Evaluation of Crop Model Based Tools for Corn Site-Specific Nitrogen Management in Nebraska

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A paper from the Proceedings of the
15th International Conference on Precision Agriculture
June 26-29, 2022
Minneapolis, Minnesota, United States

Abstract.

There is a critical need to reduce the nitrogen (N) footprint from corn-based cropping systems while maintaining or increasing yields and profits. Digital agriculture technologies for site-specific N management have been demonstrated to improve nitrogen use efficiency (NUE). However, adoption of these technologies remains low. Factors such as cost, complexity, unknown benefits, and high data input requirements were recognized as barriers for adoption. Grower's hands-on experience with these technologies coupled with targeted research could be used to promote adoption and quantify the economic and environmental benefits of these technologies. Our objectives were to (a) evaluate the impact of commercially available crop model-based N tools on yield, NUE and profit, and (b) to compare crop model-based N recommendations against the grower's typical N management and the observed economic optimal N rate (EONR). We evaluated two commercially available crop model-based N tools for directing variable rate applications in irrigated and rainfed fields in Nebraska. During the 2021 growing season, eight on-farm randomized strip trials compared crop model-based N tools versus the grower's traditional management. A set of blocks with increased N rates were applied in the field within contrasting management zones using the growers' variable rate application technologies. These N blocks were used to estimate the EONR. The performance of crop-model based N tools varied by site and management zone. The EONR for a subset of three sites was on average 195 kg N ha^{-1} and ranged from 142 to 269 kg N ha^{-1}. The range of EONR observed indicated that a variable rate N application may be required to achieve the optimized N fertilizer rate. Participating growers were performing at a high N use efficiency (more than 50 kg yield kg N^{-1}). Quantifying the performance of crop model-based N tools on corn production is a vital step towards increasing adoption of the technology among growers *and to ensure sustainable economic and environmental benefits.*

Keywords. crop models, nitrogen, corn, site-specific management, technology

Introduction

Nitrogen (N) fertilizer is necessary to attain high corn yields (*Zea mays L.*) and maintain farmer profitability. However, estimation of the economic optimum N rate (EONR) remains a challenge. The challenge is related to the biophysical complexity driving soil N mineralization, crop uptake, and N loss (Lory and Scharf, 2003; Meisinger, 1984). The complexity is further increased by the spatial variability in soil properties and temporal variability in weather which affect those processes (Tremblay et al., 2012). The uncertainty around the EONR coupled with typically inexpensive N fertilizer relative to the magnitude of crop N response often leads to overapplication (Vanotti & Bundy,1994). Overapplication decreases profitability and increases the potential for N loss that contributes to environmental degradation (van Es et al., 2007).

Precision N management could contribute to a more sustainable intensification of corn-based systems by increasing or maintaining yields and increasing nitrogen use efficiency (NUE) while reducing environmental N losses. Multiple N fertilizer rate decision tools have been developed and tested within the United States (Morris et al., 2017). However, simultaneous site-specific N management comparisons of multiple tools across various environmental conditions has been limited (Ramson et al., 2020).

Among existing tools, crop models-based N tools are now widely commercially available and provide an alternative for specific N management (Bobryk et al., 2016; Sela et al., 2016). Process based crop models account for the effect of weather, management practices, genetics, soil, and their interactions on crop and soil dynamics. Growers and crop consultants could simulate potential weather scenarios during a growing season and estimate the impact on N loss, N mineralization and optimal N rates (Setinoyo et al., 2011). Despite their benefits, adoption is low and there is a lack of regional and local testing.

Several crop growth models currently being used in the US include Maize-N (Setiyono et al., 2011), Adapt-N (Melkonian et al., 2008), Granular Agronomy (https://granular.ag/agronomy), and FieldView Pro (https://www.climate.com). These commercial N tools allow for a continual model refinement based on field and weather factors (He et al., 2017). Drawbacks of these models include cost and time associated with required inputs. The cost associated with the use and set up of the model is usually passed to the farmer (Morris et al., 2017). For commercial N model services, there may also be a consultant provided with the service built into the fee.

In this work, we evaluated two commercially available crop model-based tools for directing N variable-rate applications (VRA) in irrigated and rainfed fields in Nebraska. During the 2021 growing season, eight on-farm randomized strip trials compared commercial crop model-based N tools versus the grower's traditional management. In addition, N blocks with incremental rates of N were applied in the field within contrasting management zones. These N blocks were used to characterize the yield response to N and to estimate the EONR. Our objectives were to (a) evaluate the ability of commercially available crop model-based N tools to increase yield, NUE and profit compared to the grower's typical N management, and (b) to evaluate crop model-based N recommendations compared to the observed EONR in contrasting management zones. Quantifying the performance of crop model-based N tools on corn production is a vital step towards increasing adoption among growers and to ensure economic and environmental benefits.

Materials and Methods

Commercial Crop-model Set-up

Two commercially available crop model-based N tools were tested across the state of Nebraska: Granular a subsidiary of Corteva Agriscience™ (Model_G) and Adapt-N by Yara North America, Inc (Model_A; Fig.1A). Model_G was set-up by a Granular Certified Service Agent (CSA) or a company representative. This model utilized an enhanced digital soil map (DSM) termed Environmental Response Unit (ERU), which integrates NRCS SSURGO, high resolution elevation data and watershed boundaries (NRCS stuff, 2014).

Model_A was set up by the university team and growers were able to review the recommendation and request changes before implementation. A gridded setup was used for the VRA in Model_A. Management zones based on yield, elevation, and organic matter were used to define expected yields. When available the analysis of organic matter and pH from soil samples was used. When information was not available the option of syncing with Soil Survey was used instead (NRCS, 2021).

On-Farm Research Experimental Design

The experimental design consisted of strip-trials arranged in a randomized complete block design with a minimum of four replications per site. There were two treatments, the grower's traditional N management and the crop model-based N tool recommendation. Grower's traditional N management varied from fall, pre-plant and split-applications. Model-based N recommendation was directed by either Model_A or Model_G and was applied using VRA. As-applied data was used to verify the quality of VRA implementation and determine areas of the field to exclude before further analysis (Fig. 1C). A total of 11 sites were implemented and eight sites were kept for analysis based on data and trial implementation quality (Table 1).

To estimate site-specific EONR, two to fours sets of N rate blocks were established in contrasting management zones using VRA (Fig.1B). Within each block, four to six N rates were applied with total N ranging below and above growers typical N rates.

Table 1. Sites planting date, county, soil type, and grower's and model nitrogen timing and fertilizer source.

ID	PLANTING DATE	COUNTY	SOIL TYPE	GROWER'S N TIMING AND N SOURCE*	MODEL'S N TIMING AND N SOURCE*
DSTE	4/30/21	Richardson	Silt loam	Fall anhydrous	Fall anhydrous
MDIB	4/27/21	Hall	Silt loam	Side dress N UAN	Side dress N UAN
DLOB	5/1/21	Wayne	Silt loam – loamy fine sand	Side dress N UAN	Side dress N UAN
SWOL	4/24/21	Kearney	Silt loam	Side dress N UAN	Side dress N UAN
NTHO	4/29/21	Brown, KS	Silty clay loam	Fall anhydrous	Fall anhydrous
DBAT	4/29/21	Dawson	Silty clay loam	Side dress N UAN	Side dress N UAN
JWAL	4/27/21	Lincoln	Fine sand – fine sandy loam	Side dress N UAN	Side dress N UAN
KMEDII	4/23/21	Seward	Silt loam	Fall anhydrous	Side dress N UAN

*Other timings and sources or fertilizer were used such as pre-plant N, at-planting, strip-till, and fertigation depending on the site.

Data collection and processing

During the growing season, soil and tissue samples were taken from the N blocks. All treatments were monitored with high resolution aerial imagery (Fig. 1D). As-applied fertilizer maps were used to evaluate the accuracy of fertilizer application and yield monitor data was used to analyze differences between treatments (Fig.1E). Yield monitor data and as-applied maps were cleaned to eliminate outliers and application errors (Fig. 1F). Treatment layout, as-applied maps, and yield monitor data were aggregated using geo-spatial processing in R software (R core, 2021).

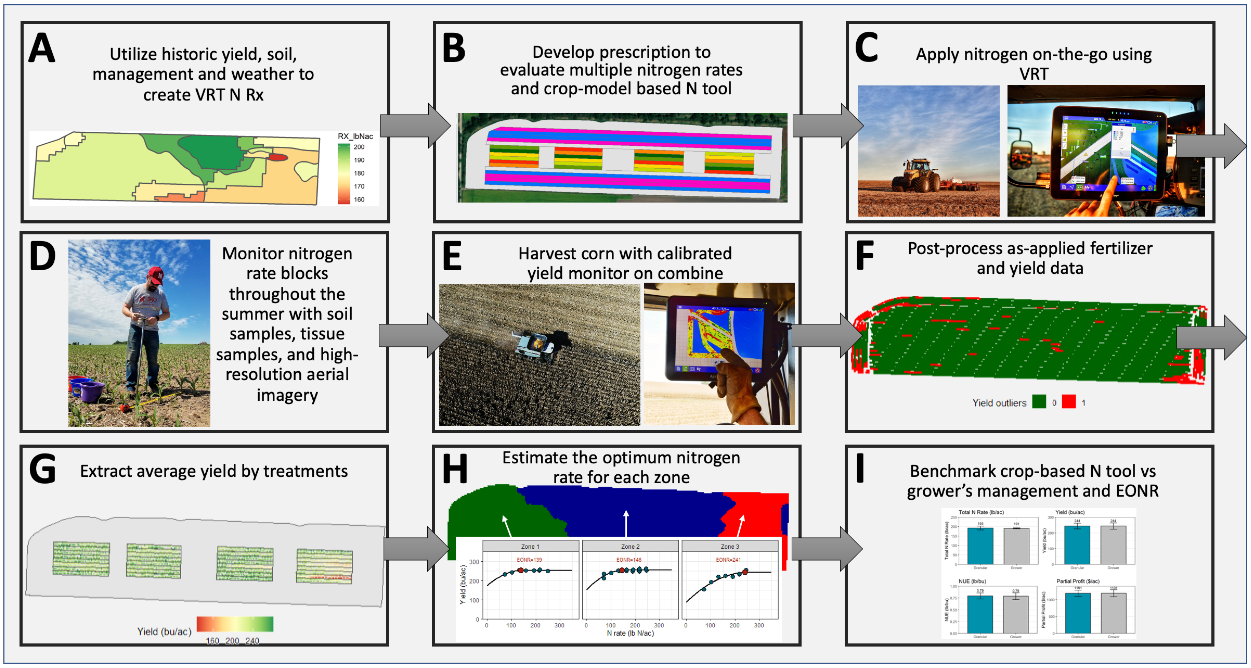

Fig. 1. Diagram of the activities and processes involved to compare crop-model based nitrogen (N) recommendation tools with growers' traditional N management and the economic optimal N rate (EONR). A) Model based variable rate technology (VRT) N recommendations prescription (Rx); B) strip-trials arranged in a randomized complete block design with grower's traditional N management (blue strip) and a crop model-based N tool recommendation (pink), and replicated N blocks with incremental N rates (red to green blocks).

Data analysis

Yield, total N, NUE and profit were summarized per treatment and management zones when available. Analysis of variance was performed to test significant differences between treatment means at alpha = 0.1. Marginal net return was calculated based on $0.20 per kg of corn and $0.88 per kg of N.

Nitrogen rate blocks were used to calculate the EONR in distinct zones using linear, quadratic or quadratic-plateau models at the prices used for marginal return (Fig.1H). The model that best fit the observed data was used for further analysis. The EONR was calculated from the N response equations by setting the first derivative of the fitted response curve equal to the corn and N fertilizer price ratio (US$ 0.22 kg^{-1} grain: US$ 0.88 kg^{-1} N).

Results

Yield, total N, NUE and Profit

The treatment models had a significantly higher N rate than the growers' N rate for five sites (Fig. 1). Two of those sites (DBAT and KMEDII) resulted in a significant increase in profit and yield for the model treatment (Fig. 1). Differences were explained by a higher N rate that resulted in a significant increase in yield (175 to 430 kg ha^{-1}) compared to the grower treatment. In the remaining three sites (JWAL, NTHO, SWOL), the models recommended on average 25 kg N ha^{-1} more than the grower's applied resulting in an average yield gain of 168 kg ha^{-1}, but not significant. Average yield difference in those cases did not significantly impact profit. For one site (MDIB), the model treatment had a significantly lower N rate than the grower (36 kg N ha^{-1}). At this site, there was no significant difference in yield or profit between the model and grower's treatment (Fig. 1).

NUE across sites for grower's management was superior or similar to the crop modeling N tools, except for MDIB site (Fig. 2). Although in some sites (e.g., JWAL) higher N rate resulted in an increase in yield, the increase in yield was not high enough to result in an increase in NUE. Average grower's NUE was 60 $\pm$ 10 while the model's NUE was on average 81 $\pm$15 and 52 $\pm$ 7 kg grain kg N^{-1} for Model_A and Model_G, respectively (Fig. 1 and Fig. 2). Overall participating growers were operating at high NUE compared to the typical N efficiencies documented for the state on irrigated (58 kg yield kg N^{-1}) and rainfed (62 kg yield kg N^{-1}) fields (Tenorio et al., 2020).

Only two sites (DLOB and DSTE) showed no significant differences between model and grower's management in all the measured metrics. At these sites, the average N rate for the model treatment was very similar to the grower's management. However, in both cases, the grower's management used a flat rate of N across the field, while the model used a VRA approach. Further analysis will investigate the impact of the VRA model approach in site-specific locations within the sites.

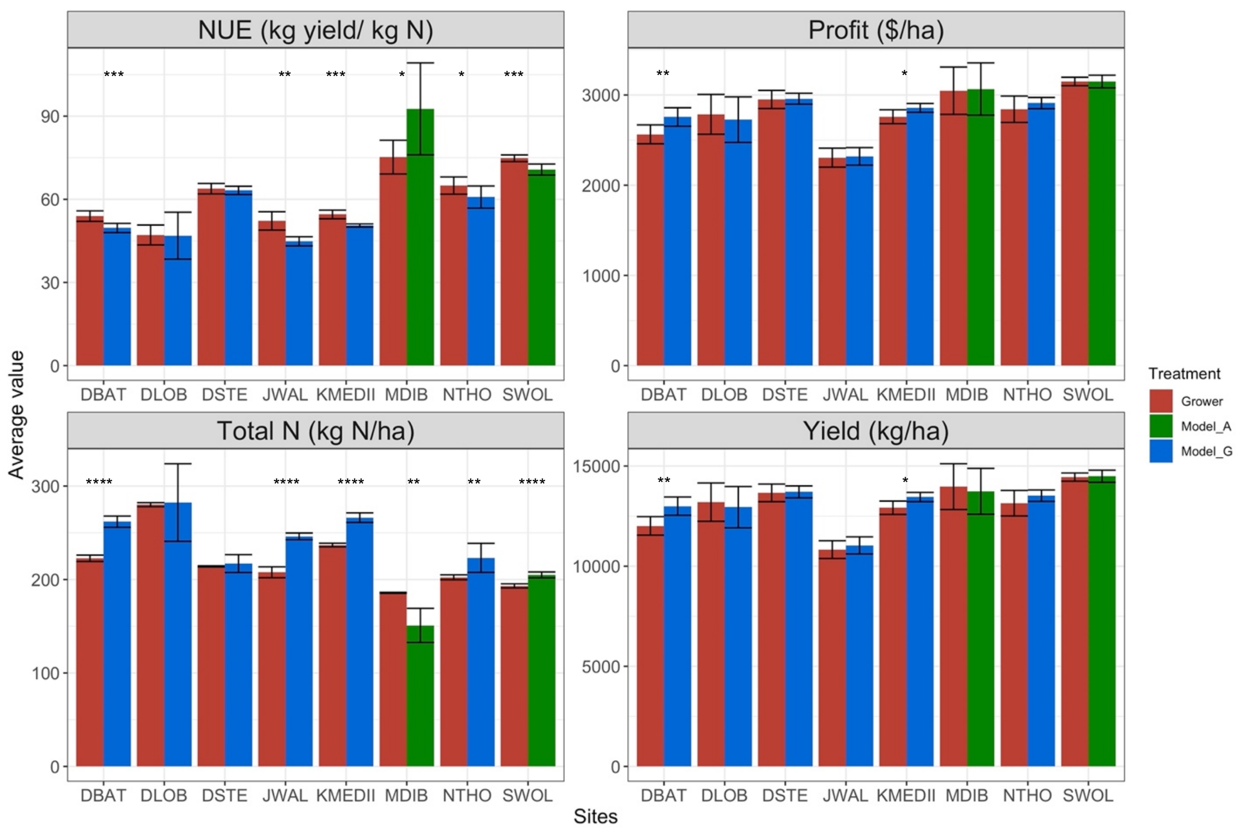

Fig 1. Nitrogen use efficiency (NUE), partial profit (profit), total nitrogen (TotalN), and Yield for grower's and crop-model based nitrogen management (Model_A, Model_B) across site in Nebraska. ** p<0.1; ** p<0.05; ***p<0.01; **** p<0.001*

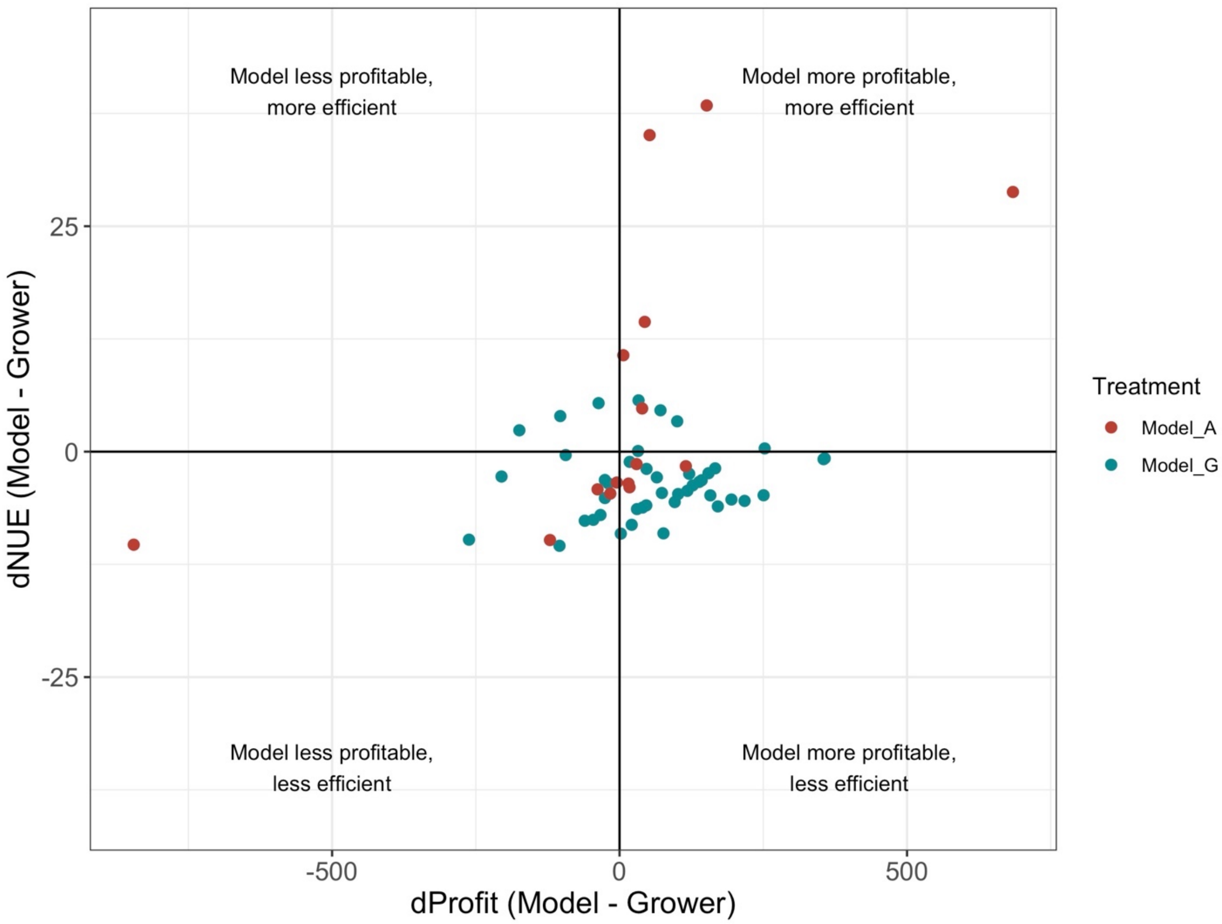

Fig 2. Relationship between delta profit ($/ha) and delta nitrogen use efficiency (kg grain/ kg N) for crop-model based nitrogen management (Model_A, Model_B) across site in Nebraska. Differences were calculated as model minus grower treatment.

Site-Specific Crop-Model Based Tools Performance

Three of the eight sites were further analyzed by management zones and compared to the observed EONR (data not shown). Across all sites and management zones, there was no significant differences in profit or yield between models and grower management (Fig. 1). However, treatments resulted in significantly different total N rate per zone (Fig. 3). For the NTHO site, two zones received between 9 to 17% more N than grower's N rate while at the DSTE site one zone received 2% and 4%, higher and lower N rates, respectively, than the grower's rate.

In contrast, MDIB site model-based N recommendations were consistently lower than the grower's N rate (21%). At MDIB Model zone 1, the observed EONR was 30% more than the Model_A recommendation. This was likely due to the lower expected yield determined in this zone. An expected yield of 12,600 kg ha^{-1} for zone 1 and 16,380 kg ha^{-1} for zone 2 was the input for Model_A. Expected yield was determined using historical yields and the grower's experience. Zone 1 yielded higher than expected (approximately 15,000 kg ha^{-1}). This demonstrates the importance of an accurate and informed expected yield and model inputs.

In DSTE site, Model_G recommended significantly less N in zone 3 relative to the grower and the observed EONR. Lower yields compared to the rest of the field were estimated for that zone and used in the model. The field was flooded following a 220 mm rainfall in less than 24 hours in June 2021. Zone 3 in this field remained underwater the longest likely resulting in more leaching and denitrification, thus, high EONR (268 kg N ha^{-1}). There was no significant differences in yield or profit between treatments in this zone but fertilization with the observed EONR would result in an increase yield of ~945 kg ha^{-1}.

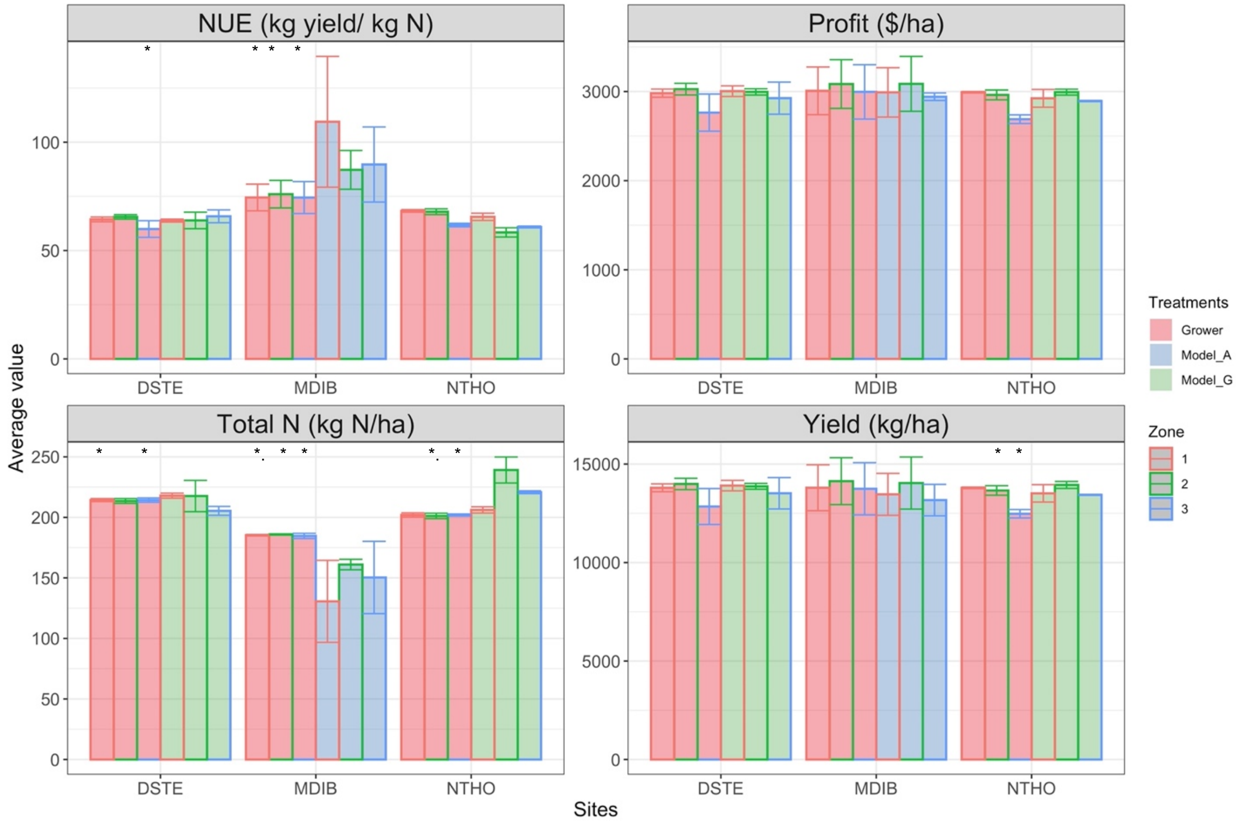

Fig 3. Nitrogen use efficiency (NUE), partial profit (profit), total nitrogen (Total N), and Yield for grower's and crop-model based nitrogen management (Model_A, Model_G) across site and zones in Nebraska. Filling colors indicate the treatment and outside line colors indicate the zone. * *p<0.1*

Economical Optimal N Rates

The EONR for three sites analyzed by management zones was on average 195 kg N ha^{-1} and ranged from 142 to 269 kg N ha^{-1}. The range of EONR observed in this subset of sites indicated that a VRA N application may be required to optimize N fertilizer use.

The performance of grower and model-based N management compared to the observed EONR varied by site and management zone. For example, on average across sites, the observed zone-specific EONR was underestimated by 40 kg N ha^{-1} or overestimated by 45 kg N ha^{-1} when using crop model-based N tools. We recognized that in some cases underestimation of the EONR was related to inaccurate expected yields within zones (MDIB, zone 1). This highlights the importance of site-specific information to better utilize crop-model based N tools.

Conclusion

Our preliminary results showed that the performance of crop-model based N tools is site specific as it varied field by field. These findings demonstrate the difficulty of estimating the EONR and that while crop model-based N tools may be successful on individual fields they were not consistently reliable over a variety of management, soils, and weather conditions in this study.

It is worth noting that all participating growers performed in a high NUE range (more than 50 kg yield kg N^{-1}). Grower's NUE across sites was superior or similar to the crop modeling tools. Thus, we expect that from the overall good performance of the tools, widespread adoption by growers operating at lower NUEs could have a bigger impact by improving their NUEs without significant profit or yield losses.

Our study suggested that data inputs such as yield expectations and management zone delineation were important factors to consider when using crop-model based N tools. Further testing is planned for 2022 and 2023 season across the state. Findings from this research will support N precision technology adoption by the growers.

Acknowledgements

This project is funded by USDA-NRCS Conservation Innovation Grants, On-Farm Conservation Innovation Trials, award number NR203A750013G014. We want to thank the cooperating growers for participating in this project and the industry partners for supporting technology use and access.

References

Bobryk, Christopher W., D. Brenton Myers, Newell R. Kitchen, John F. Shanahan, Kenneth A. Sudduth, Scott T. Drummond, Bob Gunzenhauser, and Nadilia N. Gomez Raboteaux. "Validating a digital soil map with corn yield data for precision agriculture decision support." Agronomy Journal 108, no. 3 (2016): 957-965.

Cassman, K. G., G. C. Gines, M. A. Dizon, M. I. Samson, and J. M. Alcantara. "Nitrogen-use efficiency in tropical lowland rice systems: contributions from indigenous and applied nitrogen." Field Crops Research 47, no. 1 (1996): 1-12.

He, D., Wang, E., Wang, J., & Robertson, M. J. (2017). Data requirement for effective calibration of process-based crop models. Agricultural and Forest Meteorology, 234–235, 136–148. https://doi.org/ 10.1016/j.agrformet.2016.12.015

Lory, J. A., & Scharf, P. C. (2003). Yield goal versus delta yield for predicting fertilizer nitrogen need in corn. Agronomy Journal, 95, 994999. https://doi.org/10.2134/agronj2003.9940

Meisinger, J. J., Schepers, J. S., & Raun, W. R. (2008). Crop nitrogen requirement and fertilization. In J. S. Schepers, & W. R. Raun (Eds.), Nitrogen in agricultural systems (pp. 563–612). Madison, WI.: Agron. Mon. 49. ASA, CSSA, SSSA.

Melkonian, J. J., van Es, H. M., DeGaetano, A. T., & Joseph, L. (2008). ADAPT-N: Adaptive nitrogen management for maize using highresolution climate data and model simulations. In R. Kosla (Ed.), Proceedings of the 9th International Conference on Precision Agriculture, July 20-23, 2008, Denver, CO.

Morris, T. F., Murrell, T. S., Beegle, D. B., Camberato, J. J., Ferguson, R. B., Grove, J. … Yang, H. 2017. Strengths and limitations of nitrogen rate recommendations for corn and opportunities for improvement. Agronomy Journal,110,1–37. https://doi.org/10.2134/ agronj2017.02.0112

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL. https://www.R-project.org/.

Ransom, Curtis J., Newell R. Kitchen, James J. Camberato, Paul R. Carter, Richard B. Ferguson, Fabián G. Fernández, David W. Franzen et al. "Corn nitrogen rate recommendation tools' performance across eight US midwest corn belt states." Agronomy Journal 112, no. 1 (2020): 470-492.

Setiyono, T. D., Yang, H., Walters, D. T., Dobermann, A., Ferguson, R. B., Roberts, D. F., … Cassman, K. G. (2011). Maize-N: A decision tool for nitrogen management in maize. Agronomy Journal, 103, 1276–1283. https://doi.org/10.2134/agronj2011.0053

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov/. Accessed [2021].

Tenorio, Fatima AM, Eileen L. McLellan, Alison J. Eagle, Kenneth G. Cassman, Daryl Andersen, Marie Krausnick, Russell Oaklund, John Thorburn, and Patricio Grassini. "Benchmarking impact of nitrogen inputs on grain yield and environmental performance of producer fields in the western US Corn Belt." Agriculture, Ecosystems & Environment 294 (2020): 106865.

Tremblay, N., Bouroubi, Y. M., Bélec, C., Mullen, R. W., Kitchen, N. R., Thomason, W. E., … Ortiz-Monasterio, I. (2012). Corn response to nitrogen is influenced bysoil texture andweather.AgronomyJournal, 104, 1658–1671. https://doi.org/10.2134/agronj2012.0184

van Es, H. M., Kay, B. D., Melkonian, J. J., & Sogbedji, J. M. (2007). Nitrogen management for maize in humid regions: Case for a dynamic modeling approach. In T. Bruulsema (Ed.), Managing Crop Nitrogen for Weather: Proceedings of the Symposium "Integrating Weather Variability into Nitrogen Recommendations," Indianapolis, IN. 15:6-13. Plant Nut. Inst. Publ.

Vanotti, M. B., & Bundy, L. G. (1994). An alternative rationale for corn nitrogen fertilizer recommendations. Journal of Production Agriculture, 7, 243–249. https://doi.org/10.2134/jpa1994.0243