aggregate stability, subsurface hardness, and active carbon ranked lower on the test's scales. "I look at these reds and yellows and think, this is our next project," said Arnold, indicating his scores for biological and physical measures of soil health. "To help get me to the next level, I've got to pay attention."

For more information: An in-depth 2014 training webinar on Adapt-N, manual, and further information are available at http://adapt-n.cals.cornell.edu/. The Adapt-N tool can be used from any device with internet access, and as of the 2014 sidedress season is offered through a public-private partnership between Cornell University and Agronomic

Technology Corporation for a fee ($1-3/ac, depending on area covered). Users can sign up for an account at http://www.adapt-n.com/products/, and can elect to receive email and/or cell phone alerts providing daily updates on N recommendations and soil N and water status for each management unit being simulated in Adapt-N.