Development of Variable Rate Nitrogen Recommendation Algorithms to Enhance Yield and Nitrogen Use Efficiency in High Yielding Dryland and Irrigated Corn

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Abstract

Nitrogen (N) management is becoming one of the more complex aspects of modern corn production. Changes in plant genetics, earlier planting dates, larger farm size, equipment innovations, increasing fuel and N costs, as well as concerns with potential environmental contamination create a combination of opportunities and pitfalls that contribute to this complexity. Balancing time and financial resources in an effort to maximize yield and profitability, while still being a good environmental steward has become difficult for producers. The objective of this study was to evaluate the effects of different N management systems that included split N applications utilizing UAVs equipped multispectral cameras, soil testing, and conventional side dress applications at V-4 on grain yield and N use efficiency. Frequent precipitation events made for conducive N loss conditions at all study locations during the 2016 growing season. Preliminary results indicate that lower N rates can be applied while obtaining high grain yield by adapting the time, rate, and number of N applications to be synchronized with corn N demand. However, it is essential to apply adequate early season N with optical sensor based N management systems that split N applications to compensate for potential early season N losses prior to sensor use, otherwise permanent yield loss may occur. Therefore, reducing the efficacy of optical sensor based N management systems. Additional research will be conducted during 2017 to further development optical sensor N recommendation algorithms for corn.

Introduction

Nitrogen management is becoming one of the more complex aspects of modern corn production. Changes in plant genetics, earlier planting dates, larger farm size which compresses time available for field work per acre, equipment innovations, increasing fuel and N costs, as well as concerns with potential environmental contamination all contribute to this increased complexity. Balancing time and financial resources in an effort to maximize yield and profitability, while still being a good environmental steward has become difficult for producers.

In the Midwestern portion of the United States, many states use an N recommendation system which focuses on the average economic response to N across a defined geographic area, by adjusting a general response function for changes in N and corn price (Sawyer et al, 2006). The developers of this system recognize that differences in soil organic matter (SOM) as a source of mineralizable N, soil texture and drainage and their impact on N loss, in season temperature and precipitation, and how and when fertilizer is applied to the crop, all change the shape of the response function. They address these factors by using specific response functions for states or soil regions within states (Camberato et al., 2012). While these approaches are a definite improvement over traditional “rules of thumb” of 1.1 or 1.2 pounds of N per bushel of yield, for growers managing the crop on a rate per field basis, they don't provide guidance on how to adjust rates for differences in drainage, texture or SOM found in different management zones within a field.

Other states such as Kansas, take a more mechanistic approach to making N recommendations and try to adjust "rule of thumb" recommendations for residual soil N in the profile, SOM content and resulting mineralized N availability, and previous crop (Leikam, Lamond and Mengel, 2003). These approaches are easily applied to a management zone or "on the go" application system, allowing adjustments in N rate for variation in N supply, but still have limits as they do not reflect changes in N loss due to drainage or soil physical properties, or changes in N utilization efficiency (Moll et al, 1980) and resulting changes in N need per bushel of response as yields increase.

A considerable body of information exists in the literature on the impact of soil properties crop residue levels, soil drainage and texture, fertilizer source, urease and nitrification inhibitors, and method and time of N application on nitrogen fertilizer recovery, required N rate and corn yield. Some states incorporate a portion of that knowledge through developing soil or region specific N rate functions (Camberato et al, 2012). Others make management suggestions for specific N source, additives, time of application or application method to use in different soils or cropping situations (Vitosh, Johnson and Mengel, 1995), and some do both (Bundy, 1998;).

The concept of the 4-R's, applying the right source, at the right rate, at the right time and in the right place sounds simple enough, however, all these factors interact making that right rate a moving target (IPNI, 2010). Rate is a function of each of the other three variables and the efficiency associated with that choice/decision, as impacted by yield level, soil properties, soil N supply and climate. The key is to understand how these factors interact and to design a management system which can respond to changes in these factors throughout a given field to enhance yield, NUE and farmer profits without adding additional risk or complexity to the management system.

Recent advances in crop and soil sensor technology may provide a better estimate of the interaction of soil and crop yield determining factors. The utilization of pre-plant on-the-go soil sensor technology for quantifying soil characteristics, coupled with in-season crop sensor technology at specific yield determining growth stages may provide in-depth agronomic information for improving the efficiency of N management in corn (Kweon, 2012; Raun, et al., 1998; Tucker, 2010).

Objectives:

1. Measure the impact of N rate and time of application (N management system) on yield, profitability and nitrogen use efficiency in high yielding corn production
2. Evaluate the efficacy of KSU prototype agronomic algorithms that utilize soil and crop sensor technology to determine the optimum N rate
3. Compare the costs and profitability of sensor-based N management, soil-test based N management, and traditional pre-plant N management

Materials and Methods

Experiments were established at three locations in Kansas during 2016 growing season. The Scandia, Partridge, and Rossville locations are all located on KSU experiment fields and are irrigated using center pivot or lateral move sprinkler systems. Crop rotations, tillage, cultural practices, and corn hybrids utilized were representative of each area (Table 1.). Liquid starter fertilizer was applied consisting of a blend of UAN plus APP and ATS, if sulfur was needed, at a rate of 40 pounds N and 30 pounds P_2O_5 across the study area. Each field study utilized small research plots 15 feet in width by 50 feet in length. 10 treatments were assigned and placed into a randomized complete block design with four replications. All N application were surface band applied with UAN 28% as the N source.

Treatments:

1. Starter N only.
2. Starter plus surface band UAN at pre-plant 50 lb N/ac.
3. Starter plus surface band UAN at pre-plant100 lb N/ac.
4. Starter plus surface band UAN at pre-plant 150 lb N/ac.
5. Starter plus surface band UAN at pre-plant 200 lb N/ac.
6. Starter plus surface band UAN at pre-plant 250 lb N/ac.
7. Starter plus surface band UAN at V 6-8 with KSU Active Sensor-based N Rate.
8. Starter plus surface band UAN at V 6-8 with KSU sUAS Imagery based N Rate.
9. Starter plus surface band UAN at V 6-8 and V 14-16 with KSU sUAS Imagery based N Rate.
10. Starter plus surface band UAN at V 6-8 with KSU Soil Test N Rate.

Soil samples to a depth of 24 inches were taken by block, prior to planting and fertilization to estimate residual nitrate-N present at planting. 0-6 inch samples were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, ammonium-N, nitrate-N, and zinc. The 6-24 inch samples were analyzed for ammonium-N, nitrate-N, chloride, and sulfate sulfur. Summary of the soil analysis results are presented in Table 2. Any fertilizer needs other than N were applied near planting as indicated by the soil tests. A Veris MSP3D was utilized at each location to collect fine spatial resolution electrical conductivity, organic matter, and soil pH data. A-B lines used during the operation of the Veris MSP3D was set to 10 feet centers.

Canopy reflectance of the corn was measured multiple times throughout the growing season with V-4, V-6, V-8, V-10, and R-1 being key targeted growth stages for measurement. Optical sensors utilized were the Holland Scientific Rapid Scan active optical sensor (AOS), MicaSense RedEdge multispectral imager, DJI X3 RGB camera, and FLIR Vue Pro R thermal camera. The MicaSense RedEdge was calibrated using MicaSense reflectance calibration panel and processed utilizing their Atlas processing service. The MicaSense RedEdge, DJI X3, and FLIR Vue Pro R were mounted to a DJI Matrice 100 quadcopter. The DJI Matrice 100 conducted autonomous flights at an altitude 40 meters above ground level (AGL) with flights lines that generated approximately 80% side-lap and 90% forward-lap. Autonomous missions were implemented using Maps Made Easy MapPilots mobile application for iOS. Canopy reflectance, NDVI, and thermal data was extracted from each plot using ESRI ArcGIS. The calibrated spectral data was used in a prototype KSU corn N recommendation algorithm designed for AOS and imagery to generate N recommendation to be applied.

Whole plant samples were taken at approximately half to 3/4 milk. Whole plant biomass was measured and analyzed for N content. Grain yield was measured by harvesting an area of 5 feet by 50 feet within each plot at the Partridge, Scandia, and Rossville using a plot combine. Grain yield was adjusted to 15.5 percent moisture, and grain was analyzed for N content. All analyses were conducted by the KSU Soil Testing Lab using procedures recommended by the NC Committee on Soil Testing. Statistical analysis was conducting using SAS software PROC GLM with mean separations made using a 0.05 alpha.

Results and Discussion

Results from this experiment are summarized in Tables 3-4 and Figures 1-6. The Partridge location was low yielding due to extreme weed pressure that resulted in a late replanting. No statistical significance amongst treatments was found. Due to the confounding weed issues and poor performance of the Partridge location, the results will not be elaborated upon.

The 2016 season at the Rossville location began with high intensity and high frequency precipitation events (Figure 1.). The Kansas River Valley area where Rossville resides contains variable coarse textured soils that suffer high nitrate leaching losses when heavy precipitation events occur. Only moderate yields within the range of 160-170 bushel per were achieved at Rossville, which is significantly lower than the 200 bushel often achievable at this location. Table 3 shows that the 250 lb N rate, treatment 6, applied at V-4 was the numerically highest yielding treatment. The multiple N applications based on aerial imagery, treatment 9, produced yields statistically equal to 250 lb N rate on nearly 50 lbs N less N applied. Although the 30 bushel difference between treatments 6 and 9 was not significantly different, it did warrant further investigation for this wide variance in grain yield that was observed. The heavy rainfall events shown in Figure 1 likely led to significant N leaching losses in the early season. Therefore, treatments with only the 40 lb starter N applied to support early season growth may have experienced N stress during V-6 when earsize was being determined. Which may have resulted in a permanent yield reduction. Additionally, the frequent rainfall events in the latter part of the season would continue N leaching losses (Figure 1). Figure 3 and 4 show the Rossville study area prior to R-1 treatment applications, and a significant difference in NDRE values and greenness is observed on the southern three blocks. Previous knowledge of these soils and the precipitation events experienced would suggest that heavy nitrate leaching losses likely occurred in the lower three blocks. While the northern fourth block potentially retained more of its nitrogen in the root zone of the soil profile. Veris electrical conductivity (EC) data shown in Figure 5 provides clear insight to the soil texture variability to a three feet depth in the soil profile of the study area. The southern zone of the study area has low EC readings and is indicative of deep sandy soil. However, the northern end of the study area has an increase in EC values that indicate more clay and heavier soil texture is present. When the EC data is overlaid with the Normalized Difference RedEdge Imagery (NDRE) as shown in Figure 6, the EC almost perfectly aligns with the heavier soil texture zone with the fourth block that has high NDRE values across the entire northern zone. The southern zone however is showing lower NDRE values and significant N stress across the sandier, low EC, lower three blocks. The multiple N applications made using multispectral imagery performed well at Rossville but maximum yield was likely hindered by the potentially severe nitrate leaching losses in the early season that may exceeded the support provided by the starter N application. Therefore, in order ensure the corn is not N stressed prior to its first sensor based N application, a larger at-planting N application may be necessary.

At Scandia the soils are a favorable Crete silt loam that have a high productivity potential, but can be prone to denitrification if heavy and frequent rainfall events occur. Figure 2 shows that frequent rainfall was experienced a Scandia, however, no N stress was visible in the early growth stages across the study area. N stress was not observed until V-10, and only in plots that received less than 100 lbs N per acre (Table 4, Figure 7). Treatment 6, 250 lb N at V-4, was the numerically highest yielding. However, the multiple N applications based on multispectral imagery, treatment 9, achieved statistically equal yield to treatment 6, but applied nearly 170 lbs of N less. At Scandia, the late season of assessment and application of N produced the best result in regard to agronomic optimum yield with high NUE.

Initial results show that use of multispectral imagery for multiple N applications throughout the growing season has promise and could be a viable tool for improving NUE. However, these results show that early season N applications prior to optical sensor use is critical to ensure adequate N is available in the soil profile to prevent N stress during earsize determination. This factor should be considered when using a delayed and/or a split N application system to prevent permanent yield reductions induced by early season N stress.

This research will be conducted during the 2017 season to continue to develop and evaluate optical sensor based N recommendation systems under different weather and soil conditions.

Table 1. Location Information, 2016

Location	Partridge	Scandia	Rossville
Soil Type	Nalim loam	Crete silt loam	Eudora silt loam
Previous Crop	Soybeans	Soybeans	Soybeans
Tillage Practice	Conventional	Ridge Till	Conventional
Corn Hybrid	164 PR RIB	Pioneer 1197	Pioneer 1197
Plant Population (plants/ac)	32,300	32,000	31,700
Irrigation	Yes	Yes	Yes
Starter Fertilizer lb/ac	40-30-0	40-30-0	40-30-0
Planting Date	6/15/16	6/2/16	4/14/16
First Treatment V-4	7/19/16	6/23/16	5/31/16
Second Treatment V8-10	7/19/16	7/23/16	6/23/16
Third Treatment R1-2	8/1/16	8/1/16	7/31/16
Harvest Date	10/21/16	11/9/16	9/21/16

Table 2. Location Soil Analysis, 2016

Location	Sampling Depth (Inch)	Partridge	Scandia	Rossville
pH	0-6	7.37	6.16	7.37
O.M. (%)	0-6	1.25	3.19	1.33
Mehlich P (PPM)	0-6	18.10	7.32	17.18
K (PPM)	0-6	136.00	363.00	112.50
Zn (PPM)	0-6	1.07	1.81	1.00
NH4-N (PPM)	0-6	2.24	4.94	2.67
NO3-N (PPM)	0-6	6.84	4.73	2.84
NH4-N (PPM)	6-24	4.84	5.20	2.80
NO3-N (PPM)	6-24	5.78	5.40	2.10
Cl (PPM)	6-24	13.64	4.70	3.50
SO4-S (PPM)	6-24	10.17	10.60	1.30

Table 3. Rossville treatment effects

Treatment	Starter N	V-4 N	V-8 N	R-1 N	Total N	Grain Yield
--------------------------------	lb N ac^{-1}	-----------------------------				bu ac^{-1}
6	40	250	0	0	290	171 A
5	40	200	0	0	240	161 AB
4	40	150	0	0	190	153 AB
9	40	0	163	40	243	143 AB
3	40	100	0	0	140	135 B
8	40	0	175	0	215	134 B
10	40	0	250	0	290	134 B
7	40	0	163	0	203	131 BC
2	40	50	0	0	90	99 C
1	40	0	0	0	40	32 D

Results with the same letter are not statistically different at 0.05 alpha

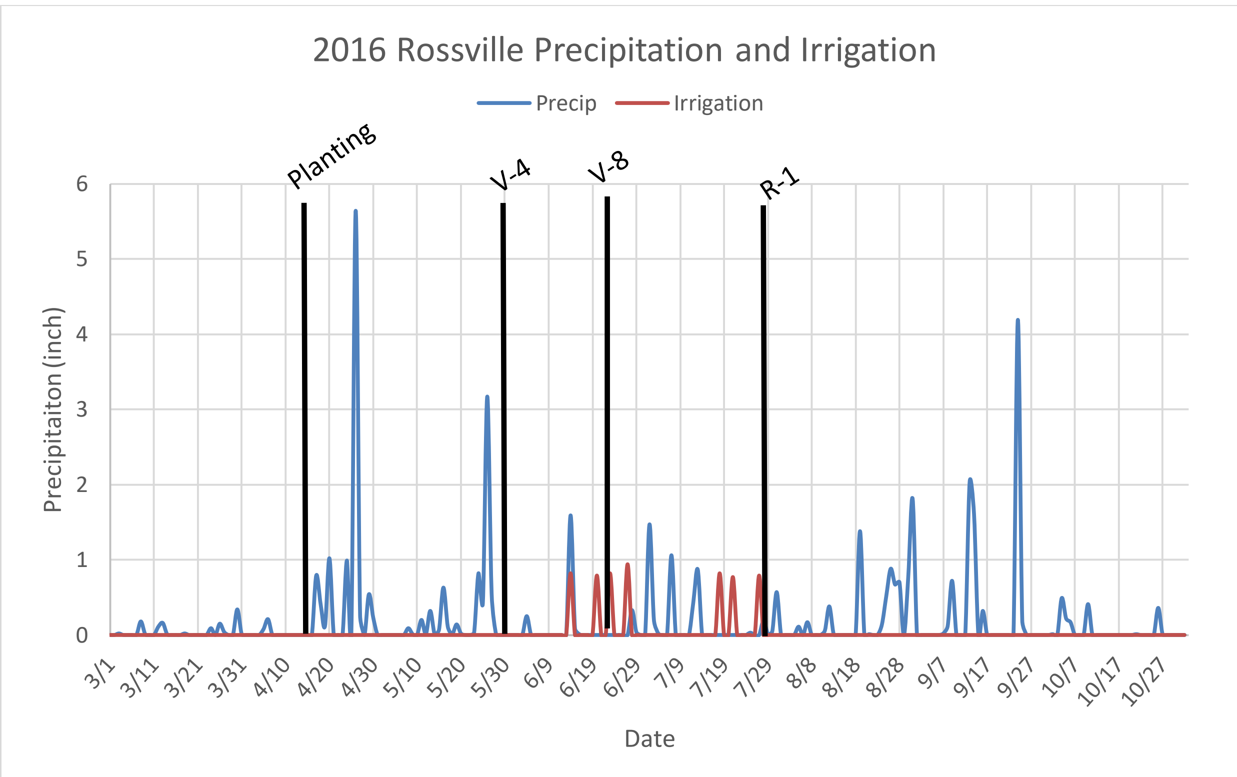

Figure 1. 2016 Rossville precipitation and treatment applications

Table 4. Scandia treatment effects

Treatment	Starter N	V-4 N	V-10 N	R-1 N	Total N	Grain Yield
-------------------------------		lb N ac^{-1}	-----------------------------			bu ac^{-1}
6	40	250	0	0	290	178 A
5	40	200	0	0	240	174 AB
9	40	0	32	51	123	166 ABC
3	40	100	0	0	140	165 ABC
4	40	150	0	0	190	165 ABC
8	40	0	69	0	109	164 BC
10	40	0	230	0	270	159 C
7	40	0	78	0	118	155 C
2	40	50	0	0	90	134 D
1	40	0	0	0	40	128 D

Results with the same letter are not statistically different at 0.05 alpha

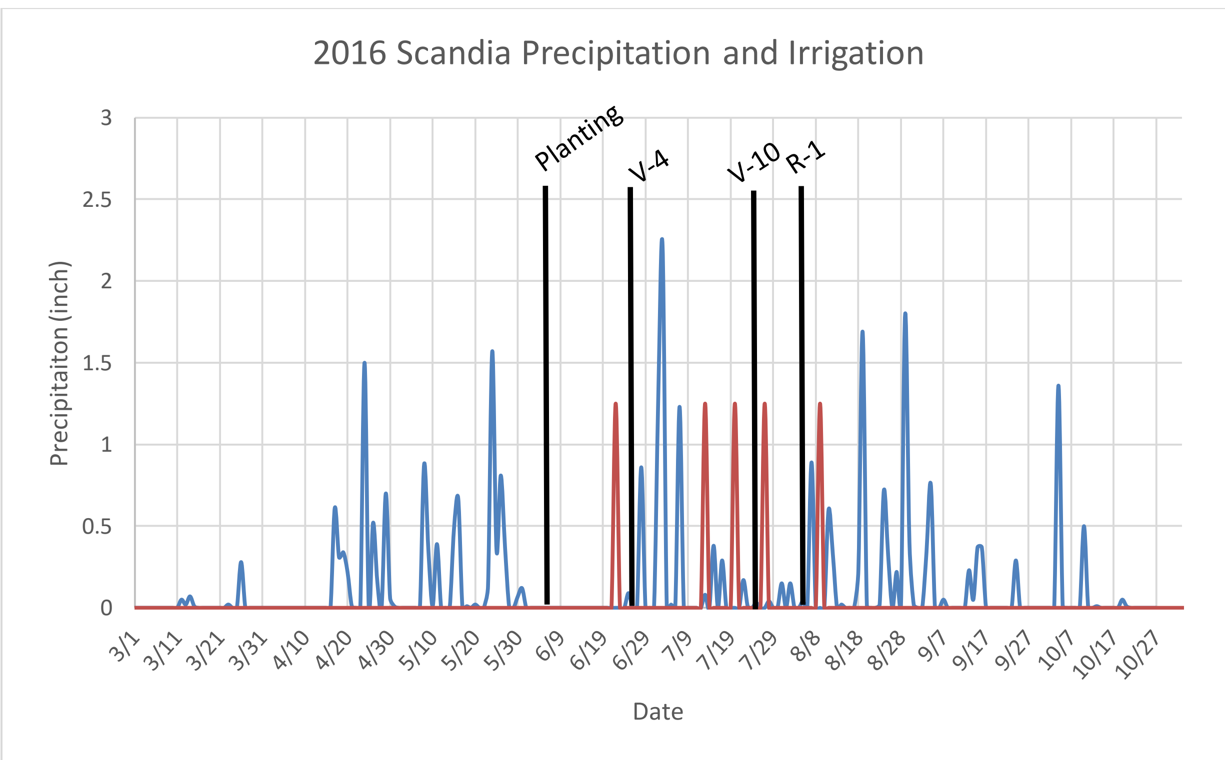

Figure 2. 2016 Scandia precipitation and treatment applications

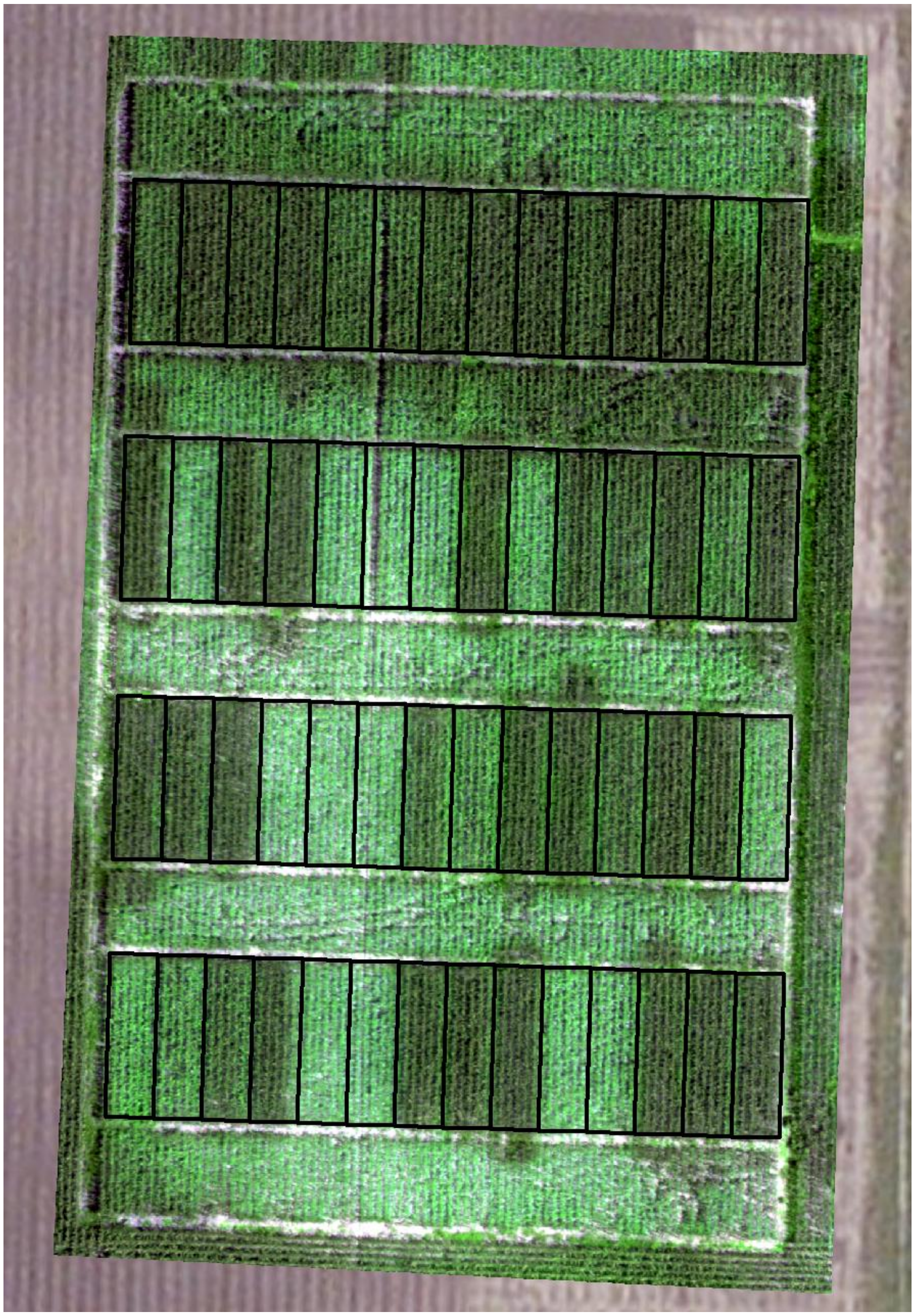

Figure 3. Rossville with plot outlines, normal color image prior to R-1 treatments, MicaSense RedEdge

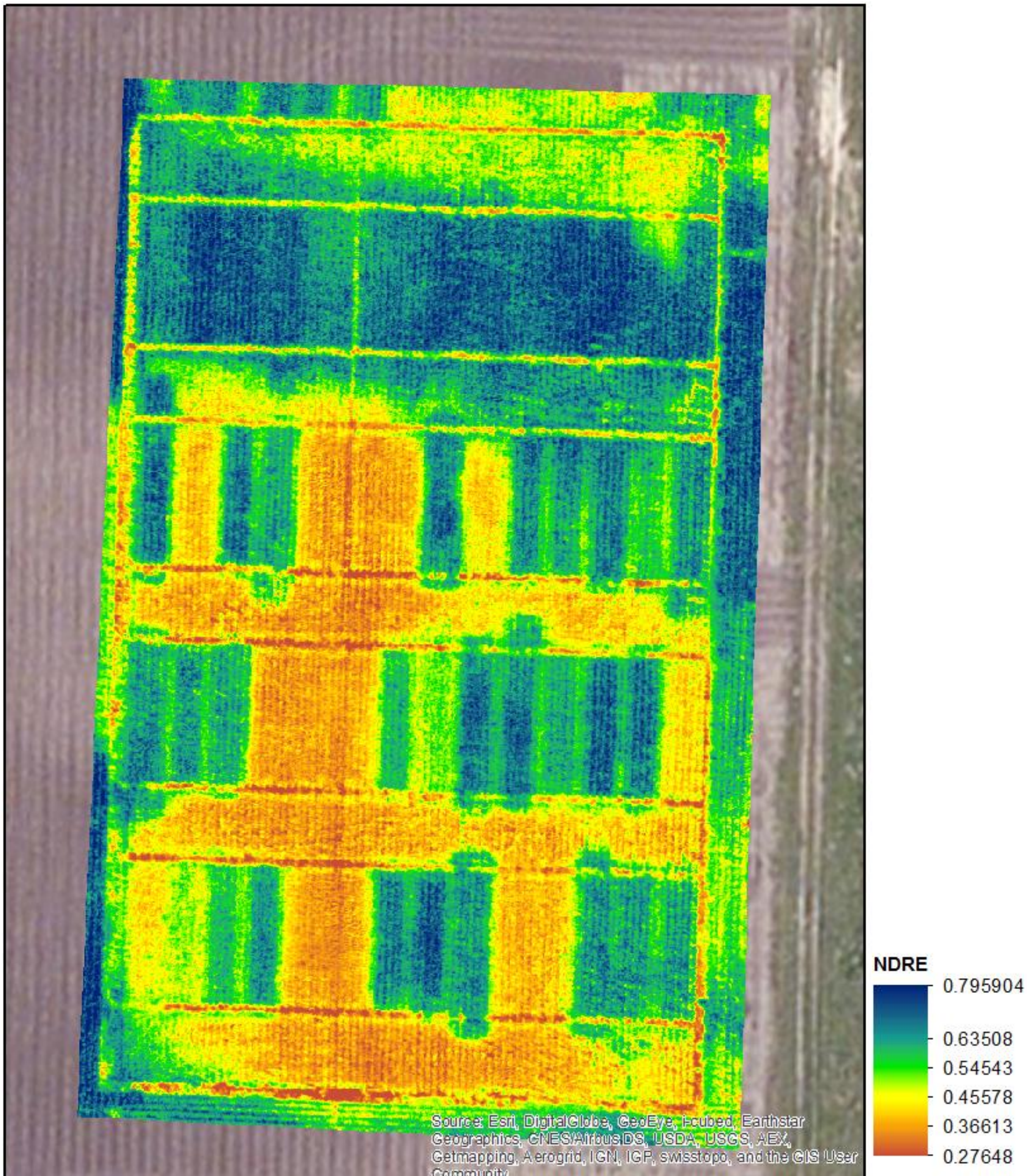

Figure 4. Rossville normalized difference rededge (NDRE), image taken prior to R-1 treatments, MicaSense RedEdge

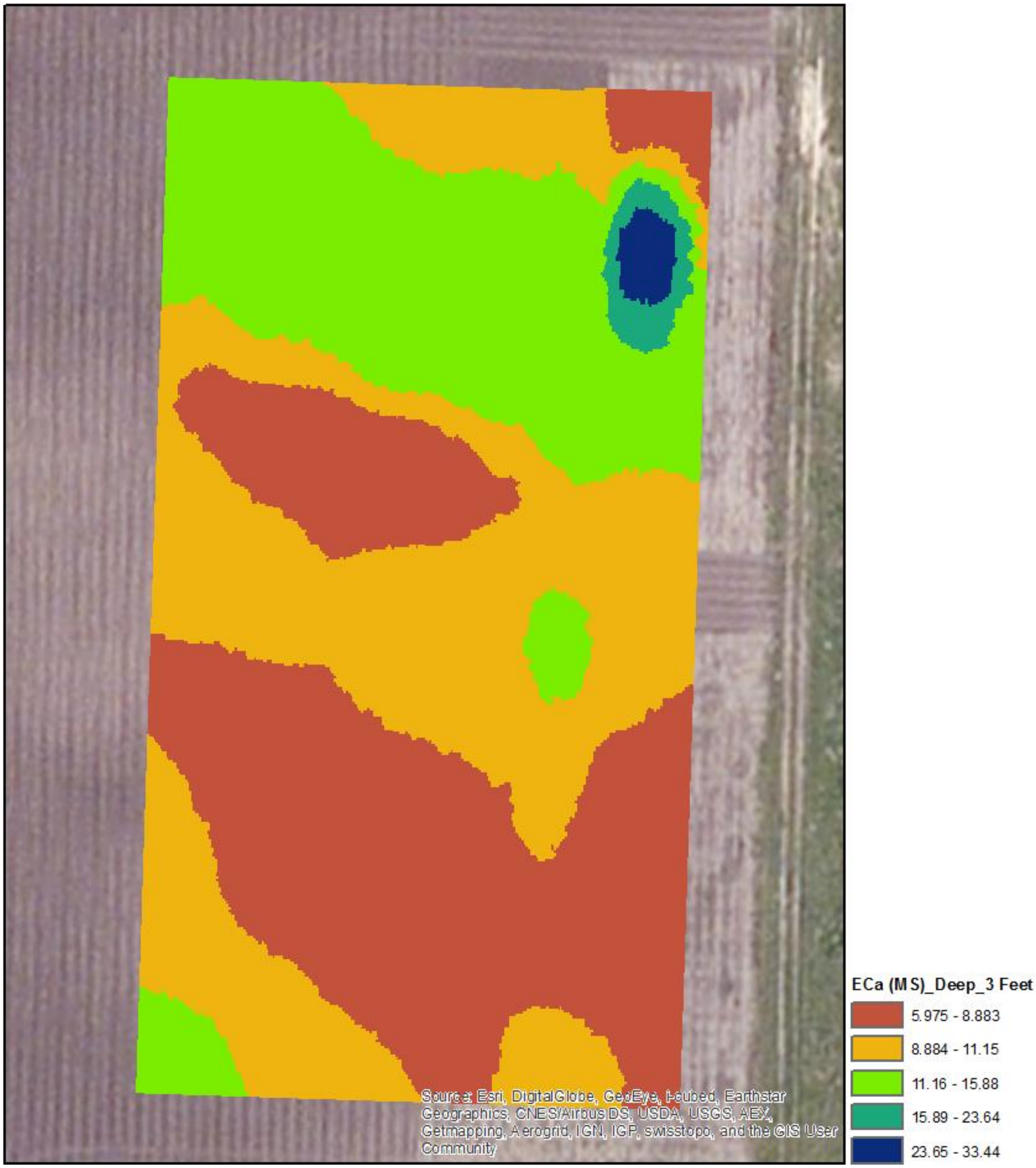

Figure 5. Rossville electrical conductivity across study area, Veris MSP3D

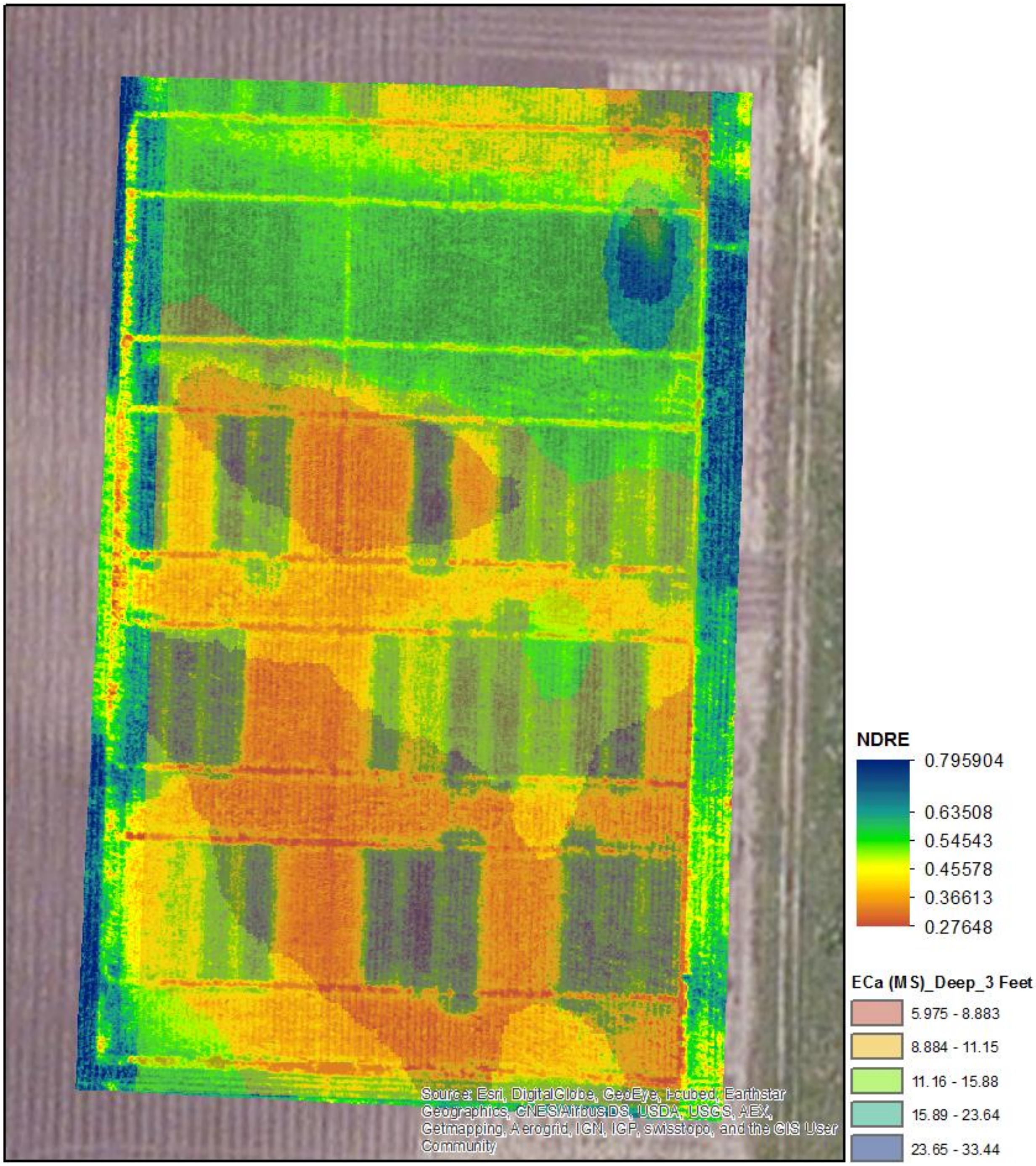

Figure 6. Rossville electrical conductivity overlayed on a normalized difference rededge (NDRE) image, image taken prior to R-1 treatments, MicaSense RedEdge and Veris MSP3D

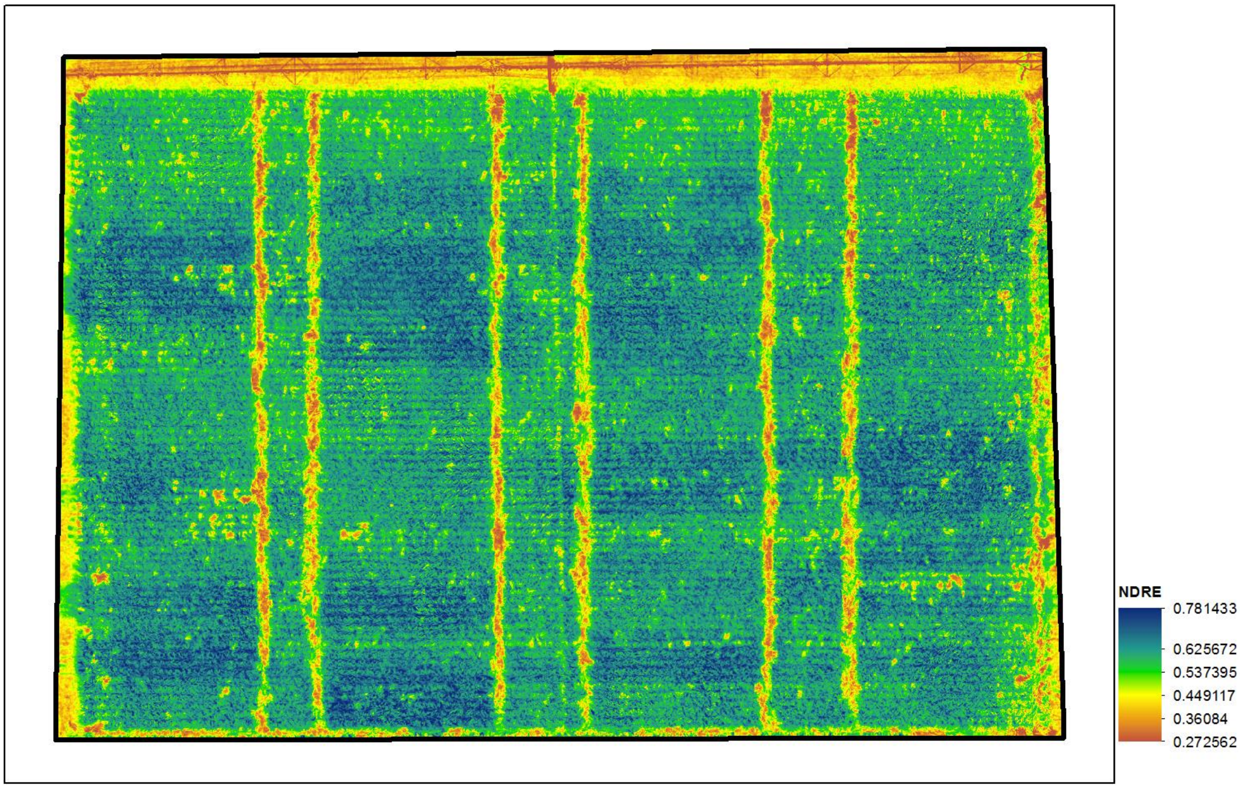

Figure 7. Scandia normalized difference rededge (NDRE), image taken prior to V-10 treatments, MicaSense RedEdge

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