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Adapt-N Outperforms Grower-Selected Nitrogen Rates in Northeast and Midwestern United States Strip Trials

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ABSTRACT

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

Core Ideas

- A dynamic, process-based, high-resolution N management tool is presented.
- The tool's adaptive nutrient management reduces applied N and increases profit compared with Grower practice.
- Site-specific N recommendations reduce environmental losses.
- Compelling use of cloud computing technology can increase adoption of the tool by growers.

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Global consumption of nitrogen (N)-based fertilizers has risen substantially in the last few decades and is expected to continue to increase due to projected global population growth (Erisman et al., 2008; Foley et al., 2011; Galloway et al., 2004; Zhang et al., 2015). Application of N fertilizer use in excess of crop demand can have an adverse effect on the environment; this effect has been well documented (Gruber and Galloway, 2008; Vitousek et al., 1997). Nitrogen losses through leaching (Andraski et al., 2000; van Es et al., 2002) and runoff (David et al., 2010) affect groundwater aquifers (Böhlke, 2002; Gu et al., 2013) and aquatic biota in downstream streams and estuaries (Carpenter et al., 1998; Diaz and Rosenberg, 2008). Nitrogen losses through denitrification can result in increased emissions of nitrous oxide (N_2O) (McSwiney and Robertson, 2005), a potent greenhouse gas for which agriculture is the main anthropogenic source (Smith et al., 2008). Altogether, increased anthropogenic N fluxes into the environment have a significant economic cost for society (Dodds et al., 2009; Sutton et al., 2011), which is largely externalized from the production economics; that is, farmers and retailers have limited economic incentives to reduce environmental N losses unless they can be coupled to higher profits.

Maize (*Zea mays* L.) accounts for 27% of the US crop land area (USDA–NASS, 2015a) and receives on average the highest N rate among the major field crops (157 kg ha^{-1}) (USDA–ERS, 2015a). Maize N management in the United States is often relatively inefficient: N recovery efficiency (the proportion of applied N taken up by the crop) is estimated to be 37% (Cassman et al., 2002) but can be as high as 67% for split N applications on irrigated maize (Wortmann et al., 2011). One of the factors leading to excess agricultural N application is that soil N is spatially and temporally variable (Kitchen et al., 2010; Scharf et al., 2005; van Es et al., 2007b). Therefore, defining a location-specific economically optimum N rate (EONR) (i.e., the N rate at which further increase in N is no longer economical) is challenging. The EONR is affected by multiple resource and production-related factors, including the timing and rate of precipitation events during the early growing season (Tremblay et al., 2012; van Es et al., 2007b), the timing of N application (Dinnes et al., 2002), N mineralization from soil organic matter, carry-over N

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Abbreviations: EONR, economically optimum nitrogen rate; PNM, Precision Nitrogen Management; SOM, soil organic matter; SSURGO, Soil Survey Geographic Database.

from previous cropping seasons (Ferguson et al., 2002; Mulvaney et al., 2001), soil texture (Shahandeh et al., 2005), crop rotations (Stanger and Lauer, 2008) and topographic position affecting soil moisture availability (Schmidt et al., 2007; Zhu et al., 2015), and organic carbon (Pennock, 2005). Considering the difficulty of estimating EONR for any location and growing season and the relatively low N fertilizer cost relative to grain, many farmers use application rates in excess of the EONR for their field to ensure that the crop yield is not limited by N (Scharf et al., 2005; Shanahan et al., 2008). Providing farmers with better tools to estimate the EONR in the early- to mid-growing season when management interventions are still feasible (Scharf et al., 2011) will allow them to manage N applications in a more sustainable and economically beneficial way.

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

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

Feature	Approach
Simulation time scale	daily time-step; historical climate data for post-date estimates
Optimum N rate estimation	mass balance: deterministic (pre) and stochastic (post) with grain/fertilizer price ratio and risk factors
Weather inputs	daily, near-real time (1 d lag): cumulative solar radiation; maximum and minimum temperature; precipitation
Soil inputs	soil type or series related to NRCS database properties; rooting depth; slope; soil organic C; artificial drainage
Crop inputs	cultivar; maturity class; population; expected yield
Management inputs	tillage (texture, time, residue level); irrigation (amount, date); manure applications (type, N and solid contents, rate, timing, incorporation method); previous crop characteristics
N fertilizer inputs	multiple: type, rate, time of application, placement depth; fertilizer price; enhanced efficiency compounds
Graphical outputs	N contributions and uptake; N losses (total, NO_3 leaching and gaseous); N content dynamics; crop development; weather inputs; site-specific fertilizer maps (advanced)
Other	Web accessible; option for automatic daily updates by email or text message; batch data upload capability; available for 95% of US corn acres

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

MATERIALS AND METHODS

The Adapt-N Tool

Adapt-N was a publicly available tool through Cornell University at the onset of this study but was licensed and commercialized in 2014 and is available as an online tool (ATC, 2016). The tool is based on the Precision Nitrogen Management (PNM) model (Melkonian et al., 2002, 2005, 2008), which is an integrated combination of the LEACHN biogeochemistry model (Hutson and Wagenet, 2003) and a maize N uptake, growth, and yield model (Sinclair and Muchow, 1995). In the PNM model the soil profile is discretized into 20 layers of 50 mm each, which serve as the basis for the soil water flux and nutrient transformations modeling domain. An important feature of Adapt-N is its dynamic access to gridded high-resolution (4 by 4 km) weather data (precipitation, maximum and minimum temperature, and solar radiation), which allows for field-specific and timely adjustments. The high-resolution weather database is derived from routines using the US National Oceanic & Atmospheric Administration's Rapid Update Cycle weather model (temperature) and operational Doppler radars (precipitation). For both, observed weather station data are used on a daily basis to bias-correct such estimates and generate spatially interpolated grids (DeGaetano and Belcher, 2007; DeGaetano and Wilks, 2009). The default soils information used in Adapt-N (such as soil texture or soil horizons) is based on NRCS SSURGO (Soil Survey Geographic Database) datasets (Soil Survey Staff–NRCS, 2016). These data could be further refined by the user by supplying data such as measured soil texture or soil organic percentage. The Adapt-N tool combines these various user inputs (Table 1) with soil and weather data to dynamically simulate early-season crop and soil N dynamics and to estimate soil N supply and crop uptake. The model currently does not simulate interactions with other nutrients. The model was tested by Sogbedji et al. (2006) and Melkonian et al. (2010) and showed low prediction errors.

The tool is highly flexible in terms of N management options with inputs for fall, spring, or split applications of fertilizer-N and a range of manure types and compositions as well as accounting for N inputs from rotation crops (soybean [*Glycine max* (L.) Merr.], sod, etc.). The tool considers N credits that vary by previous crop type and location. The tool accounts for manure by explicitly simulating N availability in the soil after the time of application. Both the manure and sod inputs have a 3-yr look-back period depending on location. Users can input various formulations of inorganic N fertilizers and select from a range of enhanced efficiency N products. One of the key user inputs is the site-specific attainable yield, which is based on long-term yield records. Further documentation regarding the data required to run a fertilizer recommendation using Adapt-N is available from ATC (2016).

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

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

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

In Adapt-N the soybean credit is a combination of a soil-specific straight credit (N_{rot_credit} in Eq. [1]) and a dynamic effective credit from a lack of immobilization associated with corn after corn (i.e., the soybean credit is partly the result of an absence of corn stover N immobilization). In most cases, the total soybean rotation credit is similar to those reported in the literature but varies with weather and soil type. Credits from manure and previous sod are dynamically simulated, generally based on amounts applied, N contents (organic and ammoniacal N for manure, C/N for sod based on legume and grass contents), termination date, and method of incorporation.

The Adapt-N tool runs on a daily time-step of a single growing season and does not allow simulation of consecutive years.

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

Validation Methodology

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

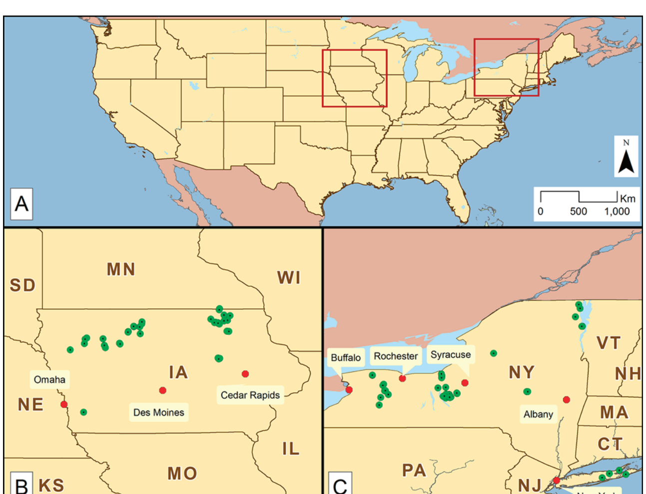

Fig. 1. (A) Map of the United States with New York and Iowa outlined and the locations (in green) of the Adapt-N strip trials in Iowa (B) and New York (C).

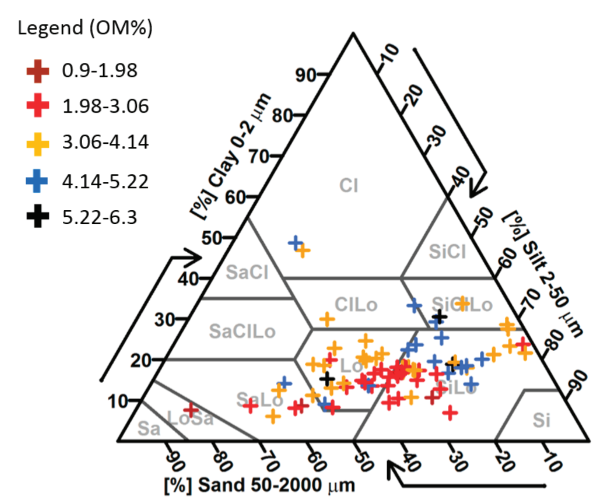

Fig. 2. Soil texture and organic matter percentage (%OM) of the trials used to validate the Adapt-N tool (produced using the "soiltexture" R software package [Moeys, 2015]).

on the cost of N application and yield revenue using an estimate of partial profit:

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

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

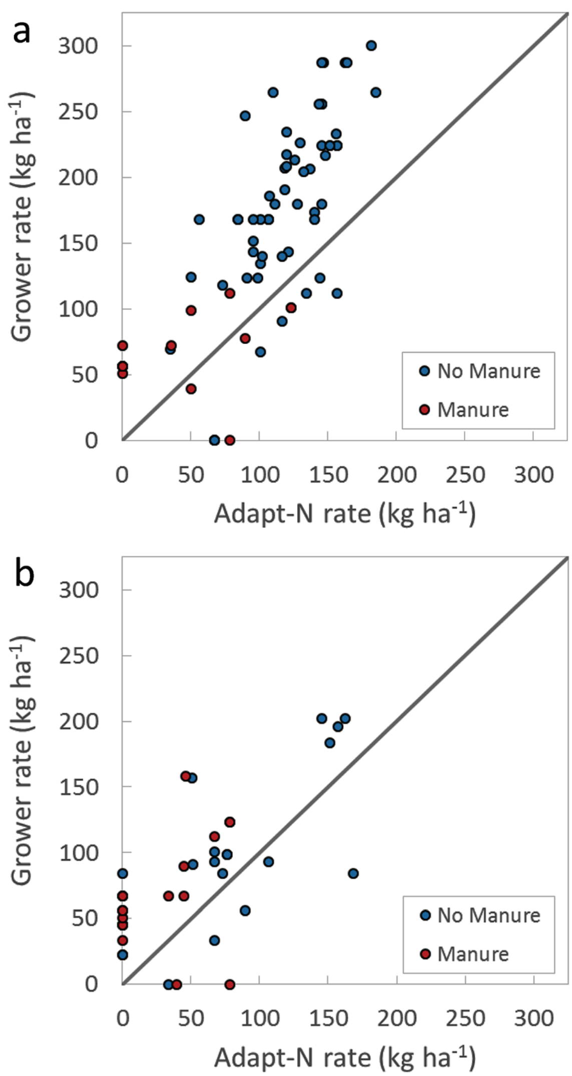

Fig. 3. The Grower and Adapt-N sidedress rates for the New York (a) and Iowa (b) experimental trials. Sites with manure application in the 3 yr before the trial are marked in red.

Estimating Environmental Fluxes

The Adapt-N tool simulates leaching losses from the bottom of the root zone and gaseous losses to the atmosphere due to denitrification and ammonia volatilization. Both leaching and gaseous losses are simulated deterministically in the PNM model in a process-based manner based on soil water dynamics and first-order reaction rate equations of N transformations that are modified by temperature and water conditions (Sogbedji et al., 2006). The current version of the model does not partition the different gaseous losses into their products (i.e., N_2O, N_2) and reports bulk gaseous losses. Nitrogen losses were simulated from 1 January (or fall application date, if applicable) until 31 December. Although substantial N losses are possible before the sidedress date (especially for the case of large preplant applications), in this analysis these losses would be the same for both the Adapt-N and the Grower treatments. Therefore, to directly compare the environmental fluxes resulting from Adapt-N and Grower sidedress N applications, only the environmental fluxes that occurred after the application of sidedress N are reported.

RESULTS AND DISCUSSION

Nitrogen Rates and Profit Analysis

The sidedress rates for trials with a history of manure application were generally lower for both the Adapt-N and Grower treatments (Fig. 3). For 13 (46%) of the manured trials, Adapt-N estimated that the applied manure and any applied starter N was sufficient to supply crop N needs, recommending zero sidedress. In 82% of all 113 trials the Adapt-N tool recommended lower N sidedress application than the respective Grower rate, with an average reduction from the Grower rate of 45 kg ha^{-1} (34% reduction; s = 50 kg ha^{-1}) (Table 2). The mean N rates applied at sidedress by the grower were substantially higher for the New York trials (159 kg ha^{-1}; s = 77 kg ha^{-1}) (Fig. 3a) than for the Iowa trials (82 kg ha^{-1}; s = 53 kg ha^{-1}) (Fig. 3b). Regardless of these differences, the Adapt-N tool showed similar efficiency in reducing these rates (34 and 37% for the New York and Iowa trials, respectively). These reduced rates resulted in an increased profit in 73% of trials and an average increase of \$65 ha^{-1} (s = \$114 ha^{-1}) over the Grower rate (Fig. 4) when all trials were considered. Paired *t* tests indicate that the average yield of Adapt-N and the Grower was not significantly different ($p = 0.24$ and $p = 0.96$ for New York and Iowa, respectively), whereas the profit was significantly higher ($p < 0.001$ and $p = 0.03$ for New York and Iowa, respectively). These economic benefits of using Adapt-N are higher than the ones reported by other adaptive N recommendation tools used in US maize production, such as crop canopy reflectance sensors (16 kg ha^{-1} reduction in N rate, \$45 ha^{-1} increase in profit) (Scharf et al., 2011).

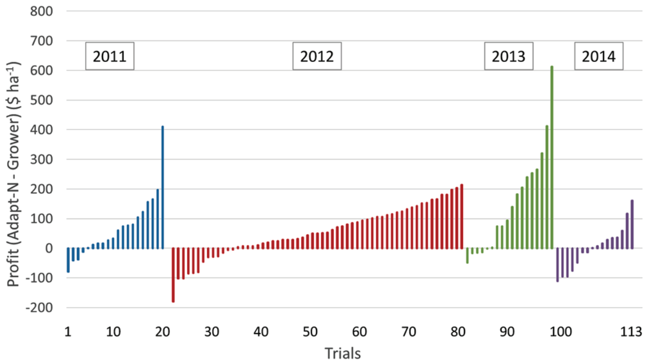

Fig. 4. Partial profit analysis of the 113 trials used to validate the Adapt-N tool.

Effect of Seasonal Rainfall on Nitrogen Rates Recommendation

In seasons with dry or average spring rainfall conditions (i.e., 2011, 2012, and 2014) (Table 2) the Adapt-N treatment had on average 55 kg ha^{-1} lower N rates (s = 45 kg ha^{-1}) than the Grower treatment, a reduction of 39%. These reduced rates suggest that the Grower rate in those years was generally in excess of crop N requirements because the Adapt-N rates were sufficient to obtain similar yields. This resulted in an average profit increase of $48 ha^{-1} (s = $90 ha^{-1}) using Adapt-N in these years (Fig. 4).

The ability of the Adapt-N tool to adjust sidedress N rates to account for early-season weather was demonstrated for the 2013 season in New York and Iowa. For the New York 2013 trials, heavy rainfall events occurred shortly after crop planting, when large amounts of mineralized N and early-applied N were susceptible to losses. Adapt-N accounted for these weather effects and recommended higher N sidedress rates in 72% of the trials compared with the grower-selected rates (an average increase of 22 kg ha^{-1}; s = 50 kg ha^{-1}). This is illustrated in Fig. 5, using data from Trial 24 (Supplemental Table S1). Similar to a third of the trials in the New York 2013 season, this grower chose to rely solely on large preplant application (197 kg ha^{-1}) to supply crop N requirements. A series of heavy rainfall events after planting (Fig. 5a) led to large simulated N losses, and the soil to become mostly depleted of available N by the middle of the growing season (Fig. 5b). In the absence of an additional sidedress application, the deficit in soil N led to a low seasonal crop N uptake of 89 kg ha^{-1} (Fig. 5b). In contrast, Adapt-N recommended an additional sidedress N application of 67 kg ha^{-1}, which replenished soil N deficits and led to a 77% increase in the simulated seasonal crop N uptake and an increase of 2605 kg ha^{-1} (42 bu ac^{-1}) in measured yield compared with the grower-selected rate (Fig. 5c). Overall, higher rates were recommended by Adapt-N for the 2013 New York trials (Table 2). These results demonstrate that an adaptive N management approach that accounts for weather effects can be highly profitable, especially during years with high early-season precipitation.

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

Environmental Losses

For all trials in both states, simulated combined leaching and gaseous losses were on average reduced by 28 kg ha^{-1} (38%; s = 39 kg ha^{-1}) for the Adapt-N recommended rates compared with the grower-selected rates (Fig. 6a,b; Table 3). The simulated total N losses for the IA trials were on average 58% lower than for the New

Table 2. Yield and profit results of the Adapt-N strip trial evaluation.

Year	*n*	Rainfall, May–June	N rate† Grower N rate	Adapt-N rate	(A-G)‡ diff.	N yield Grower yield	Adapt-N yield	(A-G) diff.	(A-G) Profit diff.
		mm	kg ha^{-1}			Mg ha^{-1}			$ ha^{-1}
New York									
2011	11	229	133	71 (46%)	–62 (46%)	8.2	8.1	–0.1	82.8
2012	42	168	187	113 (43%)	–74 (40%	11.9	11.8	–0.1	61.6
2013	11	267	80	102 (47%)	+22 (28%)	10.8	12.1	1.3	227.3
2014	9	206	154	115 (12%)	–40 (26%)	11.7	11.6	–0.1	13.4
Mean	73	217	159	106 (43%)	–53.4 (34%)	10.7	10.9	0.2	96.3
Iowa									
2011	9	269	54	36 (149%)	–18.8 (35%)	12.2	12.1	–0.1	52.9
2012	17	155	75	44 (118%)	–30.9 (41%)	9.5	9.5	0.0	35.4
2013	7	358	91	70 (32%)	–20.1 (22%)	11.0	11.0	0.0	39.9
2014	7	351	126	71 (83%)	–55.3 (44%)	10.8	10.4	–0.4	–16.5
Mean	40	283	82	52 (97%)	–30.4 (37%)	11.0	10.8	0.3	25.5
Grand mean	113	250	131	86 (63%)	–45 (34.3%)	10.8	10.9	0.1	65.1

† Nitrogen rates presented for the Adapt-N and the Grower plots are for the sidedress rate and not the total applied N rate at the trial. The average Adapt-N rate is followed by its spatial coefficient of variation. The difference in N rate is followed by the percentage reduction from the Grower treatment.

‡ (A-G) Diff. indicates the difference between Adapt-N and the Grower treatments.

York trials, presumably due to lower applied N rates and different climate and soil conditions. The partition of total N losses between leaching and gaseous N loss pathways also differed between the states, with leaching losses consisting of 61% of total losses in New York and only 32% for the Iowa simulated losses. The difference in leaching losses could in part be attributed to a soil texture effect: the New York sites generally have higher sand contents and lower clay contents (Table 3) and generally deeper rooting depths for Iowa soils (Supplemental Table S1).

The average simulated leaching losses of 40 kg ha^{-1} (s = 45 kg ha^{-1}) and 25 kg ha^{-1} (s = 29 kg ha^{-1}) (Fig. 6a and 7a; Table 3) for the Grower and Adapt-N trials, respectively, are comparable to measured leaching losses for other midwestern maize trials reported in the literature (Kaspar et al., 2007; Malone et al., 2014; Qi et al., 2011, 2012). Adapt-N rates resulted in an average reduction of 14 kg ha^{-1} (36%; s = 24 kg ha^{-1}) in simulated leaching losses compared with the Grower rates. These rates were consistently higher for the New York trials compared with the Iowa trials despite high variability among locations and seasons: 22 kg ha^{-1} (39%; s = 27 kg ha^{-1}) in New York and 0.3 kg ha^{-1} (3%; s = 1 kg ha^{-1}) in Iowa. This can be attributed to several characteristics of the Iowa sites, including (i) higher denitrification losses relative to leaching due to generally finer soil textures (Table 3), (ii) greater rooting depths causing more water and N uptake in the lower profile (Supplemental Table S1), and (iii) a higher participation rate of growers who already used highly optimized N application timing of low starter rates followed by sidedress, resulting in a modest difference in sidedress rate of 31 kg ha^{-1} between the Grower and Adapt-N.

Simulated gaseous losses (Fig. 6b and 7b) were similarly lower for the Adapt-N compared with the Grower treatment (average reduction, 14 kg ha^{-1}; 39%; s = 23 kg ha^{-1}). The 2011 and 2012 seasons for the New York trials resulted in >50% reductions in simulated gaseous losses when using Adapt-N versus Grower rates. Again, benefits were generally greater in New York than in Iowa, although the reduction in gaseous losses in Iowa was greater (18%) than the reduction in leaching losses (3%).

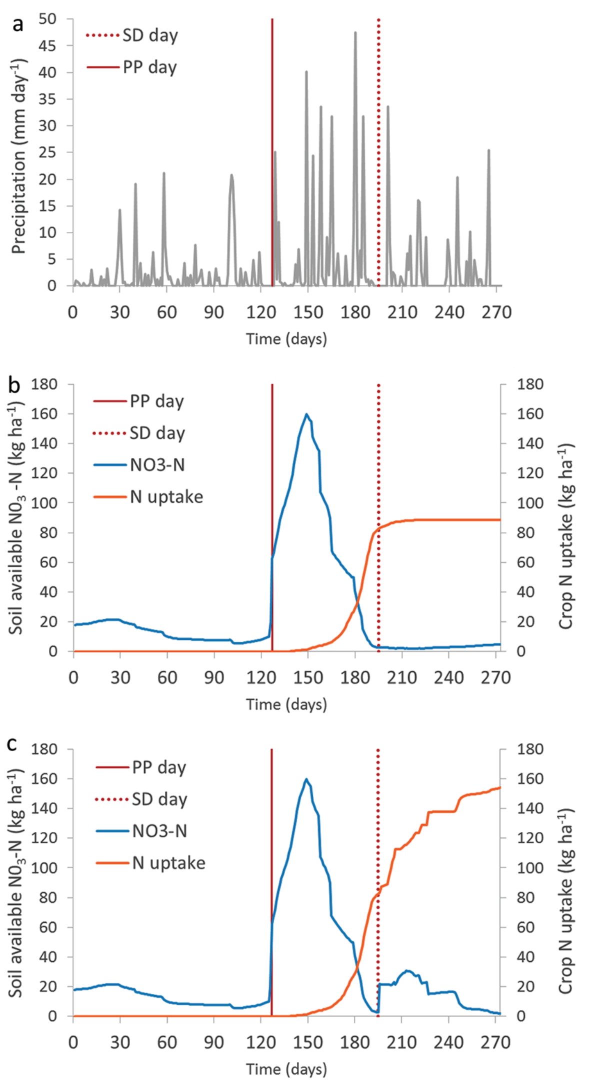

Fig. 5. The effect of weather conditions on soil N availability, demonstrated using data from 2013 season New York trial number 24. In both the Adapt-N and Grower treatments, 197 kg ha^{-1} was applied with planting. (a) Daily precipitation from 1 January to 1 October. (b) Simulated soil N availability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

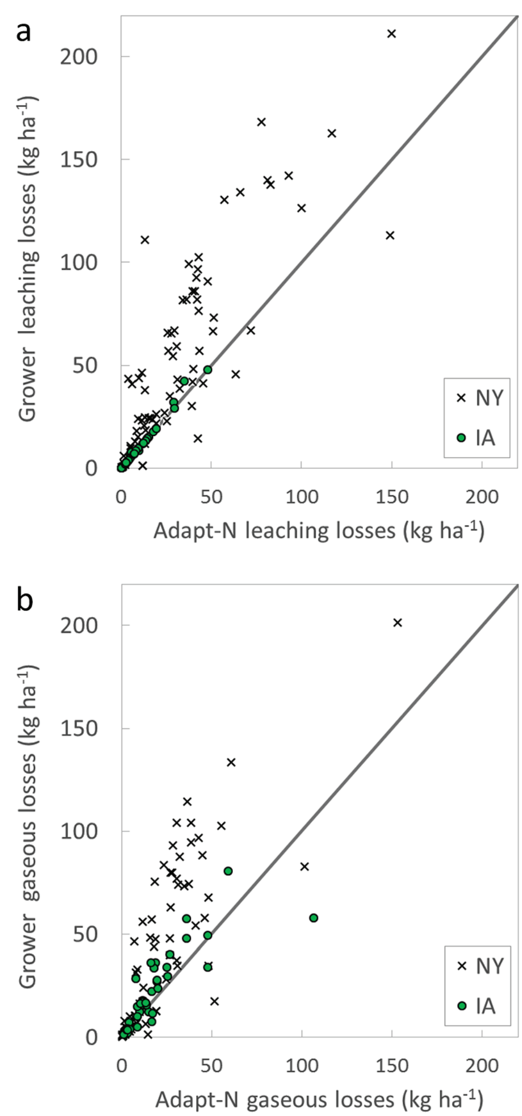

Fig. 6. Adapt-N and Grower simulated leaching (a) and gaseous (b) losses.

Table 3. Simulated leaching and gaseous losses for Adapt-N and Grower-selected N rates.

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

† (A-G) Diff. indicates the difference between Adapt-N and the Grower treatments.

‡ The clay and sand percentages represent the mean value of the trials in each season.

CONCLUSIONS

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

The potential benefits of the use of a dynamic simulation tool like Adapt-N were likely underestimated in this study because the participants represented a progressive group who already optimize N timing and placement decisions with sidedress applications. On average, only 32% of US maize growers apply in-season N applications as part of their N management practices (USDA–ERS, 2015b). The economic and environmental benefits of Adapt-N could further increase because it stimulates better N application timing with the fraction of farmers who still use high rates of preplant (especially fall) N applications. Overall, we conclude that adoption of the model and weather-based Adapt-N tool by growers, consultants, government professionals and policymakers, among others, can help reduce the environmental costs of N fertilization while increasing economic benefits to growers.

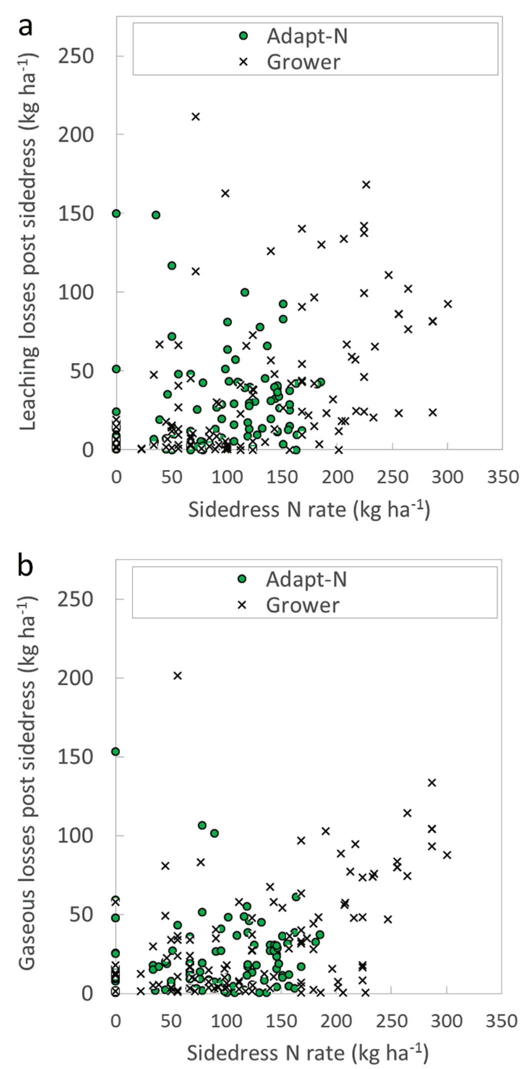

Fig. 7. Relationship between N applied at sidedress and simulated post-sidedress leaching losses (a) and gaseous losses (b).

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