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Evaluation of Nitrogen Recommendation Tools for Winter Wheat in Nebraska

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Abstract. *Attaining both high yield and high nitrogen (N) use efficiency (NUE) simultaneously remains a current research challenge in crop production. Digital ag technologies for site-specific N management have been demonstrated to improve NUE. This is due to the ability of digital technologies to account for the spatial and temporal distribution of crop N demand and available soil N in the field which varies greatly according to soil properties, climate, and management. In addition, winter wheat protein content is highly influenced by the amount and timing of N application. Despite documented benefits of site-specific N management, N in winter wheat is still typically uniformly applied to fields without considering within-field variability. Available tools for site-specific N management in winter wheat have not been extensively evaluated in rainfed and irrigated fields in Nebraska. In this research, we tested commercially available N tools for in-season, variable-rate N rate management, including active crop canopy sensors and satellite-based tools. During the 2020-2021 growing season, we conducted 11 on-farm randomized strip trials comparing a precision N management (SENSE) versus the grower's N management. A subset of three sites were analyzed from these trials. Additionally, N blocks with increasing rates of N were applied in the field within contrasting management zones. Yield from N blocks were used to estimate the economical optimum nitrogen rate (EONR). The estimated EONR allowed to benchmark the accuracy with which the tools recommended N. The objectives were to (a) evaluate the performance of commercially available N tools and N management strategies in winter wheat yield, NUE, protein content, and partial profit, and (b) to compare them against the typical grower's N management, observed EONR and the University of Nebraska-Lincoln (UNL) recommendation tool. Multi-spectral images, soil sampling, canopy cover, and protein content were collected in a subset of the on-farm trials. Overall, grower's N management was at a fixed* *rate and ranged from 68 to 126 kg N ha^{-1} while the evaluated tools provided a variable rate application that ranged from 78 to 137 kg N ha^{-1} across fields. Results showed active canopy sensors performed well for N recommendations in winter wheat when compared with the observed Grower's N management, increasing on average percentage of Yield (6.7%), Protein (4.1%), Partial Profit (6.3%), however decreasing on NUE (12.7%) across the three sites. This study showed that the on-farm research method was successful at testing and collecting data from sensor-based N management strategies for winter wheat in Nebraska.*

Keywords. *Site-specific management, winter wheat, precision ag, digital ag, crop canopy sensors, EONR, nitrogen management*

Introduction

Nitrogen (N) fertilizer management in winter wheat (*Triticum aestivum*) production is critical to maximize yield and quality while reducing environmental impacts. Insufficient N fertilization could lead to significant yield and protein reduction (Fischer et al., 1993; Scharf et al., 2011). However, estimation of the optimal N rate reminds a challenge due to the high spatial and temporal variability of soil available N and crop N demand (Cassman et al., 2002). Therefore, N recommendations that account for soil characteristics, management, and weather factors could reduce the uncertainty of estimating the economic optimum N rate (EONR) within fields and among years (Puntel et al., 2016).

Nitrogen recommendations for winter wheat in Nebraska were published in 2002 (Blumenthal and Sander, 2002) and revised in 2009 (Hergert and Shaver, 2009). Thus, producers lack updated N recommendations for modern winter wheat varieties and current management practices. Additionally, low protein values in winter wheat have reduced crop value (Baker et al., 2004) for Nebraska producers, despite high yields. Under a high fertilizer price scenario, farmers tend to reduce N inputs to decrease input costs. Reducing N applications to winter wheat will typically result in low protein (Johansson et al., 2001) and low grain yield (Gastal et al., 2015). To increase protein levels in wheat, N must be adequately managed in the soil and be available for plant uptake during grain development. Thus, it is fundamental to develop N recommendations systems to estimate the economically optimum N rate (EONR) site-specifically to maximize yield and protein content. Our objectives were to (a) evaluate the performance of commercially available N tools and N management strategies in winter wheat yield, NUE, protein content, and partial profit, and (b) to compare them against the typical grower's N management, observed EONR and the University of Nebraska-Lincoln (UNL) recommendation tool

Material and Methods

On-Farm Experimental sites

Eleven replicated on-farm research trials were conducted in winter wheat commercial dryland fields over Nebraska during the 2020-2021 growing season (Figure 1). Five studies were focused on sensor-based technologies (SENSE N management) and three are discussed in this paper. The soil type across sites were Judson silt loam (site 1 and 2), Nodaway silt loam (site 2), and Ulysses-Sulco silt loam (site 3), as well as Otoe and Wymore silty clay loam (site 2), Site 2 presents two landscape positions (Bottom and Hill) for contrasting zones evaluation. Previous crops varied between soybeans and corn.

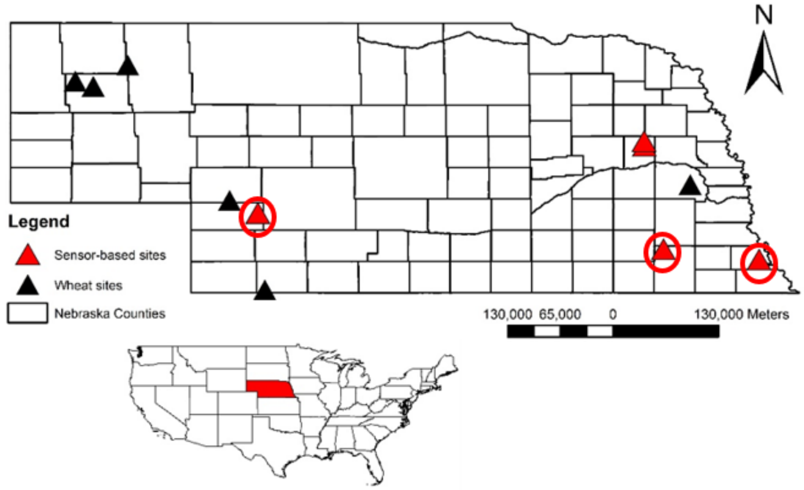


Figure 1. Map of on farm experimental trials located at farmer's field in Nebraska with Sensor-based technologies highlighted (red triangles). The red circles indicate the sites presented in this paper.

Treatments

In each site, two N management strategies were compared utilizing field-length strips (Figure 2): grower N management and SENSE N management.

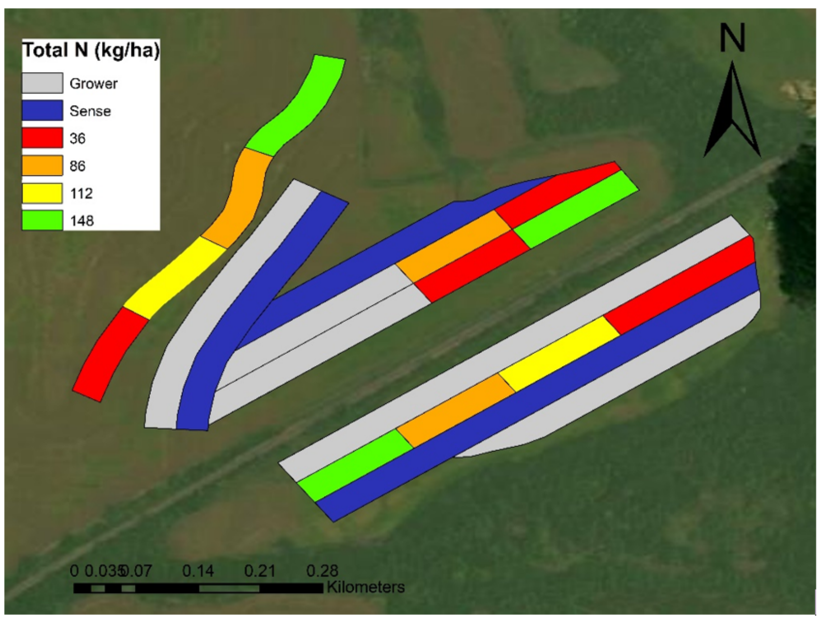


Figure 2. Example of field treatment layout comparing grower's nitrogen (N) management, Sensor-based application (SENSE), and four N blocks with increasing N rates (36, 86, 112, and 148 kg ha^{-1}) for a site located at Gage County, Nebraska (site 2).

1. Grower N management:

Traditional N rates were defined from grower to grower depending on their preferences and it ranged from 68 to 119 kg N ha^{-1}. Timing applications occurred during Fall (Feekes 2-3), Spring (Feekes 4-6), or split (Fall and Spring) according to the grower's preference. Details about timing application between Grower's N and SENSE N management are provided in Table 2.

2. SENSE N management:

The sensor-based N management utilized a high-clearance applicator equipped with OptRx sensor (Ag Leader®) which measure and record data about crop health in real time through reflectance of light emitted on the crop. OptRx sensor utilizes either NDVI or NDRE on its algorithm for on the goal N recommendations. The system requires inputs such as minimum and maximum N rate, EONR, N credits, as well as pre-topdress fertilizer. The fields were sensed, and variable-rate N was applied in real time as UAN (32-0-0) at jointing (Feekes 6).

The treatments had two replications for site 1 and three replications for sites 2 (Figure 2) and 3.

Sensor application

For all sites, NDRE indexes were obtained at jointing (Feekes 6), and it varied from 0 to 0.38 and the Total N target varied from 82 to 129 kg ha^{-1} with mean of 108 kg ha^{-1}. For example, in site 2 (Figure 3), the NDRE varied between 0.12 to 0.36 with a mean of 0.162. The N target rate varied from 22 to 126 kg ha^{-1}. Figure below shows NDRE values and its results for a target N rate application.

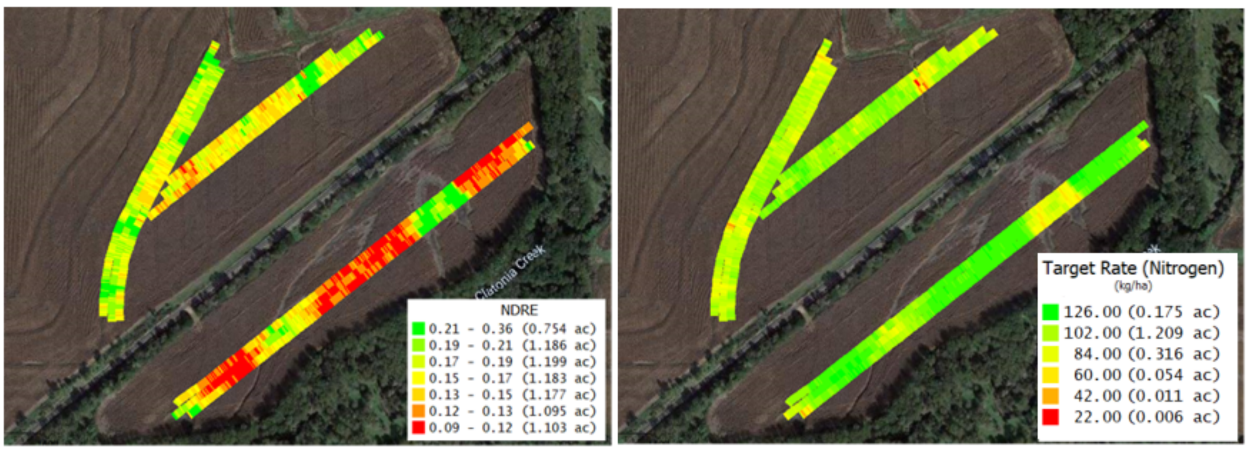


Figure 3. Example of Normalized Difference Red Edge (NDRE) values from Ag Leader® OptRx® sensors (left) and variable-rate nitrogen directed by sensors (right) from winter wheat at jointing (Feekes 6) at Gage county, Nebraska (site 2).

To calculate the EONR after harvest smaller N rate blocks were established using variable-rate applications of N. Within each block, four N rates were applied during Spring with total N ranging from 0 to 132 kg N ha^{-1}(site 1), 36 to 148 kg N ha^{-1} (site 2), and 44 to 151 N ha^{-1}(site 3). Treatments were located at contrasting landscape positions to capture variation in EONR due to elevation (site 2), soil N, apparent electrical conductivity (ECa), previous crop, and soil properties. Soil properties details are described in Table 1. Average soil properties including pH, Organic Matter (OM), Nitrate, Cation Exchange Capacity (CEC), Sand, Silt, Clay, and Texture by site. Grower N management, County and Previous crop reported per site.

Land grant university model

The land grant university models for N recommendations do not account for prescription sensors. It relies mainly on the soil nitrate residual, using soil tests features as inputs. Although, the N recommendation from the University of Nebraska – Lincoln (UNL) (Blumenthal and Sander, 2002) was not applied, we tested the algorithm to compare how this tool would perform against the grower's traditional N rate and SENSE rate. The N recommendation for winter wheat (with a maximum rate of 89 N kg ha^{-1} for dryland, 134 N kg ha^{-1} for irrigated) is calculated based on the following equation (1):

$$N\ rate = \left((N\ price\ \div\ Wheat\ price) + (NO3 - N/68.7\right) * -725) \quad (1)$$

where N price is the current fertilizer price (US\$ kg N^{-1}), wheat price (US\$ kg^{-1}), and NO_3-N is the parts per million (ppm) average of Nitrate-N in 0.3 m depth. In this case, the UNL model was benchmarked with the observed EONR, Grower N, and SENSE N management to evaluate the accuracy of each recommendation tool.

Crop measurements

The OptRx sensor (Ag Leader®) was used for measuring NDVI or NDRE during the growing season. Grain was harvested by the grower's combine and yield values were obtained from yield monitors and used to analyze difference between treatments. Grain protein concentration was measured from samples collected at harvest using near-infrared reflectance spectroscopy with a Perten DA 7250 (Perten Instruments Inc., Springfield, Illinois). Phenological stages were defined based on the Zadoks scale (Zadoks et al., 1974).

Data Analysis

One-way analyses of variance (ANOVA) were performed to determine significant difference, with a confidence interval at 90%, among treatment and N rates using the function *aov* from the package stats in R (R Core Team, 2021).The relationship between yield and N rate was described from the quadratic models using R software (R Core Team, 2021). The EONR was calculated from the N response equations by setting the first derivative of the fitted response curve equal to the wheat and N fertilizer price ratio (US$ 0.88 kg^{-1} grain:US$ 0.18 kg^{-1} N).

Soil properties

The soil organic matter (SOM) between all sites ranged from 1.8 to 4.1 %. More details about soil properties at each site are described below (Table 1).

Table 1. Average soil properties including pH, Organic Matter (OM), Nitrate, Cation Exchange Capacity (CEC), Sand, Silt, Clay, and Texture by site. Grower N management, County and Previous crop reported per site.

Site	pH	OM (%)	Nitrate N (ppm)	CEC me/100g	Sand (%)	Silt (%)	Clay (%)	Texture	Grower N (kg ha^{-1})	County	Previous crop
1	6.2	3.64	5.94	13.46	19.2	61	18.5	Silt loam	68	Nemaha	Soybean
2 Bottom	6.6	3.7	3.7	18.5	32	42	26	Silt loam	100	Gage	Soybean
2 Hill	6.4	3.7	4.8	22.4	10	52	38	Silt Clay Loam	100	Gage	Soybean
3	5.84	2.32	15.8	10.96	54	36.6	8.4	Sandy loam	119	Perkins	Corn

Results

Total N applied

The Total N applied across sites and treatments ranged from 68 to 137 kg N ha^{-1} with a mean of 97 kg N ha^{-1} (Figure 4). Comparing Grower and SENSE N management to the state average N rate of 88 kg N ha^{-1} (USDA, 2019), two out of three sites had a total N application above the state average. In two out of three sites (sites 2 and 3) Grower's N rates were lower than SENSE N rates, while for site 1 no difference was observed between N rates. The average Grower N management (95 kg N ha^{-1}) was lower than SENSE N management (106 kg N ha^{-1}). For site 1, Grower N management applied on average 14 kg ha^{-1} less than SENSE N and it did not present statistical difference (*p*-value= 0.160). For site 2, Grower's N management applied on average 28 kg N ha^{-1} less than SENSE (*p*-value= 0.019). Lastly, for site 3, the Grower N management applied on average 12 kg ha^{-1} less than SENSE, with a significance statistically (p-value= 0.001). All these results are presented on Figure 4.

Grain yield

The average yield ranged from 4368 to 6775 kg ha^{-1} with a mean of 5515 kg ha^{-1} across all sites (Figure 5). Compared to the state average yield of 3295 kg ha^{-1} (USDA, 2019), all sites and treatments yielded higher than the state average. In one out of three sites SENSE N management treatment yielded higher than the Grower N management treatment (+401 kg ha^{-1}; p-value 0.085). No statistical differences for yield between treatments were identified in sites 2 and 3. For site 1, Grower N management showed significant lower yields (4368 kg ha^{-1}) compared to SENSE N management (4764 kg ha^{-1}, Figure 5). The same trend was identified for site 2 but with no statistical differences between treatments. Moreover, the same occurred for site 3, Grower N showed yields slightly lower than SENSE N management, without statistical differences.

Nitrogen use efficiency

Nitrogen use efficiency ranged from 46.8 to 64 kg N kg^{-1} grain between Grower's N and SENSE N management for all sites (Figure 5) with a mean of 55.8 kg grain N kg-1. Sites 1 and 2 did not show statistical differences for NUE, however, SENSE tended to have a lower NUE. For site 3, Grower N management had significantly lower NUE (52.1 kg grain N kg-1, p-value= 0.003) compared to the SENSE N management (46.8 kg N kg-1 grain).

Partial profit

Average partial profit for all sites and treatments ranged from 1071 to 2169 US$ ha^{-1} with a mean of 1507 US$ ha^{-1}. Across all sites, the average partial profit was lower for Grower's (1457 US$ ha^{-1}) than the SENSE N management (1557 US$ ha^{-1}; Figure 5). For site 1, Grower management (1071 US$ ha^{-1}) had lower partial profits than SENSE (1162 US$ ha^{-1}, p-value= 0.075). For site 2 and 3, there were not significant differences in profit.

Economically Optimum Nitrogen Rate (EONR)

The estimated EONR ranged from 104 to 136 kg N ha^{-1} with a mean of 125 kg N ha^{-1} across all sites (Table 2). The average EONR was above the state average N rate of 88 kg ha^{-1} (USDA, 2019). Sites 1 and 2 had higher EONR compared to the total N used for Grower's and SENSE treatments. For site 1, the observed EONR presented a higher rate than both Grower N management and SENSE, with a difference of 68 kg N ha^{-1} and 82 kg N ha^{-1}, respectively. Similarly, for site 2, the observed EONR was136 kg N ha^{-1} and presented higher rates than both Grower N management (100 kg ha^{-1}) and SENSE N (129 kg ha^{-1}). For site 3, the observed EONR (104 kg N ha^{-1}) was 14 and 2 kg N ha^{-1} lower than the Grower's and SENSE total N rate.

Table 2. Observed protein and timing of nitrogen (N) application for grower's and sensor-based N management (SENSE).

Site	Treatment	Protein (%)	EONR (kg ha^{-1})	Timing
1	Grower N	11	135	Fall (100%)
	SENSE N	11.2		Split (40% in fall, 60% at jointing)
2	Grower N	10.7	136	Spring (100%)
	SENSE N	11.3		Spring (100%)
3	Grower N	11.5	104	Split (46% in fall, 54% at jointing)
	SENSE N	11.3		Split (25% in Fall, 75% at jointing)

Figure 4. Total N between EONR, Grower N management, SENSE N management and UNL applications by sites. Red and blue dashed lines represent the UNL and EONR, respectively. ANOVA was run by site. Values with the same letter are not significantly different at 90% confidence level.

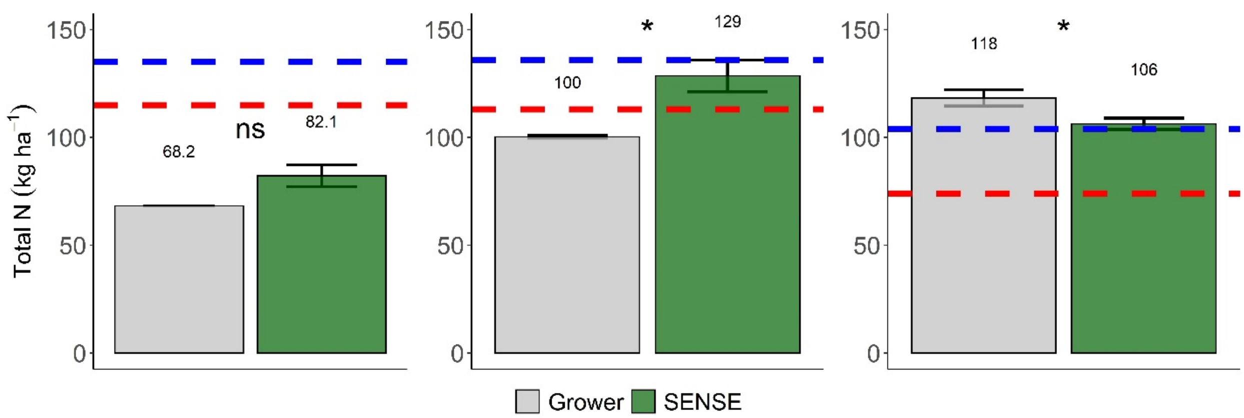
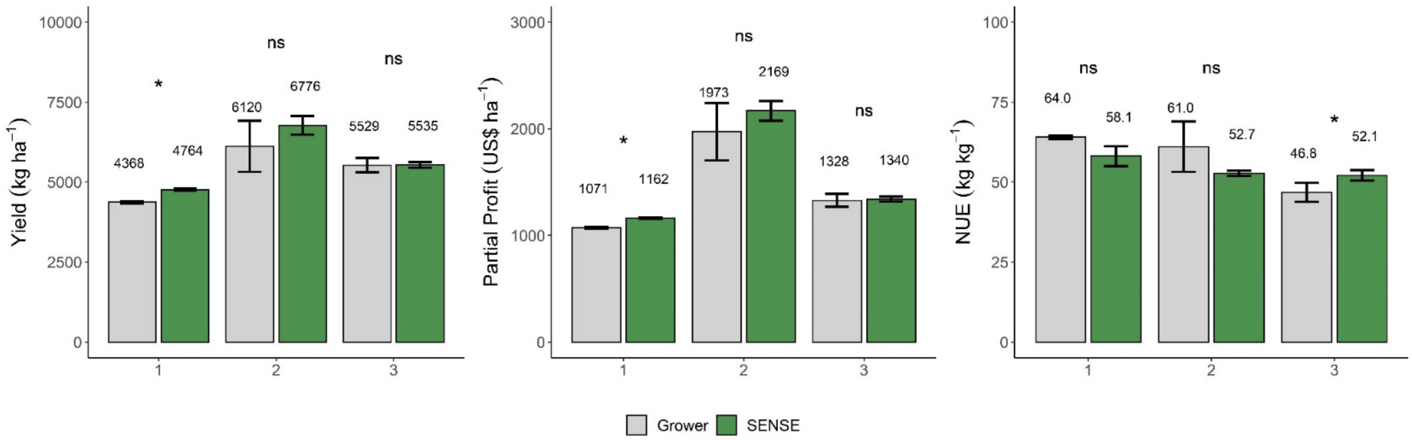


Figure 5. Yield, N use efficiency (NUE), and partial profit for grower's and sensor-base N management (SENSE). Asterisk (*) indicates significantly different and "ns" indicates not significantly different at 90% confidence level. Yield values are from cleaned monitor data expressed at 13.5% moisture. Marginal net return was calculated using $0.88/kg wheat and $0.18/kg N.



Conclusion

The performance of sensor-based in-season N management for winter wheat varied across fields. Across sites and treatments, NUE was on average 55.8 kg grain N kg^{-1}. Although not significant, SENSE tended to be more profitable than Grower N management. This is a consequence of higher N rates that resulted on slightly higher yields for SENSE compared to the Grower N management.

The EONR reported for three of the sites was on average 37 kg N ha^{-1}above the mean N rate compared to the state average for Nebraska. This suggested that there is room to refine N recommendations for winter wheat in Nebraska. Further analysis will be performed to evaluate the site-specific performance of the sensor-based variable rate application compared to the grower and the EONR. In site 3, where the statistical difference in NUE were detected, SENSE N management treatment was more efficient producing more grain with less N.

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