Using Drone Based Sensors to Direct Variable-Rate, In-Season, Aerial Nitrogen Application on Corn

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Abstract. Improving nutrient management on farms is a critical issue nationwide. Applying a portion of N fertilizer during the growing season, alongside the growing corn crop is one way to improve nitrogen management. Sidedress N applications allow the availability of N fertilizer to more closely match the time when the crop is rapidly uptaking N. Additionally, waiting to apply a portion of the N during the growing season allows for management which is responsive to current growing season conditions.

Crop canopy sensors have been used during the growing season to direct in-season N application and have been found to reduce N application and increase profit. This sensor technology is most commonly used on high clearance applicators, where sensing and application take place simultaneously.

In extreme southeast Nebraska where this project is located, in-season N application by ground-based applicators is not common due to rolling hills, contour, and terrace farming. Many farmers in this area are trying aerial N applications, and more recently, variable-rate aerial N applications. The availability of small passive, multi-spectral sensors which can be carried on a drone allows the possibility of crop canopy sensing an N application from aerial platforms, eliminating the need to drive through the field and damage the crop.

The goal of this research project is to evaluate the use of a passive crop canopy sensor to direct variable-rate, in-season N fertilizer recommendation rates on corn and apply this recommendation using variable-rate aerial technology.

The farmer's traditional N management was compared to two different sensor approaches: 84 kg ha^{-1} N applied as a base rate plus in-season application and 112 kg ha^{-1} N applied as a base rate plus in-season application. Weekly aerial imagery and sensor data was collected. Yield response and profitability for the farmer's traditional method and the drone based methods will be compared on a per strip basis and spatially, on a sub-strip basis.

Keywords. *nitrogen fertilizer, sensor, drone, UAV, site-specific crop management, precision agriculture.*

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Introduction

Improving nutrient management on farms is a critical issue nationwide. Applying a portion of the N fertilizer during the growing season, alongside the growing corn crop is one way to improve N management. In-season N applications allow N fertilizer availability to more closely match crop N uptake and allows for N management which is responsive to current growing season conditions. Active crop canopy sensors have been used during the growing season to direct in-season N application and have been found to reduce N application and increase profit (Scharf, et al., 2011; Thompson et al., 2015). This sensor technology is most commonly used on high clearance applicators, where sensing and application take place simultaneously. In southeast Nebraska and other regions of the corn belt, in-season N application by ground-based applicators is not common due to rolling topography, and contour and terrace farming practices. Some farmers in these landscapes rely on airplanes for in-season N applications. Additionally, small, passive, multi-spectral sensors can be carried on drones, enabling crop sensing to occur from the air. This study uses drone based sensing and aerial N application to demonstrate in-season N management, which is conducted without vehicles on the ground in the field.

The goal of this research project is to evaluate the use of a passive crop canopy sensor to direct variable-rate, in-season N fertilizer recommendation rates on corn and apply this recommendation using variable-rate aerial technology. Determining the correct amount of N to apply as a base rate to provide the crop with enough N to reach the in-season N application is also critical. This study evaluated two different N base rates to attempt to identify the optimum base rate for in-season sensing and application.

Materials and Methods

The research was conducted on one site in 2017 in southeast Nebraska. Soil types on the field are Nodaway silt loam, occasionally flooded, Zook silty clay loam, occasionally flooded, and Wabash silty clay loam, occasionally flooded. The site contained four replications of three treatments arranged in a randomized complete block design. The corn hybrid Pioneer 1197 was planted on May 8, 2017 at a seeding rate of 13,274 seeds ha^{-1}. The previous crop was soybean and the field was not tilled following the soybean crop. The site is not irrigated. Soil tests were collected in 2015 on a 1.01 ha grid. The average soil test values for the study area are presented in Table 1.

Table 1. Soil test values in the plot area from 1.0 ha grid sampling in 2015.

OM %	CEC	pH	P	K	S	Zn	B	Fe	Mg	Mn	Na
					--------------------------------		*(mg kg^{-1})*	--------------------------------			
2.5	14.8	6.6	45	134	9.0	3.3	0.45	149.3	231.5	103.7	11.5

Three nitrogen treatments were implemented.

1. Farmer management: 179 kg ha^{-1} + flat rate in-season N application if needed

2. 84 kg ha^{-1} N base rate + in-season N management directed by drone

3. 112 kg ha^{-1} N base rate + in-season N management directed by drone.

Additionally, two blocks 91.4 m in length received a higher nitrogen rate (252 kg ha^{-1} N) and served as a high nitrogen reference.

Pre-plant N was applied on February 15 as anhydrous ammonia. During the growing season, the field was flown with a DJI Inspire (Nanshan District, Shenzhen, China) drone equipped with a MicaSense RedEdge (Seattle, WA) five band sensor with wavelength centers of 475, 560, 668, 717, and 840 nm. Each flight was calibrated with reflectance panels and a downwelling light sensor to normalize data across dates. Imagery was obtained on June 5, June 15, June 24, July 14, and September 4.

Approximately 4,500 images were captured each flight. Imagery was stitched together into a composite image using MicaSense Atlas (MicaSense, Seattle, WA) cloud based software.

The normalized difference red edge (NDRE) index was calculated for each flight. The NDRE index uses the near-infrared portion of the spectrum and allows differences in crop vegetation to be apparent, even when not visible in regular, true-color imagery *(Figure 2)*.

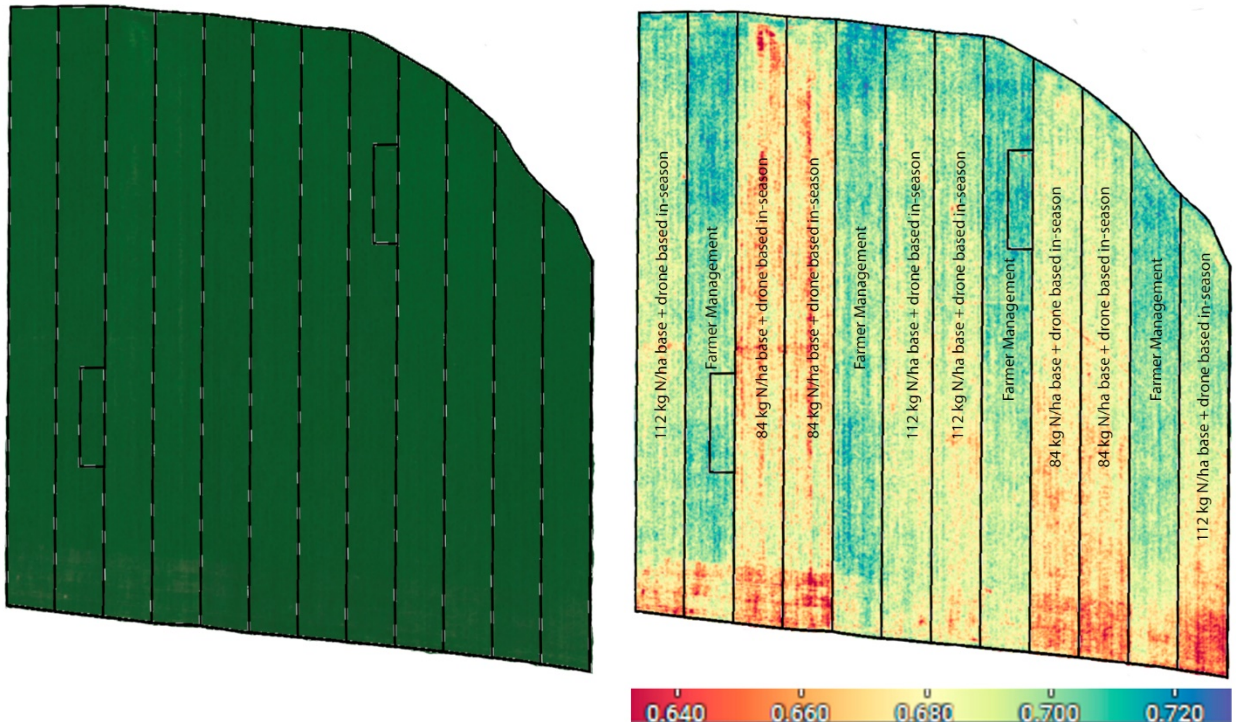

Figure 2. True color image (left) and NDRE (normalized difference red edge index) (right) of the study area on June 24, 2017 at V12.

Normalized difference red edge data was processed in ArcGIS Desktop 10.5 (ESRI, Redlands, CA) with unsupervised classification to remove pixels which are shadows and soil so that only plant pixels remain. A sufficiency index (SI) was calculated by dividing the NDRE of each pixel by the NDRE value of the top five percent of the field in accordance with the virtual reference method proposed by Holland and Schepers (2013). This allows each portion of the field to be compared with non-N limiting corn. The NDRE data from the June 24 flight *(Figure 2)* was used to create an in-season, variable-rate prescription.

The simplified Holland and Schepers (2010) algorithm was used to convert SI from June 24 to a N recommendation. For the 84 kg ha^{-1}, 112 kg ha^{-1}, and farmer management treatments, SI values were 0.86, 0.87, and 0.88 respectively. The algorithm requires an optimum N rate (ONR). A spatially varying ONR was calculated as follows:

1. 15 data layers were fused together to create management zones using Management Zone Analyst (USDA-ARS).
2. Yield goals were assigned to each zone based on past yield.
3. ONR was calculated spatially with the University of Nebraska – Lincoln nitrogen recommendation equation using the yield and interpolated organic matter.

In-season N application was applied as stablized urea (46% N) on June 29. Variable rate capabilities of the airplane dictated the length of a given rate be at least 61 m and no more than 10 rates could be used. The in-season, variable-rate prescription is shown in *Figure 3*. The farmer elected to apply 45 kg N ha^{-1} to the farmer managed strips at this time. The total N applied for each of the three treatments during the base rate application and in-season N application are in *Table 2*.

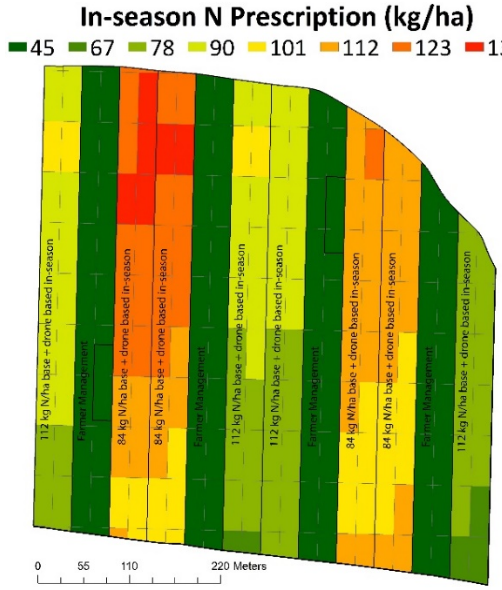

Figure 3. In-season N prescription applied on June 29 at V13 to V14 with treatment labels.

Table 2. Total nitrogen application for three nitrogen management treatments.

Treatment	Base N Rate (kg ha^{-1})	In-Season N Rate (kg ha^{-1})	Total N rate (kg ha^{-1})
Farmer nitrogen management	179	45	224
84 kg ha^{-1} base + drone based in-season	84	114	198
112 kg ha^{-1} base + drone based in-season	112	84	196

Results and Discussion

Normalized difference red edge index values from imagery prior to and after in-season N application were collected. The imagery collected before and after the in-season N application revealed that differences which existed in NDRE prior to application were no longer present after N application. This suggests that following the in-season N application, the crop was able to recover from any N deficiency or differences between treatments *(Figure 4).*

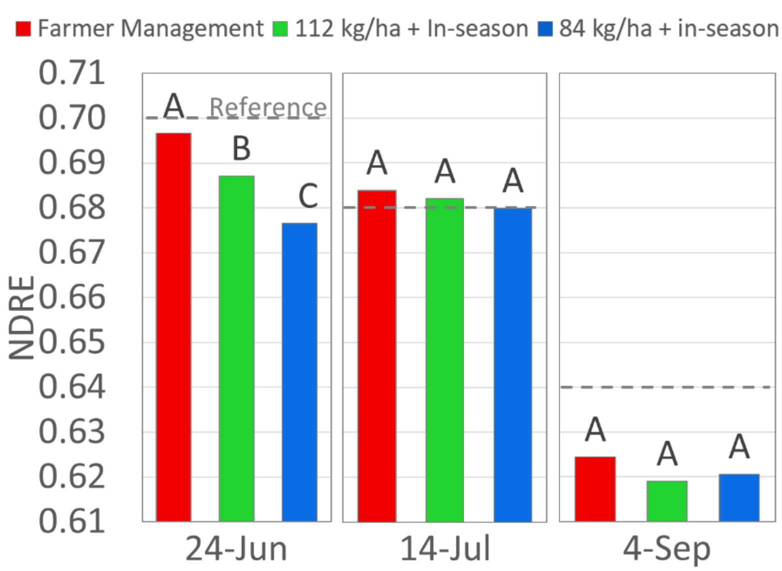

Figure 4. NDRE values for three nitrogen management treatments at three dates – June 24, prior to in-season application and July 14 and September 4, after in-season application. Bars with same letters are not statistically different at alpha = 0.10.

Yield, grain moisture, partial factor productivity of N (PFP_N), and marginal net return were calculated for the three treatments evaluated. There was no yield difference between the farmer managed strips and the drone managed strips. Both the drone and sensor based treatments resulted in less total N application than the farmer rate. This resulted in higher N use efficiency for the drone managed strips. Marginal net return was comparable between the three treatments.

Table 3. Total nitrogen rate, grain moisture, grain test weight, yield, nitrogen use efficiency (NUE), and marginal net return for three nitrogen management treatments.

Treatment	Total N rate ($kg\ ha^{-1}$)	Moisture (%)	Yield[a] ($kg\ ha^{-1}$)	PFP_N ($kg\ grain\ kg\ N^{-1}$)	Marginal Net Return[b] ($USD\ ha^{-1}$)
Farmer nitrogen management	224	15.2 A*	15,453 A	68.9 B	1704.60 A
84 $kg\ ha^{-1}$ base + drone based in-season	198	15.3 A	15,496 A	78.3 A	1711.20 A
112 $kg\ ha^{-1}$ base + drone based in-season	196	15.4 A	15,449 A	78.9 A	1711.50 A
P-Value	-	0.473	0.974	0.001	0.962

*Values with the same letter are not significantly different at a 90% confidence level.
[a]Yield values are from cleaned yield monitor data. Kg ha^{-1} corrected to 15.5% moisture.
[b]Marginal net return based on \$0.124 kg^{-1} corn, \$512..57 metric ton^{-1} anhydrous, \$360.09 metric ton^{-1} coated urea, \$34.59 ha^{-} anhydrous application, \$29.65 ha^{-1} flat rate airplane application of urea, and \$33.98 ha^{-1} variable rate airplane application of urea.

Conclusions

In order to optimize sensor-based in-season N application, N application needs to coincide with the crop expressing N differences that can be detected by the sensor, but prior to non-recoverable yield loss. A drone is one platform that allows the field to be sensed multiple times throughout the growing season with the goal of identifying the ideal timing for in-season N application. Further work is needed to develop guidelines for the ideal threshold SI for triggering in-season N application based on sensor readings. This study will be continued on two farms in 2018.

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Nomenclature

NDRE Normalized Difference Red Edge Index

SI Sufficiency Index

PFP_N Partial Factor Productivity of Nitrogen

ONR Optimum Nitrogen Rate