Improving Nitrogen Management in Wheat using remote sensing

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1.0 Rationale

Precision agriculture (PA) is the application of geospatial techniques and sensors (e.g., geographic information systems, remote sensing, GPS) to identify variations in the field and to deal with them using site-specific strategies. In particular, high-resolution satellite imagery is now more commonly used to study these variations for crop and soil conditions. However, the availability and the often-prohibitive costs of such imagery would suggest an alternative product for this particular application in PA. Specifically, images taken by low altitude remote sensing platforms such as planes, or small unmanned aerial systems (UAS), are shown to be a potential alternative given their low cost of operation in environmental monitoring, high spatial and temporal resolution, and their high flexibility in image acquisition programming.

2.0 Objectives

The objective of this study was to evaluate the capability of remote sensing from different platform (UAV, planes and satellite) in capturing spatial variability of wheat growth and to quanfity the impact of a reduce N application on yield at the field scale.

Methodology

3.1 Field site description

This research was completed on two wheat fields near Portland, Michigan during the 2015 growing season. Both fields were cultivated and planted by the farmer in a similar manner as described below.

Field #1 encompasses approximately 54 acres and included a low-Nitrogen test strip that extended from east to west along its length in the southernmost portion of the field. The entire low N test strip and the majority of the conventionally treated area of this field are classified as a Dryden sandy loam (75%). This soil typically has up to 11 inches of sandy loam over a sandy clay loam subsoil on 2-6% slopes, is well-drained, has moderate water storage potential and the depth to the water table is typically 24-36”. Two other soils that make of the majority of the rest of the field are the Barry sandy loam (15% of study area) which follows an east-west transect in the central and northern parts of the field and the Lapeer sandy loam (10%) in the northeastern portion of the field. While the texture and profile descriptions of both of these soils are similar to each other and to the Dryden sandy loam, the Barry soil differs in that it is poorly drained, experiences frequent ponding and the depth to the water table is frequently at the surface. The Barry soil is located entirely in the conventionally treated portion of the field.

Field #2 is located nearby on 18 acres of Celina loam. This well-drained soil covers the majority of the field (84%), has 2 to 6% slopes, and is characterized by up to 12” of loam underlain by clay loam. The water table is typically observed between 30” to 72” below the surface of this soil and it has high available water storage capacity. An area on the southern portion of this field includes the Conover loam (7%) which has up to 2% slopes, is somewhat poorly drained and is typified by a more shallow depth to the water table (12-24”). The Miami loam (9%), which covered an area in the easternmost portion of this field, is considered well drained (more than 80” to water table) and moderately eroded.

3.2 Field observations

Sample collection

Biomass samples were collected in the conventionally farmed areas of both wheat fields as well as in a low Nitrogen test strip (40# less N applied) planted in Field #1. Samples were taken in locations in both fields from equidistant points along transects to represent field variability. GPS coordinates were noted at each sample location so that subsequent samples could be taken from areas directly adjacent.

Samples were collected four times throughout the growing season from each field. Four samples were collected May 30 from both the test strip and conventional areas of Field #1 and 8 samples from collected June 3 from Field #2. On June 16 each of these fields was sampled in areas adjacent to the original sample site as well as 4 additional sites for a total of 8 sample locations. Four additional sites were added to these 8 for a total of twelve locations sampled on both June 23 and July 16 in both the conventional and test strip portions of Field #1 and throughout Field#2. A total of 112 samples were collected and analyzed. All aboveground plant matter in a one-square meter area was sampled, dried, weighed, ground and analyzed for total Nitrogen. Grain was segregated and analyzed separately from the remaining plant biomass for samples that were collected July 16 (final harvest). Yield data was collected through use of a yield monitor mounted on the farmer's combine. PhotosynQ measurements were also taken at each location where biomass samples were collected.

Yield Map

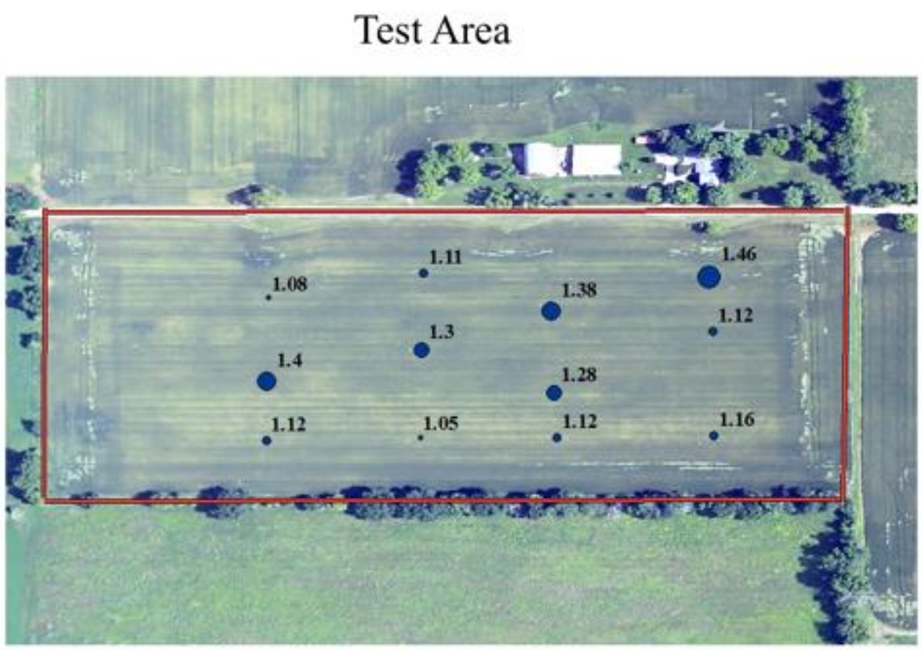
A map was created with data collected from the yield monitor mounted on the farmer's combine at the end of the growing season. Yield data collected from this monitor is located at points 0.8m along rows and from rows that are spaced 12m apart. A kriging algorithm was then used to interpolate values between points to create a yield map for the entire field. This yield map was used to evaluate vegetation indices to determine to what degree they reflected the final yield.

Imagery collected on different dates was also compared with the yield map in the same manner to determine the stage of crop growth most closely related to the final yield.

3.3 Remote sensing

Drone imagery

Unmanned aerial vehicles (UAV) were used to collect imagery from these wheat fields with a variety of sensors including LiDAR, RGB and multi-spectral cameras. A smaller UAV was also used to capture imagery with the RGB camera. These images were primarily used to visually observe variation in the field throughout the growing season. We employed LiDAR to evaluate crop height at different times over the course of the growing season, however technical difficulties arose with this technology. This process exhibited limited success and needs improvement. Throughout the season, mechanical and technological failures led to significant problems in data collection. As systems become more advanced our expectation is that more complete data sets will be collected with the drones.



Other remote sensing imagery and analysis

Airborne photos representing the RGB (red/green/blue) wavelengths were obtained from Airscout for 6 dates throughout the growing season. The original photo and the original red, green and blue wavelengths were used along with eleven additional vegetation indices that were developed from the original photo by calculating different wavelength combinations (as shown in Table 1). Data from these processed images for each of the 6 days were then compared to the final yield map to determine the index and the date that were most closely associated with the final yield.

Table 1. Vegetation Indices

Vegetation Index	Wavelength combinations
r	R* / (R* + G* + B*)
g	G* / (R* + G* + B*)
b	B* / (R* + G* + B*)
RVI	(Red / Green)
AVRI	Red / (Blue * Green) * 100
VNDVI	(Green - Red) / (Green + Red)
R_G	Red - Green
G_B-R_G	(Green - Blue) / (Red - Green)
G_B	Green - Blue
2G-R-Blue	2Green - Red - Blue
Hue	$Cos^{-1}(2R-G-B/(2*Sqrt([R^2 + G^2 + B^2 - R*G - G*B-R*B])))$

R*= R/Rmax, G* = G / Gmax, B* = B / Bmax

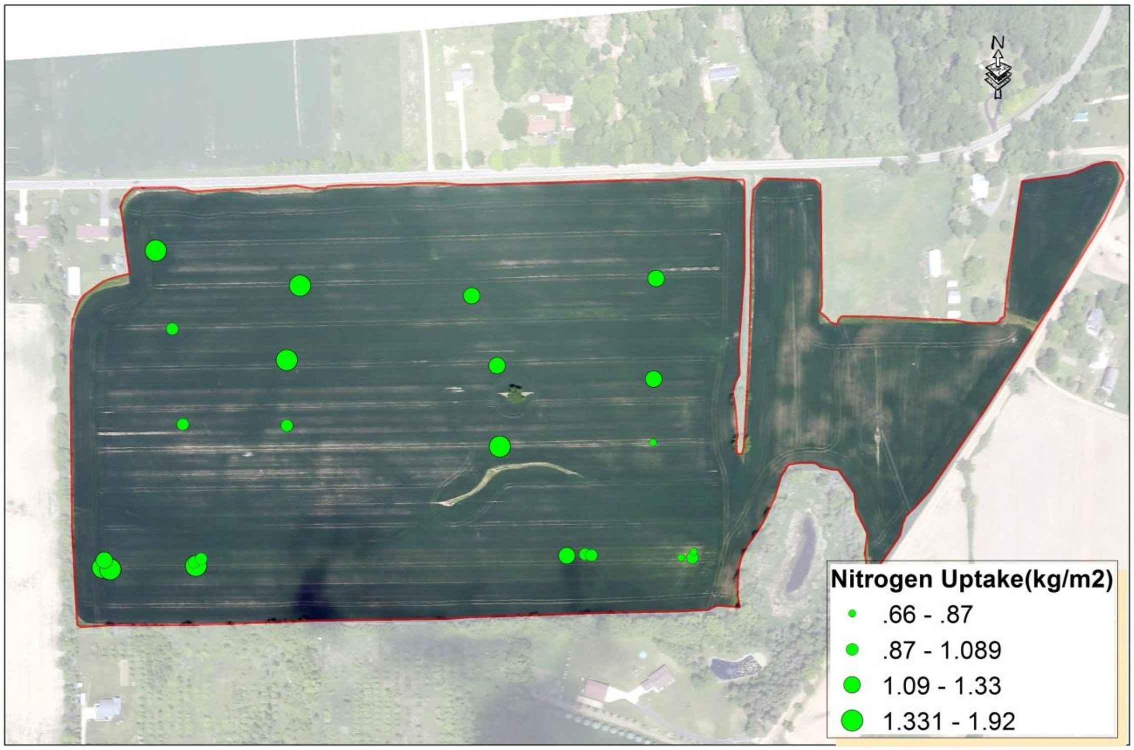
Nitrogen Uptake Map

A nitrogen uptake map was created with data obtained from samples collected throughout the growing season according to the following equation:

$$(\text{Biomass kg/m}^2)\ (\%\text{Nitrogen}) = \text{N uptake}$$

Nitrogen uptake maps were used to evaluate those areas of the field where plants utilized the most nitrogen, the stability of areas of high and low N uptake as well as whether those areas were consistent with the final yield map. Figure 1 shows a N uptake map developed with data from samples collected June 23 overlain on an Airscout image taken June 24. The size of sample location markers in Figure 1 relates to the magnitude of Nitrogen uptake at that location on that date and not to the size of the area compared with airborne imagery.

Figure 1. Nitrogen Uptake map (June 23)



PhotosynQ

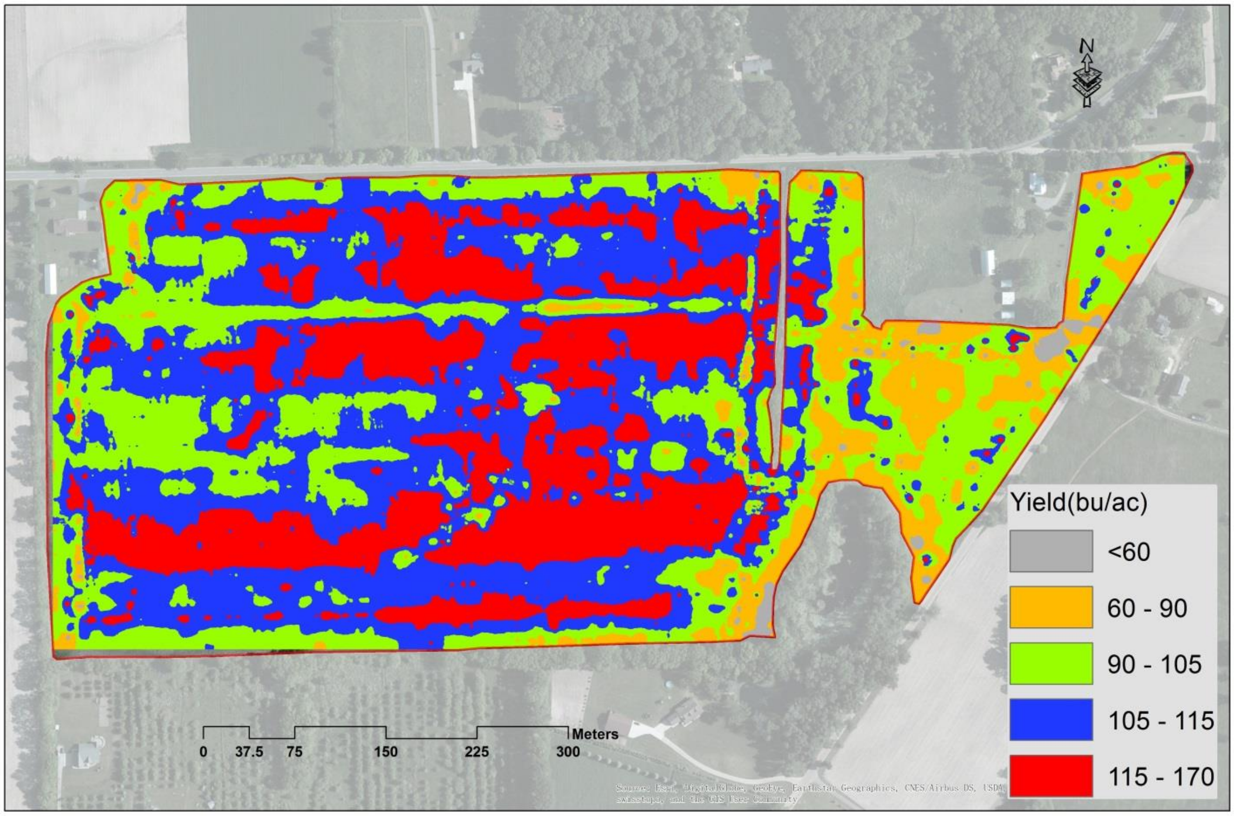
A handheld PhotosynQ device developed by MSU plant physiologists was used to take non-destructive measurements of plant health. This instrument measures chlorophyll content, Photosynthetic active radiation (PAR) and 12 other parameters to evaluate reflectance, photosynthetic efficiency and other factors related to plant health. The device used to collect data here was a prototype of one that will be in production in 2016. PhotosynQ measurements were taken of the top and middle leaves of plants at every location where biomass samples were collected beginning June 3, resulting in a database of 320 measurements. Difficulties were encountered with data collection and data retrieval early in the growing season due to software problems with the PhotosynQ device. These issues were continually addressed by the software development team as the growing season proceeded.

4.0 Results and Discussion

Yield Map

A map was created with data collected from the yield monitor mounted on the farmer's combine. Mean values obtained from the yield monitor for Field #1 was 107 bu/ac with a range of 9.8-185 bu/ac and standard deviation of 14 bu/ac. The individual classes into which the majority of pixels in the image are divided represent 25% of the overall total. Less than 2% of all pixels in this field were placed into the lowest category (<60bu/ac).

Figure 2. Wheat yield map



Comparison between Test strip and Conventional areas-Field #1

% Nitrogen

Average values for total Nitrogen content from the conventional area of Field #1 were consistently higher than those obtained for the low N test strip for all sampling dates (Table 2). These differences were not statistically significant for samples collected May 30 and June 16 but were significantly different in samples collected from June 23 (t=0.02). This relationship remained through to the end of the growing season. Data from the final harvest indicates differences that were highly significant (t=0.004) for % Nitrogen in grain between the test strip and the conventional portion of this field. No significant differences were observed for stover when data was compared between the conventional and test strip areas at final harvest (t=0.14).

Table 2. Mean values-%Nitrogen

Location:		% Nitrogen			
		May 30	June 16	June 23	July 16 (grain only)
Field #1- Test strip	mean	2.06	1.10	1.22	1.75
	range	1.93-2.13	0.84-1.28	0.95-1.57	1.52-2.01
Field #1-Conv.	mean	2.21	1.32	1.42	1.96
	range	1.91-2.34	1.13-1.66	1.2-1.58	1.8-2.21
		June 3	June 16	June 23	July 16 (grain only)
Field #4-Conv.	mean	1.3	1.15	1.21	1.87
	range	1.19-1.41	1.0-1.29	1.05-1.46	1.7-1.99

Biomass

Average values for biomass from the conventional portion of Field #1were consistently higher than those observed for the low N test strip (Table 3). The difference in mean values was most pronounced for samples collected June 16 when the test strip averaged 0.68 kg/m^2 and the average for the conventionally farmed area was 0.74 kg/m^2. However differences between these two treatments were not statistically significant for any of the dates sampled.

Table 3. Mean values -Biomass

Location:		Biomass (kg/m^2)			
		May 30	June 16	June 23	July 16
Field #1- Test strip	mean	0.49	0.68	0.88	1.04
	range	0.45-0.5	0.55-0.8	0.7-1.02	0.7-1.46
Field #1-Conv.	mean	0.51	0.74	0.91	1.11
	range	0.4-0.6	0.6-0.85	0.6-1.15	0.8-1.39
		June 3	June 16	June 23	July 16
Field #4-Conv.	mean	0.64	0.94	1.14	1.15
	range	0.5-0.75	0.7-1.15	0.85-1.6	1.3

Crop growth was clearly different in the two treatment areas of Field #1. The low nitrogen test strip was evident in airborne imagery throughout the growing season, both in images that had been enhanced and in the original R/G/B photos. In addition, areas within the test strip varied depending on the date. Early in the season samples taken from the easternmost portion of the test strip had higher N uptake values than the westernmost portion of the field. Later in the growing season this trend was reversed. This is thought to be related to the fact that while the test strip is mapped as one soil unit, the easternmost portion of the test strip at times had standing water. Areas within the conventional portion of the field that were higher producing as well as those areas that were lower producing remained consistent throughout the growing season.

Comparison between Field #1-conv and Field #2

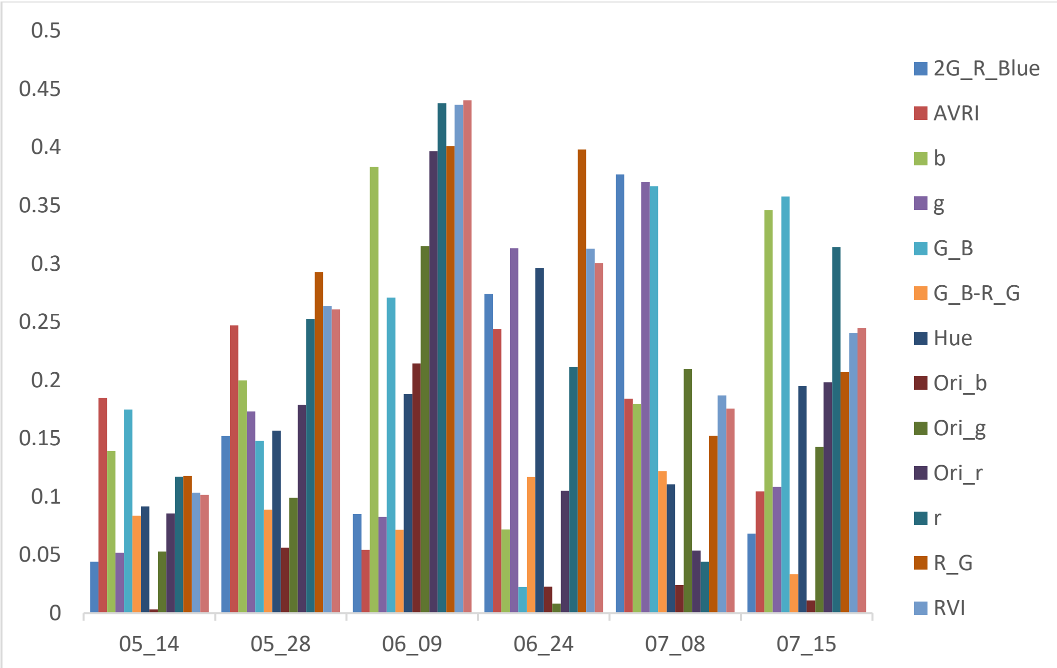
A comparison of results between Field #1 (without data from the test strip) and Field #2 showed that significant differences between the conventionally farmed areas of these two fields were present for %N as well as for biomass. Nitrogen content was significantly higher in the conventionally grown portion of Field#1 than was observed in Field#2 (t=0.001) for samples collected June 23 and July 16. Grain nitrogen content mean values at final harvest were also significantly higher in the conventionally farmed area of Field #1 than those observed in Field #2 (t=0.018). Biomass was significantly higher in Field #1 than in Field #2 for samples collected June 16 (t=0.02) and June 23 (t=0.02).

Vegetation Indices and yield

Correlation coefficients were calculated to compare fourteen visual Airscout image vegetation indices with the wheat yield data. This analysis was completed for photos collected on 6 dates throughout the growing season as shown in Figure 3. Negative correlation coefficients are considered as having the same meaning as positive ones so they are represented in this figure with positive values. Data from photos taken June 9 was best correlated to final wheat yield with the VNDVI vegetation index (r= 0.44). VNDVI is calculated from the original bands as:

VNDVI = (Green-Red) / (Green+Red)

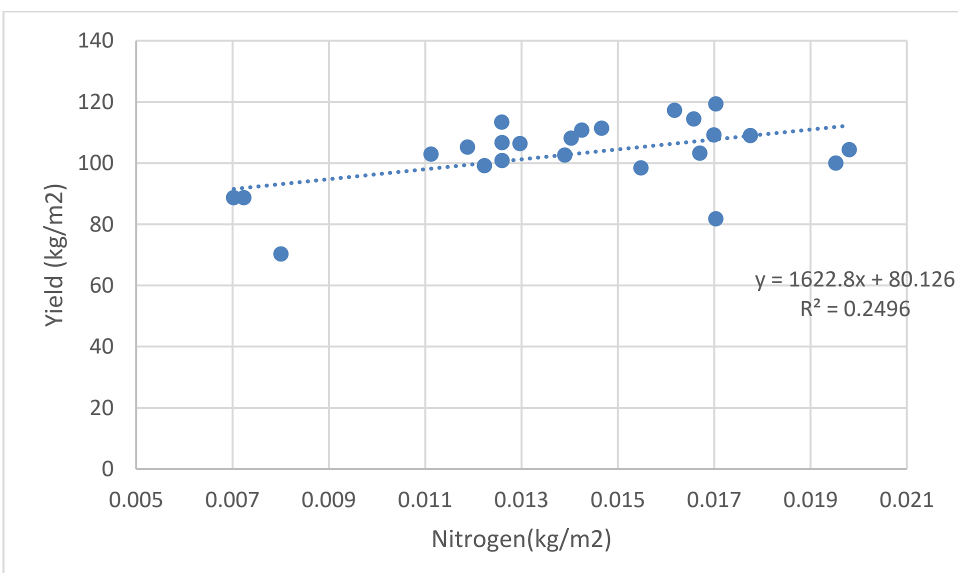
Figure 3. Correlation coefficients between vegetation indices and yield



Nitrogen uptake and yield

We calculated the correlation coefficient between nitrogen uptake and final wheat yield for three different dates. While it was not always possible to obtain Airscout photos for the exact day when samples were collected in the field, photos were within 10 days of the sample date. Sample data was converted to a 4m^2 rectangle in ARC-GIS in order to compare the two datasets. The best fit was obtained for samples collected July 16 (r^2= 0.2496) as shown in Figure 4.

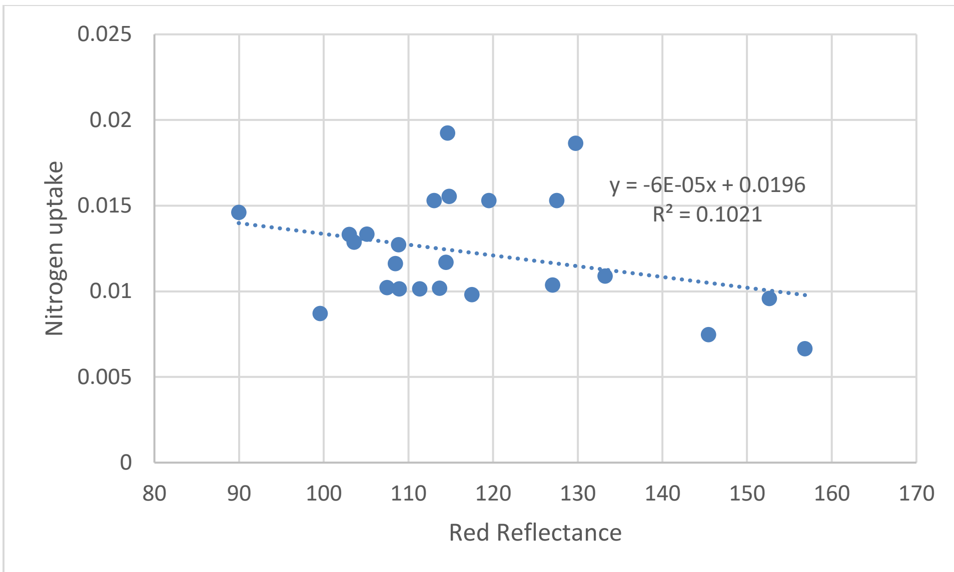
Figure 4. Correlation between Nitrogen uptake and yield (July 16)



Nitrogen uptake and vegetation indices

We analyzed the relationship of nitrogen uptake and two kinds of aerial image indices at consistent dates, original red reflectance and VNDVI. Here, we present the red reflectance analysis as an example. The nitrogen uptake and red reflectance at individual date are related, but this relationship is not statistically significant. The nitrogen uptake values for samples collected June 23 and red reflectance for imagery collected June 24 (Figure 5) demonstrated the best relationship among these scenarios (r^2=0.1021).

Figure 5. Nitrogen uptake (June 23) and original red reflectance (June 24)



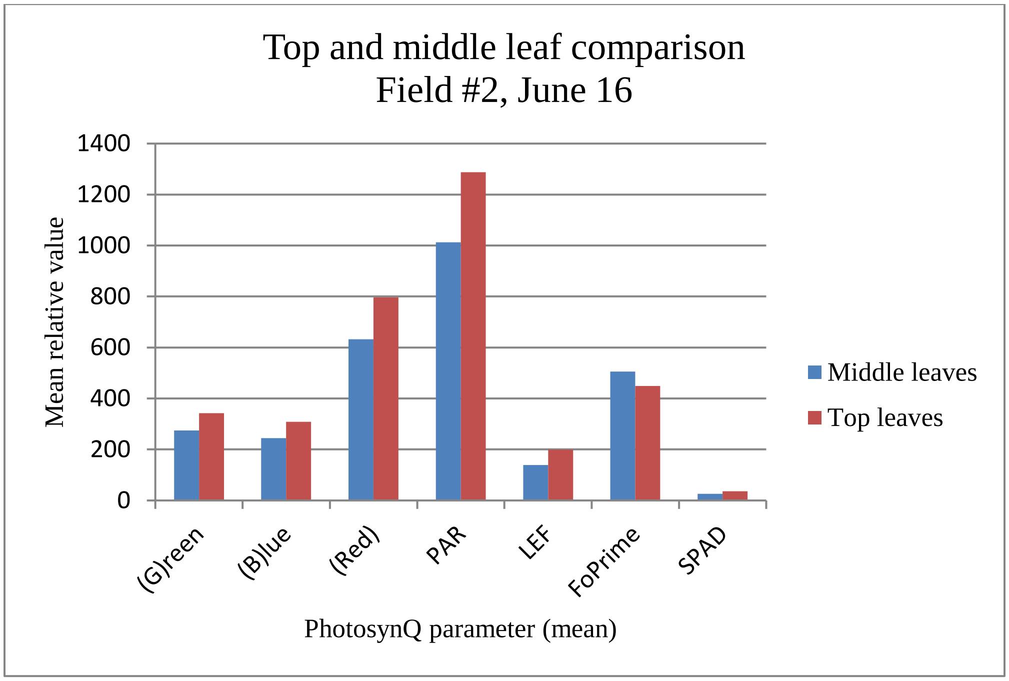
PhotosynQ results

Plant measurements were taken with the PhotosynQ device in Field #2 on June 3, June 16 and June 23 and in Field #1 on June 16 and June 23. Direct comparison between plants at a given location and comparisons between locations were less rigorous than was initially intended because data points were lost as described above. However, some general observations can be made about the measurements that were taken and about the process of taking plant measurements with this device.

Statistically significant differences were observed between the top and middle leaves for a number of the parameters measured (Figure 6). These differences were observed between top and middle leaves in both the conventional and test strip areas of Field#1 and in measurements taken throughout Field#2. Differences between top and middle leaves were not observed in Field #2 for measurements taken June 3 but were found for nearly all PhotosnyQ observations taken June 16 and June 23. These differences were statistically significant above the 90%

confidence level for nearly all of the parameters measured. This indicates that these two datasets (top leaves and middle leaves) are different enough that that they should be considered as separate datasets.

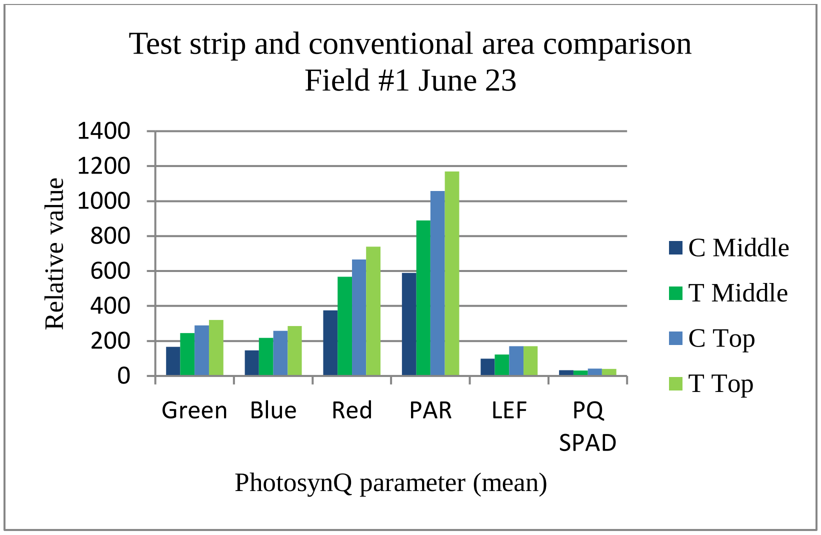
Figure 6. PhotosynQ: Top and middle leaf comparison



PhotosynQ-Test strip, conventional area comparison

Differences between middle leaves in the test strip and conventional portions of Field#1 were statistically different for PAR (Photosynthetically Active Radiation) (t=0.01), and Red (t=0.01), Green (t=0.01) and Blue (t=0.01) wavelengths for measurements taken June 23 (Figure 7). Top leaves did not demonstrate differences that were significant between the test strip and the conventional portion of Field #1 on this date for any of the parameters measured. Measurements taken June 16 also did not show significant differences between the test strip and the conventional portions Field #1 for any of the parameters measured for either top leaf or middle leaf comparisons. In addition, the parameters measured by this device did not well correlate with either %Nitrogen or biomass as measured in samples collected in the field.

Figure 7. PhotosynQ: Test Strip and conventional area comparison



This preliminary study has shown that data collected with PhotosynQ on top and middle wheat leaves should be considered separately because the parameters measured can be significantly different. It also demonstrated some of the difficulties currently associated with the use of this device. Despite these difficulties, some correlations between PhotosynQ parameters and crop growth were strong enough to warrant future investigation into use of this device, particularly because subsequent improvements have been made to both its software and hardware.

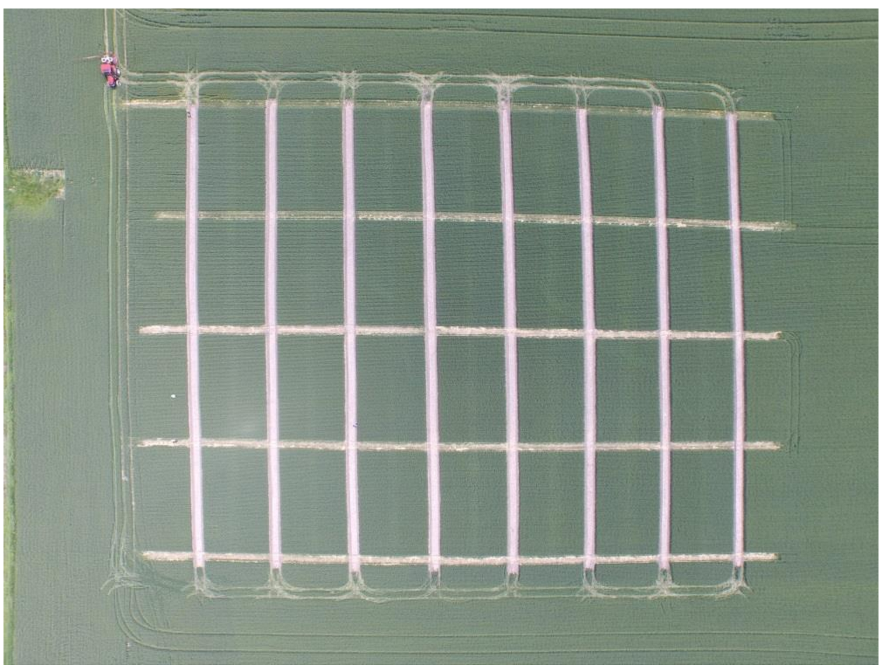
5.0 Conclusions and Recommendations

The study described a result of a study carried out at the field scale to assess the role of remote sensing in capturing yield variation across space and time. The vegetation indices provided a limited role in predicting yield, while the SALUS crop model was able to closely predict the corn and soybean yields in two different fields. We plan to continue this investigation with the goal of linking remote sensing with crop model to understand and manage the spatial and temporal variability of crop yield.

6.0 Appendices

DGI Drone Imagery

Photograph A (no modifications)

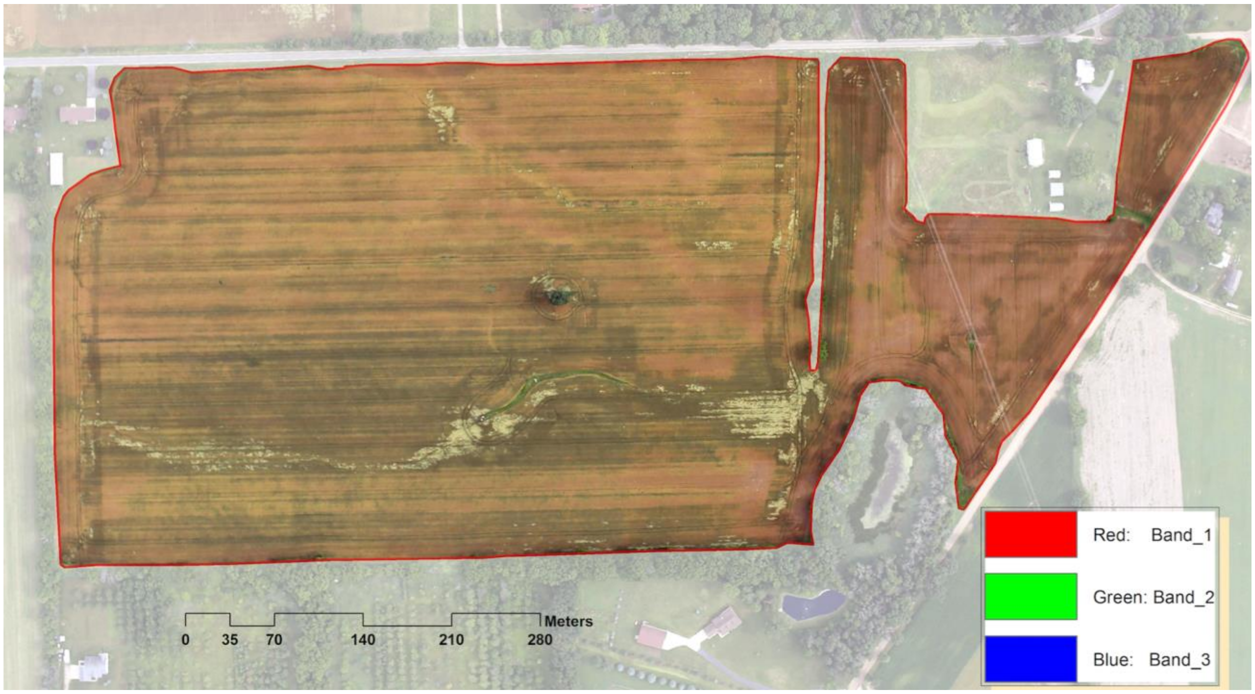


May 14

May 28

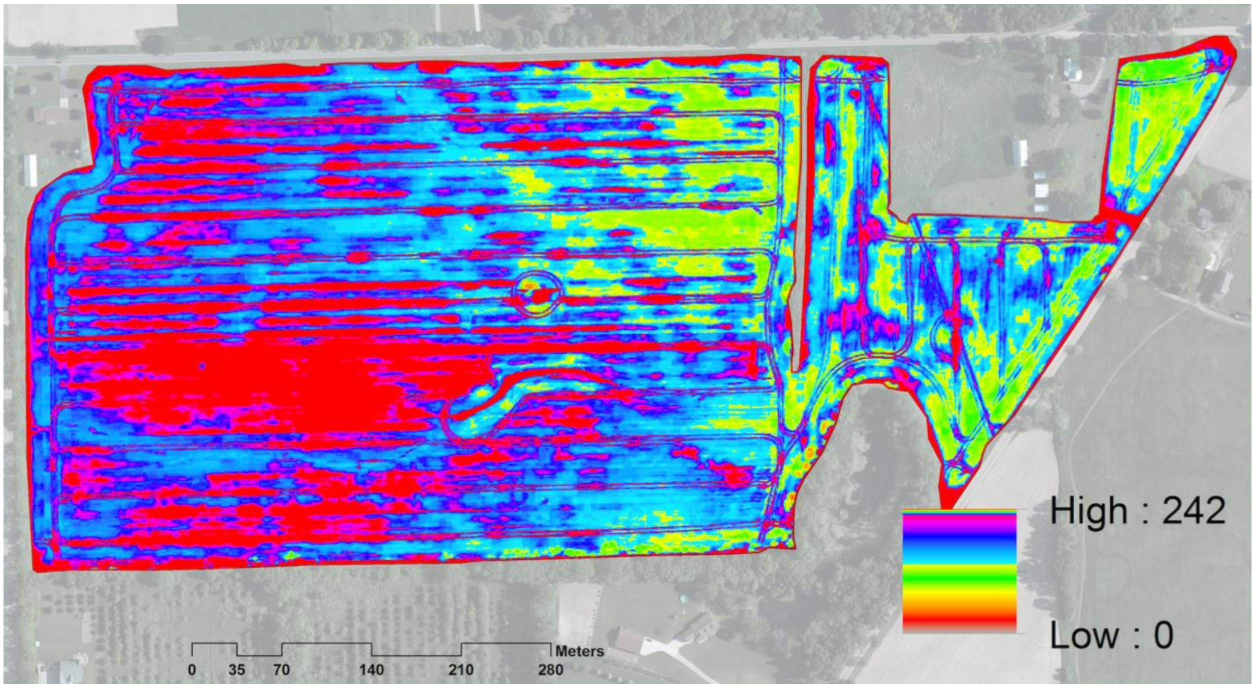
June 9

June 24



July 8

July 15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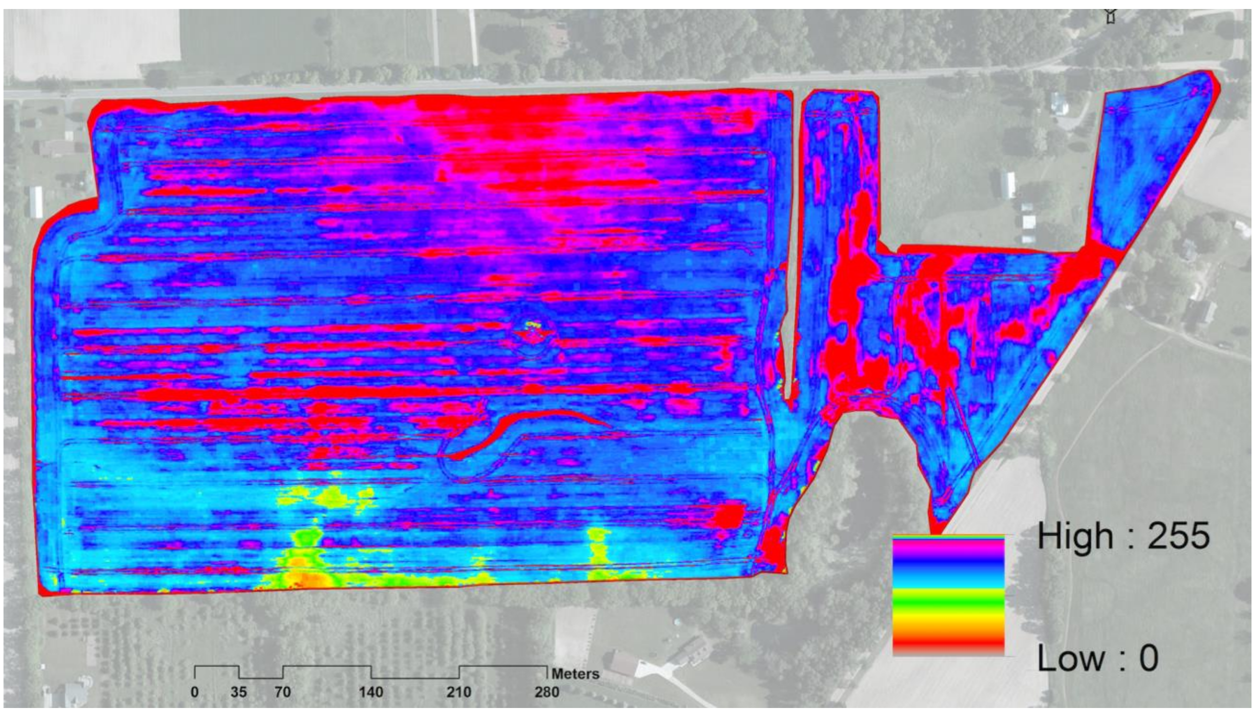
May 14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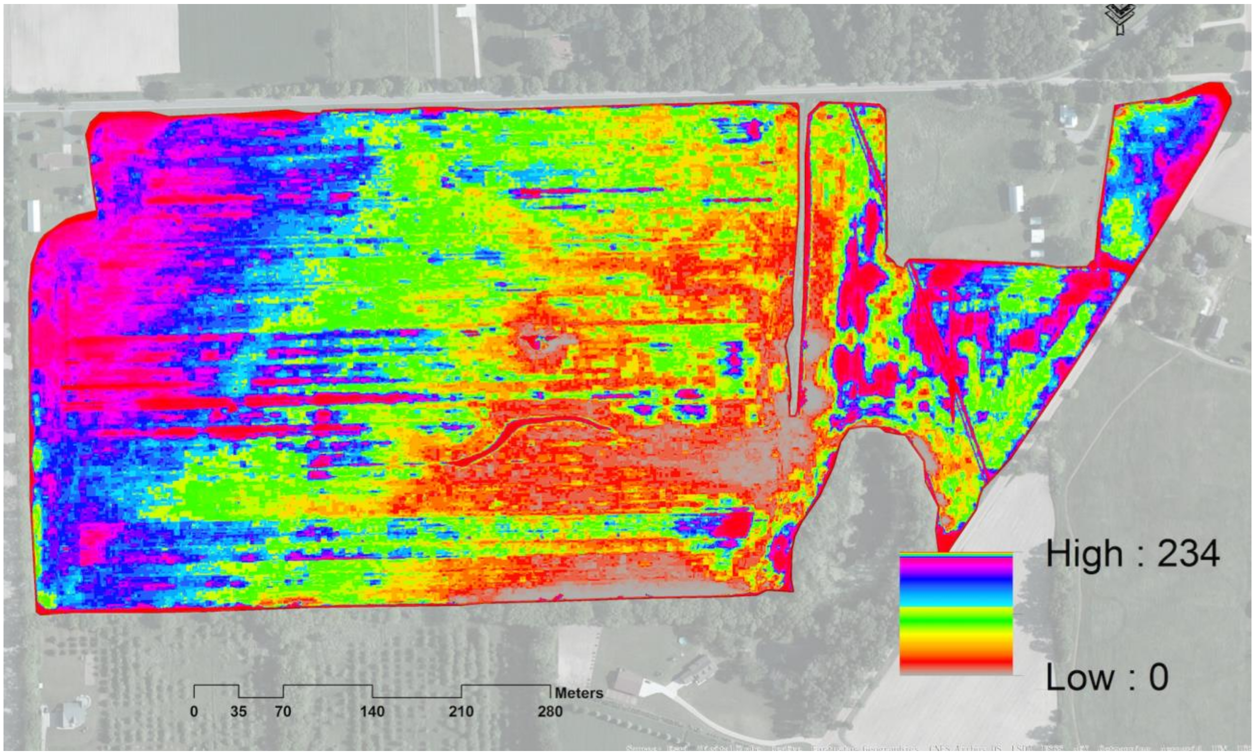
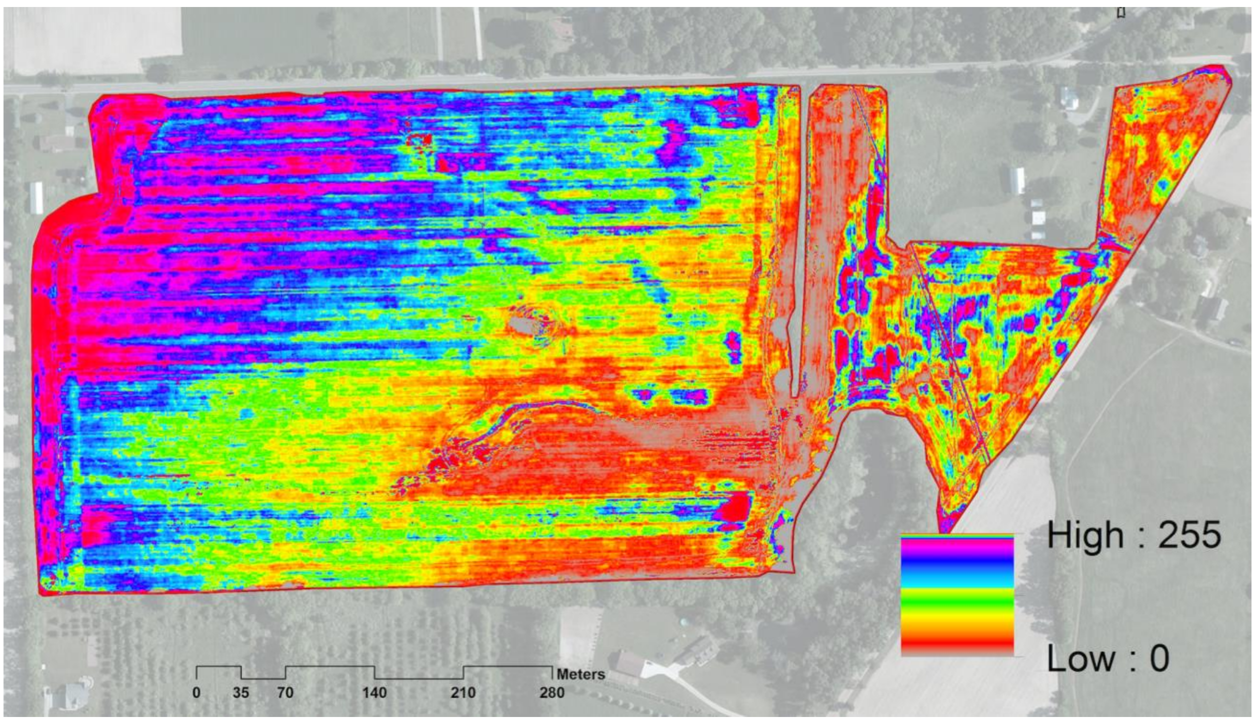
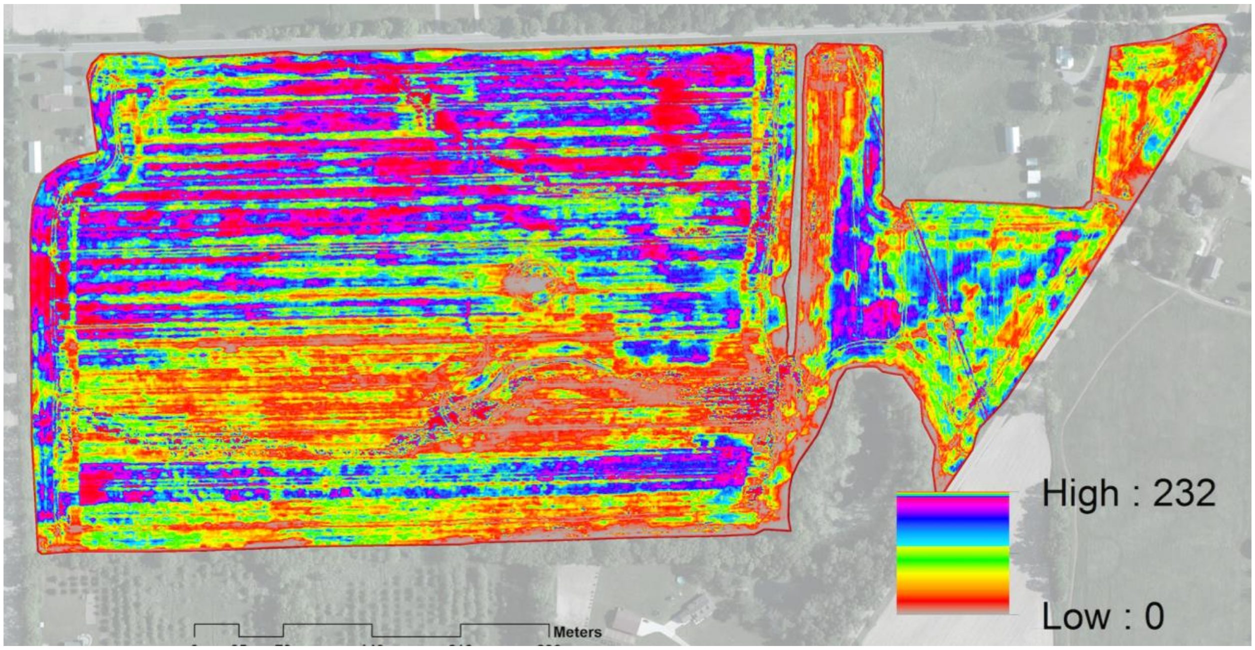
May 28



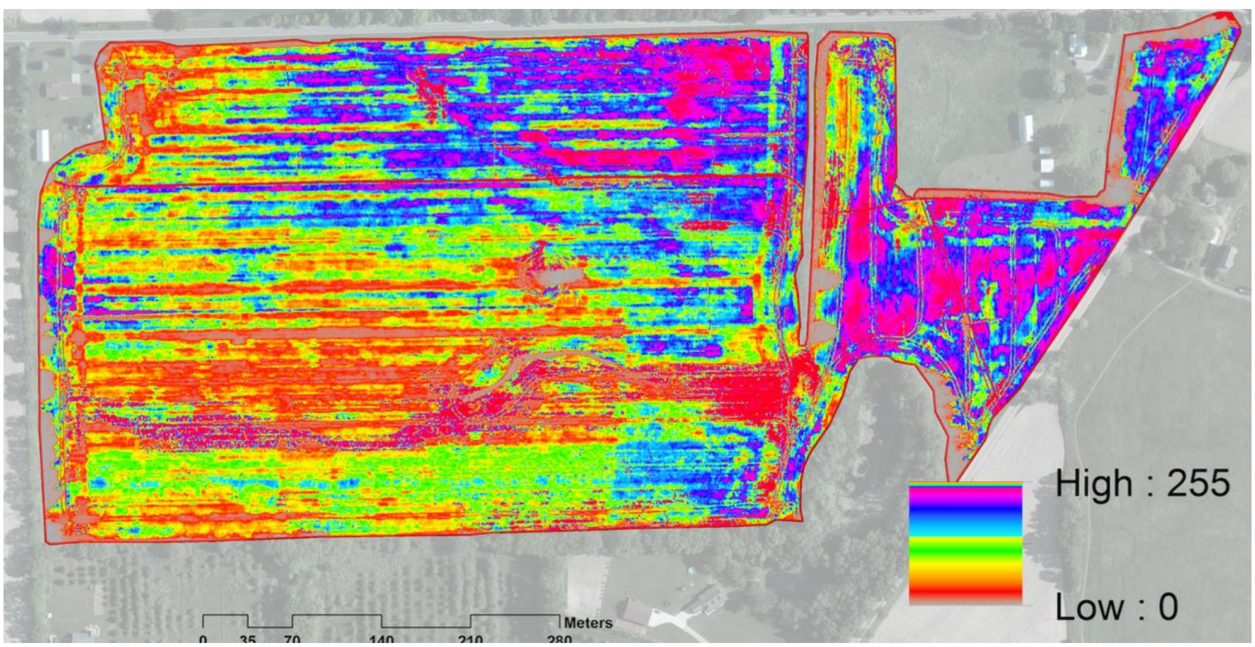
June 9



June 24



July 8



July 15

Nitrogen uptake and yield

Figure A1. Correlation between Nitrogen uptake (June 09) and yield (June 16)

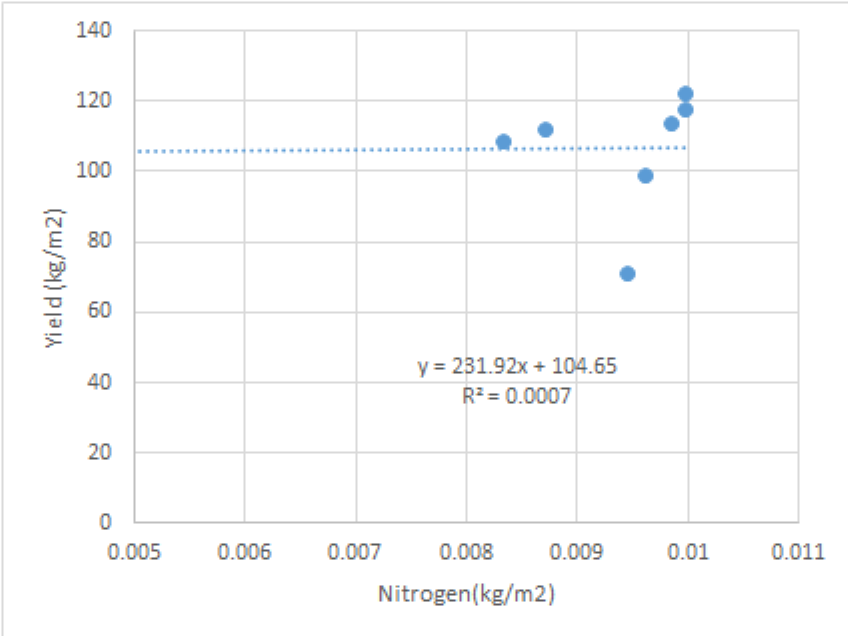
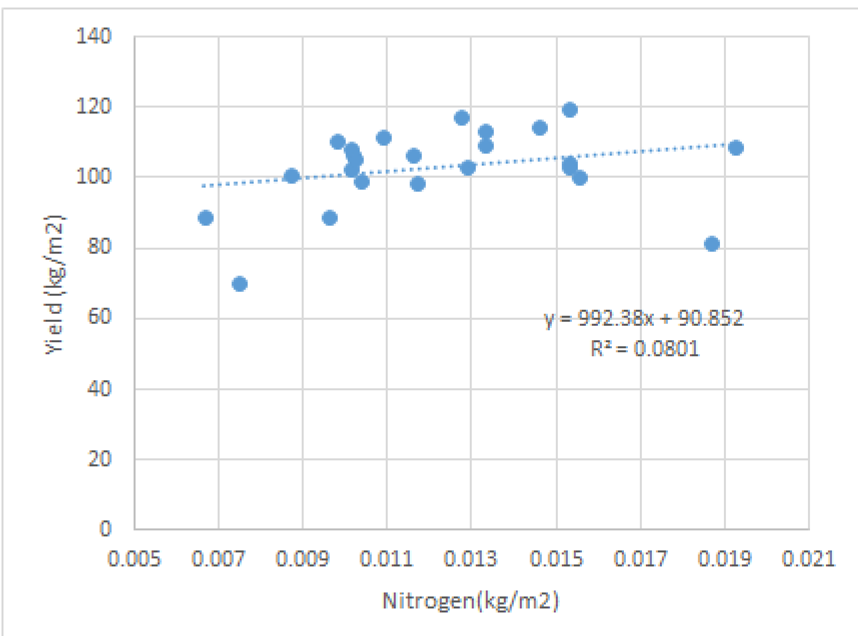


Figure A2. Correlation between Nitrogen uptake and yield (June 23)



Nitrogen uptake and vegetation indices

Figure A3. Nitrogen uptake (June 16) and original red reflectance (June 9)

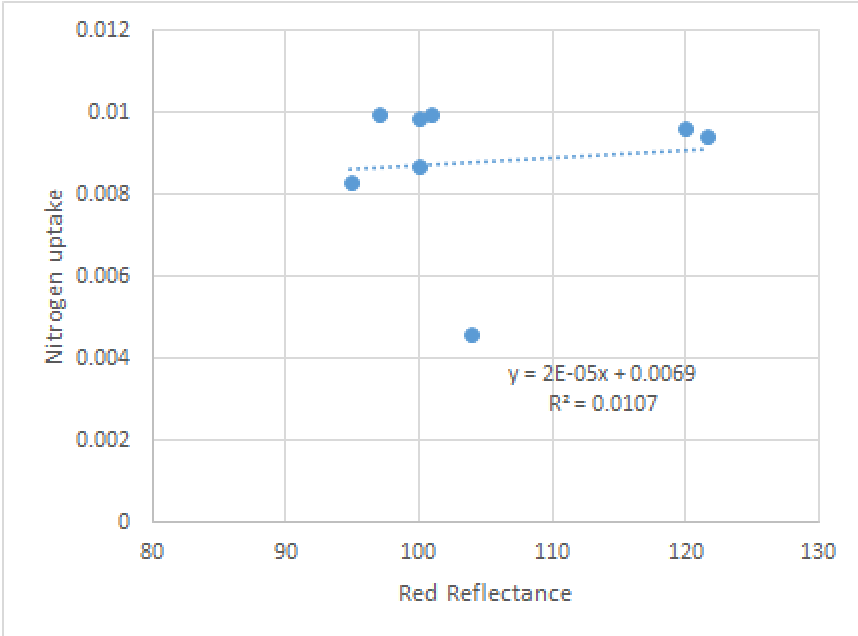


Figure A4. Nitrogen uptake including grain and stem (July 16) and original band index (July 15)