PROJECT SENSE: SENSORS FOR THE EFFICIENT USE OF NITROGEN AND STEWARDSHIP OF THE ENVIRONMENT. AN ON-FARM RESEARCH EFFORT TO INCREASE ADOPTION OF SENSOR BASED N MANAGEMENT

B.T. Krienke, R. Ferguson, J. Luck, L.T. Thompson, J. Parrish, N. Mueller, T. Mieno, J. Crowther, T. Shaver, T. Ingram, D. Krull, K. Glewen
University of Nebraska at Lincoln, Lincoln, NE
krienke.brian@unl.edu

ABSTRACT

Low nitrogen use efficiency (NUE) has been attributed to several factors including asynchrony between nitrogen (N) fertilizer application, crop demand, and spatial variability (Shanahan et al., 2008). Sidedress applied N synchronizes crop uptake demand for N, but does not address the spatial and temporal variability that exists in a field year to year. Active crop canopy sensors provide an ability to monitor and respond to spatial and temporal N variability for a given field. A three-year project, Project SENSE, is a large on-farm research effort that builds upon previous efforts to evaluate sensor use to direct in-season N management on the go in real time. In year one, 15 sites were used to compare an industry-available sensor and application platform vs. a producer's normal N management. The results showed on aggregate: 40 lb acre^{-1} less N applied, 5 bu acre^{-1} less yield, an increase in NUE of 20 lb of grain produced per lb of N applied, and a net increase in profit of $7.75 for the SENSE based treatments relative to the producer's method. The SENSE treatments provide evidence to support the use of active crop canopy sensors to direct in-season N management on a large scale.

INTRODUCTION

Low NUE has been attributed to several factors including poor synchrony between N fertilizer and crop demand, unaccounted for spatial variability resulting in varying crop N needs, and temporal variances in crop N needs (Shanahan et al., 2008). Because of the environmental and economic consequences of N loss, there is great interest in minimizing N losses and improving NUE. Managing N application based on spatial variability can reduce the overall N rate applied and increase profitability compared with a uniform N application (Mamo et al., 2003). Climate and management interactions cause tremendous year-to-year variation in both crop N requirement and yield (Cassman et al., 2002). Together, spatial and temporal variation creates uncertainty as to the optimal N fertilizer quantity for any given year (Roberts et al., 2010). Determining the amount and timing of N needed by the crop over a spatially diverse field is critical for improving NUE.

Strategies which detect crop N status at early growth stages have been suggested as a method to improve NUE (Ferguson et al., 2002). Active crop canopy sensors are available to monitor the N status of the crop, allowing growers to make management decisions that are reactive to actual growing season conditions, thereby improving NUE. Active canopy sensors can be effective indicators of in-season crop need because they integrate the conditions and stresses that have already occurred during the early growing season, thus allowing the plant to convey the N availability.

Many studies have been done to evaluate the use of sensors to direct N application during the growing season (Dellinger et al., 2008; Kitchen et al., 2010; Schmidt et al., 2011; Shanahan et al., 2008). For sensor information to be useful for calculating optimal N sidedress application rates, algorithms must be used to incorporate sensor reflectance measurements into N rate recommendations. A number of algorithms have been developed to relate sensor-derived crop reflectance data to optimum in-season N rates for corn (Teal et al., 2006; Scharf and Lory, 2009; Solari et al., 2010; Holland and Schepers, 2010). These algorithms were developed in specific geographic locations using a variety of approaches.

A number of studies have been conducted to evaluate the benefit of sensor-based N management. Roberts et al. (2010) compared sidedress sensor-based N applications to uniform N application rates determined by producers. The study found that in many situations, sensor-based N applications resulted in lower N application rates than producer-determined rates. This resulted in increased yield efficiency (increase in yield per unit of N applied) and higher N fertilizer recovery efficiency (percentage of fertilizer-N recovered in aboveground plant biomass during the growing season). When significant N mineralization during the growing season occurred, sensors were valuable as they took this into account, therefore resulting in increased yield efficiency due to reduced in-season N application.

Techniques which can address N management in-season, in response to current conditions, and in a spatially appropriate manner hold great promise for reducing over and under-application of N, therefore increasing NUE. Increased effort to encourage adoption of sensor technologies is needed. Despite the benefits that have been seen, adoption of this technology has been slow. A three-year project was started in 2015 in Nebraska with the following objectives:

- To promote technology transfer i.e. increase adoption of sensor-based N management
- Demonstrate method for improving NUE while maintaining or increasing profitability
- Collect necessary data to validate/refine sensor N recommendation algorithms currently being used

Five participating Natural Resource Districts (NRDs) in Nebraska along with the Nebraska Corn Board, and USDA provided funding to support the project and conduct on-farm research studies on collaborating producers' fields.

METHODS AND MATERIALS

Experimental and treatment design

This study compared two treatments: N management methods of producer vs. SENSE. Each site had six replicates in a randomized complete block design. In 2015, there were 15 sites located across 5 Nebraska Natural Resource Districts (NRDs) including:), Central Platte (CPNRD), Little Blue NRD (LBNRD), Lower Loup (LLNRD), Lower Platte North (LPNNRD), and Upper Big Blue (UBBNRD).

Equipment

Nitrogen (N) was applied with a Hagie DTS 10 high clearance applicator. The applicator was configured to apply liquid N to the inter-row areas for 8, 12, or 16 row spacings (rate changes were constant across the boom). Straight stream nozzles were used with 30 inch drops to band the nitrogen between rows. Canopy reflectance data was collected using OptRx® sensors connected to an Ag Leader Integra monitor. Target N rates were calculated by the Integra monitor and sent in real-time to the spray rate controller (Raven 460) by the Integra monitor. The Raven 460 controlled product pump speed to maintain desired target rates with respect to changes in sprayer ground speed. As applied data was collected via the Integra monitor for later analysis.

Site management and data collection

Each site required a base rate of N early in the season, followed by a sidedress application of N during vegetative growth stages determined and applied in real time using a high clearance applicator equipped with a spray rate controller coupled with active crop canopy sensors. Details of this method follow.

Producers managed their respective site with the exception of the SENSE sidedress N treatments. All other management including initial N base rate application and harvest was done by the producer.

Each site received an initial base rate of N at or shortly after planting. The goal was for each site to have an initial 75 lbs acre^{-1} N, but varied slightly depending on the producer's ability to establish such a rate. The initial base rate of N was intended to provide adequate N nutrition for the crop until the eighth to fourteenth leaf growth stage (V8-14), which is the optimal sidedress window for using the active crop canopy sensors (cite).

SENSE treatments received sidedress N between the eighth leaf to tassel growth stage (V8-VT). Treatment consisted of first establishing a canopy reflectance reference value before N application to treatment strips. The reference value was obtained by driving at ~5 miles hour^{-1} for a period of 5 minutes over a representative area of the field. The Ag Leader monitor logged all reflectance points during that time, and then used the average value of points greater than the 95th percentile as the reference value in the algorithm. The SENSE treatment strips were sensed and had an N rate determined and applied in real time as the applicator drove through each strip between ~5 to 12 miles hour^{-1}. Real time N rates were determined using the Ag Leader OptRx® process, based on the Holland/Schepers sensor algorithm (Holland and Schepers, 2010).

The N rate algorithm requires starting parameters to constrain the algorithm to appropriate agronomic rates specific to each site including a minimum and maximum rate, economic optimum rate, N credits, and pre-sidedress N applied. N credits were calculated from irrigation water nitrate only. The economic optimum N rate (EONR) effectively caps the N rate calculated, and rate reductions from this EONR are based on the sufficiency index (SI) (Equation 1). The vegetation index used in our study was the normalized difference vegetation red edge index (NDRE) (Equation 2).

Equation 1

$$SI = \frac{Target\ VI}{Reference\ VI}$$

Where: SI is sufficiency index
VI is vegetation index
Target VI is the area receiving N application
Reference VI is the reference value

Equation 2

$$NDRE = \frac{(NIR - RE)}{(NIR + RE)}$$

Where: NDRE is the normalized difference vegetation index
NIR is near infrared light reflectance
RE is red-edge light reflectance

Economic optimum nitrogen rates were determined using Maize N (Setiyano et al., 2011), which is an N recommendation model based on the crop growth model Hybrid Maize (Yang et al., 2004). Inputs for the model included: crop rotation (including previous crop type, yield, time of maturity, and N fertilizer application), current crop information (including planting date, maturity, and planting population), irrigation water nitrate concentration, soil residual nitrate concentration, soil texture, tillage type and timing, soil organic carbon, bulk density, soil pH, 18-35 year weather history (depending on local station record keeping history), expected current year crop price, and current year N fertilizer type and price.

Yield was collected using either a calibrated yield monitor and integrated GPS or a weigh wagon total for each treatment replicate. For sites that utilized spatial yield data, yield was cleaned to eliminate erroneous yield monitor data using ArcGIS v10.1 (ESRI, Redlands, CA) and USDA Yield Editor v. 2.0 (USDA-ARS, Columbia, MO). Cleaning consisted of trimming outer edge boundaries by 50 ft to eliminate several inaccurate data readings associated with flow delay, harvest speed, acceleration, and header position. Further cleaning used the Yield Editor automated flow delay to determine flow delays to correctly shift yield points that were offset due to delays between mechanical harvest and representation of that yield on the yield sensor. Yield was filtered to within 3 standard deviations of a radius length of 5 header widths to eliminate sensor spikes of yield. A smooth velocity filter of 0.2 miles hour^{-1} was used. Yield was adjusted to 15.5 percent moisture content using the combine moisture sensor.

Average yield and applied N rate values were obtained for each treatment strip. In most cases producers did not have as-applied N data. Nitrogen rates for producers were as reported by the producer.

Statistical analysis

Data was analyzed in SAS v. 9.3 (SAS, Cary, NC) using the GLIMMIX procedure. Statistical differences for yield and partial factor productivity for N (lb grain produced per lb N fertilizer) were calculated using an alpha = 0.05. Mean values of SENSE N rates were used to calculate differences between SENSE and producer rates.

Marginal net return was calculated using differences between mean yield and N rate values with values of $3.65 per bushel of grain, and $0.65 per lb of N.

RESULTS AND DISCUSSION

Results for difference between treatments and site means are reported in Table 1 and Table 2 respectfully. Across all sites, the SENSE treatment yielded 5 bu acre^{-1} less and used 40 lbs acre^{-1} less N than the producer treatment. The difference in N applied and yield for the SENSE treatment resulted in an increase in partial factor productivity for N (PFP_N) of 20 lbs of grain produced per lbs of N applied over the producer treatment. The marginal net return was $7.75 higher for SENSE than the producer treatment.

Table 1: Differences between SENSE and producer treatments are reported for N rate, yield, PFP, and marginal net return. [1]Numbers in this column with * are significantly different at the 95% confidence level (alpha = 0.05).

NRD	Site	Difference (SENSE - Producer) N Rate (lbs N acre^{-1})	Yield[1] (bu acre^{-1})	PFP_N[1] (lb grain lb N^{-1})	Marginal Net Return ($ ac^{-1})
UBB	Site 1	-64	-11*	27*	$1.45
	Site 2	-27	7	11*	$43.10
CP	Site 1	-21	-5	4	-$4.60
	Site 2	-31	-1	22*	$16.50
	Site 3	-67	-1	62*	$39.90
	Site 4	-131	-12*	38*	$41.35
LB	Site 1	-10	-2	4	-$0.80
	Site 2	-89	-14*	21*	$6.75
LL	Site 1	-28	1	19*	$21.85
	Site 2	14	-8*	-8	-$38.30
	Site 3	-7	2	4*	$11.85
	Site 4	-63	-6	22*	$19.05
LPN	Site 1	-45	-5*	16*	$11.00
	Site 2	-32	-20*	3	-$52.20
	Site 3	-51	-6	18*	$11.25
All	All Sites	-40	-5*	20*	$7.75

Table 2: Yield, N rate, partial factor productivity (PFPN), and marginal net return are reported for each site by treatment.

NRD	Site	Treatment	N Rate (lbs N acre^{-1})	Yield (bu acre^{-1})	PFP_N (lb grain lb N^{-1})	Marginal Net Return ($ ac^{-1})
UBB	Site 1	SENSE	136	232	95	$758
		Producer	200	243	68	$757
	Site 2	SENSE	168	204	68	$635
		Producer	195	197	57	$592
CP	Site 1	SENSE	204	234	64	$722
		Producer	225	239	60	$726
	Site 2	SENSE	128	237	106	$782
		Producer	159	238	84	$765
	Site 3	SENSE	108	282	153	$959
		Producer	175	283	91	$919
	Site 4	SENSE	149	226	86	$728
		Producer	280	238	48	$687
LB	Site 1	SENSE	164	252	86	$813
		Producer	174	254	82	$814
	Site 2	SENSE	179	235	73	$741
		Producer	268	249	52	$735
LL	Site 1	SENSE	123	213	97	$698
		Producer	151	212	78	$676
	Site 2	SENSE	164	171	59	$518
		Producer	150	179	67	$556
	Site 3	SENSE	162	240	83	$771
		Producer	169	238	79	$759
	Site 4	SENSE	167	237	81	$757
		Producer	230	243	59	$737
LPN	Site 1	SENSE	153	207	76	$656
		Producer	198	212	60	$645
	Site 2	SENSE	165	158	54	$469
		Producer	197	178	51	$522
	Site 3	SENSE	147	201	76	$638
		Producer	198	207	58	$627
All	All Sites	SENSE	155	222	86	$712
		Producer	195	227	66	$702

Table 3: Nitrogen application rates are reported in base rate applications (at or near planting) and sidedress applications for SENSE and producer treatments. Timing of application for SENSE treatment is reported.

NRD	Site	SENSE Base Rate	SENSE Sidedress	SENSE Time of Sidedress	Producer Base Rate	Producer Sidedress Rate	Soil texture
		---- (lb acre^{-1}) ----		Growth Stage	---- (lb acre^{-1}) ----		
UBB	Site 1	75	63	V12	25	175	silt loam; silty clay loam
UBB	Site 2	75	93	V10	45	150	silt loam
CP	Site 1	85	112	V9	85	140	fine sandy loam
CP	Site 2	75	68	V11	3.5	155	silt loam
CP	Site 3	40	60	V10	40	135	fine sandy loam; sandy loam; loam
CP	Site 4	75	70	V8	75	205	loam; silt loam
LB	Site 1	75	69	V12	34	140	fine sandy loam; silt loam
LB	Site 2	108	76	V10	268		silt loam; silty clay loam
LL	Site 1	75	48	V10	45	106	sandy loam; fine sandy loam
LL	Site 2	75	97	VT	50	100	fine sand; fine sandy loam
LL	Site 3	79	63	V10	75	90	loamy fine sand; fine sandy loam
LL	Site 4	102	69	V11	90	185	fine sandy loam; silt loam
LPN	Site 1	91	62	V12	91	106	silt loam; silty clay loam
LPN	Site 2	91	75	V10	91	106	loamy fine sand; silty clay loam
LPN	Site 3	75	67	V12	75	123	silt loam

When individual sites are considered the results differ widely in yield, N rate applied, timing of application, PFP_N, and marginal net return as well as soil texture (Table 2 and Table 3). There were several sites where the SENSE treatment yielded less than the producer treatment, but at all sites the N applied for the SENSE treatment was less than that applied to the producer's treatment. There was only one site in which SENSE did not increase PFP_N, which was the metric used for NUE in this study. However, there were four sites where the SENSE treatment had a negative marginal net return relative to the producer treatment. Two of those four sites had no statistically significant yield difference between SENSE and producer treatments, but the difference was treated as absolute for comparison of economic return. The other two sites had considerable loss in yield and marginal net return: site 2 in the LLNRD and site 2 in the LPNNRD. Closer examination of these two sites reveal important distinctions compared to other sites. Site 2 in the LLNRD had the SENSE sidedress applied later than the optimal sidedress growth stages window (Table 3). It is likely that the extent of the N deficiency was severe to the point that more N was applied than would otherwise be needed if sidedressed when there was only a slight N deficiency at an earlier growth stage. Site 2 in the LPNNRD had the SENSE sidedress N applied within the optimal growth stages window, but immediately following application the site received intense rainfall on a site with significant slope. It is likely that there was significant runoff of applied N down slopes. Spatial yield (data not shown) confirms areas most affected were on sloped areas of the study area.

CONCLUSION

In year one of this three-year project evaluating potential for sensor-based N management, initial results are promising for widespread adoption of such technology to guide in season N management. On aggregate, results were supportive of the initial objectives: increasing nitrogen use efficiency while also maintaining or increasing marginal net return. Individual sites varied widely with respect to yield, N rate, NUE, and marginal net return compared to the producer's current practices. Of the most significant losses affected by sensor-based management, differences were likely due to timing of application and severity of deficiency with respect to growth stage, and interaction between surface N application and subsequent intense rainfall.

REFERENCES

Cassman, K.G., A.R. Dobermann, and D.T. Walters. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31:132-140.

Dellinger, A.E., J.P. Schmidt, and D.B. Beegle. 2008. Developing nitrogen fertilizer recommendations for corn using an active sensor. Agron. J. 100:1546-1552.

Ferguson, R.B., G.W. Hergert, J.S. Schepers, C.A. Gotway, J.E. Cahoon, and T.A. Peterson. 2002. Site-specific nitrogen management of irrigated maize: Yield and soil residual nitrate effects. Soil Sci. Soc. Am. J. 66:544-553.

Holland, K.H. and J.S. Schepers. 2010. Derivation of a variable rate nitrogen application model for in-season fertilization of corn. Agron. J. 102:1415-1424.

Kitchen, N.R., K.A. Sudduth, S.T. Drummond, P.C. Scharf, H.L. Palm, D.F. Roberts, E.D. Vories. 2010. Ground-based canopy reflectance sensing for variable-rate nitrogen corn fertilization. Agron. J. 102:71-84.

Mamo, M., G.L. Malzer, D.J. Mulla, D.R. Huggins, and J. Strock. 2003. Spatial and temporal variation in economically optimum nitrogen rate for corn. Agron. J. 95:958-964.

Roberts, D.F., N.R. Kitchen, P.C. Scharf, and K.A. Sudduth. 2010. Will variable-rate nitrogen fertilization using corn canopy reflectance sensing deliver environmental benefits? Agron. J. 102:85-95.

Scharf, P.C. and J.A. Lory. 2009. Calibrating reflectance measurements to predict optimal sidedress nitrogen rate for corn. Agron J. 101:615-625.

Schmidt, J., D. Beegle, Q. Zhu, and R. Sripada. 2011. Improving in-season nitrogen recommendations for maize using an active sensor. Field Crops Res. 120:94-101.

Schmidt. J.P., A.J. DeJoia, R.B. Ferguson, R.K. Taylor, R.K. Young, and J.L. Havlin. 2002. Corn yield response to nitrogen at multiple in-field locations. Agron. J. 94:798-806.

Setiyano, T.D., H. Yang, D.T. Walters, A. Dobermann, R.B. Ferguson, D.F. Roberts, D.J. Lyon, D.E. Clay, and K.G. Cassman. 2011. Maize-N: A decision tool for nitrogen management in maize. Agron. J. 103:1276-1283.

Shanahan, J.F., N.R. Kitchen, W.R. Raun, and J.S. Schepers. 2008. Responsive in-season nitrogen management for cereals. Comput. Electron. Agric. 61:51-62.

Solari, F., J.F. Shanahan, R.B. Ferguson, V.I. Adamchuk. 2010. An active sensor algorithm for corn nitrogen recommendations based on a chlorophyll meter algorithm. Agron.J. 102:1090-1098.

Teal, R.K., B. Tubana, K. Girma, K.W. Freeman, D.B. Arnall, O. Walsh, and W.R. Raun. 2006. In-season prediction of corn grain yield potential using normalized difference vegetation index. Agron. J. 98:1488-1494.

Yang, H.S., A. Dobermann, J.L. Lindquist, D.T. Walters, T.J. Arkebauer, K.G. Cassman. 2004. Hybrid-Maize – a maize simulation model that combines two crop modeling approaches. Field Crops Research 87:131-154.

PROCEEDINGS OF THE

46th

NORTH CENTRAL
EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

Volume 32

November 2-3, 2016
Holiday Inn Airport
Des Moines, IA

PROGRAM CHAIR:
Dorivar Ruiz Diaz
Kansas State University
Manhattan, KS 66506
(785) 532-7213
ruizdiaz@ksu.edu

PUBLISHED BY:
International Plant Nutrition Institute
2301 Research Park Way, Suite 126
Brookings, SD 57006
(605) 692-6280
Web page**: www.IPNI.net**

ON-LINE PROCEEDINGS:
http://extension.agron.iastate.edu/NCE/