CONSERVATION INNOVATION GRANTS
Final Project Report

Grantee Name: Harold M. van Es	
Project Title: Precise Nitrogen Management for Corn Production: Mitigating Environmental Nitrogen Losses and Adapting to Climate Change	
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Deliverables identified on Grant Agreement: 1. Conduct at least 10 presentations and workshops, and at least one National Webcast and one conference on Adaptive N Management in collaboration with other institutions and agencies including NRCS. 2. Demonstrate and evaluate the performance of the *Adapt-N* tool compared to conventional methods for N recommendations in strip trials. Establish twenty trials in Iowa and 5 in NY including treatments such as N applied at planting; starter plus side/top-dress; and silage with manure or previous sod inputs. 3. Modify the current *Adapt-N* tool for application to the Northeast U.S. and Iowa and to include a cover crop input option. 4. Develop a training manual and a fact sheet and expand the *Adapt-N* website with new results and educational information. 5. Attend at least one NRCS CIG showcase or comparable NRCS event during the period of the project agreement. 6. Semi-annual performance progress report and a final report documenting project results 7. Fact sheet describing the new technology or approach.	

Contents

Executive Summary

NRCS designated priorities met by project

This project addressed needs related to the following national priority CIG categories:

- Energy: N fertilizer is the largest energy input, typically about 40%, in corn grain production systems
- Climate Change Mitigation and Adaptation: reduced N_2O losses and adaptation of N management to changes in precipitation and temperature were demonstrated in three years of on-farm trials
- Nutrient Management: more efficient N use was achieved through use of the tool.
- This project included efforts in the Chesapeake Bay Watershed and the Mississippi River Basin.

This project had wide impact, as the educational component reached over 7000 producers, consultants, and agency staff in several states directly, and likely tens of thousands more through secondary media coverage.

Goals, objectives and accomplishments

The goals of this project were to advance the use of precision N management by deriving fertilizer estimates from dynamic simulation modeling, combined with high-resolution climate data, and site specific soil and management information through use of the Adapt-N tool, in order to contribute significant solutions to perpetual U.S. water quality and greenhouse gas emissions issues related to corn nitrogen management. Efforts focused on two general areas: (i) advancing adoption through in-person and online training of stakeholders, on-farm demonstration trials of grower-chosen vs. model-derived N rates, and evaluation, and (ii) enhancing the *Adapt-N* tool for wider geographical areas and broader sets of agronomic practices.

Deliverables outlined above have been completed as follows, with accomplishments for outreach and trial implementation exceeding original deliverables significantly. Over 100 presentations (>10x the deliverable) were provided through conferences (including NRCS events), field day demonstrations, workshops, and webinars. These reached more than 7000 stakeholders directly, and many more secondarily through word-of-mouth, publications, secondary media publicity, etc. 104 on-farm trials (>4x the deliverable), were successfully completed in the focus states, New York and Iowa. Over 50 additional trials were completed in other Northeast and Midwest states (ME, IL, IN, MN, OH, PA, WI) through leveraged funding to inform geographic expansion. The Adapt-N tool was calibrated based on trial data and improved understanding of N dynamics from the literature and soil type information, so that it is now available for public use not only in the Northeast and Midwest, but with further broadened geographic boundaries into some Southeast and Central States. Over 1000 users had signed up for and account in the freely available Cornell version of the interface by 3/31/2014.

The tool was commercialized in April 2014, through a unique public-private partnership between Cornell and a start-up company, in order to provide sustained user services, a vastly improved interface with functionality that had been suggested by users. This partnership allows researchers to continue to focus their efforts on model capacity expansion and improvements. Geographic expansion was thus prioritized over completion of the cover crop input options for the 2014 season, but the model code has been developed and will be integrated in the new interface. A comprehensive educational website, a training manual, multiple factsheets, articles summarizing trial results, and multiple case studies were published. Funds were spent generally as anticipated, but one six month extension from September 2013 to March 2014 was provided. This brought funding availability in line with a third season of data collection and analysis, allowing for more effective use of the funding source. This funding source was critical in leveraging multiple other sources of funding over the course of the project, allowing the team to effectively deliver a much more comprehensive and impactful effort.

Outcomes and benefits

104 trials over three years in Iowa and New York show that, by adapting N recommendations for corn to weather effects at sidedress time, Adapt-N can increase profits and decrease applied nitrogen in comparison to current grower rates. In 84% of trials Adapt-N decreased applied N by 60 lb/ac on average, with insignificant yield loss, and profit increases of $23/ac on average. Conversely, in 16% of trials, Adapt-N adjusted rates upward by 38 lb/ac, resulting in an average yield increase of 17 bu/ac, and average profit increase of $65/ac. Results from this project demonstrate that use of Adapt-N provides strong incentive for shifting N applications to sidedress time from pre-plant applications, because variability due to early season weather strongly drives losses of early-applied N, and economic optimum N rates. Corn system profits can thus be significantly increased ($30/acre across all trials). This is a win-win scenario, as applying a more precise rate at each location results not only in producer profits, but also in decreased GHG losses, and reduced N losses to surface and groundwater. Thus beneficiaries of this project include not only producers and their service providers, but also the general public.

Recommendations

The project team concludes that use of the Adapt-N tool for informing sidedress application rates in corn should be strongly recommended and widely implemented in corn systems. New York and New Hampshire NRCS have already written the Adapt-N tool into their advanced 590 nutrient management practice options, and there is potential for the tool's use to be widely incentivized through cost-shares by NRCS, non-profit, and other organizations. Implementing such additional incentives along with the inherent risk- and profit-related incentives from Adapt-N will aid in improving water quality, decreasing greenhouse gas emissions, and helping producers adapt to variable early season weather and maintain profitability on broad acreages.

Introduction

Project overview

The goals of this project were to demonstrate and advance the use of precision N management by deriving fertilizer estimates from dynamic simulation modeling, combined with high-resolution climate data, and site specific soil and management information through use of the Adapt-N tool, in order to contribute significant solutions to perpetual U.S. water quality and greenhouse gas emissions issues related to corn nitrogen management. Efforts focused on two general areas: (i) advancing adoption through in-person and online training of stakeholders, on-farm demonstration trials of grower-chosen vs. model-derived N rates, and evaluation, and (ii) enhancing the *Adapt-N* tool for wider geographical areas and broader sets of agronomic practices. The focus areas were New York and Iowa, with pilot efforts originally planned in Indiana and Pennsylvania.

N fertilizer is often the most significant input cost to corn growers and much money is wasted on over-application in many growing seasons. Conversely, yield potential is lost in some wet seasons. Both scenarios result in decreased farm profits. Nitrogen is vulnerable to being lost in the spring when the soil profile can be wet, but the corn crop is not yet taking up available water and nitrogen at the rates they are supplied, or otherwise in the fall, when excess nitrogen that was not taken up by the crop becomes mobile in the root zone once uptake and transpiration slow down. More precise application of N, including precise location-specific rate determination and appropriate timing, can thus significantly reduce N loss to water and air, associated with the concerns with greenhouse gas impact, groundwater degradation, and estuary hypoxia problems.

This project built on 20 years of field research and modeling efforts, which have come to fruition in Adapt-N, a web-based N decision tool. Many scientists whose work provided the foundations on which the Adapt-N tool is based. In particular Drs. Jeff Wagenet, John Hutson, Thomas Sinclair, Russell Muchow, and Jean Sogbedji were involved in critical model development and calibration of the Precision Nitrogen Management Model at the core of Adapt-N. The underlying model had been extensively validated and tested before the project was started, and was ready for field demonstration and evaluation in a real-world environment. The availability of the newly developed unbiased high resolution climate data made available by the Northeast Regional Climate Center was critical to making Adapt-N broadly available.

The project outcomes were clearly delineated in terms of education, field demonstration, model calibration, and increased adoption. Objectives included:

- Expanding the high-resolution climate grid to Iowa, and eventually the continental US east of 100^{o} W to cover most of rain-fed corn growing regions in the U.S.
- Conducting training programs on N processes in crops and soils, the role of weather variability in driving these processes, and adaptive N management concepts and practice using the *Adapt-N* tool, focused in New York and Iowa, with pilot efforts in Pennsylvania and Indiana, and contributing to a new national initiative on adaptive nutrient management (NE_TEMP1581).
- Evaluating the performance of the *Adapt-N* tool compared to grower-practiced methods for N recommendations in strip trials on 40 farms over 2 growing seasons (2011-2012) in IA and NY, which were then extended into the 2013 growing season.
- Publishing results in stakeholder accessible formats such as a comprehensive website, manual, webinars, downloadable articles and case studies.

- Modifying the initial version of the *Adapt-N* tool for application to the Midwest U.S. and broader Northeast, to include a cover crop input option, and to integrate user feedback over time for an improved interface.
- Producing a next-generation *Adapt-N* for the Northeast and Midwest U.S.
- Having an additional 40 corn growers in participating states test the *Adapt-N* tool and implement it on at least one field on their farm.

The Team

The successful completion of the project was enhanced by well-established collaboration among participants. Stakeholders in NY, IA and other states, including a cadre of scientists, consultants and producers were ready to implement the tool, and additional collaborators joined the team throughout the project. The expanding list of collaborators over the course of the project included:

<u>Project Leadership:</u>
Dr. Harold van Es, Professor, Project PI, Department of Crop and Soil Sciences, Cornell University
Dr. Jeffrey Melkonian, Modeler, Senior Research Associate, Department of Crop and Soil Sciences, Cornell University
Dr. Bianca Moebius-Clune, Project Coordinator, Senior Extension Associate, Department of Crop and Soil Sciences, Cornell University
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Dr. Laura Joseph, Programmer

<u>Agronomic Technology Corporation:</u>
Start-up company managing the commercial version of Adapt-N made available 4/1/2014:
Steve Sibulkin, CEO
Greg Levow, President and COO
Holly Trytten, CTO

<u>New York Project Collaborators:</u>
Margaret Ball, Technician, Adapt-N and Soil Health, Cornell University
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Hal Tucker, Crop Consultant, Tucker Consulting, MGT Envirotec Ltd, Storm Lake, IA

Other Collaborators:
Jane Petzoldt, Project Coordinator, IPM Institute of North America, Inc., Madison, WI
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Suzy Friedman, Environmental Defense Fund, Washington, DC
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Scott Thompson, G & K Concepts, Inc., IN
Ken and Katie Ferrie, Crop-Tech Consulting, Heyworth, IL
Jeff Polenske, Polenske Agronomic Consulting, WI
Matt Brugger, Polenske Agronomic Consulting, WI

Growers
A large number of growers collaborated on this project and mostly remain anonymous here. Several NY producers collaborated on more intensive multi-year and/or multi-field trials and on case study articles written about their experience: Robert and Rodney Donalds, and Arnold Richardson. Several IA producers collaborated on a case study article to be published in the next months: Nick Meyer, Ken Humpbal, and Frank Moore (producer and consultant).

Leveraged Funding

The NRCS funded portion of the project was critical in starting the on-farm demonstration effort, and in sustaining the effort over three growing season. Matching funds were provided by Cornell University, New York Farm Viability Institute, and an initial investment by MGT Environtec in the project, among others. Availability of this funding source allowed us to leverage the project to obtain a large number of other funding sources, as the initial success proved promising.

Funding and resources for the beta-testing and development of Adapt-N have been provided by: Cornell University Department of Crop and Soil Sciences, Department of Earth and Atmospheric Sciences, College of Agriculture and Life Sciences, Cornell Cooperative Extension, Hatch and Smith Lever Funds, New York Farm Viability Institute, USDA-NIFA Agriculture and Food Research Initiative, USDA-NIFA Special Grant on Computational Agriculture, Northern NY Agricultural Development Program, MGT Envirotec, International Plant Nutrition Institute, Walton Family Foundation, McKnight Foundation, Northeast Sustainable Agriculture Research and Education (NE-SARE). The ability to leverage NRCS funds in obtaining complementary funding for a more comprehensive, geographically broadened effort was critical in more in-depth calibration and validation of the tools, as well as in driving adoption, ultimately through the public-private partnership with Agronomic Technology Corporation to provide a commercially available tool at a reasonable cost that can sustain the tool's availability to the public.

Background

Summary

Nitrogen management on US corn acres is inefficient, regardless of scale. Crop N recovery efficiency is currently generally only around 35-60% of applied N, sometimes lower. This is costly for producers, the environment and society. Excessive nitrate levels in groundwater and N-induced hypoxia in estuarine areas such as the Gulf of Mexico, Chesapeake Bay, Peconic Bay and Great Bay from agricultural sources have been persistent and unsolved concerns for decades. Greenhouse gas impacts from nitrous oxide (N2O) losses to the atmosphere constitute agriculture's largest greenhouse gas source, of which corn production is the largest contributor. N application is also the largest fossil fuel input on corn grain acres.

Precise N recommendations to meet, but not exceed, crop needs are essential, but N availability to the crop in a given field varies from year to year due to dynamic and complex interactions among weather, soil type and health status, hydrology, crop growth, and management practices. Optimum fertilizer N rates can therefore vary by 100 lbs/ac or more from year to year, mostly dictated by early-season weather-impacts that are predicted to be exacerbated by climate change. Thus crop N requirements cannot be accurately predicted at the beginning of the growing season in regions with spring rainfall, because N contributions from mineralization of soil organic matter (SOM) and manure and early-season losses cannot be accurately estimated. Nitrate leaching and N2O losses increase exponentially when crops are fertilized beyond crop N needs. Losses are particularly large during wet springs if nitrogen is available from early N applications or mineralization, or at the end of the season when excess N remains and is not immobilized in a cover crop.

Producers generally try to maximize their economic returns to N applications in the presence of this high uncertainty around the optimum N rate. They tend to over-apply N fertilizer in most years for several reasons, including: 1) the cost of yield penalties from under-fertilizing is much higher than the cost of over-fertilizing; 2) under-fertilization is obvious (leaf yellowing and yield reductions), whereas over-fertilization is invisible, leading to a visual bias toward higher rates (van Es et al, 2012). When the optimum rate is uncertain for a given year and field, the producer's economic incentive is to use a high rate that will be adequate for all growing seasons. If however rates can be recommended with higher certainty, then the risk of underfertilizing when following such a rate decreases significantly. Currently producers over-fertilize in most years, as was shown by this project, because they are managing the risk associated with lacking information. At the same time, losses via nitrate leaching and denitrification are high, because the largest losses happen when fertilizer inputs exceed crop N needs, or are present before the crop is able to make use of them.

Adaptive, and therefore more precise, in-season management of N on a field-by-field basis leads to higher profits by saving money on fertilizer when less is needed, but maintaining yields with higher inputs when more is needed. Computer simulation models offer an alternative management tool that can account for these dynamic soil and crop N processes, thus decreasing the risk to the producer, and increasing the incentive to decrease rates in most years. If these models are well-calibrated and tested, they can provide information to adjust in-season N applications to more precisely match crop N demand.

Environmental and Economic Concerns Addressed

Nitrogen fertilizer use on corn poses multiple critical and unresolved economic and environmental challenges. The cost of N application on corn in the US is about $5B annually, and constitutes one of the costliest crop inputs on corn farms. Improved N use efficiency in corn cropping systems has become a compelling goal with increased N fertilizer prices and concerns about environmental impacts. Excessive nitrate levels in groundwater and N-induced hypoxia in estuarine areas, such as the Gulf of Mexico and the Chesapeake Bay, from agricultural sources (McIsaac et al., 2002), as well as the high energy consumption for N fertilizer manufacturing and greenhouse gas impacts from soil N_2O losses (Smith and Conen, 2004) are persistent concerns.

Corn, a C_4 plant, is physiologically more efficient at utilizing N (more yield per unit N accumulation) than most other major crops, which are generally C_3 plants (Greenwood et al., 1990). But paradoxically, corn production systems as a whole generally have low fertilizer N uptake and recovery efficiencies (RE). Through on-farm experiments in six North-Central US states, average RE was determined to be 37% with a standard deviation of 30% (Cassman et al., 2002). This suggests both low nutrient use efficiency and thus high fertilizer cost per yield achieved, as well as high potential N losses to the environment. Intensive corn production areas therefore pose a risk for N losses to the air and to surface and groundwater systems, and have become the focus of policy debates on addressing eutrophication and hypoxia concerns in the United States.

In a recent policy report, Ribaudo et al. (2011) emphasized the significant role corn plays in the nitrogen problem: "Corn is the most widely planted crop in the United States and the most intensive user of nitrogen. In 2006, corn accounted for an estimated 65 percent of the total quantity of nitrogen applied to major U.S. field crops. Corn also accounted for half of all nitrogen-treated crop acres that were not meeting the rate, timing, or method of application criteria used in this analysis to define acceptable nitrogen management […] In addition, recent demand pressures due to the biofuels mandate, as well as increasing international demand for feed grains, suggests that corn acreage and the intensity of corn production are likely to increase. Together, these factors increase the importance of raising the NUE in corn production in the United States, especially on farms that raise livestock and apply manure to their fields."

Precise estimation of the optimum N fertilizer rates is critical to reducing N leaching losses (Ostergaard, 1997). Studies by van Es et al. (2002) and Randall (2006) reported rapid increases in nitrate leaching with N rates above the optimum, and highlighted the importance of precise estimation of seasonal fertilizer N needs. Similar concerns with N management have also been raised in the context of greenhouse gas emissions. Hoben et al. (2010) and van Groenigen et al. (2010) determined that nitrous oxide (N_2O) losses increased exponentially when crops are fertilized beyond crop uptake needs. The global warming impact of over-application is significant, and, for corn, poor management accounts for a disproportionate contribution to total agricultural greenhouse gas emissions (Ribaudo et al., 2011).

Annual Weather Variability Interactions with N dynamics

Corn generally shows high variability in N response, and economically optimal N rates (EONR) may range from zero to 250 kg N ha^{-1} (Scharf et al., 2006; Mullen et al., 2011). The need for "precise" management of N fertilizer is compelling, but the ability to estimate the true EONR has remained relatively elusive. Early season weather, particularly precipitation, has been highly correlated with seasonal variation in optimum fertilizer N rates and nitrate (NO_3)-N export via subsurface drainage from crop fields (Balkcom et al., 2003; Mitsch et al., 2001; Sogbedji et al., 2001a).

Current in-season N recommendations for corn production in most U.S. states are static and do not take into account the dynamic behavior of soil N (van Es et al., 2002). Improving the current in-season N recommendations for corn is critical to the credibility of fertility recommendation systems. Increased N use efficiency is expected to reduce unused N that, if not stored in SOM, becomes lost to other parts of the environment during the fall-winter-early spring period (van Es et al., 2002).

Tools for Estimating Optimum N Rates

Historically, the mass-balance approach has been the most widely-used method for making N fertilizer recommendations (Stanford, 1973). It is generally based on a yield goal and associated N uptake, minus credits given for non-fertilizer N sources such as mineralized N from soil organic matter (SOM), preceding crops, and organic amendments, and generally involves an efficiency factor to account for high variability and farm economic risk concerns. Several studies have documented, however, that the relationship between yield and such recommendations is very weak or non-existent for humid regions (Lory and Scharf, 2003; Vanotti and Bundy, 1994; Katsvairo et al., 2003, Sawyer et al., 2006a).

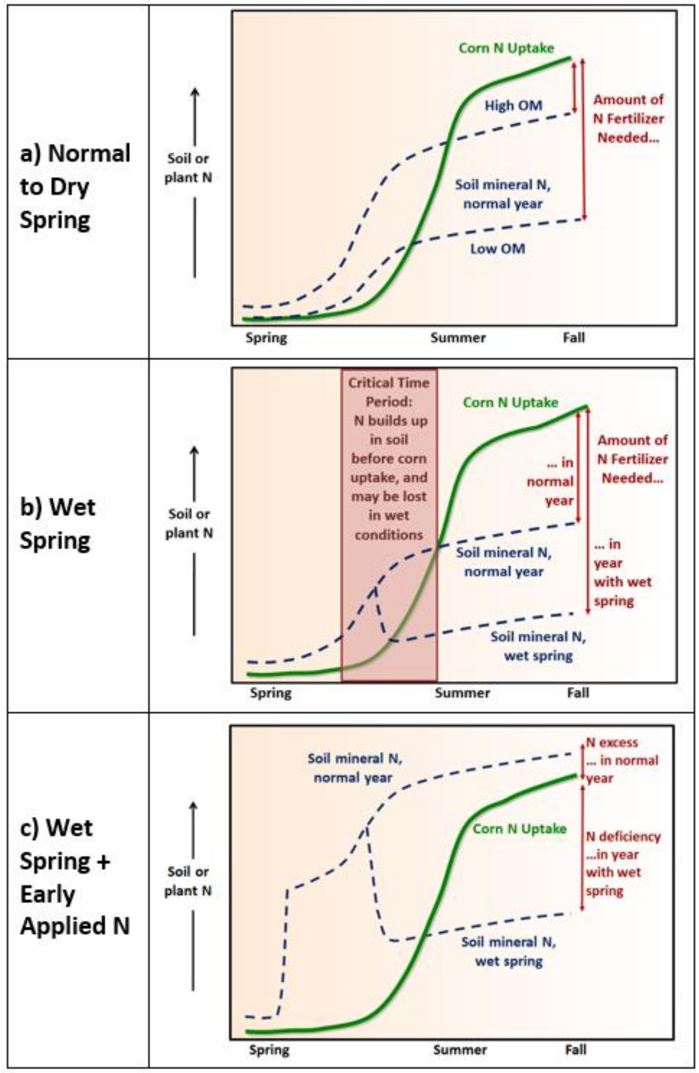
In recent years, several leading US corn producing states have adopted the maximum return to N (MRTN) approach (Sawyer et al., 2006a). It provides relatively generalized recommendations based on extensive multi-year and multi-location field trials, curve-fitting, and economic analyses (Vanotti and Bundy, 1994). The rate with the largest average net return is the MRTN, and the recommendations vary with grain-to-fertilizer price ratio. Adjustments based on realistic yield expectation are sometimes encouraged. The MRTN approach may be an improvement over the mass balance approach, since it is based on more recent and more comprehensive field-response datasets, and by using the more conservative quadratic-plateau curve-fitting technique it may better serve the goal of environmental impact reduction. However, owing to its generalization over large areas and across seasons, it does not address or account for spatial and temporal processes that affect N availability to corn.

A third general approach is the use of various types of soil tests to estimate supplemental crop N fertilizer needs. Magdoff et al., (1984) developed the pre-sidedress nitrate test (PSNT), which can be used to estimate crop N availability near the V6 stage, and allows for adjustment of in-season N applications (Blackmer et al., 1989). It is generally recognized as being successful in identifying N-sufficient sites and in some cases for making N fertilizer rate recommendations when soil nitrate levels are low (Fox et al., 1989; Blackmer et al., 1989; Magdoff et al., 1990; Binford et al., 1992; Klausner et al., 1993). Concerns associated with the test are the extensive sampling requirement (due to generally high variability in soil nitrate; Ma and Dwyer, 1999) during a short time window, and its sensitivity to early-spring and post-sampling weather conditions.

Recent advances in remote and proximal crop sensing are applied for estimation of crop N status during the growing season. Leaf chlorophyll meters (Sawyer et al., 2006b) or multi-band aerial or in-field sensing (Sripada et al., 2006) are used for assessing leaf or canopy N status, typically for the purpose of mid-season N applications. Effective use of the method is best obtained for late applications during the V10 to R1 stages of corn development, which implies the use of high-clearance fertilizer application equipment or overhead fertigation, although earlier sensing may provide guidance on yes/no decisions for supplemental fertilization. The methodology generally requires a reference strip that has received high levels of N fertilization. A concern is that some yield potential may already be lost by the time the N stress can be effectively measured, and that prior to some deficiency being expressed, N need cannot be determined by these methods. Crop sensing appears to be successfully applied for N management on other crops (esp. wheat) and shows promise for use in corn, particularly if combined with complementary modeling approaches.

Temporal Dynamics in Soil N

Multiple N sources may contribute to corn N uptake. Mineralization of SOM can supply a significant fraction, with a typical value of 100 lbs/ac for Midwestern soils (Cassman et al., 2002), and lower estimated values (average of about 70 lbs/ac) for soils in the eastern USA (Ketterings et al., 2003). The difference between the crop requirement (which itself is affected by seasonal developmentally-related environmental stresses) and the soil supply is ideally provided by fertilizer. But the precise estimation of this differential and the associated fertilizer use efficiency remains a challenge due to numerous sources of variability, as shown in the schematic below.



Dinnes et al. (2002) concluded that N dynamics in humid regions are affected by a multitude of factors including tillage, drainage, crop type, soil organic matter content, and weather factors. Others assert that the effects of weather may be larger than other attributes (Lamb et al., 1997; Eghball and Varvel, 1997), as it influences rates of N mineralization, and losses through leaching and denitrification. This is particularly the case in the late spring when relatively large amounts of mineralized N are present in the root-zone in nitrate form prior to crop uptake, and are thus easily lost if excessive wetness occurs. It appears therefore that variation in both space (site-specific-based) and time (primarily as defined by variation in weather conditions) need to be considered in determining N fertilizer rates. The static methods for determining fertilizer rates neglect the annual variations in losses, and thus in yield response to N, and so may result in overfertilization in some years (leading to excess residual soil nitrate) and underfertilization in other years (leading to unattained yield goals).

Although mid- and late-season weather may still affect corn yields, *early*-season events appear to be the strongest determinant for N availability. This is a critical period for N losses and seasonal N availability. If excessive rainfall occurs during this time, significant N losses may occur from leaching or denitrification (with warm soil). Losses are also affected by the accumulation of heat units over the first months of a growing season, which interact with the occurrence of precipitation events, as well as management factors like date-of-planting, early fertilization, manure application, tillage, and rotation, among others. The end result is that the supplemental N fertilizer rate varies greatly depending on management, as well as moisture and temperature conditions during the early season. Sogbedji et al., (2001c) found that years with excessive wetness in late spring showed lower corn yields but higher EONRs than other years, which is paradoxical to the mass-balance concept discussed above. A subsequent modeling effort was performed using LEACHM-N (Hutson and Wagenet, 1992), where soil N dynamics were simulated for the spring period in each of the five growing seasons. Estimated denitrification and leaching losses, and the total environmental losses corroborated the agronomic data, in that higher early-season environmental N losses were estimated for the years with wet early growing seasons and high EONRs, implying a greater need for supplemental fertilizer N at sidedress time in those years.

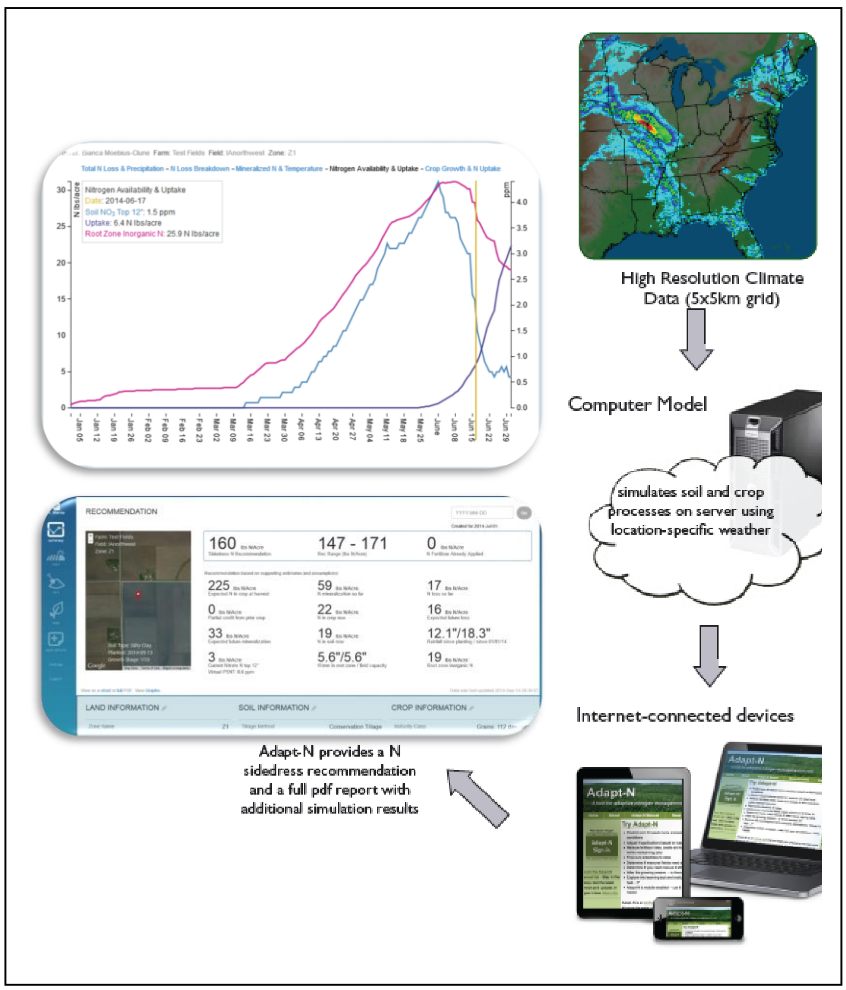
When corn N fertilizer recommendations are based on average or modal crop response using methods like MRTN (Sawyer et al., 2006a), this will generally result in excessive fertilization in years with dry springs, and inadequate fertilization in years with high early season N losses. An analogous process occurs when additional organic N inputs are applied, as is often the case with livestock farms. Organic N (manure, etc.) is commonly applied based on expected N release and corn N uptake during the following season. This results in even higher soil mineral N accumulations in the late spring and a greater potential for loss from excessive soil wetness. Livestock producers then often face the challenge of deciding whether to apply expensive supplemental sidedress N.

The Adapt-N Tool

More precise management of N in corn production in humid regions requires the explicit consideration of several interacting factors, including weather, into the recommendation system. Early-spring N applications cannot be precise, even with slow-release or nitrification-inhibition technology. This is because weather events, affecting dynamic post-planting soil organic N mineralization and loss rates, have not yet occurred at planting, and thus cannot be considered. For the same reasons, early season soil testing can only achieve limited accuracy. Also, tools like the lower-stalk nitrate test are only potentially useful as *ex-post* evaluations of crop N excess and have limited use for predicting N needs in future years.

We developed the web-based *Adapt-N* tool (http://adapt-n.cals.cornell.edu) to provide improved in-season N recommendations based on simulation of soil N dynamics and corn N uptake. In 2010, the tool was first made available for fields in the Northeast USA and then for Iowa as well.

The tool combines three critical components: a user-friendly web interface accessible from all devices with internet access, the Precision Nitrogen Management (PNM) model (Melkonian et al., 2005; Melkonian et al., 2007), and access to near-real time high-resolution climate data. The model implementation infrastructure is shown below.



PNM has two components: LEACHN, the N (and phosphorus) module of LEACHM (Hutson, 2003) and a corn N uptake, growth and yield model (Sinclair and Muchow, 1995). LEACHN is a process-based, one-dimensional model that simulates water and solute transport, and chemical and biological N transformations in the unsaturated soil zone (Hutson, 2003). LEACHN is well suited for simulating soil N processes and has been extensively used and tested (Jabro et al., 1994; Sogbedji et al., 2001a,b; Sogbedji et al., 2006). The rate constants in the equations describing nitrification, denitrification, manure mineralization and plant residue mineralization were calibrated based on multi-year, replicated field experiments (Sogbedji et al., 2000; van Es et al., 2006, among others). Several of these field experiments were conducted on large lysimeter plots located on two contrasting soil textural classes.

The crop component of PNM is based on a corn N uptake, growth and yield model developed by Sinclair and Muchow (1995). The subroutines of the corn N uptake, growth, and yield model incorporate the effects of temperature, solar radiation, water supply and parameters influencing the crop N budget. Both models were re-coded and linked in PYTHON, an interpreted, interactive, object oriented programming language. Flows between different pools of C and N are simulated in each soil segment as well as on the soil surface, on a daily time step.

In order to effectively simulate N processes, the *Adapt-N* tool requires user information. A GPS location (and/or shape file for the new commercial interface) is used to access the high resolution climate data, and relevant soil and crop input data such as soil textural class or soil type, slope, tillage practices, irrigation inputs, organic matter content, timing and amounts of previous N inputs (fertilizer, manure, sod, compost, etc.), rotation, corn crop maturity class, crop density, and tillage and planting dates. These inputs are provided by the user via the interface (screenshots of the new commercial interface shown below). The tool explicitly allows for variable-rate, site-specific management by performing simulations for areas with different soil organic matter contents and soil types in a field (Graham et al., 2011).

High Resolution Climate Data

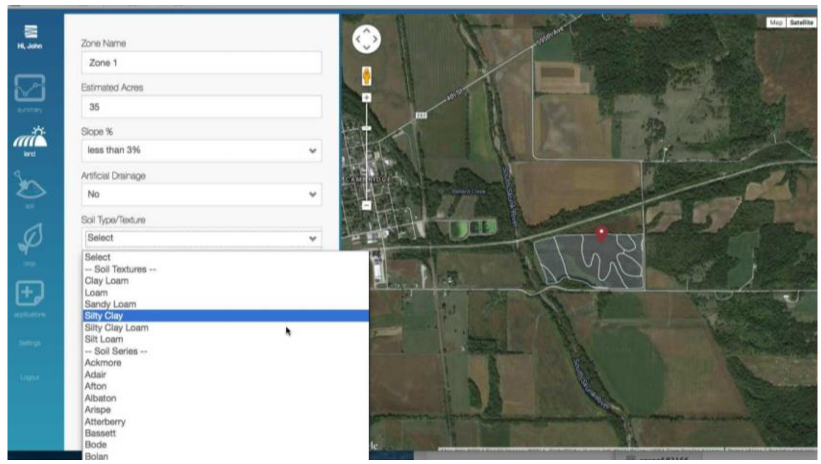
The *Adapt-N* tool accesses the most up-to-date high-resolution climate data as input information by asking the user to provide latitude and longitude information for the field under consideration. The availability of such high-resolution data was deemed essential to the successful adoption of adaptive N management strategies, because spatial patterns of precipitation (especially) and temperature during growing seasons are highly variable at short distances. The Northeast Regional Climate Center (NRCC) has developed methods to produce and distribute high resolution (4 x 4 km gridded) temperature and precipitation data. These data are updated daily on advanced database servers and can be automatically accessed by the *Adapt-N* tool for the location (longitude and latitude) inputted by the user. The high resolution temperature data are being derived from processing routines using the National Oceanic & Atmospheric Administration's (NOAA) Rapid Update Cycle (RUC) weather forecast model and data obtained from ACIS (Belcher and DeGaetano, 2005). The high resolution precipitation data are being developed from data obtained from NOAA's operational Doppler radar and data obtained from ACIS (Ware, 2005; Wilks, 2008).

An additional dimension of the use of high-resolution climate data for adaptive N management is the ability to explicitly incorporate climate change into N management. Future climates are generally predicted to involve more extreme events and periods of excessive wetness and prolonged drought. The *Adapt-N* approach can account for such extremes and incorporate these into N management recommendations as they occur, whereas past methods rely on years of repeated rate response trials before average recommendations can be adjusted, without dealing with the spatial and temporal variability at hand.

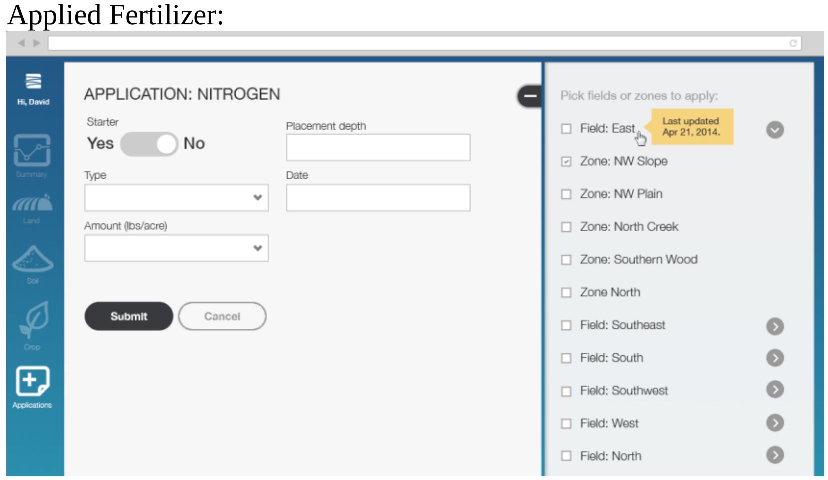
Adapt-N Outputs

The Adapt-N tool provides a multitude of outputs that provide specific N management recommendations, as well as additional simulation results that offer insights into various process components that affect N dynamics. The results page shows an N rate recommendation and the components of the N budget from which it is derived, as well as profile water availability, all of which can be downloaded for record keeping purposes in a pdf format. Graphical simulations are also provided, including the following: cumulative N mineralization; cumulative N uptake by the crop; cumulative total N losses from the root zone (leaching, total, and soon nitrous oxide emissions estimates); nitrate N in the root zone (virtual PSNT); inorganic N in the root zone; growing season daily and cumulative rainfall; post-emergence growing degree days; corn vegetative stage; and growing season daily average temperature. These graphical results allow users to gain additional insights into N dynamics for the growing season at any time. Automated email or text alerts.

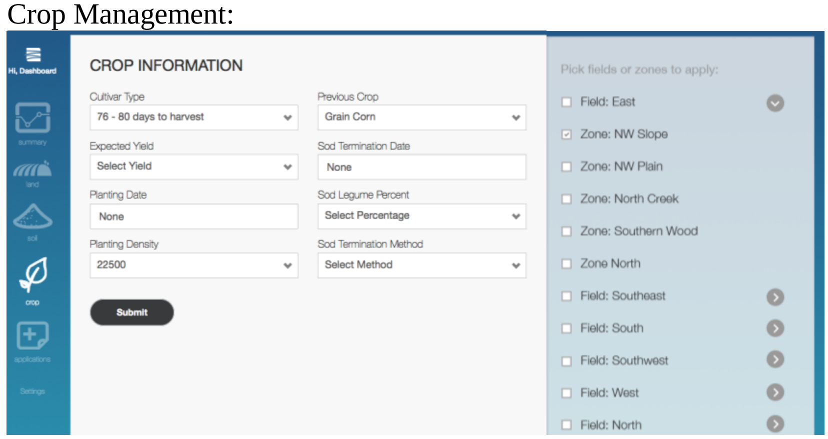
Location**:**



Applied Fertilizer:



Crop Management:



Conclusion

The EONR for any field is not a fixed quantity, but varies as a result of several interacting factors. The most significant among those are early-season weather impacts of precipitation and temperature, because they control N mineralization from organic sources, N gaseous and leaching losses, and crop development. Most currently-used N fertilizer recommendation systems ignore these dynamic processes, and are therefore inherently limited in achieving precision. We promote an adaptive N management approach that incorporates the complex interactive processes that affect soil mineral N availability. The *Adapt-N* tool uses process-based dynamic simulation of soil-crop processes and inputs of high-resolution climate data towards this goal and allows for the incorporation of multiple interacting factors and temporal processes.

Review of Methods

Schedule of Events

Date	Events	Comments
Fall-Winter 2010	Collaborators recruited and informed about project goals. Overview of trial design and timelines. Educational efforts, including on-campus Adapt-N conference	Conference well attended, a number of attendees became involved in trials in latter years of project
Spring-Fall 2011	23 strip trials completed in NY & IA; field day presentations	Dry to normal spring weather
Winter 2011-2012	Data analysis; model improvements including fixing an issue with soybean credit modeling; Educational efforts, including on-campus Adapt-N conference	Conference well attended, a number of attendees became involved in trials in latter years of project
Spring-Fall 2012	61 strip trials completed in NY & IA (one trial in MN) field day presentations	Dry to normal spring weather Summer drought across trial areas affected some outcomes
Winter 2012-2013	Data analysis; model improvements, including soil types and geographic expansion to additional Midwestern states; in-depth training webinar	High webinar attendance, webinar made available online
Spring-Fall 2013	20 strip trials completed in NY & IA, many additional trials (>50) in other states with funding leveraged by this project field day presentations	Very wet spring weather and early N losses caused Adapt-N recommended rates to increase
Winter 2013-2014	Data analysis; model improvements including drainage modeling improvements for wet weather scenarios; in-depth training webinar; commercially available version of Adapt-N introduced	High webinar attendance, webinar made available online

Producer adjustments for accommodating project

Producers needed to be willing to take the additional time for:

- Collecting more quantitative data on management practices and inputs than was their normal practice, in some cases. Others were already keeping adequate records for use with Adapt-N
- Sharing detailed management information with the team
- Learning how to use the Adapt-N tool in some cases (collaborating service providers ran the Adapt-N simulations in most cases)
- Obtain ability to sidedress strips in at least their trial field (most producers we worked with already had sidedress equipment available)
- Obtain ability to sidedress with high clearance equipment in cases where very wet spring weather was occurring during standard sidedress season
- Implementing sidedress rates as strips and quantifying yield by weigh wagon and/or yield monitor for each strip

Project Location

The project research team is based at Cornell University, Ithaca, NY. The Adapt-N tool server was housed at Cornell until April 1, 2014, when it was transferred to Agronomic Technology Corporation where it is housed in a "commercial cloud".

A variety of strip trials were conducted throughout the Northeast and Midwest US in 10 states over the 2011-2013 growing seasons, summarized on the map below (map courtesy of batchgeo.com). Trials in states other than the focus states of NY and IA were largely completed during the 2013 growing season, and were beyond the scope of this project, but leveraged through this project.

Analysis for the data obtained for this project has been completed based on the subset of NY on IA trials that were conducted using similar methods over three years in both states, located on the map below:

Field Trial Implementation

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 (one 2012 trial in Minnesota is included with the Iowa trials) to address three initial questions:

1. Can Adapt-N decrease overall N inputs and losses?
2. Can Adapt-N maintain yield and increase producer profitability?
3. Can results from on-farm data be used to further improve the tool?

Sidedress treatments thus 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), generally applied at sidedress time.

Standard Design for 2 Treatments and 4 Replications. Spatially-balanced* trial set-up with 4 replications. A = Adapt-N recommended rate. G = current Grower N practice.

G1
A1
A2
G2
A3
G3
G4
A4

***Source: H. van Es, C. Gomes, M. Sellmann, C. van Es. 2007. Spatially-Balanced Complete Block Designs for Field Experiments. Geoderma 140:346-352.**
Business card sized summary available at http://fieldcrops.org/extension/Documents/SBCBD_card.pdf

Growers generally implemented field-scale strips (some trials involved smaller plot areas, all >50ft in length, and >4 row widths). Usually the standard design shown at the right was used, with 2 to 7 (usually 4) replications per treatment. An Adapt-N simulation was run for each field just prior to sidedressing to determine the weather-adjusted Adapt-N rate to be implemented. A number of different management systems were included among trials. These included:

- Cash grain, Starter plus side/topdress. All strips received the same starter fertilizer rate. Side/topdress N rates were based on grower-chosen vs Adapt-N recommendations. The majority of trials fit into this category
- Cash grain, where the grower generally applies all N in the fall or before/at planting. Strips consisted of grower rate vs reduced rate (~50-75 lbs/ac less). Adapt-N was used to identify whether an additional side/topdress N application was necessary at sidedress time. If so, this was applied to the strips that had receiving the reduced (Adapt-N) N application rate at planting.
- Silage with manure or previous sod inputs: Fields received no N at planting or a low starter N rate. PSNT tests on grower strips determined N sufficiency, and these strips received N at rates based on standard calculations (in some cases different grower-chosen protocols were used, such as a standard flat sidedress application rate). Adaptive management strips used Adapt-N to estimate additional side/topdress N rates, where necessary.

Soil sampling for each trial generally consisted of: (i) a Cornell Soil Health Assessment, including a basic soil fertility test; and a 12" soil sample for organic matter, ammonium, and nitrate concentrations for the purposes of validating model initiation values, both taken in early spring (ii) a Pre-sidedress nitrate test taken just before sidedressing; (iii) Lower stalk nitrate test; and (iv) End-of-season soil nitrate test.

Yields were measured by weigh wagon, yield monitor, or in some 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 or loss

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 is inherently low for whole-field strip trials, and to answer the above questions, each field trial became a replicate toward the end of assessing averages, risks, and probabilities.

Total N losses to the environment (atmosphere and water) and N leaching losses were simulated by the Adapt-N model 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. Statistical analyses will be performed using ANOVA and regression techniques. More detailed descriptions of each year's methods and results were provided in a series of WCU articles funded by this project and listed in Appendix C below (Moebius-Clune et al., 2012, 2013, and 2014, among others).

Model calibrations

The Adapt-N interface and the PNM model running the simulations were updated each spring with significant improvements derived from the last year's season, using data obtained from on-farm trials and user feedback.

Some selected improvements made over the three project years include:

- Interface:
  - Automatic error correction suggestions
  - Past year simulations, and retrospective simulations to chosen dates
  - Irrigation inputs, water status reporting
  - Text/email alert feature
  - Batch upload capacity
  - Location entry using mapping and shape file upload capacity
  - Improved graphical output
  - Downloadable pdf reports for record keeping
- Model:
  - Adjustment of soybean credit
  - New previous crop options
  - Improvements in soil textural and type representation and defaults
  - Denitrification estimation
  - geographic range for the tool to 25 states, encompassing approximately 95% of the nation's corn growing areas

Until handoff of the tool to Agronomic Technology Corporation, tool updates were emailed to the list, posted to the blog, and also compiled here.

Education and Training

The Adapt-N tool and crop modeling technology were demonstrated to stakeholders through multiple channels: winter meetings, field days, workshops, webinars, written publications, as well as one-on-one support through phone, email, and in-person visits. A List of Presentations (Appendix B) is provided to demonstrate outreach activities and a Appendix C lists publications developed by the project.

What worked, what didn't, why, what would be done differently if starting today?

The goals and objectives for this project were met closely to schedule, and original deliverables were generally exceeded due to the team's ability to use this projects funding in leveraging funding for complementary work. Several challenges were encountered and overcome.

Trial completion issues: While 104 on-farm strip trials were successfully completed during 2011-2013 (in NY and IA), ~70 additional trials were begun, but lost due to a variety of issues. Poor growing conditions (spring flood, tropical storm, drought, excessive pest or weed pressure) made a number of trials unusable each year. On-farm miscommunication (such as a hired person sidedressing without implementing trial rates, laying out the trial in the wrong part of the field, or harvesting without taking yield data), error (such as herbicide damage), and equipment malfunction (such as yield monitoring equipment not working properly, or not successfully storing the data) accounted for the rest of the losses. Such challenges are expected in on-farm research, and the large number of total trials ensured that plenty of usable data. When funds were freed by trial failure, the research team opted to collect more detailed data from other trials, such as N content for total N uptake, implementation of multiple N rates in select trials, or additional trials in the next growing season.

2012 drought: In 2012, severe summer drought caused many yields to be lower than expected, affecting many results even in trials that reached completion. As well as causing significant challenge for growers, the drought also made our trial data harder to interpret than in ideal conditions. Expected yield is a main factor in determining Adapt-N's recommendations. In drought conditions, a lower recommendation than a grower's often does not impact yield, even if it were not enough for the expected yield. A higher recommendation than the grower's may not provide the yield boost it could have in better conditions. Such conditions prevented confident diagnosis of under-recommendation in some cases, for either method, and thus did not bias conclusions. Adapt-N's ability to display the season's weather and simulate later season N dynamics aided in identifying such cases. Ultimately however, late-season impacts such as summer drought, cannot be managed instantaneously, since sidedress N must be applied earlier. Thus decisions must be made with the factors known at that point.

2013 wet spring: The very wet and cold spring conditions of 2013 presented welcome challenges for the team with respect to an opportunity to improve the tool in yet untested conditions. The tool had not been extensively tested for extreme wetness, as we had not experienced such conditions in the testing area over the past years. When extreme conditions occur (and they were truly extreme is some areas – parts of Iowa set new records for spring rainfall), the tool was not be able to predict N needs as well as under less long-term saturated conditions. Thus N losses from continuously saturated fields were under-predicted in several cases, and informed a model calibration effort that was undertaken during the winter of 2013-14.

In season, we provided suggestions to tool users about how to adjust recommendations for possible high losses, based on soil test results, or extreme leaf yellowing, and knowledge of likely rooting depth decreases with prolonged saturation. Also, based on results of spring soil nitrate samples collected by Adapt-N users, we made a June adjustment in the PNM model to better account for denitrification losses.

When 2013 trial data became available after the season, we reviewed the in-season model adjustments and underlying soil type default values, and made additional improvements to the way the model handles extreme wet conditions, including a mechanistically improved input option of drainage class in some soil types, and better modeling of water flow and retention in the soil profile.

A 6-month extension was granted from the original project end date (9/30/2013 to 3/31/2014) for a number of reasons. The financial transfer of funds for the major subcontract on this grant was significantly delayed, resulting in delayed provision of cash matching funds until just before the original end date. Additional time was requested to enable the team to spend the remaining funds wisely and effectively on accomplishing final deliverables, such as the first edition of a downloadable pdf Adapt-N Training Manual that significantly more detail than previously available in the manual tab on our website. This illustrated downloadable pdf document includes basic background, results, and a detailed how-to-section, as well as FAQ's (now available at http://adapt-n.cals.cornell.edu/manual/index.html). Analysis of 2013 harvest data from trials across NY, IA, and additional states through other projects generally starts after mid-October. 2013 was a critical year, in that unlike 2011 and 2012, which had normal to dry springs, 2013 had a very wet spring. Since Adapt-N had not been tested under these conditions, using the remaining funds to facilitate using the information toward critical model adjustments for extremely wet conditions was key. The funding extension furthermore contributed to winter educational meetings and publications of 2013 results (2013 NY and IA trial results are now published here: http://blogs.cornell.edu/whatscroppingup/2014/06/02/adapt-n-responds-to-weather-increases-grower-profits-in-2013-strip-trials/). Modeling work on estimating nitrous oxide emissions and cover crop effects also progressed to near completion, and both will likely be available in the 2015 Adapt-N interface.

It is noted that if the project were started today implementation of replicated multi-rate (>3 rates) trials that enable curve fitting and estimation of an EONR would be made a higher priority due to their usefulness of assessing Adapt-N's closeness to EONR in comparison to Grower-chosen rates. However, it is also noted that the simplicity and flexibility of our field trial design enabled a large number of on-farm comparisons to address the most important question: can the tool do better than current grower practice. Assessing the actual precision of the tool is the next step, which involves more funding per trial, and generally greater trial implementation commitments on the part of the grower.

Innovative nature of project and comparison with existing practices

The Adapt-N approach is a significant leap forward in N management technology compared to current static and less sophisticated methods. It builds on new advances in web technology, cloud computing, fast database access, new high-resolution climate data, and new well-calibrated dynamic simulation computer modeling capability to account for the above-discussed factors that drive N needs for corn. With calibrations and expansion of the tool that was accomplished through this project, Adapt-N is now available to 95% of corn production acres. Due to the new ability to account for temporal and spatial factors driving N needs, corn producers will be able to reduce average per acre N inputs by reducing N inputs in most years without losing yield, while increasing N inputs when needed to maintain yield, increasing per acre net profits, and significantly reducing N loss to the environment.

2014 Adapt-N Marketing

A service area of 28 states was selected, representing approximately 95% of US corn production. Pricing studies were conducted, and a flexible set of license types and pricing options were created to service small growers, large growers, agricultural service providers/agronomists, and enterprises/crop input retailers. The product was marketed at trade shows and through direct sales efforts and networking to identify a core set of customers for the 2014 season. These efforts will continue for future seasons.

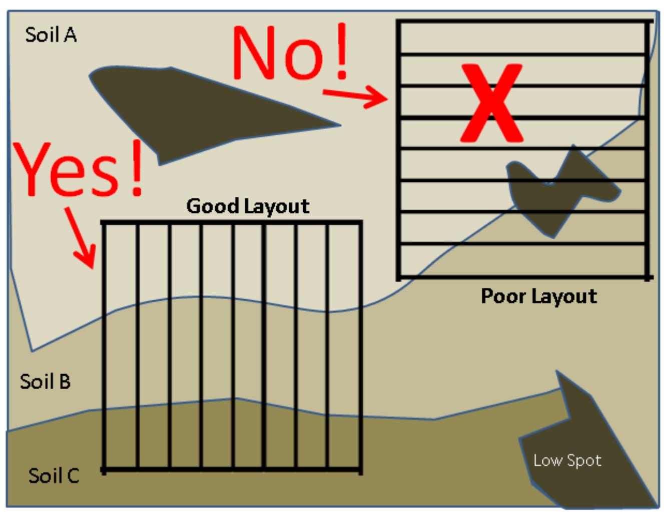
Discussion of Quality Assurance

Strip trials to beta-test Adapt-N were performed on widely distributed commercial and some research farms throughout the Northeast and Midwest US, to test the ability of the tool to provide valid recommendations in any location. Sites were chosen in collaboration with reputable independent crop consultants and extension specialists with experience facilitating on-farm research.

On-farm research provided a high degree of realism in testing the tool. Because research was conducted mostly on commercial farms, we can reasonably infer that trial conditions rep resent "real-life" conditions of tool use among producers at large. A few minor complicating factors that could make trial conditions different from real-life conditions are (i) trial producers had access to close supervision and expert advice from project collaborators, which may increase accuracy of tool use; and (ii) trial producers were self-selecting, so their previous N management practices and knowledge may differ from producers at large. On the other hand, due to the group of trial hosts self-selecting to be largely composed of growers who already practice sidedressing, it is possible that economic and environmental benefits underestimate actual potential benefits. Growers who currently apply all nitrogen prior to planting have the greatest benefits to gain from switching to sidedressing using Adapt-N rates.

Growers in IA and NY implemented field-scale strips with 2 to 7 (usually 4) replications per treatment. In some trials, treatment replicates were reported as composite harvest values due to time and equipment constraints. The standard trial design was provided above. Collaborators were trained on basic spatial heterogeneity impacts, and were guided in laying out trials to incorporate the field variability into the length of the trial strips (shown below).

Soil Health Samples were refrigerated after sampling and shipped promptly. Samples for nitrate analysis were dried before shipping and analysis. In-field variability was managed by composited subsampling of trial fields. Corn yields were measured in-field by weigh wagon, yield monitor, or in a few cases by representative sampling (two 20 ft x 2 row sections per strip). Equipment calibration, sampling and data collection were performed by experienced collaborating consultants, or by trial producers under experienced supervision. Incoming data were compiled and critically evaluated by the Adapt-N Research Team at Cornell, and discrepancies and apparent potential errors were carefully evaluated.



Strip trial design guidelines provided to collaborators. Trial design should incorporate in-field variability. While minimizing extreme variability is the goal, there will still be some variability in every field. The goal is to incorporate this into the design so that treatment comparisons will be minimally affected.

Data analysis and reporting was conducted by the Cornell-based Adapt-N Research Team, with input from project collaborators and peer researchers. Reviewers sought out by the

International Plant Nutrition Institute reviewed the 2013 article in Better Crops. While conclusions about the appropriateness of an Adapt-N recommendation can rarely be made on the basis of a single trial, especially when only two treatments are implemented, and particularly with low replication, the large number of trials in diverse geographic areas of both states over three years provide compelling evidence that the tool is improving producer ability to precisely manage N inputs.

Findings

Trial Results

Agronomic, economic, and environmental outcomes of using Adapt-N recommended rates over grower-chosen rates were evaluated over three years via strip trials comparing Grower-N and Adapt-N treatments. Because of the potential impact of field variability on the results of a single trial, analysis of all 104 trials provides the most meaningful assessment of Adapt-N performance and likelihoods for improving grower profits. Averages as well as specific trials provided insight into effective use of the tool, as well as opportunities for tool improvement.

2011 & 2012 Trials

In the first two years of strip trials in both NY and IA, most locations experienced relatively dry or normal springs, such that most of the early-mineralized soil N remained available to a corn crop, so that growers could reduce N inputs without yield loss. This was demonstrated in 2011-2012 trials (summarized in Moebius-Clune et al., 2013).

Economic and Agronomic Comparison. Profit gains from the use of Adapt-N were considerable. Profits increased in 80% of all NY trials, in 75% of all IA trials, and in 79% of all 84 trials when growers followed Adapt-N recommendations. Profit gains of $27/ac on average ($31/ac in

Average Change due to Adapt-N Use		2011 & 2012					
		NY Corn grain after corn grain (n=30)	NY corn grain after soy or other (n=16)	NY silage (n=10)	All NY trials (n=56)	All IA trials (n=28)	Grand Mean for NY and IA (n=84)
Average (Adapt-N - Grower-N)*	N fertilizer input (lb/ac)	-79	-65	-28	-66	-32	-54
	Simulated N leaching losses (lb/ac)	-9	-15	-3	-10	-1*	-8
	Total simulated N losses (lb/ac)	-63	-46	-29	-52	-2*	-39
	Yield (grain: bu/ac; silage: T/ac)	-3	0	0	-1	0	-1
	Profit ($/ac)	30	44	11	31	20	27

*IA simulated N leaching losses and total simulated N losses are from 2012 trials, only.

Agronomic, economic, and environmental assessment of model performance in 2011-2012. 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.

NY, $20/ac in IA) were primarily attributed to fertilizer cost savings due to lower Adapt-N recommended rates without significant yield losses. Profit gains were also achieved in 3 trials where Adapt-N recommended higher N rates, and consequent yield increases were achieved.

Adapt-N rates resulted in average N input reductions of 66 lbs/ac in NY, 32 lbs/ac in IA, and 54 lbs/ac overall. Yield losses were only 1 bu/ac on average in the 84 trials (a statistically insignificant yield loss), indicating that Adapt-N's reduced N recommendations were generally justified. Yield losses (not always statistically significant), and sometimes profit losses, occurred in several 2012 trials where the user's 'expected yield' input in Adapt-N was an underestimate of the yield achieved with the higher N rate (7 trials in 2012). Adapt-N is a precise tool that already explicitly accounts for the risks of uncertainty and differential losses from over and under-fertilization. If the yield potential of the field is higher than the 'expected yield' provided to the model, Adapt-N is more likely to recommend insufficient N to achieve a higher yield. Therefore, our educational programs have highlighted the importance of good expected yield estimates.

Adapt-N recommended a higher N rate than grower practice in 10% of trials, mostly due to wet spring conditions in particular locations. In 3 of these 8 trials, the higher N rate resulted in a profit increase due to corresponding yield gains, thus justifying the higher N rate. In the 5 instances where a higher Adapt-N rate resulted in profit losses, unpredictable late-season drought conditions resulted in substantial yield reductions below the expected yield in both treatments. Due to insufficient water availability, the crop was unable to make use of the additional N applied in the Adapt-N treatment, thus the additional N fertilizer cost contributed to profit losses. While such individual situations are not preventable, because post-sidedress drought cannot be predicted by tools currently available, assessment of all trials shows that use of the Adapt-N rate provided increased profitability, while decreasing N inputs, in most cases. In 2011, Adapt-N recommendations in corn-soybean rotations were low due to an error in how Adapt-N implemented soybean N crediting. However, savings from N reductions in 80% of these trials were large enough to compensate for the respective yield reductions. This error was corrected, and no further profit losses occurred in 2012 trials where corn followed soybean (Moebius-Clune et al., 2013).

Large N input reductions achieved with the use of Adapt-N can often compensate for small yield losses with the lower N rate. For example in one of the 2012 Iowa trials, Adapt-N recommended 0 lbs N/ac as compared with the conventional N rate of 75 lbs N/ac. Despite a yield reduction (9 bu/ac), the Adapt-N rate did not decrease profit (+$1/ac), due to the large reduction in sidedress fertilizer and operational expense. This trial is one of many that demonstrate that growers currently applying high rates of N can realize significant profit gains by using Adapt-N even if yields are somewhat reduced.

Environmental Benefits. Adapt-N reduced N rates in 90% of 2011-2012 trials, by 54 lbs N/ac on average, resulting in significant reductions in N losses to the environment. By the end of the growing season, simulated N leaching losses decreased by an average of 10 lbs N/ac, and total N losses decreased by an average of 34 lbs N/ac. In 2012, simulated total N losses and particularly leaching losses of sidedress-applied excess nitrogen remained relatively low by December due to widespread dry conditions during the growing season in NY and especially in IA. Further losses of residual excess N occurred over the winter and spring months of 2011-2012 and 2012-2013. In silage trials, the pre-plant application of manure, and consequent lower inorganic fertilizer rates at sidedress time, limits the potential magnitude for reductions in N losses in comparison with non-manured fields, although Adapt-N can nevertheless significantly reduce fertilizer application in these systems.

2013 Trials

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, allowing the team to answer 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?

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 earlier, in May and early June, followed by fairly dry conditions in some of the user area. That early in the season, 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. 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.

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

Agronomic, economic, and environmental 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.

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 (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. 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 late spring rains despite stabilizer. Adapt-N indicated that more N was needed, even though enough would have been available in a normal year. 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 decreased their preplant N applications this spring, and used 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 were made for the 2014 version of Adapt-N, and additional improvements are scheduled to be implemented before the 2015 growing season.

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, when growers plan on sidedressing, can inform much more significant N input reductions in Iowa during more normal or dry years, as demonstrated by our 2011 and 2012 trials. 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.

Field Trial Results 2011-2013 Summary

A summary for all three years of testing provides averages for 104 trials over 3 years of testing in NY and IA. 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% of all 104 trials when growers followed Adapt-N recommendations. Profit gains of $30/ac on average ($37/ac in NY, $17/ac in IA – a conservative estimate as discussed under the 2013 trial results above) were primarily attributed to fertilizer cost savings due to lower Adapt-N recommended rates without significant yield losses. Large profit gains were achieved in instances where Adapt-N recommended higher N rates, and consequent yield increases were achieved. 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. Yields increased by 1 bu/ac on average across the 104 trials, indicating that Adapt-N's reduced N recommendations were generally justified.

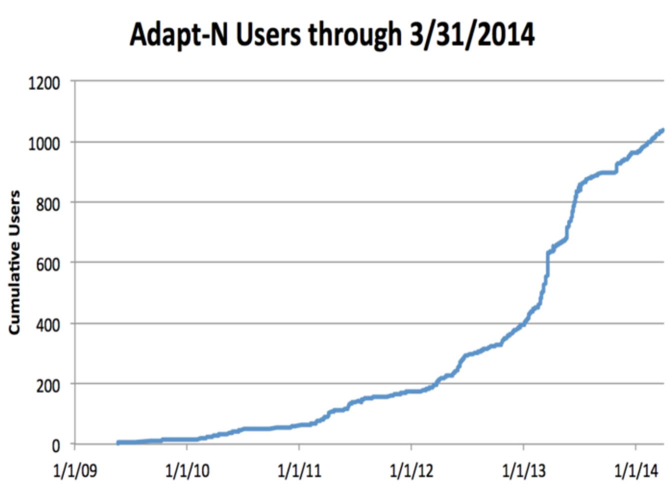
2011-2013 Adapt-N Trial Results					
Average Change due to Adapt-N use (Adapt-N - Grower-N)	By State		By N rate change		Grand Mean
	NY trials n=67	IA trials n=37	N decrease (A<G) n=87	N increase (A>G) n=17	n=104
Total N fertilizer applied (lb/ac)	-52	-29	-60	38	-44
Simulated N leaching loss (lb/ac)*	-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

Agronomic, economic and environmental assessment of model performance 2011-2013. 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. Profit calculations assume $0.50/lb N for all trials, $5.00/bu grain, $50/T silage, and $8/ac operational savings when sidedress was avoided.

Overall, in 77% of NY and IA trials (2011-2013), Adapt-N recommendations increased profits over the grower's chosen rate, by an overall average of $30/ac. In most cases, profits increased due to savings on unnecessary N fertilizer (87/104 trials; average +$23/ac). In other cases, profits increased due to yield increases when Adapt-N diagnosed N deficiency and recommended higher rates (17/104 trials; average +$65/ac). Some cases of profit loss were due to model errors (e.g. the soybean credit issue in 2011), improper tool use by the grower/ag service provider (encountered in all years), and very extreme conditions for which the model needed further calibration (2013). Correcting for these, we estimate a success rate of 80-90% for Adapt-N in comparison to grower practice, and higher average profits. These estimates are particularly appropriate for the average grower whose practices, particularly in the Midwest, according to ag service provider reports and survey results (Appendix A) still entail most N applied before planting.

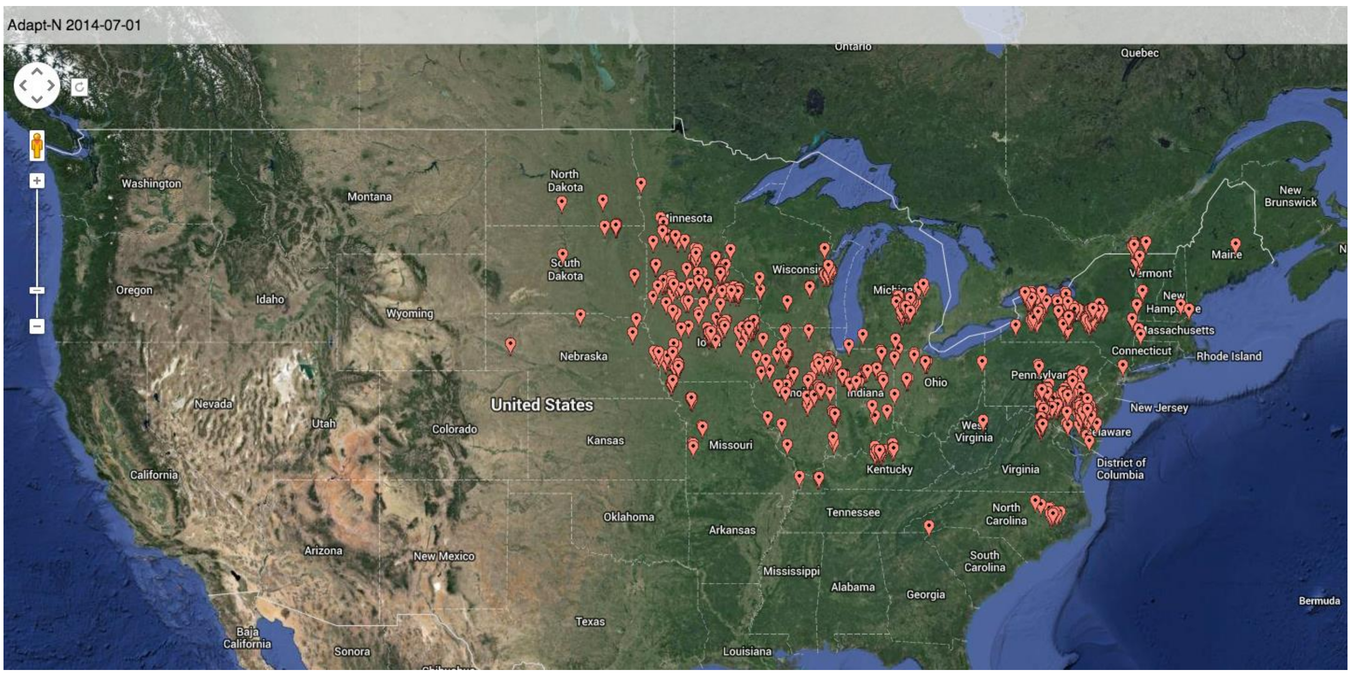
Outreach Results

Adapt-N accounts: The number of Adapt-N accounts in the original, Cornell-based interface increased steadily between 2009 and 2014, as shown at the right. On March 31, 2014, a total of 1,038 users had Adapt-N accounts.



In 2014, the Cornell Adapt-N research team established a public-private partnership with Agronomic Technology Corporation (ATC) to sustain Adapt-N availability to the public by covering increasing cost through annual license fees. ATC launched an improved commercial Adapt-N interface on April 1, 2014. Adapt-N research and testing continues in the new interface, through no-cost accounts provided by ATC for the research team and collaborators.

Adoption of the new interface has been extensive, with users in 19 U.S. states. Modeled fields span 25 states. As of July 2014, users in the new interface are modeling ~130,000 acres across ~2,000 fields in the system for the current season. The map below shows modeled fields in the new interface as of July 2014. Users represent a mix of growers, service providers (agronomists), and several enterprises – larger customers with particular service and infrastructure needs beyond a professional agronomist account. About 35% of commercial users in the new interface are continuing users (who transferred from accounts in the 2011-2013 interface). Commercial users have an average of 1.85 zones per field, but with the highest field having 51 zones; research users have an average of 3.59 zones per field. As of July 2014, about 90% of customers are fully "engaged", having gone through the full process of creating a field, configuring zones, and getting one or more recommendations. This metric has risen steadily over the 2014 season (from ~40% in April).



Primary beneficiaries are Northeast and Midwest corn producers using a variety of management styles and scales (Adapt-N is scale-neutral), but particularly those who already have sidedressing equipment. The project also benefits agricultural service providers including consultants, extension personnel, NRCS and SWCD staff, and researchers, who can use the tool to teach about N dynamics and to provide better N management advice. Society is a secondary beneficiary through improved water quality, reduced greenhouse gas losses, and mitigation of climate change associated with better N management on the most common and environmentally impactful crop in the U.S. Using average N savings of 44 lb/ac and an approximate 100,000 acres using Adapt-N recommendations, 2014 use of the tool can be estimated to have reduced the amount of N applied to these fields by over 4,000,000 pounds, saving producers a total of at least \$2-3M.

<u>Growers Shifting to Sidedressing</u>. Many of our collaborators report that the Adapt-N tool, and associated learning opportunities, are encouraging growers in their area to shift N application toward sidedressing, away from pre-plant application. For example, Iowa growers Nick Meier and Ken Humpal, working with consultant Shannon Gomes, have been shifting their N applications later, while using and testing Adapt-N since 2011 (publication in preparation). New York grower Donn Branton experienced large

losses of early-applied N in 2013, was alerted by Adapt-N to avoid large yield losses, and applied about half his normal amount of preplant fertilizer in 2014, with the rest applied at sidedress time.

Website, Articles, Materials & Press. Since the beginning of the grant period, the Adapt-N Team has published 10 articles and case studies on trial results, both in our departmental extension publication, *What's Cropping Up*, and in *Better Crops* Magazine, as well as an in-depth manual on Adapt-N, among other materials. Two further articles are close to completion. We also know of over 20 articles on Adapt-N in the popular press since 2012, published by third parties with an interest in the tool. See Appendix C for listings of articles, materials and press coverage.

The updated Adapt-N manual, email list, blog, and recordings and slides from several webinar presentations on Adapt-N are available on our website. According to Google Analytics, our website had 8,416 visits from July 2013 to June 2014, down from 11,263 visits the previous year, due to the shift to the commercial tool for the 2014 sidedress season. Total traffic changed mainly at sidedress time, with an average 57 visits per day in May/June 2013, and only 17 visits/day in the same months in 2014, likely due to the introduction of the commercial Adapt-N tool in 2014, and new commercial website (http://www.adapt-n.com/) through which all tool use is now routed.

Conclusions and Recommendations

Need for Dynamic-Adaptive Recommendations

The current institutional N fertilizer recommendation systems do not address underlying uncertainty in the economic optimum N rate. The variability in EONR, however, is not random, but mostly related to factors that can be incorporated into better recommendations as has been discussed in this report. Much can be gained by accounting for the factors that cause the EONR to fluctuate, instead of suggesting across-the-board reductions in N rates or posing strict application limits. The latter will be acceptable in some years, but will create N shortages and yield losses in other (wet) years. For this reason, the use of dynamic-adaptive approaches is critical to the credibility of N recommendation systems and is arguably the best pathway to reducing environmental impacts. This allows for significant reductions in N rates in most years, while accommodating the need for higher rates in some other years. Overall, this can increase NUE and producer profits, while also greatly reducing environmental impacts – in other words, it is a win-win solution with inherent incentives for adoption.

Recommendations for producers and their service providers:

The EONR that a corn crop needs is highly variable from year to year and field to field, and this is heavily influenced by weather, especially by early-season rainfall. The project team recommends that producers and their service providers use the Adapt-N tool to aid in N rate decision making at sidedress time, and as a learning tool to guide more in-depth understanding of N dynamics and management options.

The following recommendations for effective use of the tool will improve profits, N use efficiency, environmental impact of US corn agriculture:

- Plan to apply the majority of corn N fertilizer at sidedress time to avoid early losses after wet early season weather, reduce rates after normal or dry weather, and gain efficiencies and profitability from increased precision. This implies that fall application should be avoided, and early spring applications should be made at modest rates, even when inhibitors are used. Two factors inform this recommendation: (i) sidedress applied N is more efficiently used, because it is not subject to overwinter or spring losses from snow or rain, and (ii) the EONR can be much more precisely estimated in late spring compared to the previous fall or early spring, because seasonal weather and management conditions can be accounted for.

- Obtain access to high-clearance sidedress equipment if feasible. This prevents risks associated with missing the sidedress window due to weather challenges. In dryer regions where some of the crop water is applied through irrigation, overhead equipment allows for N spoon feeding over the growing season.
- Obtain ability to practice variable rate application for increased precision
- Determine corn N needs more precisely by using dynamic simulation modeling. Adjust in-season site-specific (field- or sub-field-tailored) N applications based on weather events, in order to reduce fertilizer rates, costs and losses in the long-term, while maintaining yield
- Determine if manured fields need additional fertilizer N in a given year, or are regularly receiving excess, based on field-specific historic yield data and management, simulated through multiple years of weather
- Use Adapt-N for a N recommendation at or after V6, ideally V6-V12; Adapt-N is not designed to provide starter/preplant N rates, as weather impacts are not yet known at that time
- Ensure that model inputs are accurate and representative of the management unit and soil conditions for which a recommendation is being calculated
    - Take penetrometer measurements to account for compaction and rootzone limitations
    - Consider weather influences that may impact rooting depth (e.g., very high rainfall tends to reduce rooting depth)
    - Base expected yields on farm data for past years (e.g. the fourth highest yield from the last five years)
    - Re-evaluate your crop's expected yield and population density before sidedress based on that season's conditions to date
    - Use Adapt-N for variable rates based on changes across a field in texture, organic matter, and expected yield
    - Set Adapt-N settings to provide text or email alerts of additional N needs for maintaining yield after heavy spring rains
    - This issue is discussed in depth in webinars and training manual (Moebius-Clune et al., 2014) available online.
- Enter sidedress applications into Adapt-N once completed to monitor mid and late-season N status
- Use Adapt-N as a learning tool
    - during the growing season, to understand N dynamics such as mineralization and losses as affected by management, soil, and weather
    - during and/or after the growing season, to understand and evaluate alternative N management options by running “What if I had…?” scenarios using current and past years’ weather data
    - Assess whether N management practices can be improved – are current application timing and rate consistently leading to high losses and/or high excess N availability?
- Assess, by field, whether excess N remains after the growing season, to aid in cover crop choices
- Further guidance on proper use of the Adapt-N tool is provided in the Adapt-N Training Manual, and more up-to-date information on how to use the commercial interface, as well as a list of FAQs is available in the help section for the Adapt-N interface at http://www.adapt-n.com/.

Recommendations for future tool improvements:

- Studies in future years should continue to monitor and quantify the economic and environmental benefits of the tool's use by region and by management.
- Calibration of the tool should be continued for use in new geographic areas, including internationally
- Model capabilities should be expanded to handle a wider range of management practices, such as diverse cover cropping practices and their interactions with tillage practices; N stabilizer use; diverse rotations; additional crops
- Detailed soil health data (aggregate stability, soil protein, etc.) should be incorporated in the model to refine recommendations, and highlight the impacts of diverse and divergent soil health status across farms on N dynamics.
- New advances in quantitative understanding of N dynamics should be incorporated into the model
- Note that, because Adapt-N is based in the 'cloud,' any of the above enhancements will be instantaneously available to all users.

Policy Recommendations

We believe that considerable progress is possible through a win-win approach. In other words, much progress in water quality and reduced greenhouse gas emissions can be made without the need to consider tradeoffs of producer vs. societal costs of N fertilizer use, the use of large compensatory green payments, or stringent regulations. We suggest a three-pronged approach: education, technology development, and policy incentives.

Education: The adoption of improved N management based on dynamic-adaptive recommendations can significantly reduce overall N fertilizer costs without yield losses. The potential savings for a typical farm can easily average tens of thousands of dollars per year as demonstrated in this project. However, most producers and their agricultural service providers (including extension personnel, industry, and independent consultants) are still unfamiliar with these opportunities and require education, promotion of good management approaches, and confidence building with new recommendation systems that may initially appear risky and complicated to them.

It is worthwhile to highlight the potential for mutual reinforcements once educational goals are being met: The availability of more precise dynamic N recommendation systems will move producers to use better application equipment and to implement improved timing of fertilizer application, because they will have an incentive to capitalize on the profit gains from lower N rates in most years. Conventional static recommendation systems do not provide such incentives, because the recommended rates do not change with timing of application.

Technology development: Tools that provide transparent, scientifically validated, dynamic-adaptive N recommendations that appropriately account for localized in-season conditions need continued development, testing, and low-risk adoption incentives on farms. The most promising new approach is the use of dynamic simulation models coupled with climate databases (Adapt-N). Canopy sensing technology also incorporates seasonal and site-specific conditions in late spring, but has limitations in diagnosing deficiencies that are not yet expressed in the crop. Late spring soil nitrate tests also have some predictive capacity for N sufficiency scenarios, and can best be used in conjunction with a modeling tool for higher certainty in recommendations. The use of end-of-season tests (soil or stalk) is of limited value as these tools have low predictive ability for a subsequent growing season with different weather conditions. Standards and benchmarks need to be established if such tools are to be used as policy instruments. New application equipment also needs to be evaluated and further developed.

Policy incentives: Producers can potentially receive multiple incentives for the adoption of dynamic-adaptive N management in corn production: USDA conservation payments (e.g., EQIP, CSP), carbon offset credits from reduced N_2O losses, water quality trading credits, and corporate sustainability initiatives. An effective policy framework is needed that couples management tools with estimates of achieved environmental benefits. In addition, it is noted that

- The use of better N recommendation systems provides considerable economic benefits to corn producers once adopted and will therefore likely be sustained. Incentives should focus on promoting initial testing and adoption (e.g., BMP Challenge and similar approaches).
- Uncertainty around N recommendations can be greatly reduced, but not eliminated. Mid-late season droughts (as experienced in most of the Corn Belt in 2012), hail, pest problems, etc. can still affect optimum N rates, usually via decreased yield potential. A concern with usual corn N research is that it focuses on the *ex-post* optimum fertilizer rate (determined at the end of the growing season) rather than the best recommendation at sidedressing, when fertilizer rates need to be chosen and implemented.
- Fertilizer dealers, consultants and custom applicators often have incentives to recommend high N applications at inappropriate times. Public-private partnerships between industry and other stakeholder groups need to be an important component of the policy framework to incentivize more efficient N use.

Appendices

A. Webinar evaluation and survey – selected results

Webinar Attendees

We held a free 4-hour Adapt-N Training Webinar, "Cloud Computing Technology for Precision Nitrogen Management in Corn," on April 3, 2014, covering the following topics:

- N concerns and Adapt-N results
- Adapt-N inner workings
- How to use Adapt-N effectively
- Complementary technologies (cover crop interseeder; VRT; etc)
- Overview of all-new 2014 interface and model improvements
- Hands-on training on Adapt-N

The workshop was targeted toward agricultural professionals and corn growers. 3.5 CCA Credits in Nutrient Management were offered. The webinar is available here.

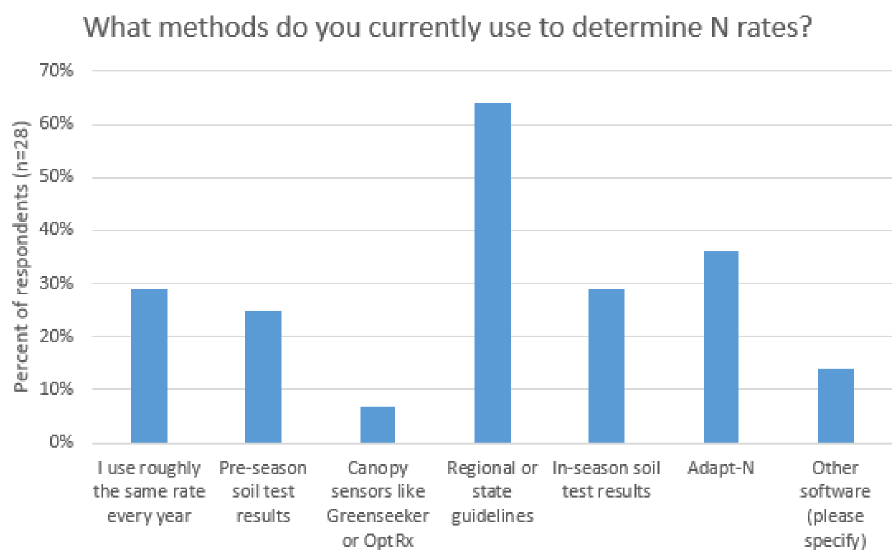
Nine host locations in the Northeast and Midwest advertised and broadcast the webinar for public viewing. 78 people registered for the webinar online, representing 20 US states and 2 foreign countries. 69 of these registered to attend from their personal computer or mobile device. Many more registered with the host location only, or attended a host location as walk-ins that we were unable to count.

The webinar reached a wide audience, many of whom were had little experience with Adapt-N before the webinar. 37% of respondents did not have an Adapt-N account; 46% had never simulated fields in Adapt-N; 59% had never attended an Adapt-N training; and 66% had never implemented Adapt-N recommendations. Registrants had the following occupations (some reported multiple occupations): Grower, 45%; Consultant, 32%; Extension Staff, 4%; NRCS Staff, 4%; Soil and Water Conservation District Staff, 9%; Environmental Non-Profit Staff, 4%; Researcher, 14%; Ag Supply Company Staff, 9%; Other, 8%. Online registrants who responded managed over 48,500 total corn acres, and provided recommendations and services for 5,385,470 acres (5 million of these acres from one large soil testing laboratory).

98% of respondents reported that their understanding of adaptive N management improved during the webinar. All respondents reported that the topics covered were effective, informative, and useful. 97% of respondents found the webinar format effective. After the webinar, 28% of respondents said they now feel comfortable using the Adapt-N tool, and 69% said they feel somewhat comfortable.

Acreage and N practices

Most growers who reported N timing practices (63%) apply none or less than 25% of their N at sidedress. Across all respondents, the most common current method for determining N rates was Regional or State Guidelines (64% of respondents). This was followed by Adapt-N at 39% of respondents. (Multiple methods could be chosen).



After the webinar, many more of the respondents planned to use Adapt-N in the future. A majority of respondents said they would use Adapt-N on at least some fields in 2014 to implement/recommend implementing Adapt-N rates (82%); get a second opinion on an N rate (78%); and/or check on previous year recommendations (65%).
29% of respondents had already changed N management practices/recommendations due to what they learned from Adapt-N, most by later application timing (more sidedress) and slightly lower rates. When asked how management practices have changed due to Adapt-N, responses included "Emphasis on sidedress and less reliance on fall applied N," and "Will be applying more sidedress in the future."
Adapt-N rates were lower than current N rates for 43% of respondents, and about the same for the other 57%. In dry to normal springs, Adapt-N rates differed from current rates by around 15, and up to 50 lb/ac. In wet springs, they differed by around 40, and up to 100 lb/ac.

Comments

In comments before the webinar, registrants seemed generally enthusiastic about the tool:

- "I like getting another opinion on my fields. Last year I did not see a benefit to the additional applied N at sidedress, but I would have applied even more sidedress N if I had not had the recommendation from Adapt-N. (We had an extremely wet May-June)" ---*Grower, IA*
- "Enthused." ---*Grower, IL*
- "It is a useful tool." ---*NRCS Staff person, NY*
- "Adapt-N is a big leap forward and I'm excited about its potential." ---*Extension Staff person & Researcher, NY*
- "Pretty simple to use and great tool for conservation planning with producers. Since moving towards a fee-based service, and being in a public office, I'm hoping that I will still be able to use this tool in the future." ---*SWCD Staff person, IN*

- “…now that I have an iPad I would like to start using it on a couple of farms.” ---*SWCD Staff person, VT*

After the webinar, when asked what they like best about Adapt-N, respondents usually mentioned the new Adapt-N interface and abilities. People also liked that the model “gives the pounds of lost N,”… “It’s the most accurate I have seen so far,” … “I like the discipline required to account for all N sources, I was pleased how well rainfall in the model seemed to correlate with actual rainfall, I feel like it gives me an added tool to best estimate the optimum return on N applications and it can give me an immediate recommendation the day equipment can get into the field. It takes into account a lot of information that is location specific.”

Asked what was best in the workshop, attendees most often commented on appreciating the hands-on demonstration of new interface in comments. Attendees also appreciated being able to attend online; seeing trial results info; education about N dynamics; and the opportunity for CEU credits. One person best liked “The follow up results and the reason why they worked or did not. Where it did not appear to work, you identified a flaw in the system and are working to correct that.”

Barriers to Implementation

Respondents estimated that less than 25% of growers in their area have access to high clearance sidedress equipment, and most rated this as a moderate or serious constraint for both themselves and other growers. Most respondents also rated lack of grower willingness to pay as a moderate or serious constraint to Adapt-N adoption. 77% of respondents don’t currently pay or charge for N recommendations. Among those who do, most charge per acre or per hour. The necessity of a paradigm shift; lack of grower willingness to sidedress; and lack of availability or validation of Adapt-N in their area were also rated by some respondents as serious constraints.

Improving the Webinar

Most comments for webinar improvement suggested better audio quality, and a few mentioned showing live video of the presenter. Other suggestions included additional interactive Q&A, and additional specific hands-on scenario testing topics.

Improving the Model

Respondents are particularly looking for the following improvements to the model:

- integrating cover crops info, N stabilizer info, more tillage options, prescription planting populations
- ability to import zones or as-applied amounts from shp files
- option to integrate soils/zones info with Soil Survey info
- lower price
- better navigation and “tooltips”/descriptions for buttons in the interface
- better description of numbers on Summary page
- Probabilistic yield projections

Many of these have either been addressed, or are on the list of items to address.

B. List of Presentations

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
SSSA webinar	SSSA	van Es and Moebius-Clune	Adaptive Nitrogen Management for Corn, Part I	60	10/5/2010	international access	42
SSSA online seminar series	SSSA	van Es and Moebius-Clune	Adaptive Nitrogen Management for Corn, Part II - Implementation Using Field and Model Tools	60	10/12/2010	international access	100
Dealer Meetings	Cornell Cooperative Extension	Moebius-Clune	Mitigating and Adapting to Climate Change through Adaptive Management of Nitrogen and Soil Health	30	10/19/2010	Clifton Park, NY	40
Dealer Meetings	Cornell Cooperative Extension	Moebius-Clune	Mitigating and Adapting to Climate Change through Adaptive Management of Nitrogen and Soil Health	30	10/20/2010	Utica, NY	54
Dealer Meetings	Cornell Cooperative Extension	Moebius-Clune	Mitigating and Adapting to Climate Change through Adaptive Management of Nitrogen and Soil Health	30	10/21/2010	Batavia, NY	39
Dealer Meetings	Cornell Cooperative Extension	Moebius-Clune	Mitigating and Adapting to Climate Change through Adaptive Management of Nitrogen and Soil Health	30	10/22/2010	Auburn, NY	38
Owasco Lake Ag Forum	American Farmland Trust	Moebius-Clune	Table & posters: Adaptive Nitrogen Management and Soil Health Testing for Lake water quality	180	3/2/2011	Auburn, NY	50
Short Course for credits for his grower friends/customers	Dave Votypka, Springwater Ag Products	Moebius-Clune	Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component	60	3/9/2011	Wayland, NY	40
Adaptive N Management and Soil Health Workshop	van Es Lab Group	Harold van Es, Moebius-Clune, Bob Schindelbeck, Jeff Melkonian		480	3/23/2011	Ithaca, NY	30
Adaptive N Management Workshop	Auburn CCE	Moebius-Clune		120	3/30/2011	Auburn NY	7

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Ag Machinery Conference		Frank Moore	Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component	15	5/3/2011	Waterloo, IA	100
Adapt-N training workshop	Ad-hoc	Harold van Es	Adapt-N training and demo	180	5/10/2011	Nashua, IA	5
The Role of Carbon Offsets in Climate Policy: Theory and Practice	Atkinson Center for a Sustainable Future	Bianca Moebius-Clune	Adaptive Nitrogen Management for Corn	25	5/15/2010	Cornell University, Ithaca, NY	25
Informal meeting	Champlain Valley Agronomics	Bianca Moebius-Clune	na	240	6/9/2011	Peru, NY	3
Willsboro Research Farm Open House and Tour	Willsboro Research Farm	Bianca Moebius-Clune	Integrating Adaptive N Management and Soil Healt for Corn	20	7/7/2011	Willsboro, NY	50
2011 InfoAg Conference		Harold van Es	Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component	120	7/16/2011	Springfield, IL	160
Field Day	Todd Dumond of Dumond Ag Farm	Bianca Moebius-Clune, Harold van Es, Keith Severson	Using Adapt-N to Manage N in Corn	50	8/16/2011	Dumond Ag Farm, Union Springs, NY	40
ENTSC MRBI webinar	NRCS	Bianca Moebius-Clune and Harold van Es	In-Season Adaptive Nitrogen Management Tools for Corn - managing the weather component	90	8/24/2011	online, nationally accessible	125
Field Day	Jennifer Simpson, Orange County Cornell Cooperative Extension	Bianca Moebius-Clune	Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component	60	9/14/2011	197 Pine Hill Road, Westtown, NY	35
National meetings - Adaptive N Management NEERA 1002 committee meeting	SSSA-ASA-CSSA	na	na	10	10/18/2011	San Antonio, TX	15
National meetings - Z session, poster section	SSSA-ASA-CSSA	Harold van Es, Jeff Melkonian, Bianca Moebius-Clune	The Adapt-N Tool Facilitates Both Adaption and Mitigating of Climate Change	150	10/18/2011	San Antonio, TX	20

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
National meetings - poster session	SSSA-ASA-CSSA	Bianca Moebius-Clune	Incorporating Local Weather and Soil Variation In Adaptive Nitrogen Management: Validating the Adapt-N Tool for On-Farm Sidedress Recommendations for Corn	150	10/19/2011	San Antonio, TX	12
Inservice Training for extension specialists	Cornell Cooperative Extension	Harold van Es	Adapt-N - what did we learn from our strip trials this year?	90	11/13/2011	Ithaca, NY	20
Extension-Industry Conference	North Central Extension Industry Conference	Harold van Es	*Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component*	60	11/16/2011	DesMoines, IA	200
Field Crops Dealer Meetings	Cornell Cooperative Extension	Bianca Moebius-Clune, Harold van Es	*Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component*	45	11/21/2011	Geneva, NY	133
CCA Training	Northeast Region CCA	Harold van Es	*Adaptive Nitrogen Management Using Adapt-N - Incorporating the Weather Component*	45	11/29/2011	Syracuse, NY	120
Interactive workshop to look at Adapt-N trial data	Cooperative Extension of Suffolk County	Bianca Moebius-Clune and Sandy Menasha	Adapt-N: A New Tool for Accurate Nitrogen Management in Corn?	180	12/20/2011	Riverhead, NY	6
New England Fruit and Vegetable Conference	Cooperative Extension Systems of CT, MA, ME, NH, NY, RI, VT & the New England and MA Veg, Berry and Fruit Grower's Associations	Bianca Moebius-Clune	Adapt-N: A New Nitrogen Management Tool for Sweet Corn?	30	12/15/2011	Manchester, NH	80
New England Region CCA Training	University of Maine Extension and other partners for New England Region CCA	Bianca Moebius-Clune	Informal presentation/demo and conversation during breaks and meals on Adapt-N tool	180	1/25-26/2012	Portsmouth, NH	10
Soil Health Management Tools seminar	Sustainable Agriculture Initiative Platform	Bianca Moebius-Clune	Soil and Soil Health (with a section on Adapt-N, and discussion of it during networking time after seminar)	30	2/15/2012	Winter Park, FL	8
Iowa Soybean Association On-Farm Network® 2012 Conference	Iowa Soybean Association	Jeff Melkonian	Adapt-N: An On-Line Nitrogen Management Tool. Background/Results from 2011 Strip Trials	60	2/16/2012	Ames, IA	150

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Cedar Basin Client Meeting	Cedar Basin Crop Consulting	Shannon Gomes	Adapt-N	30	2/23/2012		19
2012 Focus on Precision	National Association of Independent Crop Consultants	Harold van Es, Shannon Gomes, Hal Tucker, Frank Moore	The Adapt-N Tool: The Components that Drive the Engine; What We Have Learned from the Adapt-N Tool	90	2/28/2012	Madison, WI	80
Capital District Small Fruit & Vegetable Growers Winter Meeting	Cornell University Cooperative Extension Capital District Vegetable & Small Fruit Program	Bianca Moebius-Clune	Adapt-N: A New Nitrogen Management Tool for Sweet Corn?	40	2/29/2012	Albany, NY	85
Annual meeting of Western NY Crop Management Association Membership	WNYCMA	Bianca Moebius-Clune	Adaptive Nitrogen Management in Corn using the Adapt-N Tool	60	2/29/2012	Varysburg, NY	150
Client Meeting	Tucker Consulting	Sara Linn	Adapt-N: an on-line tool for precision corn N management	30	3/14/2012	Storm Lake, IA	15
March on-campus in-depth workshop	Adapt-N Team	Bianca Moebius-Clune, Jeff Melkonian, Harold van Es	Adaptive Nitrogen Management in Corn using the Adapt-N Tool	480	3/19/2012	Ithaca, NY	31
Northern NY webinar Adapt-N training broadcast to two locations	CCE Lewis County	Bianca Moebius-Clune	Adaptive Nitrogen Management in Corn using the Adapt-N Tool	180	4/4/2012	Lewis County Extension office and Miner Institute	10
Vermont and Northern NY webinar on Adapt-N training broadcast to two locations	University of Vermont Extension	Bianca Moebius-Clune	Adaptive Nitrogen Management in Corn using the Adapt-N Tool	240	4/5/2012	Middlebury, VT Extension office and online	15
Willsboro Field Day	Willsboro Research Farm and Cornell Cooperative Extension	Bianca Moebius-Clune	Soil Health and Adapt-N	30	7/10/2012	Willsboro, NY	25
Aurora field day	Musgrave Research Farm	Moebius-Clune	Precision Nitrogen Management with Adapt-N	120	7/18/2012	Aurora NY	100

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Empire State Farm Days		Mary McKellar	informal booth featuring various tools and info including Adapt-N	300	8/7-9/2012	Rodman Lott & Son Farms in Seneca Falls, NY	100
Nitrogen Use Efficiency Conference	North Dakota State University	Hal Tucker	Adapt-N: A tool for Adaptive Nitrogen Management in Corn	50	8/7-8/8/2012	Fargo, ND	70
UVM Extension Crops & Soils Field Day	UVM extension	Bianca Moebius-Clune	Adapt-N, An Online Tool for Precise Nitrogen Management in Corn Production Accounting for Weather	130	8/9/2012	Borderview Farm, Alburgh, VT	150
Crops Tour at Dumonds	NY Corn and Soybean Growers' Association	Ken Ferrie, Harold van Es, Bob Schindelbeck, Keith Severson	Adapt-N – NY successes of an online tool incorporating weather in precise corn nitrogen management	120	8/14/2012	Dumond Farm, Union Springs, NY	230
Seed Company Field Day	Prairie Hybrid Seed Company	Michael McNeill	Balancing Minerals for Optimum Corn Production	45	8/30/2012	Deer Grove, IL	385
Fertilizer Dealer Field Day	FHR Farms	Michael McNeill	Optimum Nutrient Management	30	9/3/2012	Stewartville, MN	65
Fertilizer Dealer Field Day	FHR Farms	Michael McNeill	Optimum Nutrient Management	35	9/4/2012	Osage, IA	80
Fertilizer Dealer Field Day	BRT Ag and Turf	Michael McNeill	Optimum Nutrient Management	45	9/5/2012	Stockton, IA	105
Tools and Measurements workshop	EDF	Harold van Es	Adapt-N: A Tool for Precision Nitrogen Management in Corn Production	50	9/24/2012	Washington DC	
Nitrogen Management Technology Symposium	USDA Partnership Management Team (ARS – NIFA – NRCS)	Harold van Es	Adapt-N: A Tool for Precision Nitrogen Management in Corn Production	30	9/25/2012	Washington DC	
ASA-CSSA-SSSA Annual Meetings	ASA-CSSA-SSSA	Harold van Es	Building Uncertainty Into N Recommendations for Maize: Addressing Insurance Applications	15	10/22/2012	Cincinnati, OH	70
ASA-CSSA-SSSA Annual Meetings	ASA-CSSA-SSSA	Bianca Moebius-Clune	Adapt-N On-Line Tool for Site-Specific and Weather-Adjusted Nitrogen Management in Maize: On-Farm Strip Trial Results	15	10/23/2012	Cincinnati, OH	50
ASA-CSSA-SSSA Annual Meetings	ASA-CSSA-SSSA	Harold van Es	Use of Computer Simulation Models and Databases for Nitrogen Recommendations for Corn	20	10/23/2012	Cincinnati, OH	100

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Cayuga Community College	Sustainable Agriculture Symposium	Keith Severson	Adapt-N table display		11/1/2012	Auburn, NY	25
CCE Inservice Training	Cornell University Cooperative Extension	Bianca Moebius-Clune	Adapt-N online tool for precise, weather-based N recommendations in corn: 2011 and 2012 results, and new developments	40	11/13/2012	Cornell University, Ithaca, NY	20
Northeast Regional CCA Conference	American Society of Agronomy and others	Bianca Moebius-Clune	Incorporating weather and management factors into nitrogen management on corn using the Adapt-N tool	50	11/27/2012	Syracuse, NY	72
Mississippi River Nutrient Dialogues Planning Workshop	U.S. Water Alliance	Shannon Gomes	informal networking discussions, no presentation	60	11/28-30/2012	Racine, WI	30
Field Crops Dealer Meetings	Departments of: Crop and Soil Sciences, Animal Science, Plant Pathology and Plant-microbe Biology, & Cornell Cooperative Extension	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn	35	12/12/2012	Syracuse, NY and other locations via webinar	100
Indiana CCA Conference	NAICC	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn	60	12/18-19/2012	IN	200
Long Island Ag Forum	Cornell Cooperative Extension of Suffolk County	Bianca Moebius-Clune	Adapt-N: Incorporating Weather Information Into Sweet Corn Nitrogen Management	30	1/11/2013	Riverhead, NY	100
Long Island Ag Forum	Cornell Cooperative Extension of Suffolk County	Bianca Moebius-Clune	Adapt-N: Hands-On Training	45	1/11/2013	Riverhead, NY	7
Corn Congress	Northwest NY Dairy, Livestock and Field Crops Team, CCE, Pro Dairy	Jonathan Comstock	Climate Change Adaptation and Mitigation	15	1/16-17/2013	Batavia, NY	683
PA Educational Agronomic Society Annual Meeting	PA Educational Agronomic Society	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn	50	1/16/2013	State College, PA	150

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
PA Educational Agronomic Society Annual Meeting	PA Educational Agronomic Society	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn - Demonstration of the Adapt-N tool	50	1/16/2013	State College, PA	60
New England CCA Conference	University of Maine Extension and other partners for New England Region CCA	Bianca Moebius-Clune, John Jemison, Tom Morris, Erin Roche	Adaptive Nitrogen Management Workshop	210	1/30/2013	Portsmouth, NH	30
Midwest regional NAICC meeting	NAICC	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn	45	2/19-20/2013	Des Moines, IA	70
Triple Bottom Line Grower Group Meeting	Vela Environmental	Harold van Es	Adapt-N Tool for Precision Nitrogen Management in Corn	60	2/21/2013	Kansas	8
NNY ADP stakeholder meeting	NNY ADP	Bianca Moebius-Clune	Update on Adapt-N: A Tool for Precision Nitrogen Management in Corn	15	2/26/2013	Watertown, NY	20
NNY ADP stakeholder meeting	NNY ADP	Bianca Moebius-Clune	Update on Adapt-N: A Tool for Precision Nitrogen Management in Corn	15	3/8/2013	Chazy, NY	25
Presentations to Coop participants		Troy Jenkins				IN	
Field Day		Michael McNeill	Using the Adapt-N Tool			Riverside, IA	110
Field Day		Michael McNeill	Using the Adapt-N Tool			Stewartville, MN	95
Crop Management Seminars	Pioneer	Jake Vossenkemper	Crop Management Seminars		Feb and March 2013	Multiple locations in Illinois	500
Intensive Adapt-N Training Webinar	Adapt-N Team	Bianca Moebius-Clune, Harold van Es	Cornell Adapt-N Intensive Workshop by Webinar: Precision Nitrogen Management in Corn using the Adapt-N Tool	240	3/21/2013	Webinar Broadcast to Personal Computers and Multiple Host Locations in Northeast and Midwest	
Intensive Adapt-N Training Webinar host site	Shannon Gomes, MGT Envirotec	"	"			Borlaug Learning Center at Iowa State Research Farm, 3327 290th Street, Nashua, IA 50658	21
Intensive Adapt-N Training Webinar host site	Hal Tucker, MGT Envirotec	"	"			Iowa Central Community College, 916 N Russel Street, Storm Lake, IA	22

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Intensive Adapt-N Training Webinar host site	Michael McNeil, MGT Envirotec	"	"			Iowa Lakes Community College, 2111 Highway 169 N., Room 16, Algona, IA 50511	20
Intensive Adapt-N Training Webinar host site	Jim Cambarato, Purdue University	"	"			Beck Agricultural Center, Purdue University, 4540 U.S. 52 West. West Lafayette, IN 47906	
Intensive Adapt-N Training Webinar host site	Scott Gabbard, AgNR Educator, Purdue Extension, Shelby County	"	"			Shelby County Extension, IN	3
Intensive Adapt-N Training Webinar host site	Crop-Tech Consulting, Inc.	"	"			Crop-Tech Consulting, Inc., 9051 Bucks Road, Heyworth, IL 61745	20
Intensive Adapt-N Training Webinar host site	CCE Suffolk county	"	"			423 Griffing Ave, Riverhead, NY 11901	2
Intensive Adapt-N Training Webinar host site	Clinton County CCE	"	"			Clinton CCE, 6064 State Route 22 Plattsburgh NY 12901	7
Intensive Adapt-N Training Webinar host site	Cornell Hudson Valley Lab	"	"			Cornell Hudson Valley Lab 3357 US Rt. 9W, Highland, NY 12528	4
Intensive Adapt-N Training Webinar host site	Erie County Soil & Water and USDA-NRCS office	"	"			SWCD, 50 Commerce Way, East Aurora, NY 14052	
Intensive Adapt-N Training Webinar host site	Cayuga CCE	"	"			248 Grant Ave in Auburn, NY	8
Intensive Adapt-N Training Webinar host site	CCE Rennselaer County	"	"			61 State Street, Troy, NY 12180	4
Intensive Adapt-N Training Webinar host site	CCE Oneida County	"	"			Oriskany, NY	5

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Intensive Adapt-N Training Webinar host site	Agricultural Consulting Services	"	"			Ithaca, NY	3
Intensive Adapt-N Training Webinar host site	Stuart & John's Sugarhouse, UNH extension Cheshire County	"	"			Stuart & John's Sugarhouse, 31 NH Rte. 63, Westmoreland, NH	7
Intensive Adapt-N Training Webinar host site	UVM Middlebury Extension	"	"			23 Pond Ln, Middlebury, VT	4
Intensive Adapt-N Training Webinar host site	UVM St Johnsbury Extension	"	"			374 Emerson Falls Road, St. Johnsbury, VT	3
Intensive Adapt-N Training Webinar host site	UVM St Albans Extension	"	"			Conference Room at Church of the Rock, 1091 Fairfax Road St. Albans, VT 05478	12
Intensive Adapt-N Training Webinar host site	various organizations/individuals	"	"			Webinar viewed on personal computer	96
CSS Seminar	Department of Crop and Soil Sciences	Bianca Moebius-Clune	Adapt-N On-Line Tool for Site-Specific and Weather-Adjusted Nitrogen Management in Corn: On-farm Strip Trial Results	50	4/18/2013	Ithaca, NY	40
Beck's Hybrids large grower meeting and workshop	Beck's Hybrids	Harold van Es	Adapt-N, a tool for precision N management in corn systems	120	4/30/2013	Atlanta, IN	30
Informal meeting	G&K Concepts and others	Harold van Es			7/16/2013	Fort Wayne, IN and region	10
InfoAg Conference		Harold van Es	Precision N Management with Adapt-N: Updates and Results	50	7/16/2013	Springfield, IL	250
InfoAg Conference		Harold van Es	Workshop: Adapt-N	50	7/17/2013	Springfield, IL	30

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
Musgrave Research Farm Field Day	Cornell College of Ag and Life Sciences and Cooperative Extension	Bianca Moebius-Clune, Bob Schindelbeck, Dan Moebius-Clune, Matt Ryan, Paul Salon	Soil Health, Adapt-N and Cover Crop Interseeding for Adaptation and Resilience	25	7/18/2013	Musgrave Research Farm	100
Nitrogen Use Efficiency Conference	Soil Science Society of America (SSSA)	Harold van Es	Precision Nitrogen Management In Corn Production Using Models and Weather Data	120	8/14/2013	Kansas City, MO	150
Informal meeting	La Coop Federee	Harold van Es	Adapt-N, a tool for precision N management	30	9/5/2013	St Hyacinth, QC	4
Northeast Iowa farmer field day	Cedar Basin Crop Consulting	Harold van Es	Adapt-N, a tool for precision N management	30	9/18/2013	LaPorte, IA	30
Departmental seminar	Iowa State University-Dept of Agronomy	Harold van Es	Adapt-N: Employing Cloud Computing Technology for Corn Nitrogen Management	60	9/19/2013	Ames, IA	60
Conference on Preserving Water Quality in a Changing Climate	Cornell Cooperative Extension Onondaga County, NY	Harold van Es	Agriculture and Climate Change: Adaptation and Mitigation	30	9/26/2013	Skaneateles, NY	25
NY Interagency Soil Health Initiative	NY NRCS	Bianca Moebius-Clune	NY-CIG Project: Soil Health Training and Quantifying Benefits for Precision N Management	30	10/18/2013	Morrisville State College, Morrisville, NY	20
Tile Drainage Conference	Miner Institute	Bianca Moebius-Clune	Adapt-N for Site-Specific and Weather-Adjusted Nitrogen Management in Corn: A Tool to Minimize Nitrogen Leaching to Tile Drainage Water … and More	45	10/24/2013	Miner Institute, Chazy, NY	90
ASA-CSSA-SSSA Annual Meetings	ASA-CSSA-SSSA	Bianca Moebius-Clune	Site-Specific and Weather-Adjusted Nitrogen Management in Maize: Adapt-N Increased Grower Profits and Decreased Nitrogen Inputs in Two Seasons of On-Farm Strip Trials	120	11/4/2013	Tampa, FL	50
ASA-CSSA-SSSA Annual Meetings, Symposium on adaptive N management and optical sensor	ASA-CSSA-SSSA	Harold van Es	Can Models and Weather Databases Enhance the Use of Sensor-Based Nitrogen Management?	20	11/5 & 11/6/2013	Tampa, FL	90

Group or Event	Sponsoring Agent	Speaker	Title or Subject	Duration (min)	Date	Location	# in Audience
NC State University, Murphy Brown meeting	NCSU	Harold van Es	Adapt-N, a cloud based tool for precison nitrogen management	60	12/5/2013	Raleigh, NC	11
Indiana Adapt-N Project Meeting	Indiana State Department of Ag	Bianca Moebius-Clune	Adapt-N: An Overview and Update. Employing Cloud Computing Technology for Corn Nitrogen Management	90	2/17/2014	Indianapolis, IN	7
Focus On Precision Conference	National Association of Independent Crop Consultants	Bianca Moebius-Clune	Adapt-N: An Overview and Update. Employing Cloud Computing Technology for Corn Nitrogen Management	60	2/18/2014	Minneapolis, MN	100
Crop-Tech	Crop-Tech Consulting and IPM Institute of America	Bianca Moebius-Clune	Overview of Adapt-N and New Changes: Employing Cloud Computing Technology for Corn Nitrogen Management	60	3/11/2014	Heyworth, IL	50
MD Adapt-N Data Discussion	IPM-Institute/Agflex	Bianca Moebius-Clune and Harold van Es	Overview of Adapt-N MD trial data and New Changes coming for Adapt-N	90	3/21/2014	webinar	6
Adapt-N Training Webinar	Cornell University	Bianca Moebius-Clune, Harold van Es, Greg Levow	Adapt-N Training Webinar: Cloud Computing Technology for Precision Nitrogen Management in Corn	300	4/3/2014	Broadcast out of Ithaca, NY	135
Madison County Field Crops Meeting	Cornell Cooperative Extension of Madison County	Bianca Moebius-Clune	Weather Challenges and how to meet them using better Nitrogen and Soil Health Management	60	4/4/2014	Cazenovia, NY	80
Number of presentations:	116		**Hours of material presented:**	127		**Total audience reached:**	7599

C. Adapt-N Publications

Articles

Date	Publication	Title and Link
12/1/2011	What's Cropping Up?	A Case Study on the Use of Adapt-N
2/1/2012	What's Cropping Up?	Donald & Sons Farm Sees Money-Saving Potential in Adapt-N Tool for Corn N Rate Recommendations
3/1/2012	What's Cropping Up?	Adapt-N Increased Grower Profits and Decreased Environmental N Losses in 2011 Strip Trials
5/1/2012	What's Cropping Up?	Corn Stalk Nitrate Test: Low Accuracy in 2011 Strip Trials
5/1/2013	What's Cropping Up?	Adapt-N Proves Economic and Environmental Benefits in Two Years of Strip-Trial Testing in New York and Iowa
5/1/2013	What's Cropping Up?	Adapt-N Increased Grower Profits and Decreased Nitrogen Inputs in 2012 Strip Trials
5/1/2013	What's Cropping Up?	Case Study – Part II: Central NY Farm Applies Adapt-N Rates on Whole Farm, Saves Money and Reduces Environmental Impact
9/1/2013	Better Crops	Adapt-N uses Models and Weather Data to Improve Nitrogen Management for Corn
6/1/2014	What's Cropping Up?	Adapt-N Responds to Weather, Increases Grower Profits in 2013 Strip Trials
6/1/2014	What's Cropping Up?	New York Farm Delves Deeper with Adapt-N
coming soon	What's Cropping Up?	additional case study of IA producers, and summary of all three years of data.

Additional Online Materials

Date	Type of Material	Link	Description
2/1/2012	Webinar	Adapt-N: A New Nitrogen Management Tool for Sweet Corn?	Webinar of presentation to audience at Cornell Cooperative Extension Capital Distirct Vegetable and Small Fruit Program's 2012 Annual Winter Meeting in Albany, NY on Feb 29, 2012. Includes overview of Adapt-N tool and preliminary 2011 results. Workshop materials
3/1/2012	Workshop powerpoint	A1: Overview of N dynamics, environmental issues and available tools	
3/1/2012	Workshop powerpoint	A2: The Adapt-N tool: its inner workings and upcoming changes	
3/1/2012	Workshop powerpoint	A3: Adapt-N 2011 on-farm trial results	

Date	Type of Material	Link	Description
3/1/2012	Workshop powerpoint	A4: Adapt-N guided hands-on exercise	
4/1/2012	Webinar	Basic training on how to use Adapt-N	A recorded training session provided to audience at Middlebury, VT extension office, with support from UVM on April 5, 2012
6/1/2012	Brochure	Adapt-N Brochure	Color Brochure for Adapt-N created in 2012 that was made available at most field days and other events in print, and was also made available as a pdf online
3/1/2013	Webinar	3/21/2013 National Training Webinar on Adapt-N	Broadcast from Ithaca, NY to 18 host sites and personal computers, reaching over 200 people
1/1/2014	Manual	Adapt-N Manual	We published an updated, professionally laid out, pdf version of the Adapt-N manual on our website in January 2014
4/1/2014	Webinar	4/3/2014 National Training Webinar on Adapt-N	Broadcast from Ithaca, NY to 9 host sites and personal computers, reaching well over 130 people
ongoing	Website	Adapt-N commercial version website	ATC developed a new website for the sale of licenses for the commercial version of the tool that will sustain the tool's availability and provide customer service beyond the means of grant funded activities
ongoing	Website	Cornell Team's Adapt-N website	We have updated information on our website throughout the project period
ongoing	E-list and Blog	Adapt-N email list and blog	Maintained by the Adapt-N Team at Cornell University, this list is set up as an announcement list. It allows us to email users updates about the tool, trial results, added features, or publications. Relevant emails are also published on our blog (http://blogs.cornell.edu/adaptn/). This list will continue to be available to subscribers of the new Adapt-N by ATC, but ATC has take on communications that are more commercial in nature.

Selected Third Party Media Coverage

Date	Publication	Title and Link
2/24/2012	No-Till Farmer	Strip Tiller Uses New Nitrogen Management Tool
3/22/2012	Iowa Farmer Today	Data driven
5/3/2012	Successful Farming Magazine	Adapt-N for Efficiency
9/26/2012	Corn & Soybean Digest	Space Age Sidedressing Ties N Dose to Weather | New Online Tool Brings New Accuracy Level to N Prescriptions
12/?/2012	AgProfessional Magazine	Top 10 New Products of 2012 Selected
12/17/2012	HyMark Blog post	HyMark High Spots on Adapt-N
1/7/2013	AgProfessional Magazine	Today is deadline to vote for 2012 Top Product
2/6/2013	AgProfessional Magazine	2012 Top Product of the Year Chosen
3/21/2013	Rowbot blog	Cornell's Adapt-N: A tool for determining corn's nitrogren needs during the season
4/?/2013	Fine Tune Nitrogen Website Launched by Third Party Supporter 'Vela Environmental'	Fine Tune Nitrogen - Using the Adapt-N Tool to save farmers money and meet emerging supply chain needs
5/13/2013	Cornell Chronicle	New tool helps farmers nip nitrogen losses
5/14/2013	Empire State Farming Blog	Software Tool That Saves Farmers Money Has its Roots in Northern New York, Cornell
5/15/2013	New York Ag Connection	Adapt-N Award-Winning Farm Tool has NNY Roots
5/15/2013	Corn & Soybean Digest	Nitrogen Testing Tool Increases Corn Profits
5/30/2013	Farming Magazine Online	
5/31/2013	Farm Aid Farmer Resource Network	Web-Based Farmer Assistance Tools
6/5/2013	Empire State Farmer	
6/10/2013	Farm and Dairy	How much nitrogen does your field really need?
7/26/2013	Corn and Soybean Digest	Adapt-N tool calculates for weather extremes and soils
9/28/2013	New York Farm Viability Institute Newsroom	New management tool improves farm profitability and protects the environment
9/?/2013	Larry Reichenberger, The Furrow Magazine, John Deere	Finetuning fertility: Adaptive nutrient management tools and techniques are helping maximize yields while reducing overappliction of crop nutrients
9/?/2013	Walmart	Integrated Adapt-N into Fertilizer Optimization Initiatives
3/?/2014	NESARE	Posted our training manual on their website for broader access
5/15/2013	Corn and Soybean Digest	Nitrogen Testing Tool May Improve Corn Profits
7/26/2013	Corn and Soybean Digest	Adapt-N tool calculates for weather extremes and soils
4/1/2014	Prairie Farmer	Adapt-N gives real-time nitrogen answers.
2014 season	Increasing press coverage with ATC's commercialization of Adapt-N	
8/20/2014	The Guardian	New technology helps farmers conserve fertilizer and protect their crops

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Technology Review Criteria

Technology Description

Adapt-N is an online tool that helps precisely manage nitrogen (N) inputs for grain, silage, and sweet corn production. It can provide automatic daily updates of each field's N status and sidedress N recommendations, based on real-time weather influences, and can be used with any device with internet access. As of 2014, Adapt-N is available commercially at through a public-private partnership with Cornell University. Annual licenses can be obtained by producers, agricultural service providers, or larger enterprises.

The tool uses a well-calibrated computer model, high-resolution daily precipitation and temperature data on a 3x3 mile grid, and soil, crop and management information to generate N recommendations for each management unit. It is a recently validated approach for managing N for corn, based on site-specific conditions. The web-based decision support tool provides field-specific, locally-adjusted sidedress N recommendations for corn production that incorporate the effects of local early-season weather, as it interacts with soil, management and crop factors, to generate N recommendations. By basing recommendations on local conditions, the tool improves the accuracy and precision of N recommendations, thus improving farm profits, while reducing environmental N losses.

How purposes of an existing standard are met

Use of Adapt-N can more effectively meet the purposes of the Nutrient Management 590 standard than currently broadly used methods that provide static or average recommendations, or those that make adjustments based on weather (PSNT, LSNT) using simplistic regression data instead of dynamic simulation modeling. Purposes of the Nutrient Management 590 Conservation Practice Standard such as the following are addressed:

- *To budget, supply, and conserve nitrogen for corn production.* The new interface allows for budgeting at the farm-wide scale once all management units are enabled for simulation. By strongly incentivizing applying the bulk of N inputs at sidedress time, the tool helps producers to carefully budget, supply at a more appropriate time, and thus conserve nitrogen.
- *To minimize agricultural nonpoint source pollution of surface and groundwater resources*. By waiting until sidedress time, early season losses are minimized, and total N inputs can be reduced in most years. Applications are increased only when the crop will need more, such that these higher application will not be lost.
- *To properly utilize manure or organic by-products as a plant nutrient source*. Temperature and precipitation significantly impact the amount of N that becomes available to the crop from organic inputs. By using dynamic simulation modeling, actually available mineral N provided from the manure can be better estimated.
- *To protect air quality by reducing nitrogen emissions via ammonia and oxides of nitrogen.* Better rate and timing will reduce losses.
- *To maintain or improve the physical, chemical, and biological condition of soil.* Adapt-N incentivizes building higher organic matter, preventing compaction, and leveraging the advantages of cover crops, as the tool enables the grower to directly quantify the economic benefits with respect to nitrogen that can be achieved from building soil health.

Process monitoring and control system requirements

Producers must keep good records, and ensure that inputs into the tool are appropriate, in order to receive proper Adapt-N recommendations. Further details are provided in the operation and maintenance plan.

An example of warranties

Example of warranties on all construction materials, equipment, or applied processes not covered by other NRCS Conservation Practice standards: Not Applicable.

Operation and maintenance plan

The Adapt-N interface is being maintained by Agronomic Technology Corporation. Fees for annual licenses pay for upkeep of the system. The Precision Nitrogen Management Model underlying Adapt-N is being continually updated by the research team as additional data become available. Due to the nature of Adapt-N as a cloud computing tool, no maintenance of the tool itself on the part of the producer is required.

The farm and/or their consultant is, however, responsible for maintaining accurate management records by field or management unit, as well as maintaining soil test information up to date. This information must be provided to Adapt-N by the user, so that accurate recommendations can be obtained. Users of

Adapt-N should familiarize themselves with available educational material about the tool and underlying concepts, to enable appropriate 'expert' use of the tool. Accurate input information is particularly important for a modeling tool.

Basic recommendations for effective use of Adapt-N to improve N use efficiency and profits while minimizing and preventing environmental impact:

- Plan to apply the majority of corn N fertilizer at sidedress time to avoid early losses after wet early season weather, reduce rates after normal or dry weather, and gain efficiencies and profitability from increased precision. This implies that fall application should be avoided, and early spring applications should be made at modest rates, even when inhibitors are used. Two factors inform this recommendation: (i) sidedress applied N is more efficiently used, because it is not subject to overwinter or spring losses from snow or rain, and (ii) the EONR can be much more precisely estimated in late spring compared to the previous fall or early spring, because seasonal weather and management conditions can be accounted for.
- Obtain access to high-clearance sidedress equipment if feasible. This prevents risks associated with missing the sidedress window due to weather challenges.
- Obtain ability to practice variable rate application for increased precision
- Determine corn N needs more precisely. Adjust in-season site-specific (field- or sub-field-tailored) N applications based on weather events, in order to reduce fertilizer rates, costs and losses in the long-term, while maintaining yield
- Determine if manured fields need additional fertilizer N
- Use Adapt-N for a N recommendation at or after V6, ideally V6-V12; Adapt-N is not designed to provide starter/preplant N rates, as weather impacts are not yet known at that time
- Ensure that model inputs are accurate and representative of the management unit and soil conditions for which a recommendation is being calculated
    - Take penetrometer measurements to account for compaction and rootzone limitations
    - Consider weather influences that may impact rooting depth (e.g., very high rainfall tends to reduce rooting depth)
    - Base expected yields on farm data for past years (e.g. the fourth highest yield from the last five years)
    - Re-evaluate your crop's expected yield and population density before sidedress based on that season's conditions to date
    - Use Adapt-N for variable rates based on changes across a field in texture, organic matter, and expected yield
    - Set Adapt-N settings to provide text or email alerts of additional N needs for maintaining yield after heavy spring rains
- Enter sidedress applications into Adapt-N once completed to monitor mid and late-season N status
- Use Adapt-N as a learning tool
    - during the growing season, to understand N dynamics such as mineralization and losses as affected by management, soil, and weather
    - during and/or after the growing season, to understand and evaluate alternative N management options by running "What if I had…?" scenarios using current and past years' weather data
    - Assess whether N management practices can be improved – are current application timing and rate consistently leading to high losses and/or high excess N availability?
- Assess, by field, whether excess N remains after the growing season, to aid in cover crop choices

- Further guidance on proper use of the Adapt-N tool is provided in the Adapt-N Training Manual, and more up-to-date information on how to use the commercial interface, as well as a list of FAQs is available in the help section for the Adapt-N interface at http://www.adapt-n.com/.

Estimated installation and annual operation cost

Annual license fees for the use of Adapt-N are set by Agronomic Technology Corp. the most up to date prices are available at http://adapt-n.com. The cost of tool use is in the range of $1-3/ac as of the 2014 season, depending on the number of acres being simulated.

Since the tool is cloud-based, there is no need for software installation. Initial costs are those of the annual license, and the cost of learning a new software program and potentially new concepts, depending on the user's familiarity with corn nitrogen dynamics. Annual operation costs will depend on acreage, number of management units, management data organization, and user's comfort with basic browser activity. There is anticipated to be a net profit for tool use, which will vary depending on current producer N application rates and practices, local weather factors, and soil characteristics, among others. In 104 trials in NY and IA over 3 years, the average profit from using Adapt-N instead of producer practice was $30/ac.

Contact information for individuals that have implemented this technology successfully

A large number of producers and agricultural service providers have implemented this technology successfully. The following individuals are selected contacts who would be happy to share their experiences.

- Keith Severson kvs5@cornell.edu.
- Robert Donald, Donald and Sons Farm, Moravia, NY: rdsons@localnet.com.
- Arnold Richardson, Richardson Farms, Red Creek, NY: arnold.richardson@gmail.com.
- Dave DeGolyer, Executive Managing Consultant, Western New York Crop Management Association, Warsaw, NY: ddegolyer@wnycma.com.
- Shannon Gomes, Consultant, Cedar Basin Crop Consulting, Decorah, IA: cbcc@earthlink.net.
- Frank Moore, Consultant and Producer, Three Rivers Ag Consulting, Cresco, IA: crescoflm@agristar.net.

Independent, verifiable data

Independent, verifiable data demonstrating results for the use of the measure, equipment, facility or process in other similar situations and locations:

Additional data are being collected annually by the research team, as well as independent interested stakeholders to further broaden the on-farm evidence for increased N management precision using Adapt-N recommendations. Two decades of evidence (in part listed in the Reference section above and at http://adapt-n.cals.cornell.edu) are available to validate the overall approach of using modeling to address previously unsolved environmental concerns with corn N management.

Credentials of the individual collecting the data

The credentials of the individual collecting the data along with a disclaimer of any conflict of interest on the part of the individual:

The data were collected by a distributed network of extension educators, independent crop consultants, and non-profit organizations, working together with producers hosting the trials. Credentials of those collecting the data vary, but most individuals are Certified Crop Advisors and/or have masters degrees or higher. The team of scientists at Cornell who compiled, analyzed, and presented the data have PhD's in soil and crop sciences, and are experienced in such analysis. According to Cornell University policy, Dr. Harold van Es discloses that he has an equity interest in Agronomic Technology Corporation, which has received a license for the use and further development of the Adapt-N tool. This tool was developed as part of his Cornell research program, and Agronomic Technology Corporation is providing some support to the program for the further development of this technology.

Contact information for the technology provider

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