BENCHMARKING NITROGEN RECOMMENDATION TOOLS FOR NEBRASKA WINTER WHEAT

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ABSTRACT

Winter wheat producers are challenged with achieving high yields, profits, and nitrogen (N) use efficiency (NUE). The use of site-specific N management and digital ag technologies has been demonstrated to increase NUE. During the 2020-2021 and 2021-2022 growing seasons, we conducted eighteen on-farm randomized strip trials comparing sensor-based variable-rate N tools versus grower's N management. Tools for sensor-based, variable-rate N management included commercially available active crop canopy sensors and satellite-based tools (SENSE). Nitrogen rate blocks were placed in the field to estimate the economic optimum N rate (EONR). A subset of five sites was included here. The objectives of this research were to (a) evaluate the performance of commercially available N tools for winter wheat on yield, NUE, and partial profit, (b) to compare them against the typical grower's typical N management strategy, and (c) benchmark tool performance using the University of Nebraska-Lincoln (UNL) N recommendation algorithm and the observed EONR. On average, the yield for SENSE and grower treatment were similar ~ 77 ± 13 bu ac^{-1}. Sensor-based N management applied 10% lower N rate compared to grower's traditional management. In addition, At all sites, SENSE N recommendations was closer to EONR than grower was to EONR. This resulted on higher N use efficiency with an average of 1.2 lb N bu^{-1} grain for SENSE. Further analysis will aim to investigate what factors influenced the performance of sensor-based N management in winter wheat and their performance at a site-specific level.

INTRODUCTION

Winter wheat (*Triticum aestivum*) production requires effective (N) fertilizer management to maximize yield and quality while reducing environmental impacts. Insufficient N fertilization may lead to significant yield and protein reductions (Fischer et al., 1993; Scharf et al., 2011). However, estimating the optimal N rate is challenging because soil available N and crop N demand are highly variable between years and across fields (Cassman et al., 2002). Therefore, N recommendations that account for soil characteristics, management, and weather factors could better estimate the economic optimum N rate (EONR) within fields and over the years (Puntel et al., 2016).

Several approaches exist to recommend N in winter wheat. For example, the University of Nebraska-Lincoln (UNL) developed a recommendation published in 2002 (Blumenthal and Sander, 2002) and revised it in 2009 (Hergert and Shaver, 2009). However, this recommendation method does not account for the year-to-year variability in weather conditions and the variation in soils. Sensor-based fertilization using active and passive sensors has been shown to effectively manage N in winter wheat, improve nitrogen use efficiency (NUE) and maintain yields (Raun et al., 2001; Li et al., 2009). This approach indirectly captures soil and weather variability through the N status of the crop

(Boyer et al., 2011). In addition, sensor-based technology can now be applied at a large scale using satellite images (Shou et al., 2007; Fabbri et al., 2020). Despite positive results from sensor-based N management in winter wheat, the adoption remains low. Thus, on-farm and hands-on experience with these tools could support adoption and improve yield, profit, and NUE in winter wheat.

Despite high yields, low protein values in winter wheat have reduced crop value (Baker et al., 2004) for producers. And, in the event of a high fertilizer price scenario, growers reduce N inputs to reduce costs. Reducing N applications to winter wheat typically results in low protein (Johansson et al., 2001) and low grain yield (Gastal et al., 2015). Thus, it is fundamental to promote adoption of N technologies that can better estimate the EONR site-specifically to maximize yield and protein content. Our objectives were to (a) evaluate the performance of commercially available N tools in winter wheat based on yield, NUE, and partial profit, and (b) to compare them against the grower's typical N management, observed EONR, and the UNL recommendation method.

MATERIALS AND METHODS

On-Farm Experimental sites

Eighteen on-farm research trials were conducted in winter wheat commercial dryland fields in Nebraska during the 2020-2021 and 2021-2022 growing seasons. Fields were distributed in the southeast (n= 4), east (n=4), northwest (n=3), and southwest (n=7) regions of Nebraska. Studies were focused on sensor-based technologies (herein SENSE N management), and five sites are discussed in this paper. The soil types, soil properties, and previous crops across sites are described in Table 1.

Treatments

In each site, two N management strategies were compared utilizing replicated and randomized field-length strips (Figure 1):

- *Grower's N management*: Traditional N rates varied among growers based on their preferences. The N rates varied from 73 to 115 lb N ac^{-1}. Timing of N 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 1.
- *Sensor-based N management (SENSE):* Growers had access to two sensor-based N tools for SENSE N management. In 2020-2021, we tested the Ag Leader® OptRx sensor, and in the second year (2021-2022), we used data from Planet® SkySat satellite-based imagery and the handheld Trimble® GreenSeeker in the Ninja Ag platform. Both methods utilized either NDVI or NDRE and an algorithm to prescribe N recommendations. The fields were sensed, and variable-rate N was applied as UAN (32-0-0) (Figure 1).

Grain was harvested using the grower's combine, and yield values were obtained from yield monitors and used to analyze the difference between treatments. Site IV was hand harvested. Wheat phenological stages were defined based on the Feekes scale (Large, 1954).

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Table 1. Average soil properties including pH, organic matter (OM), nitrate, cation exchange capacity (CEC), sand, silt, clay, and texture are reported by site. Grower N management, county, previous crop, and growing season in which the study occurred are reported for each site.

Site	pH	OM (%)	Nitrate N (ppm)	CEC me/100g	Sand (%)	Silt (%)	Clay (%)	Texture	Grower N (lb ac^{-1})	County	Previous crop	Growing season	Timing Grower | SENSE
I	6.2	3.6	5.9	13.4	19	61	20	Silt Loam	76	Nemaha	Soybean	2020/2021	Fall | Split
II	6.5	3.7	4.2	20.5	21	47	32	Clay Loam	112	Gage	Soybean	2020/2021	Spring | Spring
III	5.8	2.3	15.8	10.9	54	36	9	Sandy Loam	133	Perkins	Corn	2020/2021	Split | Split
IV	6.7	2.3	4	17.8	27	55	18	Silt Loam	140	Butler	Soybean	2021/2022	Split | Split
V	7.5	2.2	1.8	27.3	24	50	26	Silt Loam	103	Gage	Soybean	2021/2022	Split | Split

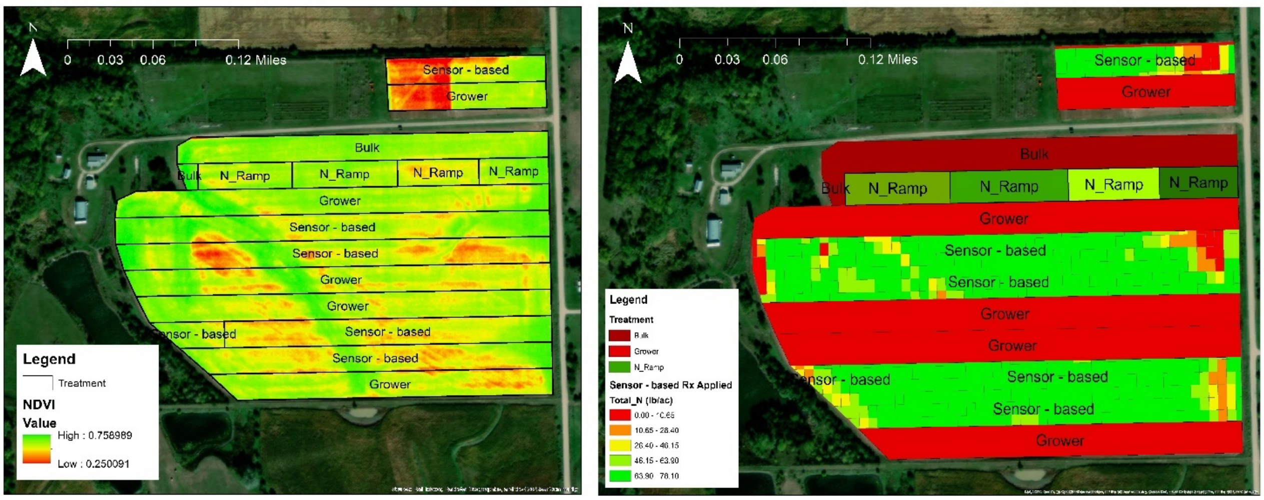

Figure 1. Example of a winter wheat nitrogen (N) treatment layout overlayed on the normalized difference vegetation index (NDVI) derived from Planet® SkySat satellite imagery (left) and a variable-rate N prescriptions from satellite-based N recommendation (right) applied on winter wheat at jointing (Feekes 6) at Butler County, Nebraska.

Economic optimal N rate (EONR)

Small blocks with a range of N rates were established in contrasting zones within each field using variable-rate N technology. Contrasting zones were established to capture variability due to differences in elevation (e.g., site II), soil N, apparent electrical conductivity (ECa), and soil properties (Table 1). In each site, four N rates were applied during the spring, with total N ranging from 30 to 117 lb N ac^{-1} (site I), 32 to 132 lb N ac^{-1} (site II), and 39 to 134 lb N ac^{-1} (site III), 19 to 106 lb ac^{-1} (site IV), and 23 to 120 lb ac^{-1} (site V). Yield data from these N rate blocks was used to calculate the EONR (ex-post) and benchmark the performance of grower and SENSE treatments. We also calculated the University of Nebraska-Lincoln (UNL) N recommendation (Blumenthal and Sander, 2002) for each site and compared it to the grower and SENSE treatments and EONR. This tool relies mainly on the soil residual nitrate test using soil test features as input to prescribe a N rate.

Data Analysis

One-way analysis of variance (ANOVA) was performed to determine significant differences between treatments (confidence interval of 95%) on yield, total N applied, and partial profit using the function *aov* (R Core Team, 2021). The relationship between yield and N rate was described with a quadratic function 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$ 9 bu ac^{-1} grain: US$ 0.56 lb N ac^{-1}).

RESULTS AND DISCUSSION

Across sites and treatments, winter wheat yield ranged from 63 bu ac^{-1} to 100 bu ac^{-1} with a mean of 77 bu ac^{-1}, and total N rates ranged from 61 lb ac^{-1} to 139 lb ac^{-1} with a mean of 95 lb ac^{-1} (Figure 2). On average, the yield for SENSE and grower treatment was similar (76±15 and 78±10 bu ac^{-1}, respectively, Table 2, Figure 3). Across sites, SENSE N management applied a 10% lower N rate than the grower's traditional management. This resulted on higher N use efficiency with an average of 1.2 lb N bu^{-1} grain for SENSE (Table 2). Across sites, profit varied between SENSE and grower. In site I, SENSE was more profitable than grower, while in Site V, grower had a higher profit compared to SENSE. For site V, the SENSE treatment was applied a month later than the grower. We also expect that a N base rate of 23 lb N ac^{-1} for the entire field was low for an application in May possibly due to low mineralization associated with dry conditions that could produce early N stress in the crop.

Table 22. Total nitrogen (N), economic optimal N rate (EONR), UNL N recommendation, grain yield, NUE, and partial profit between sites and treatments.

	Total N (lb N ac^{-1})		*Benchmarking rates (lb N ac^{-1})*		*Grain yield† (bu ac^{-1})*		*NUE (lb N bu $grain^{-1}$)*		*Partial profit‡ (US$ ac^{-1})*	
Site	Grower	SENSE	EONR	UNL	Grower	SENSE	Grower	SENSE	Grower	SENSE
I	61 a	73 a	121	92	65 b	71 a	0.9 a	1.0 a	550.8 b	598.1 a
II	89 b	115 a	121	90	91 a	100 a	1.0 a	1.1 a	769.2 a	835.6 a
III	106 a	95 b	93	59	82 a	82 a	1.3 a	1.1 b	679.2 a	684.8 a
IV	139 a	80 b	100	77	70 a	63 b	2.0 a	1.3 b	552.2 a	522.2 a
V	103 a	85 b	72	97	82 a	63 b	1.2 b	1.4 a	680.3 a	519.4 b

Values with the same letter are not significantly different at a 95% confidence level, comparisons run by site. ‡Partial profit based on $9/bu wheat. †Grain yield values are from weight wagon method. Bushels per acre corrected to 13.5% moisture.

The EONR ranged from 72 lb N ac^{-1} to 121 lb N ac^{-1} with a mean of 101 lb N ac^{-1}. At all sites, SENSE N recommendations was closer to EONR (18 lb N ac^{-1}) than grower was to EONR (35 lb N ac^{-1}). The estimated UNL N recommendation ranged from 59 lb ac^{-1} to 97 lb ac^{-1}, with a mean of 83 lb N ac^{-1}. The average difference between UNL recommendation with grower and SENSE treatments was 29 lb ac^{-1} and 19 lb ac^{-1}, respectively (Table 2). Average differences were calculated by subtracting the UNL recommendation from SENSE and grower N rate (Figure 2).

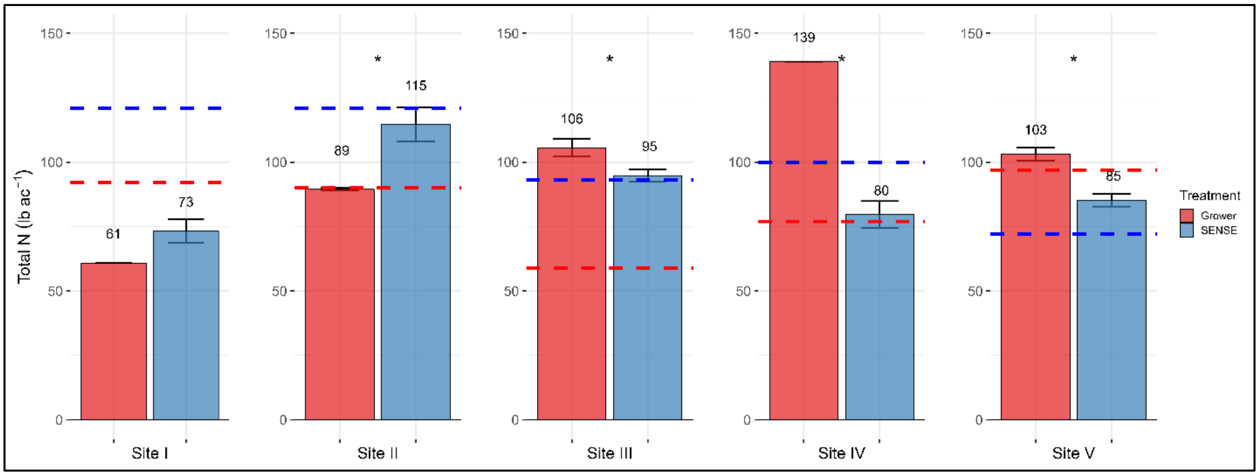

Figure 2. Average total nitrogen (N) between grower and sensor-based (SENSE) N management. Red and blue dashed lines represent the UNL and economic optimal N rate (EONR), respectively. Asterisk (*) indicates significant difference at 95% confidence level between treatment means at each site. Vertical bars represent the standard deviation of the mean.

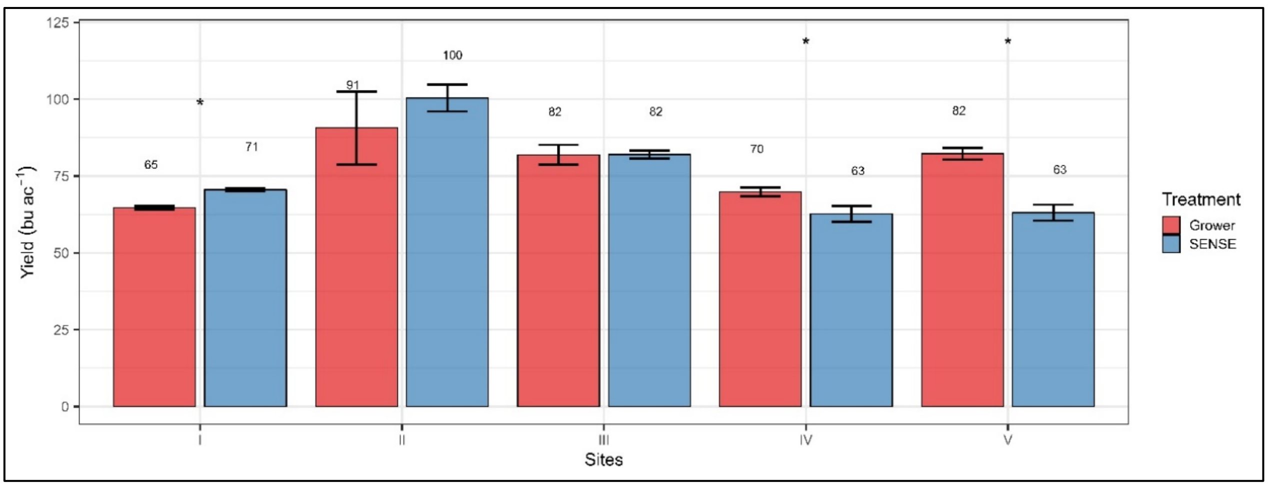

Figure 3. Average yield for Grower and sensor based (SENSE) N management. Asterisk (*) indicates significantly different at 95% confidence level. Yield values are from cleaned monitor data (except site IV) expressed at 13.5% moisture. Vertical bars represent the standard deviation of the mean.

CONCLUSIONS

The performance of SENSE N management for winter wheat varied between fields and growing seasons. On average, the SENSE and grower treatment yield was similar ~ 77 ± 13 bu ac^{-1}. Sensor-based N management applied 10% lower N rate compared to grower's traditional management. In addition, SENSE N recommendations was closer to EONR than grower was to EONR. This resulted in higher NUE with an average of 1.2 lb N bu^{-1} grain for SENSE. Despite some differences in yield, SENSE had similar profits than grower's management. The underperformance of sensor-based N recommendations could be related to the timing of the N application, the N base rate applied before the sidedress, and the method used to make the N recommendation (active vs. passive sensors). Further analysis will aim to investigate in-depth each of these factors affecting the performance of this technology and technology performance at a site-specific level.

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