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Comparing Adapt-N to Static N Recommendation Approaches for US Maize Production

H.M. van-Es[1], S, Sela[1], B.N. Moebius-Clune[1], R. Marjerison[1], R. Schindelbeck[1], and D. Moebius-Clune[1]

[1] Soil and Crop Sciences Section, Cornell University, Ithaca, NY

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Abstract. *Large temporal and spatial variability in soil N availability leads many farmers across the US to over apply N fertilizers in maize (Zea Mays L.) production environments, often resulting in large environmental N losses. Static N recommendation tools are typically promoted in the US, but new dynamic model-based tools allow for more precise and adaptive N recommendations that account for specific production environments and conditions. This study compares two static N recommendation tools, one based on the Stanford equation (Cornell University Corn N Calculator) and another based empirical response curves (MRTN), to a dynamic simulation tool that combines weather, soil, crop and management information to estimate optimum N application rates for maize, Adapt-N. The efficiency of the tools in predicting the economically optimum N rate (EONR) is compared using field data from multiple N rate strip trials conducted in New York, Indiana, and Ohio. By accounting for weather and site-specific conditions the precision Adapt-N tool was found to improve the prediction of the EONR. Furthermore, using a dynamic instead of a static approach leads to reduced N application rates, increased profits and resulted in reduced simulated environmental N losses. This study shows that application of precision N management through a dynamic tool such as Adapt-N can help reduce environmental impacts while sustaining farm economic viability.*

Keywords. *Adapt-N; Nitrogen; Models; Stanford Equation; MRTN*.

Introduction

Maize accounts for the largest crop area in the US (27%) and generally receives the highest N inputs of all major crops (average of 157 kg ha^{-1} (USDA_ERS, 2015)). The application of N to maize fields is often in excess of actual crop N needs, resulting in environmental problems such as nitrate leaching into groundwater and streams (David et al., 2010), and emissions of N_2O, a reactive greenhouse gas, into the atmosphere (Millar et al., 2010).

Soil N availability varies in time and space, and is affected (among others) by soil type and texture, N availability from previous crops, organic amendments such as manure applications, and weather effects that drive N losses and availability (van Es et al., 2007). To address this variability and help growers fertilize as close as possible 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 most Midwest US states; proximal crop canopy sensing of crop N deficits (Scharf et al., 2011); and simulation tools such as the Adapt-N tool (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 the efficiency of N uptake by the crop (Stanford, 1973). This 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, it is also (i) very generalized over diverse growing conditions; and (ii) static, thereby neglecting the effect of weather on soil N dynamics and availability within the growing season (van Es et al., 2007). The Cornell University Corn N Calculator (CNC, (Ketterings et al., 2003) is based on the Stanford approach, and has been the standard recommendation tool for maize N fertilization in New York.

The Maximum Return to Nitrogen (MRTN; Sawyer et al., 2006) approach is promoted in several US Corn Belt States. It provides state-wide or regional N-rate recommendations based on multi-year and multi-location N-rate field trials and an average economic N response rate based on yield response curves. Like the Stanford approach, these recommendations are highly generalized over large areas and are static, i.e., not adaptive to seasonal growing conditions.

Adapt-N (Melkonian et al., 2008) is a web-based commercial N recommendation tool for maize (adapt-N.com), which applies a dynamic approach to the mass balance equation. It accounts for spatial and temporal variation in weather, which updates the soil and crop N availability in the mass balance equation on a daily basis.

This study compares Adapt-N to the static Stanford-type CNC tool and the MRTN approach to evaluate whether accounting for weather effects and field-specific conditions improves N rate recommendations and can reduce environmental N losses. It had the following objectives:

a) To compare the CNC, MRTN and Adapt-N tools in estimating the EONR rate observed in on-farm strip trials in New York, Indiana, and Ohio;

b) To compare the sidedress N recommendation rates and relative profits of these tools; and

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

Methods

Adapt-N: Adapt-N is a cloud-based precision N recommendation tool for maize (Melkonian et al., 2008). It was developed by Cornell University and is now commercially available to farmers in the US (Adapt-N.com). It is based on the Precision Nitrogen Management (PNM) model (Melkonian et al. 2005), which in turn 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). An important feature of Adapt-N is its dynamic access to gridded high-resolution (4x4 km) weather data (precipitation, max-min temperature and solar radiation), which allows for field-specific and in-season adjustments to N application based on plant need. The weather data are derived from routines using the US National Oceanic & Atmospheric Administration's Rapid Update Cycle weather model (temperature) and operational Doppler radars (precipitation). 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. The Adapt-N tool generates precision 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 under-fertilization vs. over-fertilization (adapt-N.com).

Cornell University Corn N Calculator (CNC): The CNC tool, an Excel-based version of the Stanford-type model for NY 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 applications or rotations. The tool assumes contributions of N from organic matter and efficiency factors based on soil type. It generates N rate recommendations according to (Ketterings et al., 2003):

$$N_{rate} = (Y_p * 10.1 – N_{soil} – N_{rot}) / (E_f /100) \quad [2]$$

Where N_{rate} is the N recommendation; Y_p is the yield potential (Mg ha^{-1}); N_{soil} is a soil-specific credit accounting for mineralization of soil organic matter (kg ha^{-1}); N_{rot} is a credit accounting for soil N availability from various types of previously rotated crops (kg ha^{-1}) if applicable, and E_f is a nitrogen uptake efficiency factor that varies by soil type and drainage.

The CNC tool facilitates the use of a default yield potential from an internally linked database (based on soil type and drainage level), or the user can manually enter a value. For this analysis we generated CNC-based N recommendations based on realistic yields (grower-estimated based on historical yield performance).

MRTN: The Maximum Return to N (MRTN) method is also a static approach which is based on the average economically optimum nitrogen rate (EONR) from multi-site and multi-year field trial data and is promoted in most Midwestern US states (Sawyer et al., 2006). MRTN recommendations are highly generalized into state-wide or regional N rate recommendations with adjustments generally limited to prices for grain and fertilizer and rotation effects.

Field Trials

For the CNC comparison, field data from sixteen site-years of field scale strip trials at multiple locations during the 2011-to-2015 growing seasons in NY were used to compare the sidedress N recommendations generated by the CNC and Adapt-N tools. The trial sites were located in Central-Western NY and Northern NY on a range of soil types. The strip trials used a split N management approach (i.e. a starter amount at planting followed by an in-season application). While the Adapt-N tool was primarily developed for sidedress N recommendations, the CNC tool generates a total N recommendation for the field conditions regardless of nutrient management approach.

In each trial, multiple N rate applications were applied in replicated, spatially-balanced randomized complete block designs, allowing the respective EONR of each trial to be calculated. Half of the trials had three N rates applied (usually zero, an intermediate and high rate of N), while others had five or six N rates. Trials had three or four replicates for each rate, except for three (19%) that had only two replicates for all rates, and another five trials (31%) that had two or three replicates depending on the rate.

For the MRTN comparison, 23 strip trials were conducted during the 2013 growing season in Indiana and Ohio. All were implemented on production fields of commercial farms in Northeast and North-Central Indiana, and Northwest Ohio. Each trial included four nitrogen rates, which were applied through a combination of early-season and sidedress applications. The rates generally included 112, 168, 224, and 280 kg ha^{-1} of nitrogen or 140, 196, 252, and 308 kg ha^{-1}, mostly decided based on historical information on optimum N rates. Trials involved three or four replications. The experimental units were implemented in spatially balanced complete block designs where the strips extended along the length of a field. The previous year crop was soybean, except in two cases that involved wheat, and one with maize. The MRTN rate was based on the published recommended rate for the appropriate regions in Indiana and Ohio, as determined by the N rate calculator (http://extension.agron.iastate.edu/soilfertility/nrate.aspx), which was 224 and 197 kg ha^{-1}, respectively for IN and OH.

Quadratic functions were used to fit the yield vs. N rate data and calculate the EONR using code written in the R software for statistical computing (https://www.r-project.org/). Prices of \$1.098 kg^{-1} and \$0.195 kg^{-1} for N fertilizer and maize grain, respectively, were assumed, corresponding to the mean US prices during the years 2007-to-2013 (USDA_NASS, 2015b). It should be emphasized that the EONR represents the optimum nitrogen rate that is determined at the end of the growing season. It is therefore a retrospective reference point that can be used for evaluation of N recommendations that were made early in the season when fertilizer needs to be applied.

Composite soil samples were collected in the field and soil texture and organic matter percentage were determined using a rapid soil texture method (Kettler et al., 2001) and Loss-on-Ignition (Nelson and Sommers, 1996), respectively. Both the CNC and the Adapt-N mass balance approaches are driven by the potential yield, and its estimation is critical to accurate N rate recommendations. Therefore, to eliminate the cases of user-input errors associated with underestimation of the actual potential yield for each field, in three cases (19%) where the achieved yield in the experiment was more than 1.25 Mg ha^{-1} higher than the potential yield supplied by the grower, the potential yield estimate was corrected and set as (achieved yield – 1.25 Mg ha^{-1}). This correction does not fit in hindsight the potential yield to the achieved one, but instead leaves a difference accounting for common grower estimation errors.

Estimation of Environmental Losses

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 Adapt-N tool. The trials used for the analysis had different N management approaches, depending on collaborator preferences, such as pre-plant N or manure applications in different quantities. While these management decisions might have led to high simulated N losses prior to sidedress time, these losses would have been the same for the Adapt-N and the CNC tools. Therefore, to compare the simulated environmental losses resulting from the Adapt-N or the CNC sidedress recommendations, only the environmental fluxes that occurred after the application of sidedress N and until the end of the year (Dec 31st) are reported.

Results and Discussion

Adapt-N vs. CNC

Using realistic, grower-estimated potential yield, the CNC recommended on average 239 kg N ha^{-1} for non-manured trials and 131 kg N ha^{-1} for manured trials. The average recommendation rate for Adapt-N was 158 and 45 kg N ha^{-1} for the non-manured and manured trials, respectively, a substantial decrease of 81 (51%) and 86 kg ha^{-1} (65%) from the CNC rate.

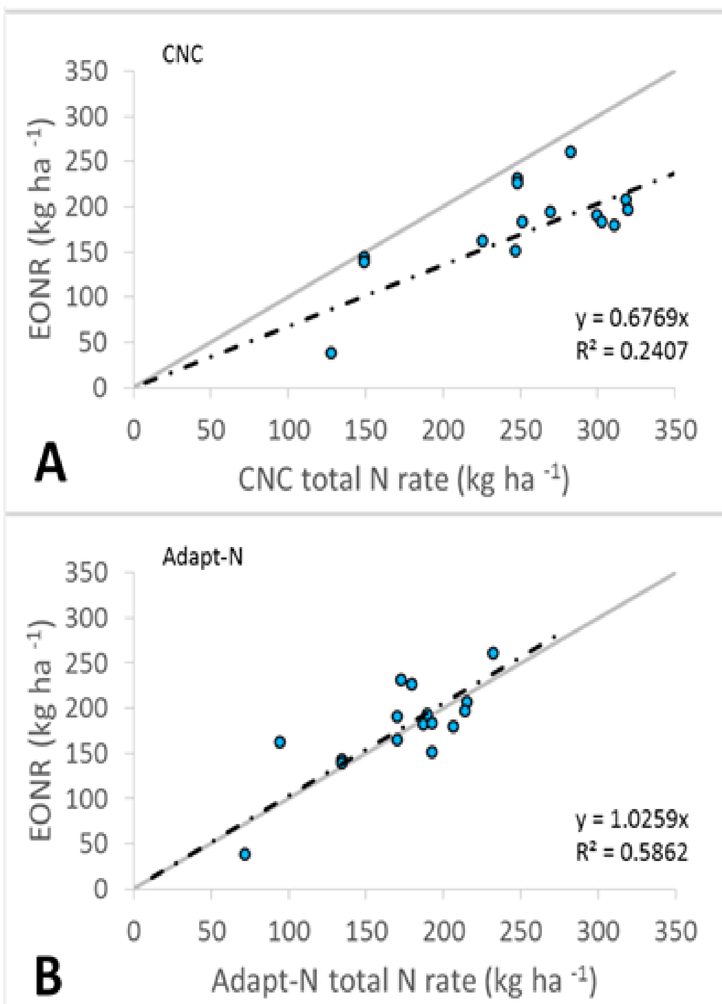

Figure 1. CNC (A) and Adapt-N (B) recommendations compared to the EONR using multi-rate trials in New York.

Overall, the CNC recommendations substantially overestimated the optimum rate, by an average of 257 kg ha^{-1}, or 79 kg ha^{-1} above the EONR, and the average profit loss from the EONR was \$83 ha^{-1} (Fig. 1A). Adapt-N accurately predicted the EONR with an average N rate of 172 kg ha^{-1}, only slightly below the 178 kg ha^{-1} calculated value of the EONR (Fig. 1B). Consequently, the average profit loss from the EONR was \$19 ha^{-1} for Adapt-N, a significant improvement over the losses from the CNC rates. The differential profit between Adapt-N and CNC was \$64 ha^{-1}. By basing recommendations on local conditions, Adapt-N improved the accuracy and precision of the N recommendations in these trials, and achieved RMSE values of 31 kg ha^{-1}.

Environmental losses, leaching and gaseous, were estimated using Adapt-N simulations. Adapt-N rates reduced on average 29 kg ha^{-1} of leaching losses (53% reduction) and 24 kg ha^{-1} of gaseous losses (54% reduction) compared to the CNC rates with realistic yields.

Adapt-N vs. MRTN

For the Indiana and Ohio trials, the Adapt-N recommendations similarly estimated the range of EONR values with small bias or deviation from a 1:1 relationship (b=1.02; R^2=0.42; Fig. 2), while the static MRTN recommendations were fixed at 224 and 197 kg ha^{-1} for Indiana and Ohio, respectively. The mean EONR for these sites was 209 kg ha^{-1}, while the mean Adapt-N recommendation was very close at 198 kg ha^{-1}. Profit differences between Adapt-N and MRTN and differences in environmental losses are still being analyzed.

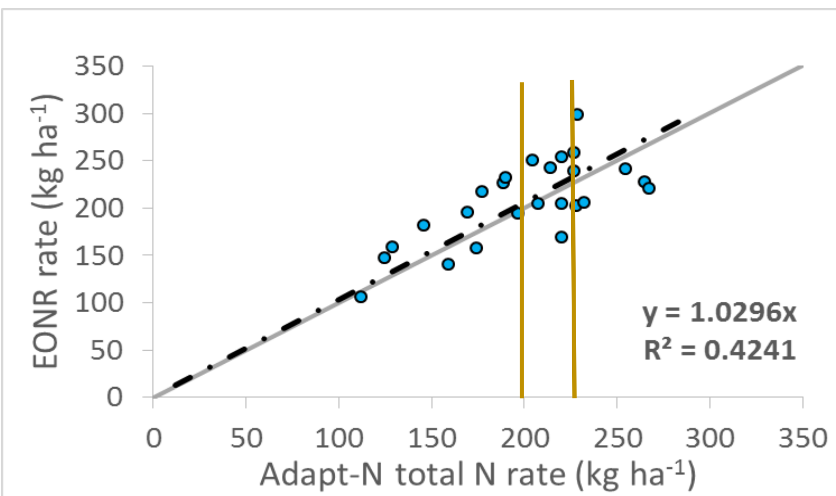

Figure 2. Comparison between the Adapt-N recommendations and the EONR using multi-rate trials in IN and OH. The vertical lines refer to the static MRTN rates in IN and OH (224 and 197 kg ha^{-1}, respectively).

Conclusions

This study presents a comparison between three N recommendation tools for corn nutrient management: CNC and MRTN, which use static approaches, compared to the highly adaptive Adapt-N approach. Adapt-N recommendations were found to account for the different production environments and weather effects, and were therefore superior to those of the CNC and MRTN in terms of reconstructing the experimental EONR under the different management scenarios. It also suggests that adoption of a dynamic N recommendation tool can significantly increase farmers' profits while reducing environmental N losses.

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