Dynamic Model Improves Agronomic and Environmental Outcomes for Maize Nitrogen Management over Static Approach

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Abstract

Large temporal and spatial variability in soil nitrogen (N) availability leads many farmers across the United States to over-apply N fertilizers in maize (*Zea Mays* L.) production environments, often resulting in large environmental N losses. Static Stanford-type N recommendation tools are typically promoted in the United States, but new dynamic model-based decision tools allow for highly adaptive N recommendations that account for specific production environments and conditions. This study compares the Corn N Calculator (CNC), a static N recommendation tool for New York, to Adapt-N, a dynamic simulation tool that combines soil, crop, and management information with real-time weather data to estimate optimum N application rates for maize. The efficiency of the two tools in predicting the Economically Optimum N Rate (EONR) is compared using field data from 14 multiple N-rate trials conducted in New York during the years 2011 through 2015. The CNC tool was used with both realistic grower-estimated potential yields and those extracted from the CNC default database, which were found to be unrealistically low when compared with field data. By accounting for weather and site-specific conditions, the Adapt-N tool was found to increase the farmer profits and significantly improve the prediction of the EONR (RMSE = 34 kg ha^{-1}). Furthermore, using a dynamic instead of a static approach led to reduced N application rates, which in turn resulted in substantially lower simulated environmental N losses. This study shows that better N management through a dynamic decision tool such as Adapt-N can help reduce environmental impacts while sustaining farm economic viability.

Core Ideas

- Dynamic N recommendation tool reduces environmental impacts over static approach.
- Dynamic N recommendation tool accounts for different production environments.
- Dynamic N recommendation tool is successful in estimating field-measured EONR.

MAIZE (*Zea Mays* L.) is a major crop, accounting for 27% of US cropland area (USDA–NASS, 2015), and receives the largest nitrogen (N) input of all major US crops (average of 157 kg ha^{-1}; USDA–ERS, 2015). While environmental N losses naturally occur due to mineralization of organic matter to soil nitrate N, in modern agriculture, these N losses are exacerbated by the application of external N sources to maize fields, which is often in excess of actual crop N needs. This results in environmental problems such as nitrate leaching into groundwater and streams (Fenn et al., 1998; David et al., 2010; Cameron et al., 2013) and emissions of N$_2$O, a reactive greenhouse gas, into the atmosphere (Millar et al., 2010). High levels of nitrate in drinking water and an increase in atmospheric N$_2$O emissions are associated with both ecosystem and human health issues (Townsend et al., 2003). Altogether, there is a pressing need to increase the sustainability of agricultural production and reduce the losses of N fertilizer into the environment (Tilman et al., 2011; Norse and Ju, 2015; Zhang et al., 2015).

Soil N availability varies in time and space (van Es et al., 2007b) and is affected (among others) by soil type and texture (St. Luce et al., 2011), soil mineralization and N availability from previous cropping seasons (Gentry et al., 2001, 2013; Ferguson et al., 2002), organic amendments such as manure applications (Eghball et al., 2004; Woli et al., 2015), and weather effects that drive N losses and availability (Kahabka et al., 2004; Kay et al., 2006; Xie et al., 2013; Deen et al., 2015). To address this variability and help growers fertilize at the Economically Optimum N Rate (EONR), several N recommendation methods have been developed over the years. These include the Stanford-type mass balance methods (Stanford, 1973) that are most widely promulgated by US extension systems; an empirical approach known as the Maximum Return To N (Sawyer et al., 2006) that is promoted in Midwest US states; proximal crop canopy sensing of crop N deficits (Scharf et al., 2011; Schmidt et al., 2011); in-season soil testing, e.g., the Pre-Sidedress Nitrogen Test (Magdoff et al., 1984); and simulation tools such as the Maize-N model (Setiyono et al., 2011) and the Adapt-N tool (van Es et al., 2007b; Melkonian et al., 2008).

Stanford-type mass balance equations are driven by crop yield potential, internal cycling of N within the specific soil type, and

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Abbreviations: CNC, Corn Nitrogen Calculator; EONR, Economically Optimum Nitrogen Rate; PNM, Precision Nitrogen Management.

the efficiency of N uptake by the crop (Stanford, 1973). In a general form, a Stanford-type equation could be written as (Lory and Scharf, 2003):

$$N_f = (aY_p - N_s)/E_f \qquad [1]$$

where N_f is crop N fertilizer requirement (kg ha^{-1}); a is a constant (typically 21.4) to be multiplied by the yield potential Y_p (Mg ha^{-1}, 85% dry matter) to derive the total seasonal crop N need; N_s is the N supplied by the soil from mineralization of organic matter, previous crops or manure (kg ha^{-1}); and E_f refers to N use efficiency, or the proportion of applied N that is recovered by the grain (Lory and Scharf, 2003). The Stanford-type mass balance approach is potentially appealing, as it allows site-specific N recommendations depending on soil and crop N availability, and its relative simplicity makes it easy to implement. However, this approach, as implemented in most growing environments, has drawbacks: (i) it is very generalized over diverse growing conditions and therefore often fails in predicting the field-specific EONR (Lory and Scharf, 2003; van Es et al., 2007b), and (ii) it is static, neglecting the effect of weather on soil N dynamics and availability within the growing season. Stanford himself acknowledged that "... it largely ignores the dynamic nature of the water–soil–plant–nitrogen system" (Stanford, 1973).

The Corn N Calculator (CNC; Ketterings et al., 2003) is based on the Stanford approach and has been the standard recommendation tool for maize N fertilizer in New York (Ketterings et al., 2007; Lawrence et al., 2008, 2009; Sadeghpour et al., 2016). Adapt-N (Melkonian et al., 2008) is a web-based commercial N recommendation tool for maize (Agronomic Technology Corporation, www.adapt-n.com) that applies a dynamic approach to the mass balance equation. The tool is based on a biogeochemical model that accounts for spatial and temporal variation in weather, soil N transformations (i.e., mineralization, nitrification, denitrification, volatilization, and leaching losses), and crop N uptake.

The overall objective of our study was to compare N rates generated by Adapt-N and the CNC tools to determine if accounting for weather and site-specific conditions could improve the accuracy of sidedress N rate recommendations and reduce environmental N losses. Sidedress N application in this study refers to in-season fertilizer application that is typically done at growth stages V6 through V10 (~30–50 d from emergence). The specific objectives of our study were

1. to evaluate the efficiency of the CNC and Adapt-N tools to predict the EONR rate observed in on-farm strip trials in New York State;

2. to compare the simulated environmental losses resulting from these recommended N rates.

Materials and Methods
Corn N Calculator

The CNC tool, an Excel-based version of the Stanford-type model for New York conditions, was downloaded from http://nmsp.cals.cornell.edu/software/calculators.html. Generating a recommendation requires the user to input a soil series name and information on manure or sod applications. It generates N rate recommendations according to Eq. [1], using 21.4 as the yield goal multiplier (Meisinger et al., 2008). The tool assumes contributions of N by mineralization of organic matter (based on soil type) and N use efficiency factors (E_f) based on soil type

(Ketterings et al., 2003). The tool accounts for previous N applications, such as starter N applied with planting or N availability from manure applications or sods (e.g., hay). All are treated as "N credits" that are subtracted from the N rate from Eq. [1]. Manure N availability is estimated from a decay series that includes manure applications during the previous 2 yr. The tool does not account for contribution of N from previous crops, such as soybean [*Glycine max* (L.) Merr.], or for seasonal weather. Given the same field conditions, CNC recommendations are fixed from year to year. The tool acknowledges an 11-kg ha^{-1} uncertainty margin in its recommendations. The CNC tool facilitates the use of a default yield potential from a linked database (based on soil type and drainage class), or the user can manually enter a value. For this analysis, we generated CNC-based N recommendations using both database yield potentials and those based on realistic yields (grower-estimated based on historical yield performance).

Adapt-N Tool

Adapt-N is a dynamic, in-season, sidedress N recommendation tool, designed to optimize N applications where the bulk of N is applied in season (Melkonian et al., 2008; Sela et al., 2016). It is currently calibrated for use on 95% of the US maize production area and is offered in a Cloud-based environment, making it accessible through any internet-connected device that supports a web browser. The tool has dynamic access to gridded, high-resolution (4 × 4 km), near-real-time (1 d lag) weather data derived from routines using the US National Oceanic & Atmospheric Administration's Rapid Refresh (NOAA RAP) weather model and operational Doppler radars. Observed weather station data are used to correct the estimates and the spatially interpolated grids on a daily basis (DeGaetano and Belcher, 2007; DeGaetano and Wilks, 2009).

Adapt-N requires multiple soil and management inputs such as soil texture or series name, organic matter content, crop characteristics and management (yield potential, maize relative maturity, planting date and population, crop rotation), previous N applications (synthetic fertilizer, manure), and soil management (Supplemental Table S1). The engine of the Adapt-N tool is the Precision N Management (PNM) model (Melkonian et al., 2005), a biogeochemical model that simulates soil water and N fluxes, crop N uptake, and crop growth on a daily time step. The PNM model itself is a combination of (i) the LEACHN model (Hutson and Wagenet,1995; Hutson, 2003), which simulates the soil hydrology and biogeochemistry, and (ii) a maize N uptake, growth, and yield model (Sinclair and Muchow, 1995). These two components of the PNM model were validated previously in multiple studies (e.g., Khakural and Robert, 1993; Jabro et al., 1995; Sinclair and Muchow, 1995; Unlu et al., 1999; Jabro et al., 2006). The PNM model and the constituent LEACHN model were extensively validated against leached N and water drainage measurements in previous New York-based studies on a range of soil types, providing reasonable confidence to simulated N-loss estimates in this study. Sogbedji et al. (2001a, 2001b) found the LEACHN model to perform well in reconstructing measured cumulative nitrate leaching (RMSE = 1.8 and 1.5 kg ha^{-1} yr^{-1} for a loamy sand and a clay loam soil, respectively). For the PNM model, Sogbedji et al. (2006) found good agreement between measured and simulated nitrate leachate, with RMSE of 2.9 to 9.7 mg L^{-1} mo^{-1}. The PNM model was further validated in

New York for daily cumulative drainage (RMSE = 37 mm yr^{-1}) and leached N (RMSE = 3 kg ha^{-1} yr^{-1}; Marjerison et al., 2016). On the same study, the PNM was also validated on different climatic and soil conditions in the state of Minnesota and found good agreement with cumulative nitrate leaching (RMSE = 10 kg ha^{-1} yr^{-1}), soil inorganic N (RMSE = 10 kg ha^{-1} yr^{-1}), and crop N uptake (RMSE = 50 kg ha^{-1} yr^{-1}).

Details on Adapt-N input data and how N recommendations are calculated are discussed in Sela et al. (2016). Adapt-N generates N recommendations according to a mass balance equation that is solved on a daily basis (all units in kg ha^{-1}):

$$N_{rec} = N_{exp\_yld} - N_{crop\_now} - N_{soil\_now}$$
$$- N_{rot\_credit} - N_{fut\_gain\_loss} - N_{profit\_risk} \qquad [2]$$

where N_{rec} is the N rate recommendation, N_{exp_yld} is the crop N content needed to achieve the expected (potential) yield, N_{crop_now} and N_{soil_now} are the N content in the crop and inorganic N in the soil, as calculated by the model for the current simulation date accounting for previous N applications (i.e., starter N rate, or fall or spring manure applications), N_{rot_credit} is the (partial) N credit from crop rotation (e.g., hay or soybean crop), $N_{fut\_gain\_loss}$ is a probabilistic estimate of future N gains from organic N mineralization 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 model recommendations were recently compared with grower-based N rates using strip trials from Iowa and New York (Sela et al., 2016). Results showed that Adapt-N sidedress N rate recommendations were 34% lower and did not result in a significant yield loss.

Field Trials

Field data from 14 site–years of multiple N rate trials at multiple locations during the 2011 to 2015 growing seasons in New York were used to compare the sidedress N recommendations generated by the CNC and Adapt-N tools (Supplemental Table S2). The trial sites were located in central-western and northern New York (Fig. 1) on a range of soil types (Supplemental Table S2, Fig. 2). The size and length of the experimental strip trials varied according to field dimension, soil texture distribution, and collaborator preference. The strip trials used a split N management approach (i.e., a starter amount at planting followed by an in-season application). Two of the trials (9 and 10) had dairy manure application in the fall previous to the growing season (28,062 L ha^{-1}, equivalent to a loading of 34 and 17 kg ha^{-1} ammonium and organic N, respectively).

In each trial, multiple N rates were applied in replicated, spatially balanced randomized complete block designs (van Es et al., 2007a). Yield and N-rate data from each trial were used to fit a quadratic response curve, allowing the respective EONR of each trial to be calculated (Table 1). Confidence intervals around the EONR of 68% (one standard deviation) were calculated using the methodology presented in Jaynes (2011). Economic losses from the retrospective EONR rates based on the CNC and the Adapt-N rates were calculated and compared. For a detailed description of the EONR confidence interval calculation and how the loss from the EONR was calculated, see Supplemental Material S1.

Half of the trials had three N rates applied (usually zero, an intermediate, and a high rate of N), while others had five or six N rates. Trials had three or four replicates for each rate, except for two (14%) that had only two replicates for all rates, and another five trials (36%) that had two or three replicates, depending on the rate (Supplemental Table S2). In three of the trials (21%), the crop grown was maize silage and the yield was
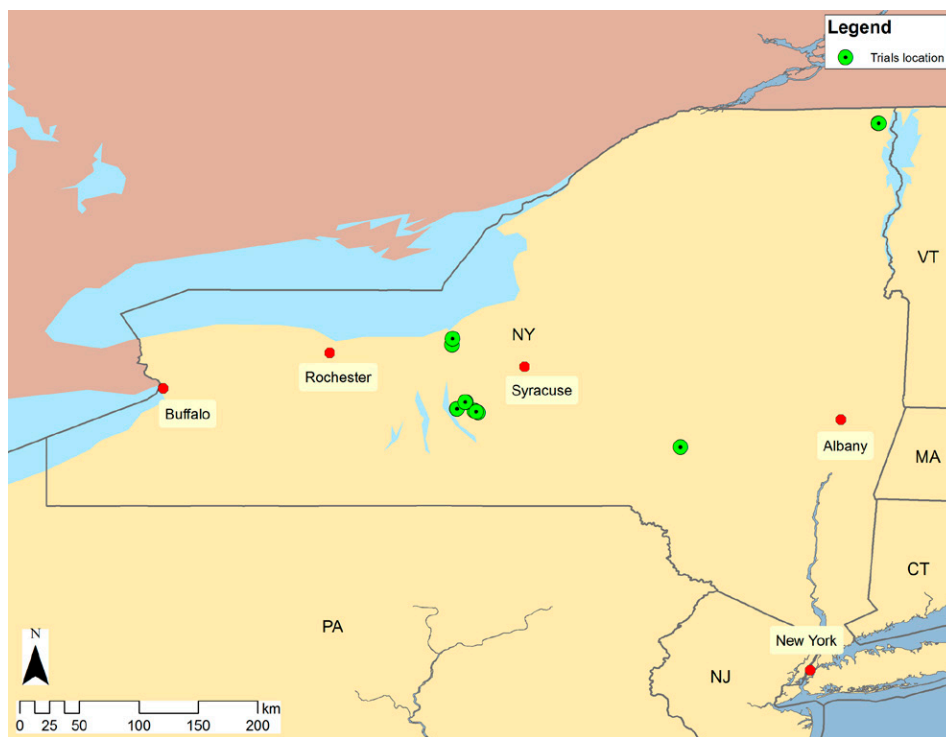

Fig. 1. Locations (marked green) of the New York State multiple nitrogen (N) rate trials during 2011 to 2015. Some farms were used in multiple years, but not the same fields.

Legend (OM%)
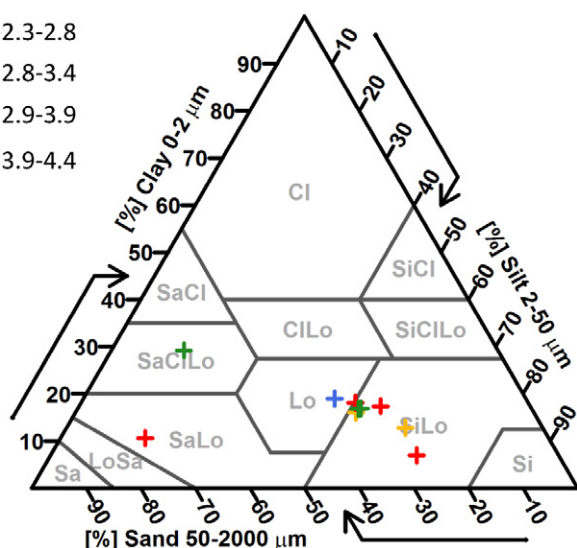- 2.3–2.8
- 2.8–3.4
- 2.9–3.9
- 3.9–4.4

Fig. 2. Soil texture and percent organic matter of the trials (produced using the "soil texture" R software package; Moeys et al., 2015).

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). Composite soil samples were collected in the field, and soil texture and organic matter content were determined using a rapid soil texture method (Kettler et al., 2001) and loss on ignition (Nelson and Sommers, 1996), respectively.

Environmental N Fluxes

Leaching losses from the bottom of the root zone and gaseous losses to the atmosphere due to denitrification and ammonia volatilization were simulated by the PNM model based on soil water dynamics and rate equations of N transformations (Sogbedji et al., 2006). To compare the environmental losses resulting from the

Adapt-N and the CNC N recommendation rates, the PNM model was used to simulate both leaching and gaseous losses resulting from the N rates recommended by the two tools (starter + sidedress). Relevant climatic data for the simulations such as precipitation and temperature were obtained from gridded, high-resolution (4×4 km) weather data derived from NOAA RAP and from operational Doppler radars. The trials used for the analysis had different N management approaches according to grower preferences, such as pre-plant N or manure applications in different quantities. These losses would have been the same for the Adapt-N and the CNC tools prior to the sidedress date, and therefore in this analysis, we only compare the environmental N losses occurring during the period from sidedress N application until 31 December.

Results and Discussion
Potential Yields and N Recommendation Rates

Potential yields supplied for each field by the grower based on historical performance were generally higher than those derived from the CNC database (Fig. 3a), averaging 11.9 and 8.5 Mg ha^{-1}, respectively, or an average difference of 3.4 Mg ha^{-1} (54 bu ac^{-1}). This difference, representing a 29% reduction from the grower-estimated yield, was highly statistically significant in a paired t test ($p < 0.0001$). Conversely, the average grower-estimated potential yield of 11.9 Mg ha^{-1} slightly overestimated the average achieved yield in the trials of 11.3 Mg ha^{-1} (Fig. 3b).

Since the CNC and Adapt-N tools are based on a mass balance approach that is driven by the potential yield, sidedress N recommendations of the CNC tool were strongly impacted by the underestimated yield assumptions from the default yield database (Fig. 4a). The CNC recommended, on average, 115 kg N ha^{-1} for the non-manured trials (41 kg N ha^{-1}), 26% lower than the respective Adapt-N rate, but it remained higher than Adapt-N's recommendation for the manured trials, with an average rate of 90 kg N ha^{-1} (100% increase).

Table 1. Regression between nitrogen (N) rate and yield, the resulting Economically Optimum Nitrogen Rate (EONR) based on the regression and confidence interval of one standard deviation (68%), the total N rate recommended by the Adapt-N and Corn Nitrogen Calculator (CNC) tools, and the calculated losses from the EONR.

Site	Year	Response curve regression fit and significance	EONR (CI ± 1 SD)	Adapt-N rate	Adapt-N loss from EONR	CNC rate DY†	CNC loss from EONR DY	CNC rate GY‡	CNC loss from EONR GY
			——— kg ha^{-1} ———		US\$ ha^{-1}	kg ha^{-1}	US\$ ha^{-1}	kg ha^{-1}	US\$ ha^{-1}
1	2011	$R^2 = 0.89, p < 0.01$	143 (132–155)	135	5	145	0	149	2
2	2012	$R^2 = 0.95, p < 0.01$	231 (203–259)	178	59	167	82	248	5
3	2012	$R^2 = 0.97, p < 0.01$	191 (180–201)	170	20	145	101	265	75
4	2012	$R^2 = 0.93, p < 0.01$	183 (172–202)	176	0	139	35	247	57
5	2012	$R^2 = 0.69, p = 0.012$	165 (146–184)	159	0	139	12	247	73
6	2012	$R^2 = 0.81, p < 0.01$	207 (169–245)	170	25	139	84	247	27
7	2013	$R^2 = 0.90, p = 0.015$	226 (185–268)	179	59	168	91	248	13
8	2014	$R^2 = 0.84, p < 0.01$	179 (167–192)	206	26	114	371	311	141
9	2014	$R^2 = 0.00, p = 0.89$	38 (2–74)	72	22	113	64	128	80
10	2014	$R^2 = 0.15, p = 0.06$	163 (106–219)	94	35	129	7	225	36
11	2014	$R^2 = 0.42, p = 0.014$	151 (126–176)	193	41	139	10	247	101
12	2014	$R^2 = 0.26, p = 0.016$	197 (172–223)	214	5	161	17	319	113
13	2015	$R^2 = 0.32, p = 0.04$	193 (132–256)	189	0	126	119	269	71
14	2015	$R^2 = 0.71, p < 0.001$	261 (234–289)	232	15	164	156	282	7
Grand mean			181 (152–210)	169	22	142	82	245	57

† DY, based on default potential yield.
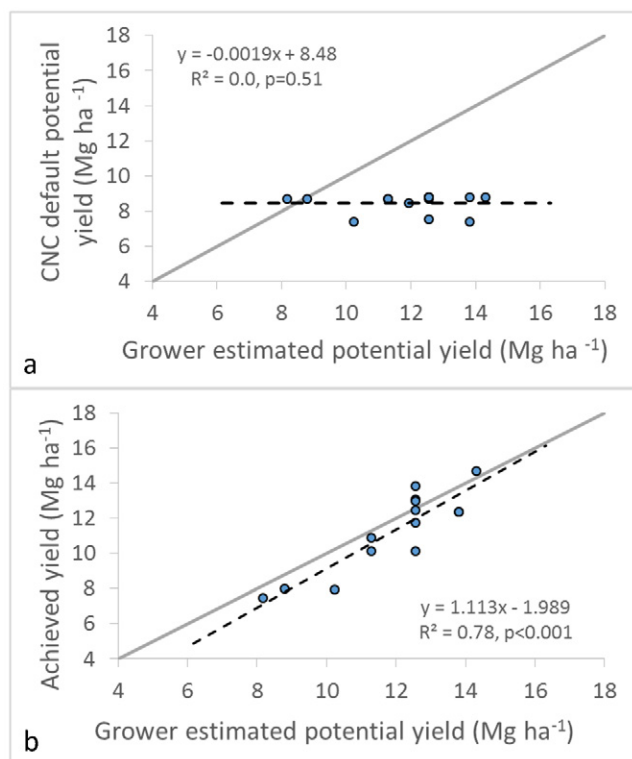
‡ GY, based on grower potential yield.

Fig. 3. (a) Grower-estimated potential yields and those from the Corn Nitrogen Calculator (CNC) database and (b) grower-estimated potential yields and the achieved ones. The 1:1 line is presented in gray.
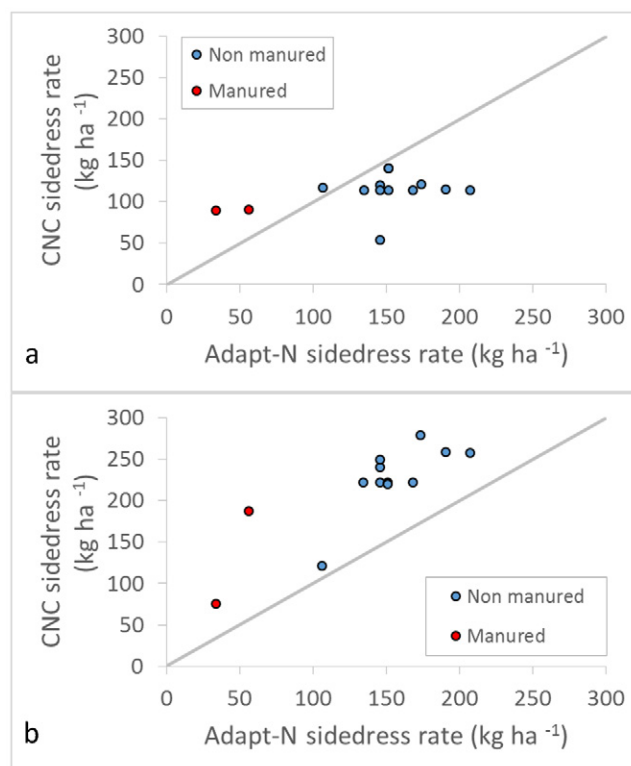

Fig. 4. Comparison of sidedress nitrogen (N) rates recommended by the Adapt-N and Corn Nitrogen Calculator (CNC) tools. The Adapt-N rate was calculated in both panels using potential yield estimate supplied by the grower. The CNC rate was calculated either (a) using the default potential yield or (b) using a potential yield supplied by the grower. The 1:1 line is presented in gray.

Using the grower-estimated potential yield (Fig. 4b), the CNC recommended, on average, 228 and 131 kg N ha^{-1} for the non-manured and manured trials, respectively. The average recommendation rate for Adapt-N, which is driven by the grower-estimated potential yield, was 156 and 45 kg N ha^{-1} for the non-manured and manured trials, respectively, or 72 (32%) and 86 kg N ha^{-1} (66%) lower than the CNC rate based on the more realistic grower yield estimates.

The large difference in N recommendations based on different potential yields highlights the dependency of mass balance approaches on an accurate estimation of potential yield, which ideally is based on each field's yield history. Such data are more available with the growing use of yield monitors. Alternatively, a realistic yield estimate for each field could be predicted using simulation tools (e.g., Morell et al., 2016).

Economic Analysis

The calculated EONR rates for each trial, along with the statistical parameters of each response curve, are presented in Table 1. For 2 of the 14 trials, the quadratic regression between the N rate and the yield was not statistically significant (trials 9 and 10). For these trials, N was applied in the form of manure during the fall previous to the growing season. Since both Adapt-N and the CNC tools accommodate manure application in their calculations and fall manure application on maize fields is a common practice in New York, these trials were not excluded from the study database. Instead, we report the data for all the trials here in the text, followed by results excluding the manured trials in parentheses.

The average EONR value and the range of the 68% confidence interval were 181 ± 29 kg ha^{-1} (194 ± 26 kg ha^{-1}). The range of the EONR within the 68% confidence interval in this

study is higher than the range reported by Jaynes (2011), possibly due to the relatively low number of N rates in trials used for the analysis. The CNC tool recommendations based on the default potential yield were found to typically underestimate the EONR rate, with a mean value of 134 (145) kg ha^{-1} (Fig. 5a). These rates are lower than the calculated EONR (deviation of 39 [49] kg ha^{-1}), even when the confidence intervals around the EONR and the reported uncertainty in the CNC recommendations are accounted for. The average profit loss from the EONR was US$82 (US$90) ha^{-1}, and the RMSE between the CNC recommendations and the EONR was 56 (55) kg ha^{-1}.

Conversely, when the CNC tool was used with a realistic (grower-estimated) potential yield, the CNC recommendations were found to overestimate the EONR by 64 (62) kg ha^{-1}, with an average rate of 245 (256) kg N ha^{-1} (Fig. 5b). The average deviation of the CNC tool from the EONR is higher than the EONR confidence interval and the CNC tool uncertainty, further suggesting that the CNC tool overestimates the EONR when the grower-estimated potential yield is used. The respective RMSE with the EONR was 75 (74) kg ha^{-1}. These high N recommendations for the CNC tool lead to an average profit loss from the EONR of $57 ($57) ha^{-1}.

Adapt-N generated more precise and accurate N recommendations compared with the CNC tool and accurately predicted the EONR with an average N rate of 169 (184) kg N ha^{-1}, an average deviation of 12 (10) kg ha^{-1}, and RMSE of 34 (30) kg ha^{-1}. The respective calculated loss from the EONR was $22 ($21) ha^{-1}, substantially lower than for the CNC

tool with either yield assumption. These results suggest that a dynamic approach to N recommendation offers a significant improvement over the static approach of the CNC tool. Further comparison of these results to other maize N recommendation tools is difficult, as a literature review found very few studies that presented RMSE values with EONR among N recommendation methods. Furthermore, the confidence interval computed for the EONR in our study necessitates some caution when directly comparing our results with other studies. Thompson et al. (2015) found that a crop simulation model performed better than crop canopy reflectance sensing in providing in-season sidedress N recommendations for experimental sites in Missouri, Nebraska, and North Dakota but still had an estimated (by digitizing the published data) RMSE of 70 kg N ha^{-1}, (compared with 34 kg N ha^{-1} for Adapt-N in our study). Adapt-N's ability to predict the EONR was also more precise and was an improvement over most RMSE values

presented for five different Midwest static state regional N recommendations (Kim et al., 2013). These results demonstrate that accounting for in-season weather effects and site-specific growing conditions such as weather can improve the prediction of the EONR.

Effects of Growing Environment on N Rate Recommendations

The growing environment, especially early-season rainfall events (Supplemental Table S2), can have a large effect on soil N availability (van Es et al., 2007b) and the EONR. To illustrate this, Fig. 6 presents Adapt-N recommendations and cumulative rainfall precipitation for trial 13 from planting to sidedress date for 7 yr (2010–2016). Planting date was fixed on 7 May as in the original experiment, 10 kg ha^{-1} was applied as starter with planting, and the sidedress date was assumed in all simulated years at growth stage V6. Two levels of organic matter were simulated (2.5 and 3.5%).

Whereas the CNC tool recommended a fixed rate of 259 kg N ha^{-1} for all the simulated cases, Adapt-N dynamically adjusted for different weather conditions and soil organic matter levels, with recommended sidedress N rates ranging from 140 to 196 kg ha^{-1}. Adapt-N sidedress N rates were positively related to the cumulative early-year rainfall amount, accounting for higher N losses from the soil before sidedress and inversely related to organic matter levels (accounting for N gains from mineralization). The CNC tool's N rates are substantially higher than Adapt-N, even for the wettest years and lowest organic matter levels. This dynamic approach can increase grower profitability by avoiding excessive N applications or recommending more N if needed in wet years, all while minimizing the risk of nitrate N leaching and gaseous N losses to the environment (Sela et al., 2016).

Environmental N Losses

The PNM model was used to simulate environmental N losses (following sidedress until 31 December) on an annual basis for both Adapt-N and CNC N recommendations for all 14 trials (Fig. 7, Supplemental Table S3). Total N losses were divided almost evenly between leaching and gaseous losses for either tool, reflecting the medium texture of the soils at most
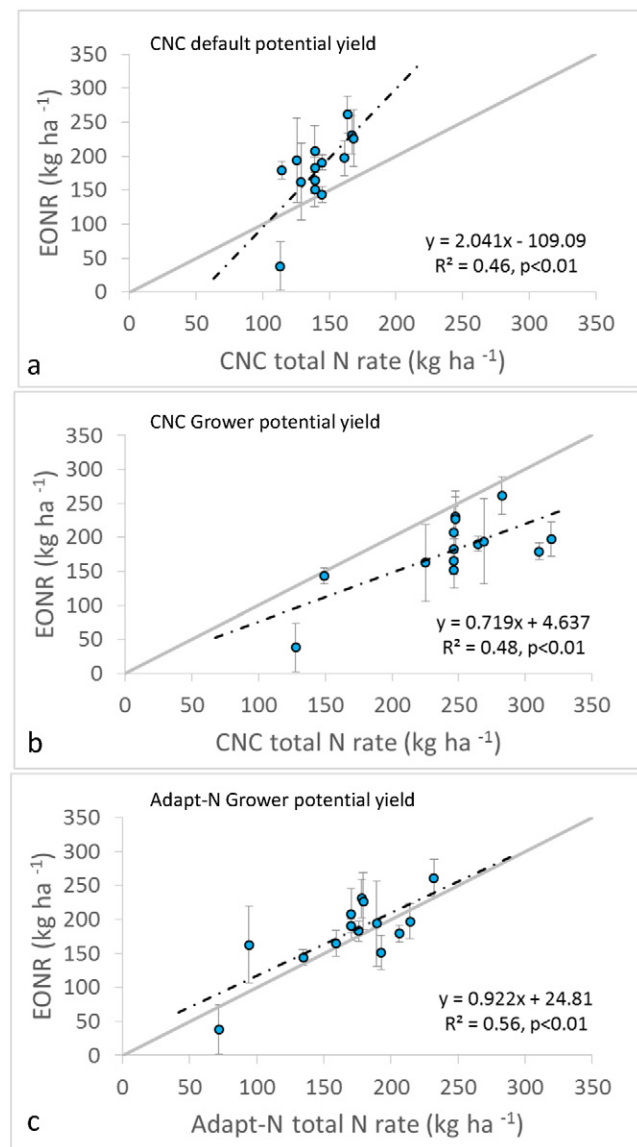
Fig. 5. Comparison between the Economically Optimum Nitrogen Rate (EONR) and (a) Corn Nitrogen Calculator (CNC) recommendations based on the default potential yields, (b) CNC recommendations based on the grower potential yields, and (c) Adapt-N recommended rates. The error bars represent the 1-SD (68%) confidence interval of the EONR. The 1:1 line is presented in gray.
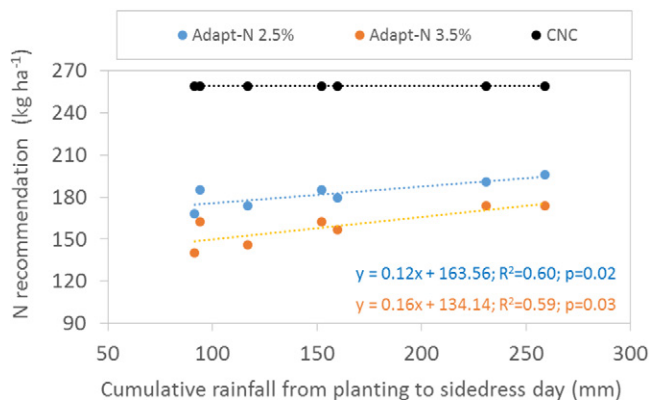
Fig. 6. The effect of early season rainfall amount and variation in soil organic matter on Adapt-N and Corn Nitrogen Calculator (CNC) recommendations for field trial 13 for seven seasons (2010–2016). The CNC recommendations were identical (259 kg ha^{-1}) regardless of seasonal rainfall amount.
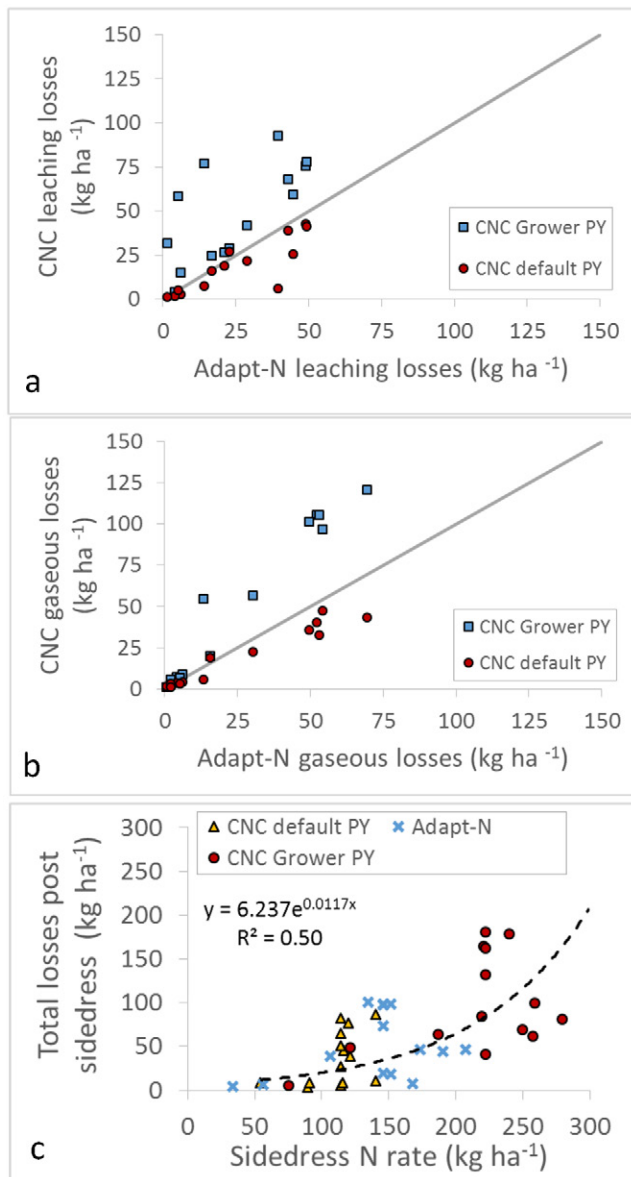
Fig. 7. Adapt-N- versus Corn Nitrogen Calculator (CNC)-simulated (a) leaching and (b) gaseous losses. For the CNC tool, the losses from both the default potential yields (PY) and the grower-estimated potential yields are presented. The 1:1 line is presented in gray. Panel (c) shows the relationship between the total simulated losses post sidedress and the sidedress rate for the two tools.

field sites (mean sand and clay texture fractions of 40 and 16%, respectively). The leaching and gaseous losses simulated for the Adapt-N rates were substantially lower than those for the CNC rates based on the grower-estimated potential yield, with a mean reduction of 24 kg N ha^{-1} for both. This reduction was statistically significant when subjected to a paired t test ($p <$ 0.001).

Conversely, when potential yields for the CNC were derived from the CNC database, simulated post-sidedress leaching and gaseous losses were found higher for the Adapt-N tool, with a statistically significant increase of 6 and 7 kg N ha^{-1} for leaching and gaseous losses, respectively ($p = 0.03$ for leaching and $p = 0.01$ for gaseous losses). However, the modestly lower N losses associated with the CNC rates based on default yields compared with the Adapt-N rates are associated with substantial losses in yield and farmer profitability (Table 1).

The relation between total post-sidedress environmental N losses and sidedress rate (Fig. 7c) showed an exponential relationship between application amount and simulated N losses, in agreement with field studies (McSwiney and Robertson, 2005; Lawlor et al., 2008; Hoben et al., 2011), indicating that the relative amount of N lost to the environment is much larger when excessive N rates are applied. The presented data are a compilation of N recommendations and the respective simulated losses by the two tools across all sites. The amount of N application in which a large increase in N losses will occur is directly related to the N rate in which the maximum yield is achieved in each site and crop N uptake ceases. The amount of N needed to reach maximum yield is, in turn, related to the site-specific seasonal crop N availability, which varies between seasons and fields due to weather, soil, and management effects. Underfertilization does not accrue substantial environmental or economic benefits, while overfertilization increases environmental losses without gaining profitability advantages. The Adapt-N model recommendations were close to the EONR and, as such, minimized both economic and environmental costs.

Conclusion

This study compared two N recommendation tools for maize cropping: CNC, which uses a static Stanford-type approach, and Adapt-N, which employs a fully dynamic model simulation approach. For the 14 trials used in this study, Adapt-N generated more precise N rate recommendations compared with CNC-based estimates in terms of profitability and reconstructing the experimental EONR in the different production environments. The default yield estimates with the CNC tool were found to be unrealistically low compared with both the grower-estimated potential yields and the actual achieved yields at the experimental sites. However, using the CNC tool with realistic potential yields resulted in substantial overestimation of the EONR and large environmental N losses as predicted by Adapt-N. Our results suggest that Adapt-N has the potential to increase farmer profits in New York while reducing environmental N losses compared with a static N recommendation tool.

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