Using Satellite Imagery for Variable Rate Application of Fertilizer Nitrogen and Ag-Lime in Dryland Production

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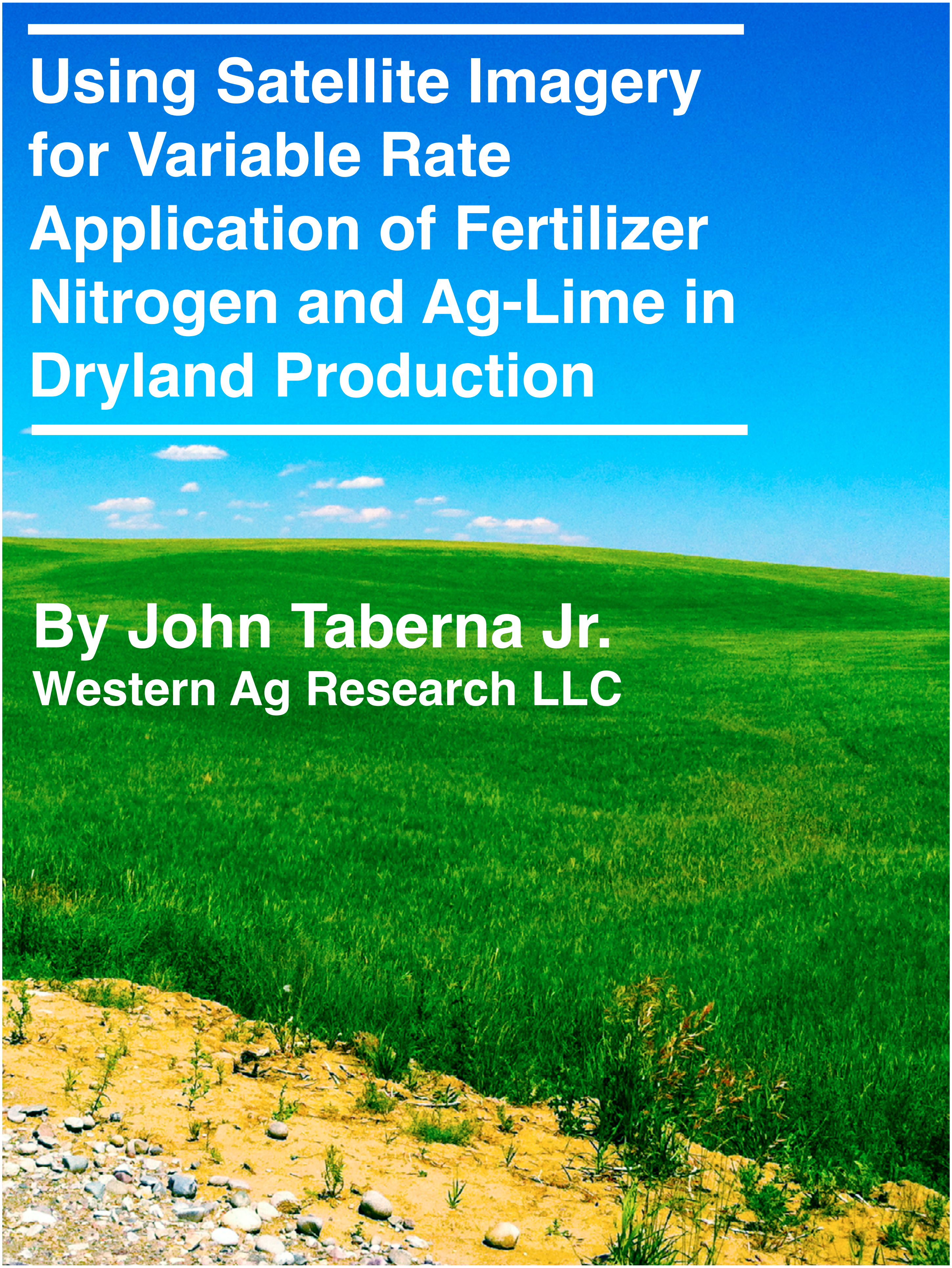

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Acknowledgements

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Summary

- Applied 0 to 8,000 lb/acre of Ag-Lime using Variable Rate Technology
- Showed that Variable Rate Nitrogen fertilizer can be applied while maintaining yields
- Compared two satellite systems—Landsat 8 and GeoEye
- Reduced fertilizer N by 10 lb/acre through VRN technology

This project was funded by a USDA Conservation Innovation Grant.

Background

FROM 1997 to 2000, the U.S. Geological Survey (USGS) and the Idaho Department of Environmental Quality (DEQ) discovered that numerous potable water wells in Ashton, Idaho, and surrounding rural areas were contaminated with nitrates. The nitrate levels exceeded the Environmental Protection Agency (EPA) Maximum Contaminant Level (MCL) for human consumption. Further studies by USGS and DEQ expanded this area to more than 76,000 acres that included the city of Ashton and surrounding farming areas, both irrigated and non-irrigated. Area farms were determined to be the primary contributor to groundwater nitrate contaminantion due to their widespread use of nitrogen (N) fertilizer.

Water Quality Problems

- The only two public water system wells for the city of Ashton exceeded the Safe Drinking Water MCL for nitrates, 10 mg/L, for several months in 1997 and again for several months in 1998 through 2006.

- The concentration of nitrates in 84% of private domestic wells sampled near Ashton exceeded 5 mg/L and 20% of the wells exceeded 10 mg/L.

Yellowstone Soil Conservation District's Nitrogen Fertilizer BMP Study

These findings led to a Best Management Practices (BMP) study of agricultural practices, conducted by the Yellowstone Soil Conservation District (YSCD) from 1999 to 2002. The YSCD's goal was to determine how on-farm nitrogen management practices compared to realistic yield goals and the University of Idaho fertilizer guidelines for nitrogen application for most crops grown in the Ashton area. While numerous crops were included in the study, the main focus was on seed potatoes, since potatoes require more fertilizer N and irrigation water than the other crops.

Unexpectedly, the study showed that dryland barley and other dryland grain fields had levels of residual nitrates at postharvest similar to some of the irrigated seed potato fields. The project then addressed the following question: Why would dryland grain fields show nearly as much residual soil nitrates at postharvest as irrigated seed potatoes when dryland fields receive at least 30% less fertilizer N than seed potatoes? Through further investigation, the BMP project found the answer was related to the affects of soil pH on grain yields and crop uptake of fertilizer N.

When the YSCD began working with producers to put BMPs into action and reduce nitrate leaching, they found that these practices did not reduce nitrate levels as much as they had hoped. Soil tests conducted during this time indicated pH levels in many soils were unexpectedly low. Low soil pH inhibits plant uptake of fertilizer N, and this factor, coupled with residual nitrogen from low crop yields, resulted in a year by year accumulation of excess fertilizer N in the soil. Eventually, the excess N leached down through the soil profile, and into groundwater systems as nitrate contaminants.

Soil scientists have known for a long time that fertilizer N acidifies the soil in areas where soil pH is less than 6.5. Yet in the Ashton, ID, area, there are thousands of acres of fields with a soil pH less than 6.5, and thousands more with pH less than 5.5. All of these fields are applied with fertilizer N at the same rate as less acidic soils, with no attention to the varying conditions. Crops are less effective at removing N from the soil in low pH and therefore low yielding areas. However, not all crop yields are effected equally by soil pH less than 5.5; potato yields do not appear to be effected as much as barley, wheat, or alfalfa.

During the BMP study, single soil samples from fields showed soil pH ranging from 5.9 to 6.3. When grid sampled, those fields showed soil pH variability of 5.1 to 6.8. It became clear that if soil and groundwater quality were to improve, then the soil pH variability issue would need to be addressed.

The two primary factors contributing to nitrate contamination of ground water would need to be addressed in order for Ashton farmers to reduce residual soil nitrates, successfully meet EPA standards and also meet annual yield goals (1) soil pH variability, and (2) soil nitrate variability, resulting from variable yields on different pH soils. The soil pH issue was most important, so it was addressed first.

YSCD's Variable Rate Ag-Liming Project

In 2009, the YSCD applied for Environmental Quality Incentives Project (EQIP) funding through the Natural Resources Conservation Service (NRCS). This grant would fund the application of Ag-Lime (Sugar Beet Lime) at variable rates across fields, based on soil pH. The project goal was to decrease residual soil nitrates by alkalizing soil in low pH areas, through lime application. This would increase crop yields, and hopefully reduce postharvest residual N. In 2010, the project was funded. Over a 4 year period, more than 20,000 acres were sampled for soil pH, on 2 acre grids, and Ag-Lime was applied at variable rates, based on soil pH maps. No lime was applied in some areas of the field. In other areas of the same field, as much as 8,000 lb/acre were applied, in grids where soil pH was 5.0 or less.

The EQIP Lime project was well-received by farmers, since they could see the increase in yields where Ag-Lime had been applied. The need for Ag-Lime, applied at variable rates, was effectively demonstrated on 20,000 acres in the Ashton area. Plus, the YSCD effort showed positive results in terms of improved water quality. Water quality analyses from 2012 to 2014 showed a reduction in nitrate contamination.

The State of Idaho has designated 34 Nitrate Priority Areas (NPAs), in need of water quality improvement. Prior to 2010, Ashton was the 5th most critical NPA out of these 34 locations. In 2014, Ashton dropped from 5th to 17th on the list, due in part to the Variable Rate Ag-Liming Project. This was the largest decline of all 34 NPAs within the past 5 years.

Variable Rate Nitrogen Fertilizer Application

While the application of lime was found to be beneficial, this practice alone is insufficient to completely address problems associated with excessive residual fertilizer N. To more fully address the problem, N must also be applied at a variable rate.

The improved water quality was likely also due to wider adoption of BMPs. Based on nutrient management planning with numerous producers in the area, Western Ag Research estimates that on average, 10 lb/acre less fertilizer N are being applied today than were applied 10 years ago. While a reduction of 10 lb/acre may seem small, it collectively represents a reduction of more than 760,000 lb annually, throughout the entire Ashton Groundwater Protection area, which covers more than 76,000 acres. The reduction in residual nitrate levels is an important factor in preventing groundwater pollution each year.

The YSCD EQIP Lime Project ended in October, 2014, and with that end came an end to funding available for Ag-Lime application. Participating farmers received a $48/acre cost share, not enough to cover all of the lime application expenses. Fertilizer grade lime costs around $50/ton and sugar beet lime, around $18/ton. Rural Ashton farmers have to make 150 to 320 mile trips to haul lime from Shelley or Paul, Idaho. An average 120 acre field may need up to 2 tons/acre Ag-Lime, or eight 30 ton truckloads. Applying fertilizer N at a variable rate would reduce the amount of lime needed to alkalize soil, and therefore reduce cost to farmers.

While farmers apply lime to their fields every 4 to 10 years, based on soil pH, they apply fertilizer N every year, in order to meet crop nitrogen needs each season. Nitrogen fertilizer acidifies soil where the pH is below 6.5. Soil with a lower pH is more suseptable to acidification because of its lower soil buffering capacity (too many hydrogen ions and not enough basic ions, primarily calcium). For example, 70 lb/acre N applied to soil with a pH of 6.3 will be acidified less than areas with a soil pH of 5.5.

Western Ag Research's studies demonstrated the acidifying effect of N on soil around Ashton. An expereiment conducted in a greenhouse setting was used

Is there a benefit to applying Ag-Lime at varied rates across a field and then applying fertilizer N at uniform rates?

- To realize the full benefit, fertilizer N needs to be applied at variable rates, based on reliable maps, produced with satellite imagery each year.

as a control for the Ashton study. In the greenhouse setting, 70 lb/acre N were applied to soil with either a pH 4.8 or 6.8. After nitrogen application, the pH 4.8 soil was reduced to 3.6, while the pH 6.8 soil was lowered to just 6.6. The soil with lower pH (high soil acidity) was turned more acidic by the addition of N. The soil with higher pH (more basic) was less effected by the N application.

In the field, we used GPS to identify 14 grid points with low soil pH. Prior to fertilizer N application, the field showed an average soil pH of 5.12 ± 0.40. One month after the application of 70 lb/acre N, the same 14 grids were sampled and showed a soil pH change to an average of 4.44 ± 0.25. If lime had been applied, the drop in soil pH would have been buffered and not as drastic.

Using Satellite Imagery Mapping for Fertilizer N and Ag-Lime Applications

In order to use precision agricultural technology for applying fertilizer N and Ag-Lime at variable rates, a farmer must have their field mapped. There are a number of mapping options. Grid sampling is effective, but time consuming. One could also pay for services that involve driving over the field and dividing it into zones, but this is cost-prohibitive. Satellite imagery mapping provides a single image of an area as large as 25,000 acres. This method is effective and fast. With satellites, images can be taken several times a year, allowing for more detailed observations.

Satellite photos are acquired about every 17 days, equalling 6 to 8 images during the growing season. A skilled Geographical Information Systems (GIS) specialist can clip the field boundaries out of the 25,000 acre satellite image to allow for easy mapping and planning.

Although satellite imagery has been used in agricultural production for over 40 years, the use of GIS mapping in dryland crop production is still not commonplace. Millions of acres are devoted to dryland production in the United States and Ashton is merely a microcosm of the larger issues of soil pH and yield variability that likely affect all dryland agriculture. As service providers improve their technology, and farmers increasingly access field data through mobile devices, like smart phones and tablets, the popularity of GIS mapping will grow in the agriculture industry.

Project Overview

Farmers know that their yields vary considerably within a field under dryland production. Weather, slopes, swales, pH, and soil water content all affect the outcome of a crop. Grain yields often vary between 40 and 90 bushels/acre in the same field. Yet, fertilizer N is almost always applied at uniform rates, regardless of the yield potential within different areas of the field. The excess N applied to lower yielding parts of the field can lead to further reduced soil quality in those areas.

Our goal for this project is to apply fertilizer N at levels that closely match yield potential within different areas of the field. This in turn will improve soil quality, groundwater quality, and complement future variable rate Ag-Lime applications.

Project Goals

- Promote producer adoption of variable rate fertilizer N application in dryland farming
- Reduce residual soil nitrates through variable rate application of fertilizer N
- Demonstrate the use of imagery from two satellite systems for detecting plant health

This project uses satellite imagery and GIS mapping, with the ability to predict yields through a vegetation index model called Modified Soil-Adjusted Vegetation Index (MSAVI2). Satellite images can map stressed or healthy plants on a spectrum of red for lowest quality, to yellow for medium plant health and green for the highest rates of photosythesis and vegetation. Farmers can use this data to apply different N levels based on the conditions in each part of the field. The focus of the project is to determine whether a simplified 3 color scale for plant health and vegetation can produce reliable data for developing annual variable rate nitrogen (VRN) fertilizer maps.

Satellite Image Acquisition and Interpretation

The GIS specialist for this project gathered satellite images from two satellite systems, GeoEye and Landsat 8. The specialist clipped the images to show our project fields and then color coded them using a vegetation index. The vegetation index is a function of photosynthetic activity and vegetation health. Plants absorb red light (RL) and reflect near infrared light (NIR). The satellite sensors detect RL and NIR. From calculations of the ratio of RL and NIR, a qualitative vegetation index is measured. The photosynthesis analysis is qualitative, in that healthy plants absorb RL and reflect NIR. A higher NIR value shows us that more red light was absorbed. It's an indirect measure of increased photosynthesis activity. The Normalized Difference Vegetation Index (NDVI) maps are made from the formula

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}.$$

There are two popularly used vegetation index models: Modified Soil-Adjusted Vegetation Index (MSAVI2) and NDVI. This project used the MSAVI2 model, since it compensates for soil interference that the NDVI alone does not. Scientists in the 1990s found that NDVI models can have errors caused by soil interference, especially when vegetation is young. The errors result from different reflectance or absorbance from soil organic matter, soil lime, clay content, soil water, slope percentages, and so forth. The MASVI2 has a soil interference factor to compensate for these errors. For more information on vegetation indexes, see the reference section.

To simplify satellite imagery interpretation, Western Ag Research chose a 3 color scale system, using the vegetation index method MSAVI2, where colors are based on a scale of 0 to 1. Red represents the lower end , 0 to 0.35, Yellow represents the middle, from 0.35 to 0.59, while green represents the upper end at 0.60 to 1.00. With the 3 color system, red indicates areas of the field with less photosynthesis activity or vegetation than the yellow and green areas.

One can choose to have more colors on the scale, or even just 2, if that is the preference. More than 3 colors would add detail unnecessary for making accurate fertilizer N and Ag-Lime application maps. A 3 color scale seems to be sufficient for color coding plant health in dryland agriculture production. To determine if a simplified 3 color ramp would be valuable in the production of fertilizer N and Ag-Lime variable rate application maps, we secured satellite images from two different systems, each with different resolutions: GeoEye and Landsat 8. The following is a comparison of the two systems.

GeoEye

DigitalGlobe provides satellite products based on a constellation of satellites, including IKONOS and GeoEye-1. This is a high resolution system. The GeoEye includes the following features:

- Higher resolution of 50 cm True and 80 cm
- Panchromatic, natural color, color infrared, and 4 band pan sharpened
- Multispectral resolution of 1.64 to 3.28 m
- Smaller swath collection of 11.3 to 15.2 km width at nadir reference
- Fee required for use

Landsat 8

USGS operates the Landsat system, using a constellation of satellites. The Landsat 8 includes the following features:

- Lower resolution of 15 to 30 m
- Larger Swath collection, around 25 km
- No fee required for use

The difference in resolution between the two satellite imagery systems can also be expressed by the approximate number of separate soil cores (samples) collected per acre, for analysis.

Satellite Imagery System	Soil samples/acre (pixels)
GeoEye	500+
Landsat 8	6

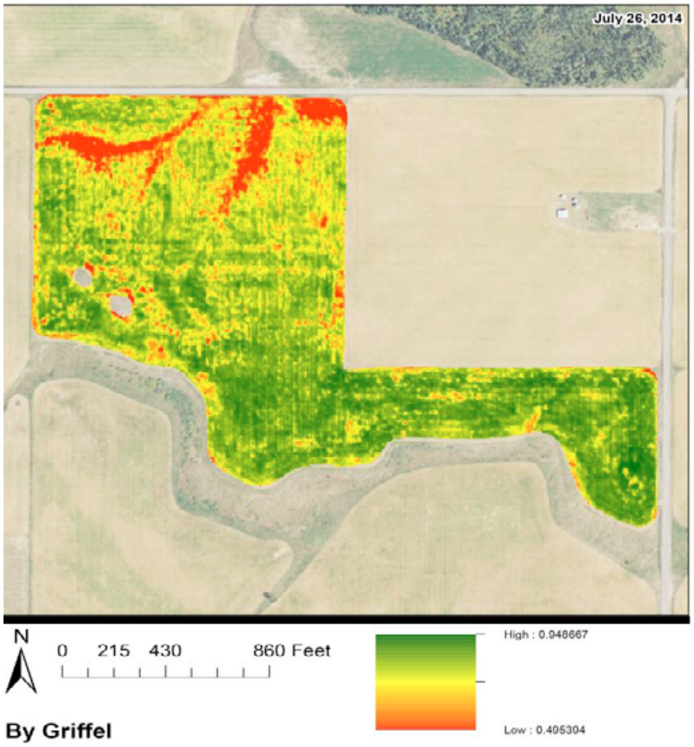

Image 1: Vegetation index map using MSAVI2, from the GeoEye satellite, with sub 5 m resolution

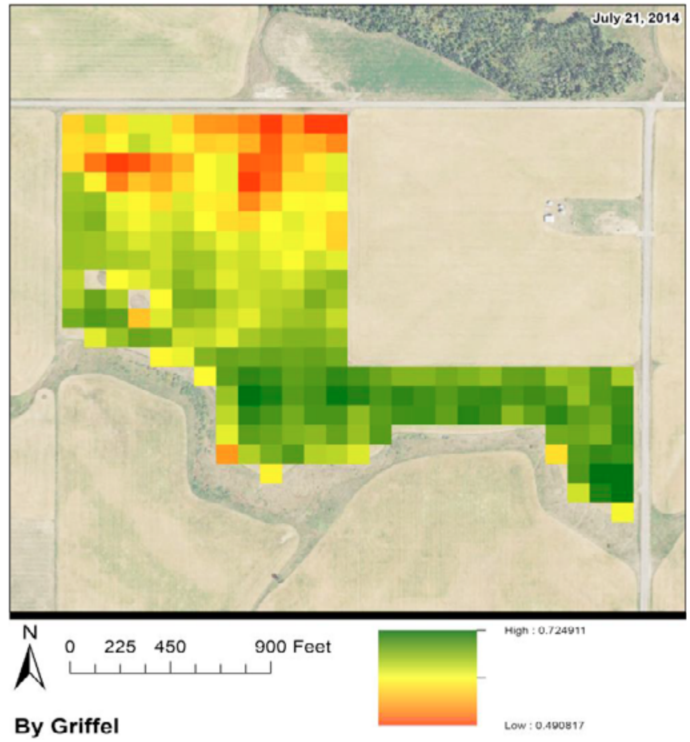

Image 2: Vegetation index map using MSAVI2, from the Landsat 8 satellite, 30 m resolution

The higher resolution images capture more information, which can be correlated with a higher frequency of soil samples, resulting in a greater amount of detail available to the farmer.

With this wide gap in resolution quality between the two systems, it is necessary to determine how much resolution is appropriate for the creation of variable rate maps for fertilizer N and Ag-Lime distribution on dryland farms. To decide this, we considered the limitations a farmer must operate within and how the characteristics of each satellite match that criteria. Planters, cultivators, and sprayers vary in width from 12 to 70 ft. Most fertilizer applicator equipment varies in width between 40 and 90 ft, with the most common equipment spanning 70 ft. The outlying application equipment can span up to 120 ft.

Images 1 through 5 demonstrate the difference in resolution between the two satellite systems. Image 1 illustrates the GeoEye, sub 5 m resolution, with a higher level of detail. Image 2 shows the Landsat 8, 30 m resolution, with each pixel representing 30 m sq plots of land. The GeoEye sub 5 m resolution is valuable for assessing details like fertilizer skips, cultivation differences, and for comparing the effectiveness of products applied using machinery 30 to 70 ft wide. The Landsat 8 resolution misses some important details that vary at less than 30 m, whereas the GeoEye sub 5 m resolution can detect those details.

While Image 1 (GeoEye, sub 5 m resolution) clearly shows more detail than Image 2 (Landsat 8, 30 m resolution), both images produce a similar pattern. This similarity was evident when comparing all of the images taken for this project.

Image 3 is a modification of Image 2 (Landsat 8, 30 m resolution). The pixels have been 'smoothed' using kriging software in ArcGIS. Agronomists prefer the smoothed maps because the color codes are obvious and easy to follow when sampling soil and making application maps. A strong correlation between the 2 satellite systems, at least 90 %, was achieved when the dominant colors were set to a 1 or 2 acre level of convergence, using the 'smoothing' technique called kriging, as in Image 3. This smoothing technique is discussed in Appendix A of this article, 'How to Use Satellite Imagery to Make VRN and Lime Application Maps.'

In order to choose an appropriate image resolution,

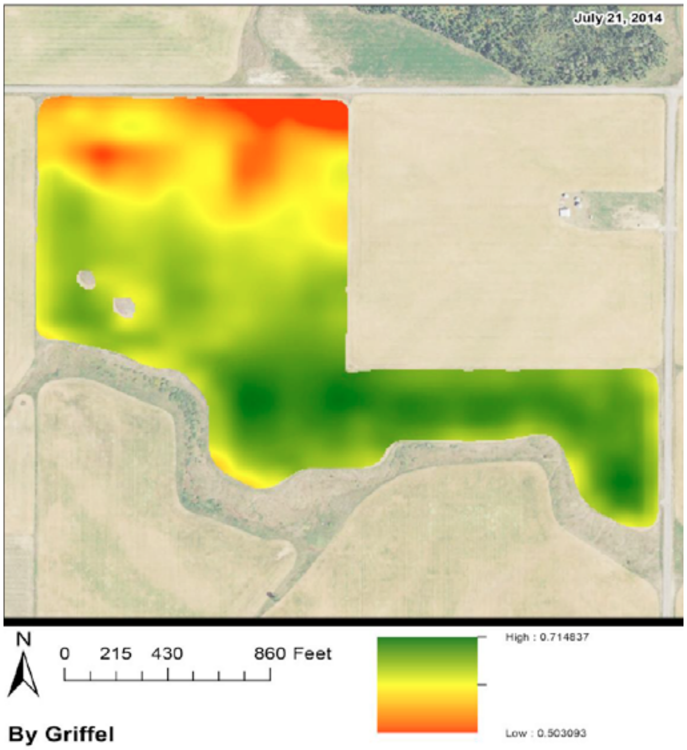

Image 3: Vegetation index map using MSAVI2, from the Landsat 8 satellite, 30 m resolution, with 'smoothing' in ArcGIS

one must also consider the speed of equipment moving through a field. Application equipment cannot make rate changes every 3 to 10 seconds throughout a field. The processing speed and controllers are not designed to make abrupt changes in product flow. Instead, application equipment works best if variable rate application changes every 1 to 2 acres. Rather than following a map with several rate changes in each acre, the rate of change must reflect this reality. For instance, an applicator with a 70 ft swath, traveling at 10 mph, covers 150 ft (over a quarter of an acre) in 10 seconds. So an acre can be spread with fertilizer in under a minute.

Maps developed with the GeoEye high resolution often contain many greens and yellows within an acre. In this situation, the 70 ft applicator boom can cover an area with three different colors, but cannot spread product at different rates within that acre. The nuance in detail is beyond the ability of the machinery. This presents a challenge: how can one make the application using the existing equipment? Because application equipment cannot respond to more detailed information, the fertilizer and lime maps must be modified to match the width of current application technology and the speed that they travel. Because of these realities, the lower resolution Landsat 8 images do not pose the same complications as do GeoEye images.

The sub 5 m resolution shown in Image 1 contains great detail and has many areas where 2 colors, or even 3 colors, are in the same acre. This GeoEye image contains more detail than is needed, so instead we will use the lower resolution Landsat 8 image, with pixels representing a greater area. Each pixel should represent at least one acre in order to reflect the dominant color within that acre. For example, if there are 280 pixels/acre in a GeoEye image and 190 of those pixels are green, 60 pixels yellow and 30 pixels are red, then the dominant color within the acre is green. That area would simply be displayed as a green pixel in the Landsat 8 and it would be spread with fertilizer N at a rate correlating with the green.

On Landsat 8, if 4 of the 6 pixels are green and 2 are yellow, then the dominant color is green and it also would receive the amount N corresponding with green. When the dominant color in each acre is used, GeoEye and Landsat 8 match up about 95% of the time, rather than a 70% correlation when the GeoEye sub 5 m resolution is compared to Landsat Eight 30 m resolution.

In Landsat 8 (Image 2), the low resolution pixels encompass a larger area of land, 30 m, and are square shaped, instead of dot-like, as in GeoEye (Image 1). The low resolution Landsat 8 is useful for visualizing color trends, the averages, and for making a plan for soil sampling and variable rate application. But even with the pixels spanning a larger area in Landsat 8 images, an agronomist will still need to enlarge the images in order to fit a 1 or 2 acre application pattern.

The 3 color ramp in Image 3 is perfect for variable rate application of fertilizer N. With the smoothed detail, the map is easy to understand. The change in rate more closely matches the ability of the applicator technology. The green areas will be applied with the largest, normal amount of fertilizer N. The yellow areas will receive slightly less and the red areas will receive the least amount of N, which best matches the yield potential. This map is also easier for a farmer to correlate with yield monitors and will help farmers to plan for future N applications.

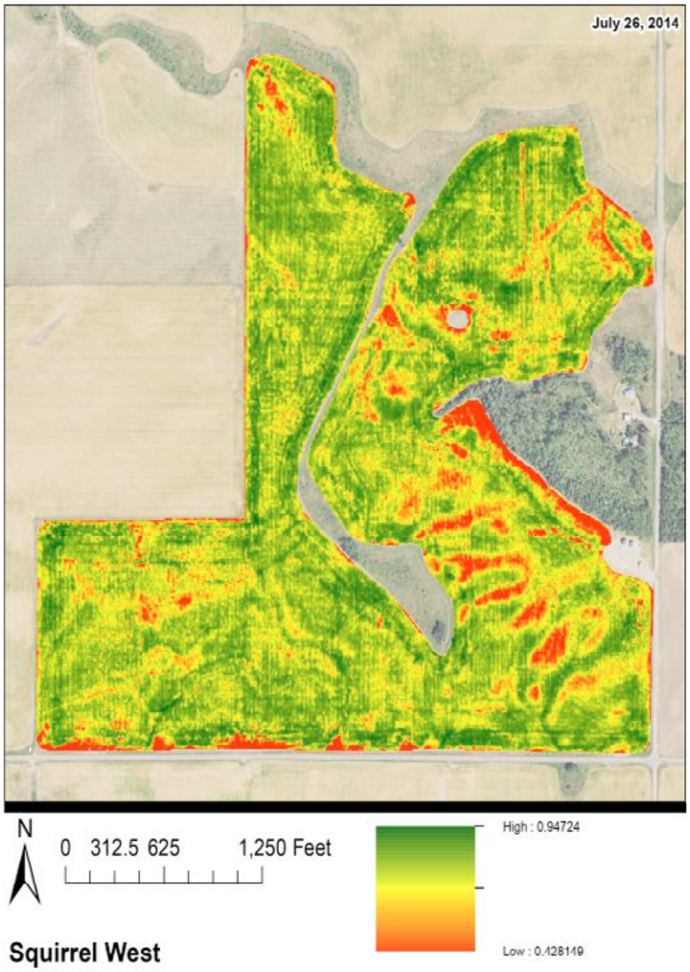

Image 4: Vegetation index map using MSAVI2 of the Squirrel-Sharpe area from the GeoEye satellite sub 5 m resolution.

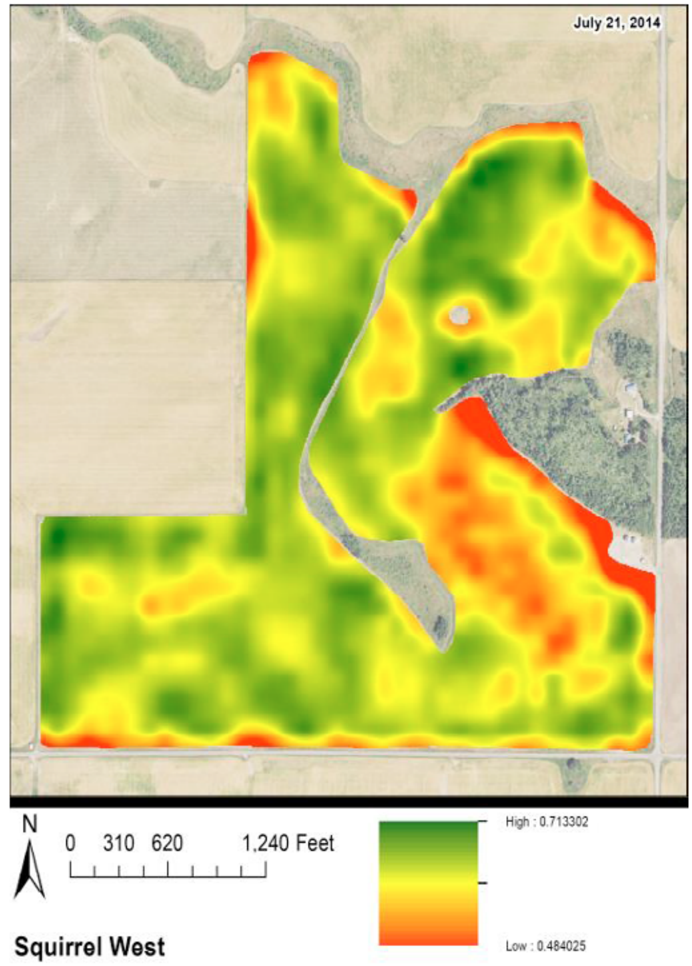

Image 5: Vegetation index map using MSAVI2 of the Squirrel-Sharpe area from the Landsat 8 satellite 30 m resolution with 'smoothing' in ArcGIS.

Images 4 and 5 provide another example of how resolution differs between the two satellite systems. This field is located in the Squirrel-Sharpe area of Ashton, ID, where most soil pH is low (pH 5.8>). The southeast portion of the field, mapped with the GeoEye satellite, shows red ripples with green in between the red (Image 4). This area contains rolling hills. The red shades indicate areas of higher soil pH, averaging 5.3, on the hilltops. Green shades, in between the red, represent lower soil pH, averaging 4.6, in the lower spots between the hills(swales). The swales are higher in organic matter content and hold more soil moisture (Photo 1).

Photo 1: Moisture and organic matter collect in swales, or areas at the bottoms of hills. For example, in this photo, snow remains in the swales but has melted and evaporated off of the hill ridges of this field in the Squirrel-Sharpe area.

These details are clearly detected with the GeoEye satellite, but are smoothed over in images from the Landsat 8, Image 5. While the image developed with GeoEye, Image 4, more closely represents the true landscape, the image from Landsat 8 closely corresponds to that from GeoEye. The Landsat 8 image misses some of the green areas in the swales and over estimates the red areas on the hilltops.

In summary, the Landsat 8 satellite system provides enough detail to make fertilizer N and Ag-Lime application maps, but more detail is needed for other related jobs on the farm. The GeoEye satellite system can also be used to make the application maps, when the pixels are aggregated to make a lower resolution, but it should primarily used in situations requiring more detail: research such as fertilizer trials, soil and landscape surveys and for monitoring detailed farming practices.

Project Area Field Characteristics

Western Ag Research chose two diverse dryland farms, managed by the same farmer, to conduct the satellite imagery analysis: Lamont Farm, shown in Image 6, and Squirrel-Sharpe Farm, shown in Image 7. The two farms were selected for their variation in percentage slope, soil pH and annual precipitation.

Our goal was to apply fertilizer N, based on a 3 color mapping system, created using satellite imagery. Instead of applying fertilizer at a uniform rate of 73 lb/acre, the 3 different colors of the scale would receive 3 different levels of N. Depending on the results of the soil N samples and yield goals, the red areas might receive 48 lb/acre N, the yellow areas, 68 lb/acre N, and the green, 73 lb/acre N. This method would reduce groundwater contamination by nitrates, addressing the problem of applying higher levels of N to areas where crop yields were not high enough to remove the residual N.

These GeoEye satellite images show all 7 project fields at the 2 farms, on June 10 (Images 6 and 7). Areas of low photosynthetic activity or vegetation index, according to MSAVI2, shown in red, are already appearing on both farms by early June. While these farms are only five miles apart, known differences in field characteristics, besides just pH, are contributing to the

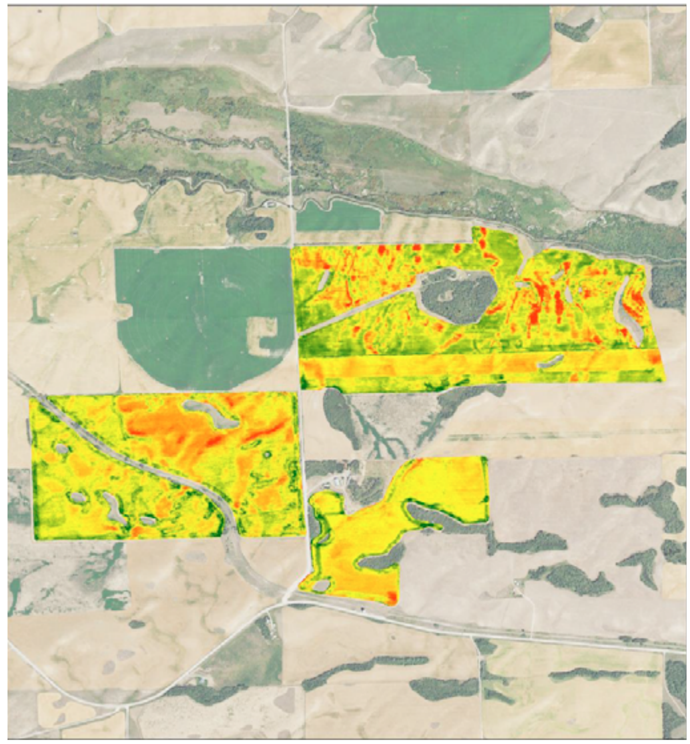

Image 6: Vegetation index map using MSAVI2 for project fields on the Lamont Farm, taken in early June 2014, with the GeoEye satellite.

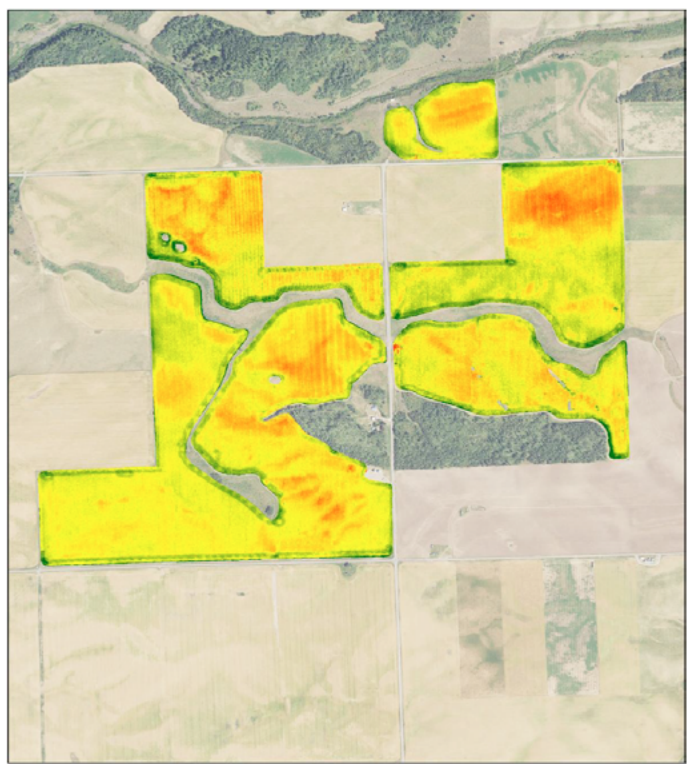

Image 7: Vegetation index map using MSAVI2 for project fields on the Squirrel-Sharpe Farm, taken in early June 2014, with the GeoEye satellite.

Table 1: Soil types on the Lamont Farm project fields according to the Soil Web Survey.

Map Unit #	Map Unit Name	% Slope	Acres	% of Area
92	Rin silt loam	1 to 4	43	5.6
93	Rin silt loam	4 to 12	204	26.7
94	Rin silt loam	12 to 20	75	9.7
121	Tetonia-Lantonia silt loam	0 to 4	4	0.5
129	Tetonia-Lantonia silt loam	1 to 4	38	5.0
130	Tetonia-Lantonia silt loam	4 to 12	11	1.4
132	Tetonia-Rin silt loam	4 to 12	130	17.1
133	Tetonia-Rin silt loam	12 to 20	260	34.0

Table 2: Soil types on the Squirrel-Sharpe Farm project fields according to the Soil Web Survey.

Map Unit #	Map Unit Name	% Slope	Acres	% of Area
26	Greys-Robana silt loam	4 to 12	45	10.6
72	Marystown silt loam	1 to 4	103	24.6
73	Marystown silt loam	4 to 8	8	2.0
92	Rin silt loam	1 to 4	97	23.2
93	Rin silt loam	4 to 12	72	17.1
100	Robana-Rin silt loam	1 to 4	53	12.6
101	Robana-Rin silt loam	4 to 12	41	9.9

low photosynthetic activity (red color) at each farm.

Most of the low-yield areas at Lamont are a result of natural soil lime, which raises the pH, and in addition, low available soil moisture. The Lamont Farm has many more steep hills than the Squirrel-Sharpe Farm, and those hills hold less moisture. Low yield red areas in the Squirrel-Sharpe fields show that there is more moisture accumulation in swales, large depressions in the field. The swales of Squirrel-Sharpe tend to collect more snow drifts and other precipitation. The hill ridges at the Lamont Farm tend to dry off sooner.

Image 6 of the Lamont Farm shows fields that are planted with barley, except portions of the north field. This area contains numerous 12 to 20% slopes (steep areas). More than half (56%) of the soil pH values from 2 acre grids are 6.0 to 8.1. The other 44% of the grids have soil pH values under 6.0. These fields are located five miles south of the Squirrel-Sharpe area. The 2 acre grid sampling was conducted in the fall of 2012. Lime was applied to these fields, for the first time, using variable rate technology, in the fall of 2013. Lime was applied at an average of 3,165 lb/acre. The elevation is 5,940 ft.

In Image 7, the Squirrel-Sharpe fields are also planted with barley. Less than 1% of the 2 acre grid soil samples collected have a soil pH above 6.0. The 2 acre grid samples were also collected in the fall of 2012. Lime was applied to these fields for the first time, using variable rate technology, in the fall of 2013, just like at Lamont, but at an average of 6,685 lb/acre, double the rate. The elevation is similar to Lamont, 5,990 ft.

The two farms differ in three primary soil variables: percentage slope, soil pH, and annual precipitation. Both farms have steep slopes, but Lamont fields have steeper ones. Both farms have swales, where snow accumulates, but Squirrel-Sharpe fields receive more snow than Lamont fields do. Lamont soil dries quicker than the Squirrel-Sharpe area. And Squirrel-Sharpe fields are more acidic in general, a result of increased precipitation and moisture.

Table 3: Soil pH levels of 2 acre grid samples collected from fields at Lamont Farm and Squirrel-Sharpe Farm in September 2012.

	Lamont Farm Fields		Squirrel-Sharpe Farm Fields	
Soil pH Range	**Number of 2 acre grids**	**Percent of Area**	**Number of 2 acre grids**	**Percent of Area**
4.0 - 4.9	5	1.7	172	73.9
5.0 - 5.5	59	19.9	49	21.0
5.6 - 5.9	65	22.0	10	4.3
6.0 - 6.5	76	25.7	0	0.0
6.6 - 7.1	53	17.9	1	0.4
7.2+	38	12.8	1	0.4
Totals:	**296**	**100 %**	**233**	**100 %**

Percentage Slope

The farms differ in the percentage of acres governed by steep slope. Data gathered from a USDA Web Soil Survey shows that more than 42% of slopes on the Lamont Farm fields are 12 to 20%, while no slopes exceed 12% on Squirrel-Sharpe Farm fields (Tables 1 and 2). Slope position and slope percentage can affect plant health, soil water content, and the reflectance shown on a satellite image which will give differing VI values when using MSAVI2. For instance, a 15% slope that faces east is often different than a 15% slope that faces north, due to soil moisture differences alone.

The steep slopes of the Lamont Farm fields have soil erosion layers where natural soil lime is exposed (Table 1). The natural soil lime in the Lamont Farm fields appears red during the growing season, via satellite imagery from GeoEye (Image 6). This indicates less photosynthetic activity or vegetation index. The red areas in the Squirrel-Sharpe Farm fields also indicate areas of low vegetation index, not related to natural soil lime content, but rather, other causes (Table 2 and Image 7).

Photo 2: The snow has melted from the Lamont Farm field by April 15th, 2014.

Photo 3: Snow remains at the Squirrel-Sharpe Farm field on April 15th, 2014.

Soil pH

The project fields at the two farms also differ in soil pH, according to soil samples collected in 2012. More than 50% of the Lamont Farm fields have a soil pH of 6.0 or greater (Table 3). In contrast, less than 1% of the Squirrel-Sharpe Farm fields exceed a soil pH of 6.0 (Table 3). Nearly 75% of the grids on the Squirrel-Sharpe fields had a soil pH of 4.0 to 4.9, while less than 2% of the Lamont fields were in that range. In contrast, 56% of the Lamont fields had a soil pH of 6.0 or higher, while only 1% of the Squirrel-Sharpe fields were in that range. Overall, Lamont fields are more basic than those of the Squirrel-Sharpe farm.

Despite these clear delineations, when each of the farms are color coded using the vegetation index MSAVI2, there will be areas of red, yellow, and green in all fields. An agronomist must be familiar with the field characteristics and ground-truth of the data in order to be sure of the accuracy of the maps, for use in variable rate application of fertilizer N and Ag-Lime.

Annual Precipitation

The project fields at the two farms also differ in soil moisture and annual precipitation. Dryland farms rely on good soil moisture levels for their yields. If areas of a field are drier than others, red on the vegetation index map could be reflecting low soil moisture levels, rather than high soil pH or high levels of N. The annual precipitation at Lamont Farm and Squirrel-Sharpe Farm project area is 18 to 22 acre-inches. However, the Squirrel-Sharpe Farm usually receives about 3 acre-in more precipitation than the Lamont Farm, annually. This difference in annual precipitation is illustrated in photos 2 and 3, which were both taken on April 15th, 2014. The snow had already melted on the 765 acre Lamont field (Photo 2), whereas the snow-pack on the 419 acre Squirrel-Sharpe field varied from 3 to 6 inches (Photo 4).

Photo 4: The Squirrel East field of Lamont Farm, has a significant snow cover on April 15th.

Comparison Summary

In summary, the red areas on the vegetation index map of Lamont Farm (Image 6) are characterized by soil pH levels generally exceeding 6.5, steep slopes, and lower soil moisture than the soil of the Squirrel-Sharpe Farm. In contrast, the red areas on the vegetation index map of Squirrel-Sharpe Farm (Image 7) are characterized by soil pH levels generally in the 5.1 to 5.6 range, flatter slopes, and more soil moisture than that of the Lamont Farm.

Before satellite imagery can be used effectively, an agronomist needs to know the soil types and landscape features of a particular field. Dryland crop yields are related to some of the following factors:

1. Landscape positioning (N,S,E,W)
2. Slope percentages (flat, 5%, 10%, 20%, etc.)
3. Soil moisture (drought, good, excessive)
4. Seasonal rains (timely or untimely)
5. Soil pH
6. Soil fertility
7. Weeds

While not exhaustive, the list does reflect the many variables that can affect satellite imagery interpretations in dryland environments. For example, a steep north slope on a vegetation index map may appear red, not because of soil pH or levels of N, but because of colder soil temperatures, deeper snow drifts, or lack of sunlight, compared to south facing slopes.

This description of the project area field characteristics illustrates that a farmer should not apply Ag-Lime or fertilizer N to an area that appears red on a vegetation index map, just because it is red. Separate soil samples must be collected from each field and for each of the colored areas, red, yellow and green, to determine the reason for the color difference.

Project Methods

Variable Rate Lime Application

As apart of the YSCD EQIP Lime Project, Western Ag Research collected soil samples on 1,500 acres of the Squirrel-Sharpe and Lamont

Farms in 2012. All of the fields were soil sampled using 2 acre grids, collected down to an 8 in depth, and analyzed for soil pH. The soil pH data were entered into a GIS database, along with GPS coordinates and the lime recommendations. All of this information was stored as geo-referenced data.

In fall of 2013, Valley Wide Cooperative spread Ag-Lime on the 1,500 acres, using variable rate technology. Valley Wide Cooperative received the variable rate lime maps from Western Ag Research in both the target file (.tgt) and shape file (.shp) format. From these 1,500 acres, Western Ag chose 1,184 acres on 2 farms, on which to study the effects of VRN application. On the Squirrel-Sharpe Farm, 419 acres were selected. On the Lamont Farm, 765 acres were chosen. These properties were selected because of their close proximity.

The same satellite images used for fertilizer N application maps can also be used for distributing Ag-Lime. While an agronomist is soil sampling based on the 3 color scale for fertilizer N, soil pH can be tracked and monitored simultaneously for Ag-Lime application, based on the same 3 color index.

Fertilizer N Application

In May, 2013, 73 lb/acre N was applied at a uniform rate to all 7 project fields (all 1,184 acres) on Lamont and Squirrel-Sharpe Farms. In this first year of the project, the uniform application of fertilizer N was used as a constant, to show that yields varied across the vegetation index map, based on crop vigor, as represented by the 3 different colors (red, yellow and green).

In 2014, Western Ag Research met with the collaborating farmer, who manages both farms, to choose numerous areas on the farms where researchers would test VRN application, comparing it to normal, uniform fertilizer N application. The VRN application rates were established as follows: red = 48 lb/acre, yellow = 68 lb/acre, and green = 73 lb/acre. In the non-plot areas, all of the fields received a uniform fertilizer N application of 73 lb/acre, except one field on the Lamont Farm. The exception, called 'By Home' at Lamont Farm, received a uniform application of 68 lb/acre. Fertilizer N was applied in May, as a liquid, using a John Deere 4930 with a 120 ft swath. The different fertilizer N application rates were recorded across the fields, using GPS technology. The uniform fertilizer N rate was 73 lb/acre (70 lb/acre preplant + 3 lb/acre in the starter P fertilizer mix).

To determine if there was a dramatic yield difference in dryland barley grown with either 63 or 73 lb/acre N, Western Ag Research conducted a two year trial. In 2013 and 2014, we worked with the cooperating farmer to select a small field called 'Sharpe-26' in which we would apply strips of the field with either 63 or 73 lb/acre N. With a 120 ft fertilizer applicator swath, we applied 73 lb/acre to 4 strips of land, 120 ft by 1,300 ft. In addition, we applied 63 lb/acre N to 3 strips of land, 120 ft by 1,300 ft. The seven strips spanned a single 28 acre field, excluding about 3 acres of field border.

Harvest Data Collection

The GPS coordinates of the different fertilizer N application areas were used to harvest the plots separately. Yields in each of the different areas were hand recorded during harvest and then entered into an excel spreadsheet. We had to cut out the strips and record them separately because the collaborating farmer did not have software to store the entire yield data across the field. For example, the harvest dataset might read as follows: red/2.3 acres/112 bushels; yellow/1.72 acres/110 bushels; green/1.29 acres/98 bushels, etc. We then converted the yield data, at harvest, into yield/acre on the spreadsheet.

Soil and Tissue Sampling

On April 15th, 2014, we collected soil samples from the top 12 in, looking for soil moisture content data on the Lamont Farm fields (Table 4). We had to wait until April 22nd, to collect the soil samples from the Squirrel-Sharpe Farm fields. Western Ag Research collected the soil samples based on the 3 ramp color Vegetation Index from the Landsat 8 satellite. Soil moisture was determined by the gravimetric analysis method:

$$\frac{(weight\ of\ wet\ soil - weight\ of\ dry\ soil)}{(weight\ of\ dry\ soil) * 100} = \%\ soil\ moisture.$$

Soil samples were taken in April, May and October to document pH, nitrates, phosphorus, calcium, and the micronutrients iron, manganese, copper and zinc. Soils were gathered in 5 gal buckets, in 2013, for a greenhouse study by Western Ag Research and the USDA, in Kimberly, ID. Soils for this greenhouse study were mostly taken from soil pH areas of 4.1 to 4.5. The Western Ag Research greenhouse data collection project was completed in 2014. The USDA greenhouse study is still ongoing and will be published at a later date.

Tissue samples were pulled as needed from both the Lamont and the Squirrel-Sharpe Farms**.** We compared normal looking barley plants with those that didn't look quite as healthy. There was no correlation between soil pH and levels of copper and zinc found in Barley tissue. Basically, copper and zinc levels were relatively consistent regardless of soil pH.

Manganese and iron levels of the soil tests were elevated at soil pH greater than 5.5. There were even elevated levels of manganese and iron in soil with a pH 6.1 to 6.3 in some areas, but not all, compared with soils at 5.5 or less. The barley tissue did show some correlation. According to Western Laboratories, the sufficiency range for barley tissue concentrations of iron and manganese are 55 to 90 parts per million (ppm) and 26 to 100 ppm, respectively. In weak barley plants, tissue concentrations of iron and manganese often exceeded 400 ppm and 250 ppm, respectively -levels above sufficient for normal health.

Results and Discussion

2013 Barley Yields

In 2013, the first year of the project, we needed data to support our premise that a 3 color ramp system from satellite imagery could be used successfully for the variable rate application of fertilizer N and Ag-Lime on dryland fields. The collaborating farmer applied fertilizer N to all of the project fields at uniform rates in this year. Then, beginning July 2nd, Western Ag Research gathered 4 Landsat 8 satellite images from each of the 7 project fields. Yields were recorded from each of the 7 fields, using the 3 color ramp technique. The purpose of this was to demonstrate that even with uniform applications of fertilizer N, there are other factors, besides fertilizer N, that contribute to yields on dryland production.

Prior to the launch of this project, the collaborating farmer had applied fertilizer N at a uniform rate of 80 to 85 lb/acre. In 2013, the farmer lowered his uniform N application rate to reduce risk of ground water contamination by nitrates. He had learned of this risk from the findings of the Yellowstone Soil Conservation District's BMP study. There was an additional motivation to lower his rates of application: over fertilizing with N can lower soil pH and therefore harm barley plants, reducing yields (pH 5.8>). The collaborating farmer lowered the fertilizer N rates from 80 to 85 lb/acre to a new rate of 73 lb/acre, in order to increase soil pH. The result was improved soil health.

Table 4: 2013 average barley yields from the 3 different color ramps of the vegetation index MSAVI2, after uniform application of 73 lb/acre N.

	Yield (bushels/acre)		
Field	**Red**	**Yellow**	**Green**
Moms	36	51	75
West of Home	27	36	41
By Home	40	53	58
Squirrel East	31	61	68
By Griffels	35	58	63
Sharpe 26	20	41	49
Average Yield	**32**	**50**	**59**

Table 4 shows the average yield of the vegetation index color ramps in 6 of the project barley fields. The 7th field was in mustard. Lower photosynthetic activity areas, in red, yielded an average 32 bushels/acre. Middle photosynthetic activity areas, in yellow, yielded an average 50 bushels/acre and the highest photosynthetic activity areas, green, yielded an average 59 bushels/acre.

Table 5 shows results from harvested test cuts in the six project barley fields. On average, barley in the red color ramp area yielded 34 bushels/acre. The yellow ramp area yielded 50 bushels/acre and the green ramp area yielded 57 bushels/acre.

Table 7: 2014 barley yields in ten comparison areas receiving either VRN fertilizer or normal, uniform nitrogen application.

	Variable Rate Nitrogen Application		Normal, Uniform Nitrogen Application	
Site Number	Fertilizer N lb/acre	Yield bushels/acre	Fertilizer N lb/acre	Yield bushels/acre
1	60	71	73	82
2	60	74	73	78
3	63	80	73	81
4	57	62	68	64
5	63	46	73	42
6	62	79	73	81
7	63	86	73	75
8	62	74	73	71
9	63	65	73	69
10	67	75	70	73
Ave ± Stdev:	**62 ± 2.6**	**71 ± 11.3**	**72 ± 1.8**	**72 ± 11.9**

There was high variability of yields, as shown by the standard deviation, even though 21 or 22 test cuts were collected in each color ramp. Considering the standard deviation, the averages are not that distinct. Thirty or more test cuts for each color ramp would have helped to reduce the variability in the data set. Despite the variability, Western Ag Research determined that there were meaningful differences in yields based on the color ramps.

Table 5: 2013 barley yields of all 64 test digs, according to the color ramp, after uniform application of 73 lb/acre N.

Color Ramp	Average Yield	Standard Deviation	Number of plots
Red	34	9.5	21
Yellow	50	13.9	22
Green	57	15.6	21

Barley Fertilizer Trial

Western Ag Research also conducted a barley fertilizer study, in 2013, with two different fertilizer rates: 63 and 73 lb/acre. Fertilizer N was applied to four strips at a rate of 73 lb/acre and three strips at a rate of 63 lb/acre, each 120 ft wide by 1,300 ft long.

Results from the 2013 trials were supportive of our hypothesis that yields depend on conditions besides just the application of fertilizer N. According to the 3 color ramps of the vegetation index, barley yields differed despite a uniform rate fertilizer N application.

Table 6: 2013 and 2014 barley yields from the Sharpe-26 field after application of 63 or 73 lb/acre N.

	Yield (bushels/acre)		
Fertilizer N lb/acre	2013	2014	2 Year Average
63	46	65	55.5
73	42	69	55.5

In one of the smaller fields called Sharpe-26, the trial was conducted in both 2013 and 2014. The 2 year average results were identical for both fertilizer rates, 55.5 bushels/acre (Table 6). While this does not prove that we are over fertilizing with the additional 10 lb N/acre, it does indicate that VRN application is a viable method to reduce fertilizer N while maintaining yields.

The 63 and 73 lb/acre strips also yielded exactly the same amount during the 2 year study on the smaller field. The same application rates were repeated in the same plots each year of the study. The 63 lb/acre areas had 20 lb/acre less N within the 2 year period, compared to the 73 lb/acre N areas; and yet they all

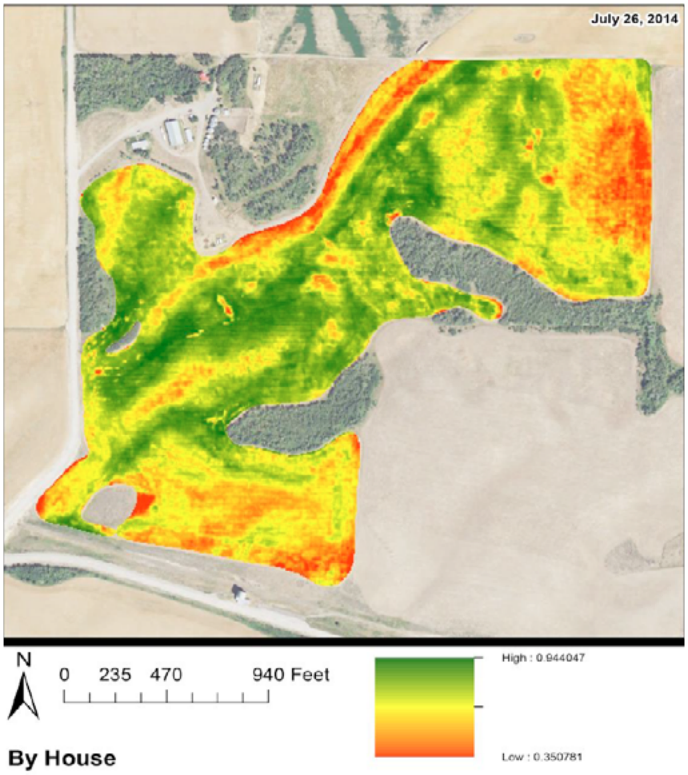

Image 8: The Modified Soil-Adjusted Vegetation Index (MSAVI2) for the lower right field (by Home) at Lamont Farm, taken on July 26th with the GeoEye satellite.

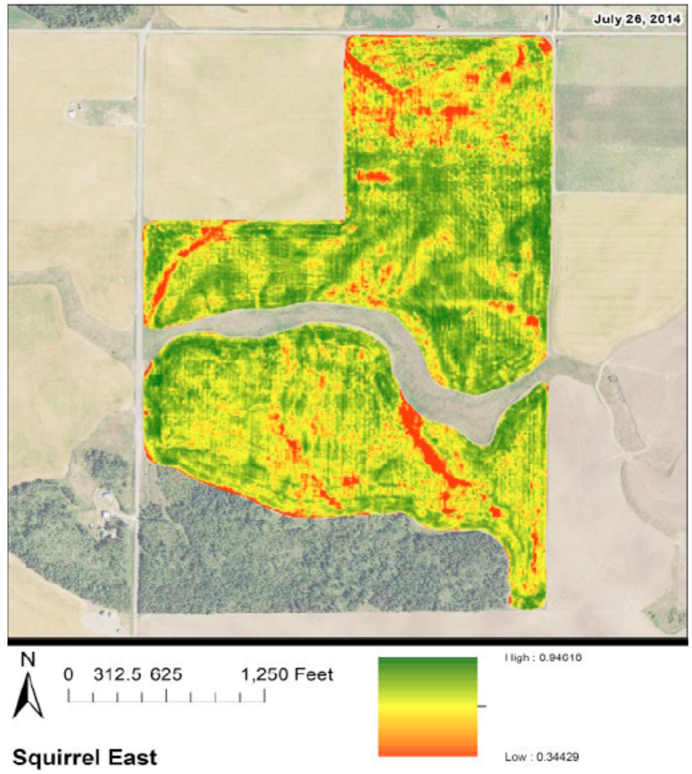

Image 9: The Modified Soil-Adjusted Vegetation Index (MSAVI2) for the same Squirrel- Sharpe field shown in photo 3. Image taken on July 26th with the GeoEye satellite.

produced equal yields.

2014 Barley Yields Using VRN Application

This project is focused on demonstrating that satellite imagery can be can be used to effectively vary the rates of fertilizer N, while maintaining crop yields. Results from the 2013 trials were supportive: barley yields differed under uniform fertilizer N application, according to the 3 color ramp of the vegetation index.

In 2014, our goal was to apply less fertilizer N/acre, using VRN application, rather than using the normal, uniform application rates. We conducted 10 comparisons of VRN applications versus normal, uniform rate applications. The average barley yield was 71 bushels/acre with VRN application and 72 bushels/acre with uniform rate application (Table 7). The areas of the field under VRN application received an average 62 lb/acre while the uniform application areas received an average 72 lb/acre.

The data showed that normal barley yields can be achieved with slightly less fertilizer N, if VRN application is practiced (Table 7). The decrease in fertilizer N, however, may not be large enough to entice farmers to spend extra money for satellite imagery. There are also additional fees to spread nitrogen at a variable rate. When the difference is only a savings of around 10 lb/acre N, the change may not be worth it to a farmer. The additional cost for satellite imagery, VRN map making, and VRN application is at least $18/acre, while a reduction of 10 lb/acre of fertilizer N only saves a farmer around $6/acre.

Farmers apply fertilizer N annually, and so the effects of over fertilization can compound annually. The degradation of soil quality takes time and so does the reclamation of soil quality. Considering that there is little financial reward in using the VRN method, and also that a farmer may only see the benefits of improved soil health after several years, it may be difficult for farmers to change their practices. Consequently, using satellite imagery and VRN application must be considered both as an annual and long-term investment. The long term investment would eventually pay off with improvements to soil quality, where grain

Table 8: Soil moisture levels in April 2014, from the green, yellow and red color ramp areas of the Modified Soil-Adjusted Vegetation Index (MSAVI2) at Lamont and Squirrel-Sharpe Farms.

		Lamont Farm	Squirrel-Sharpe Farm
		4/15/2014	4/22/2014
Rep	Color	% Soil Moisture	% Soil Moisture
1	Green	23.5	23.3
2	Green	20.4	33.2
3	Green	22.0	34.0
4	Green	22.7	24.1
5	Green	19.0	-
	Ave.	21.5	28.7
	St. Dev.	1.81	5.73
1	Yellow	18.7	26.9
2	Yellow	21.2	27.3
3	Yellow	20.6	25.4
4	Yellow	20.1	23.2
5	Yellow	17.2	-
	Ave.	19.6	25.7
	St. Dev.	1.61	1.86
1	Red	18.5	25.8
2	Red	17.5	27.1
3	Red	17.8	24.3
4	Red	17.9	24.1
	Ave.	17.9	25.3
	St. Dev	0.42	1.41

yields are currently below field averaged yields (red imaged areas of field).

Satellite Imagery and Soil pH in 2013 and 2014

The correlation between satellite imagery colors and soil pH was not concrete. There was no correlation between soil pH and the satellite imagery 3 color ramps in the Squirrel-Sharpe project area. On Squirrel-Sharpe Farm, the majority of soil pH was 5.5> within all colors: red, yellow and green.

At the Lamont Farm, the correlation was not any better; soil pH varied from 4.9 to 8.0 in all 3 color ramps. However, the red areas at Lamont did have a higher percentage of soil pH above 7.0 than the yellow or green areas. This could indicate that satellite imagery is more useful for variable rate N application than for variable rate application of Ag-Lime. To use satellite imagery for Ag-Lime application, an agronomist would need to take 3 to 4 separate soil samples for each color ramp in a field. One would use these samples to determine the color ramp's soil pH variability in the particular year that the field will be receiving an Ag-Lime application.

Soil Variability, Moisture, and Uniform Application of Fertilizer N

The Lamont Farm fields are characterized by eroded layers that are calcareous, slopes exceeding 12% (Image 8, Photo 2). The 12%+ slope areas usually hold less soil water and yield less than the areas with 5% or less slope. Shallow slopes hold more water and have higher organic matter content in their soil. The steep slopes at Lamont Farm averaged 17.9% soil moisture (Table 8) and had an average yield of 47 bushels/acre, with the uniform 68 lb/acre N application (Image 8, red areas). The lower elevation areas of the field averaged 21.5% soil moisture (Table 8) and yielded an average 64 bushels/acre, with the same uniform application of 68 lb/acre N (Image 8, green areas). The yellow areas had an average soil water content of 19.6% (Table 8) and an average yield of 60 bushels/acre, with the uniform 68 lb/acre N. Overall, the field averaged 60 bushels/acre with a uniform 68 lb/acre N applied.

These results confirm two scenarios—(1) uniform rates of fertilizer N do not solve soil variability issues, and (2) soil moisture content affects yields just as much as fertilizer N. Therefore, uniform rates of fertilizer N do not compensate yield variability when there is also soil moisture variability in the field (Table 8).

Precipitation and Available Soil Water Variability

The Squirrel-Sharpe Farm 'Squirrel East' field showed some interesting results related to soil moisture levels (Photo 3 & 4, Image 9). In general, the color ramps red, yellow, and green had the same soil moisture content, statistically (Table 8). The soil moisture percentage was 25.3%, 25.7% and 28.7%, respectively. These soil moisture levels are roughly 7% higher than the Lamont Farm field averages. Their ability to hold more moisture gives them a higher yielding potential for dryland grain, as long as soil pH does not become too low (Table 8). The gravimetric soil moisture content in Lamont was 17.9%, 19.6% and 21.5%, for red, yellow and green, respectively.

Soil moisture variability in a field should not be overlooked when making a VRN map. An area can receive an annual precipitation of 17 to 22 acre-in of moisture through snow and rain, but that does not mean the 17 to 22 acre-in are distributed evenly. In the region of Lamont Farm, and heading east towards the Grand Tetons, there are many fields with slopes above 15%. Those areas have low spots (swales) that are pretty wet after snow melts. These low spots are accumulating run off from the steep slopes. Lower soil water content in a field should show red in satellite imagery by early to mid July, maybe sooner.

At Lamont Farm, applying normal, uniform fertilizer N to a red area in a drought scenario could be a disaster because this could cause plant growth that would utilize the low available soil water before kernel development at crop maturity. The grain kernel would not receive the levels of moisture required for it to form. In Squirrel-Sharpe, applying normal, uniform fertilizer N to a red area could also be a disaster because it appears that these areas lack soil organic matter, compared to the green areas, and therefor have a lower capacity to buffer.

Analysis of Fertilizer N Needs Using Satellite Imagery

The yield potential of dryland barley is directly related to the available soil water during the crop growing season. It takes about 1 acre-in of available soil water to produce a yield of 6 bushels/acre. The annual precipitation of this area (Ashton, Lamont, and Squirrel) is around 17 to 22 acre-in. But not all the moisture from this precipitation is available to plants. Rains after late July are too late to support crop yields and may actually hurt crop quality. For the crop, the critical water needs are from mid-October (snow-pack) to mid-July (rain). The crops are able to use 15 to 18 acre-in of precipitation during the growing season.

Provided a field uses the maximum 1 acre-in of available water for every 6 bushels of barley, yield maximums will fall in the 90 to 108 bushel range (15 x 6 = 90 or 18 x 6 = 108). Soil test data from this project showed 50 to 80 lb of soil N available in the 0 to 24 in soil profile. So, in order to achieve a goal of 90 bushel yield, one would need to apply a variable rate of 60 to 85 lb fertilizer N, using University of Idaho guidelines. On most dryland fields there is no soil moisture uniformity in the field because of the steep slopes that are characteristic in the region. Therefore, yield variability is almost always fixed by the variability of soil moisture, according to the slope variability within the field boundary.

Some fields with ‘flatter’ terrain yield 90 bushels on good years, but for most fields normal yields are in the range of 55 to 80 bushels/acre, depending on precipitation, soil pH and the number of steep slopes. To achieve this average yield of 70 bushels/acre, one would use the same soil test numbers to calculate an application rate. Fertilizer N requirements will range from 40 to 60 lb/acre.

These satellite imagery project results compliment the results found earlier by the YSCD BMP study. That is, most dryland barley crops require between 50 and 80 lb/acre N to achieve yield goals of 65 to 90 bushels/acre. When using VRN application techniques, the red areas seem to need 40 to 55 lb/acre. The yellow areas require around 60 to 68 lb/acre and the green areas need a range of 65 to 75 lb/acre. The fertilizer N requirements are site-specific and they vary based on yield potential, soil test results, soil moisture content, the number of steep slopes, soil pH, soil organic matter, and timely precipitation.

Barley Yields in Red Areas

So far, we have compared yield data with satellite imagery color codes. We’ve also compared yields of fields using VRN application, to the yields of normal, uniform application of fertilizer N. One of the interesting results from this study came from comparing these rates when applied on the Squirrel-Sharpe Farm: VRN application methods improved barley yields, even with reduced overall use of N.

When a VRN map is created for a given growing season, it must be made using the previous year's satellite imagery. For example, our VRN maps for 2015 will be based on satellite images and MSAVI2 3 color ramps taken in 2014. Our project and fertilizer N plots for 2014 were created with 2013 satellite images. Red areas received 48 lb/acre N, yellow areas received 68 lb/acre N and the green areas received 73 lb/acre N.

There were 16 red sites at Squirrel-Sharpe Farm, shown in 2013 imagery, where 48 lb/acre N was applied. Eight of those red sites turned green in 2014 satellite images. Those green areas produced higher yields, shown in Table 9. This demonstrates that the lower fertilizer N rates of 48 lb/acre, along with receiving Ag-Lime for the first time, actually improved soil quality and therefore, the yield potential of these areas. The soil pH was not lowered as much as it would have been, had the red areas received a uniform rate of fertilizer N.

Table 9: Barley yields in Squirrel-Sharpe

Fertilizer N lb/acre	Sample #	Yield bu/acre	St. Dev.
48	16	71	11.7
63	9	72	16.9
73	33	77	18.8
83	2	67	3.5

Table 9 shows the resulting yields after VRN application at 60 sites, based on the specific rates of fertilizer N applied. Table 9 indicates that we can reduce fertilizer N by another 8 to 10 lb/acre if we are using satellite imagery and VRN application methods.

Table 9 also shows we still have more to learn. In a Lamont Farm field the red areas with 48 lb/acre N averaged a yield of 64 bushels/acre (only 2 sites). Nearby red areas averaged 60 bushels/acre with 73 lb/acre N applied. This demonstrates that red areas are not necessarily lacking in fertilizer N, as one might assume.

Next Steps

In 2015, we will apply fertilizer N at variable rates on 3 fields, using the satellite images from this project. In the course of this project, the collaborating farmer has increased his comfort level with variable rate fertilizer N application. He learned the value of a yield monitor on his grain combine. This device records yields every three seconds during harvest and can help interpret yield maps, matching them to satellite imagery maps.

This study will be made available to all farmers in the Ashton area, through the YSCD and Western Ag Research. The final step of this project will be to hold a grower meeting with the YSCD. Western Ag Research will review satellite imagery and share study results with farmers.

Conclusions

We expected a more concrete observation of satellite imagery and the influences on plant health, as it related to soil pH. Additional factors, besides just nitrogen levels, affect soil health, and so there was not a one to one correlation between color ramps and the causes of poor yields. The satellite imagery's 3 color ramps were influenced by 4 main factors:

1. Slopes and terrain
2. Soil moisture content
3. Soil organic matter content
4. Soil pH.

All 4 of these factors must be considered when making an accurate VRN application map.

The use of VRN application proved to be successful in boosting crop yields and reducing the amount of fertilizer required to produce those yields. The use of this practice is expected to grow in dryland farming areas. Farmers may be slow to adopt the technology because of the financial investment required, but the use of the practice will increase gradually. As farmers start using yield monitor data and acquire satellite imagery, they will want to address lower yielding areas of their fields, made evident by the technology.

Farmers must also strike a balance between the amount of data they collect and the usefulness of that data. It's possible to collect more data than is actually needed to make fertilizing decisions. A lower resolution satellite image, spanning a 2 acre grid system, is the most manageable and effective tool for reducing fertilizer N with variable rate applications.

Each field is unique, and faces unique factors determining the yield potential. Farmers should not assume that all red, yellow and green areas are the same from field to field. One must draw conclusions using the gamut of information about a field available to them. Land characteristics vary, even within a region. Heading West, from Lamont Farm, towards Ashton, the annual precipitation is less and so is the yield potential for dryland farming. Heading East, toward Flagg Ranch and the Grand Tetons, precipitation is higher but soil pH can often be lower. Each field is unique and the MSAVI2 color codes of red, yellow and green must be analyzed field specifically. The cause of red or low photosynthesis and vegetation vigor can be unique to each field.

With these variabilities in mind, the satellite images of GeoEye and Landsat 8 can accurately aide a farmer in setting variable rates for fertilizer application on their farm. Walking through fields and ground-truthing, one can see the vegetation health differences between green, yellow and red on a satellite image.

The best time frame for satellite acquisition of an image is July 18th through August 2nd, for dryland production in the Ashton, ID, area. Farmers should choose a date and consistently retrieve satellite data at that same time from year to year, for the best results.

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Appendix A: How to Use Satellite Imagery to Make VRN and Lime Application Maps

Photo 4: A GPS receiver is attached to a truck, in order to record the field border points.

Step 1: Fix Field Boundary and Geo-Referenced Points, Using GPS

To lock in the field boundary, a four-wheeler or truck is driven around the edge of the field with a mounted GPS receiver. The field area is locked in and calculated using GPS software. This method provides the most accurate acreage and identification of grid points within the field. Because the field boundary and points are all fixed and geo-referenced, an agronomist can acquire an image and have confidence that the application maps will be applied accurately.

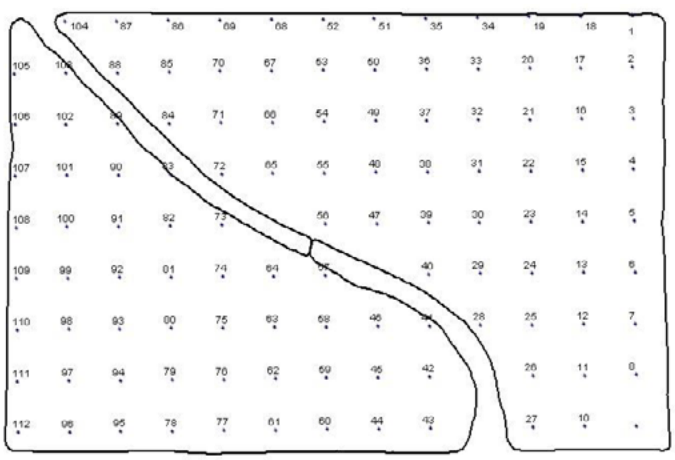


Image 10: A grid is created for "West of Home" using the GPS data collected with a GPS receiver mounted on a truck: a field border and fixed points every 2 acres.

A skilled GIS specialist can clip a field boundary from satellite imagery files, using this GPS data. They will assess soil test points within the field, based on these fixed data points. An agronomist with GIS software may perform this step themselves, so that the geo-referenced information is contained in a database they have access to and can reference. This data is not only used for creating VRN application maps, but also for variable rate seed planting and variable rate starter fertilizer applications.

Image 10, shows the GPS data collected using a mounted GPS receiver: a field border and fixed points every 2 acres. Its field boundary has an error of 3 ft or less. The fixed points are on a 2 acre grid. Each one of the grid points can be used in the future for grid soil sampling or used as a database for satellite imagery results.

Step 2: Acquire Satellite Images

ArcGIS, MapInfo, Manifold, and Summit Professional are just a few of the many GIS software systems that can be used for acquiring satellite imagery from Landsat 8, GeoEye and other satellite systems. To open an image in GIS software, you need to know the image extension and projection.

Image files come in a variety of file types, each with their own extension: Joint Photographic Expert Group (.jpg), Bitmap Image (.bmp), Tag Image File Format (.tiff), Seamless Image Database (.sid), Band Sequential Image File (.bsq) and so forth, with many others when satellite images are acquired from Europe, Russia, Canada, or other countries besides the United States. Earth projections can be transformed in the State Plane format, the Universal Transverse Mercator (UTM) format, and others. Map projections and extensions that differ from one source to another often cause a lot of frustration. This is why Step 1 is important and must be completed.

The satellite imagery maps do not come color-coded; those must be constructed with special software and specific knowledge about geo-statistics. A GIS Special-

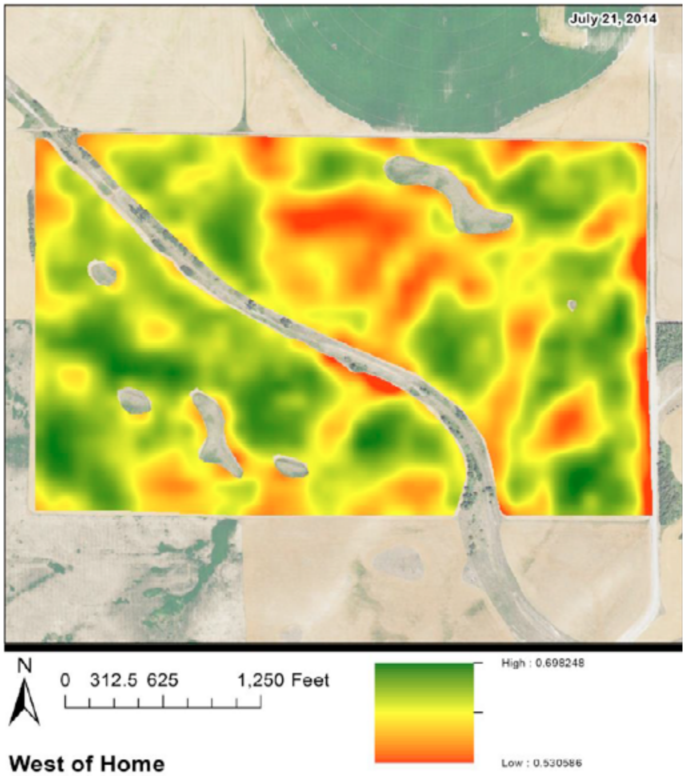


Image 11: Vegetation index map of a Lamont Farm project, field from the Landsat 8 satellite system, using a 3 color ramp and smoothing.

ist should be hired to convert the satellite imagery into the desired color ramps. The GIS Specialist will create a map that correlates GPS data to the satellite images. Then they can overlay data to show the 3 color ramp index of your plot of land (Image 11).

For dryland farming, we suggest that only one image for each field is needed each year for analysis of field variability. This image needs to be acquired on the same dates each year, for consistency. The best image will foremost show the stressed areas as red. The healthy plant areas with the best chlorophyll content, will still have a good green color. For the Ashton, ID, region, July 18th through about August 2nd will give the best imagery data for variable rate management decisions.

Step 3: Enter Map Colors and N Rates into GIS Database

The field boundary of the satellite image needs to match the field boundary generated in Step 1 before fertilizer levels can be assigned to each grid point. Image 12 show the vegetation index map from the

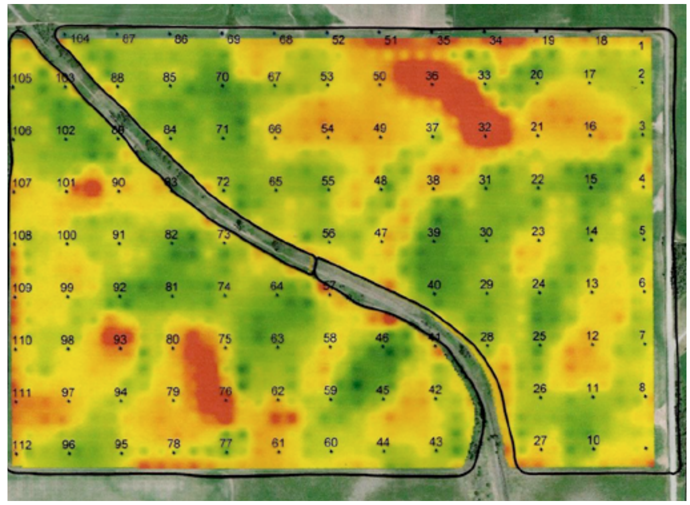


Image 11: Vegetation index map from the Landsat 8 satellite system with the field boundary and grid points from step 1 as an overlay.

Landsat 8 satellite, overlaid with the field boundary and grid points from Step 1. The field boundary in Image 12 does not match the satellite boundary perfectly in this example image, so the image must be scaled until it fits. If step one is completed correctly, these will match up without the aide of scaling.

From this combined image, an agronomist can match the color ramp to each grid point and then prescribe the appropriate fertilizer N level (Table 10). Each grid point with the same color can be prescribed the same fertilizer N level, or different fertilizer N levels if deemed necessary. For example, edges of fields, swamp areas, or nearing rock piles would require less nitrogen, despite their red color in the satellite image.

For instance, the red grid numbers 34, 35 and 51, in Image 12, could all be treated the same with an application rate of 48 lb/acre N, as with the other red areas. Or, they can be treated differently using a grid overlay system. With a grid overlay, these three grid points could each be treated differently, if the yield data shows a need for that. Since field edges usually do not yield as well, there is no need to fertilize at the same rate as other red areas of the field. For Image 12, an agronomist might prescribe 40 lb/acre N to grid points 34, 35 and 51, and a uniform 48 lb/acre to the other red areas.

The yellow and green areas of the field can be treated in a similar manner. This is where results from grain

Table 10: A portion of the GIS database with color ramp and fertilizer N level, developed using Image 11.

Grid #	Longitude North	Latitude West	Image Color	Fertilizer N lb/acre
1	44.0408	-111.2084	Red	48
2	44.0408	-111.2075	Yellow	68
3	44.0408	-111.2063	Green	73
4	44.0408	-111.2052	Yellow	68
5	44.0408	-111.2041	Green	73
6	44.0408	-111.2042	Yellow	68
7	44.0408	-111.2053	Green	73
8	44.0408	-111.2065	Red	48

yield monitors can be used in concert with satellite imagery to make fertilizer application recommendations.

A GIS database contains geo-referenced grid points, the color ramp and fertilizer N application levels (Table 10). Image 12 is a VRN map, created using this data. It contains 112 soil data points, 112 GPS coordinates and grid points with the corresponding color ramp and fertilizer N level. This data is all entered into a GIS database, from which the map is created. Data for multiple years can be kept in the same spreadsheet, which is useful for tracking information over the years and seeing long term trends in yields and soil health.

Step 4: Construct VRN Application Map

After the data is entered into the GIS database, a fertilizer N application map is constructed using GIS software. Image 12 shows a variable rate fertilizer N map displaying lb/acre N. This project field at Lamont Farm is 225 acres and will receive an average 65 lb/acre N, rather than the normal 73 lb/acre when using uniform rates. As shown on the map, 114 of the 225 acres will receive the normal 68 to 73 lb/acre N (kriging). Fifty acres will receive 61 to 68 lb/acre N. Sixty acres will receive only 39 to 61 lb/acre N. These fertilizer levels are recommended based on the previous year's satellite imagery, realistic yield goals, and soil tests.

The slight variability of fertilizer N between points is due to kriging. Kriging is an interpolation of data, based on geostatistics, which uses a mathematical model that is weighted from the data of the nearest

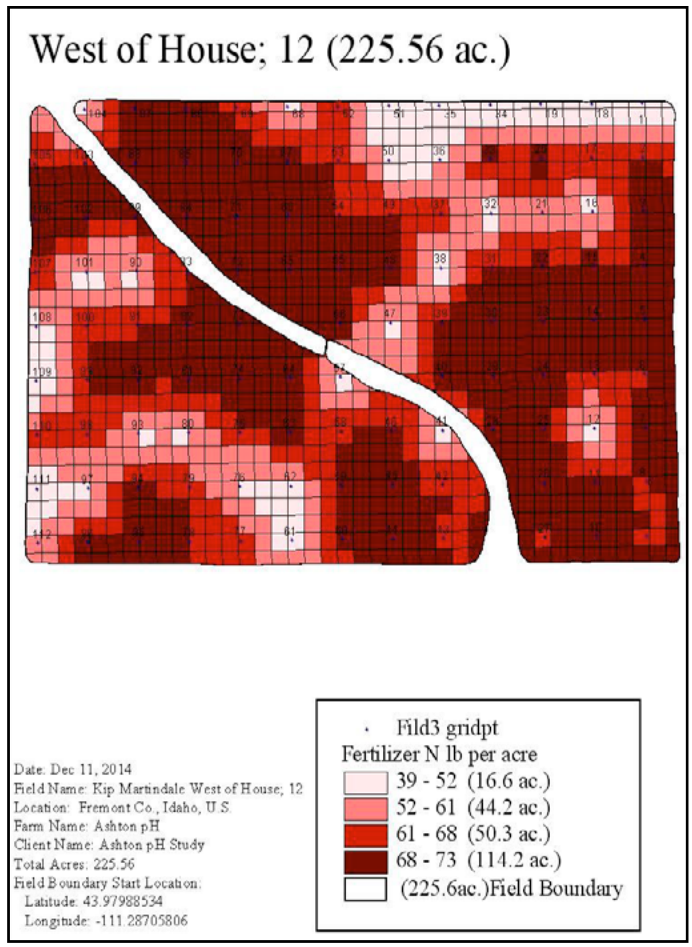
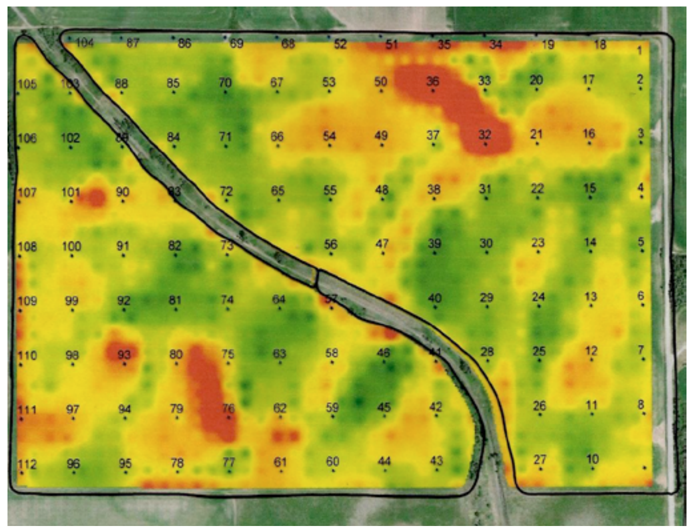


Image 12: VRN fertilizer map made with specialized GIS software and data from Table 10.

neighbor data sets. This allows for smoother fertilizer changes, instead of abrupt ones. For instance, if point A is calling for 73 lb/acre N and point B is 48 lb/acre, then as the fertilizer applicator applies fertilizer N from point A to point B the rate of application should slowly adjust from 73 lb/acre to 48 lb/acre.

If point A and point B are both in the green area, then both points would receive the recommended 73 lb/acre, a uniform application; no kriging is needed.

Photo 5: This picture shows a dry slope on the Lamont Farm.



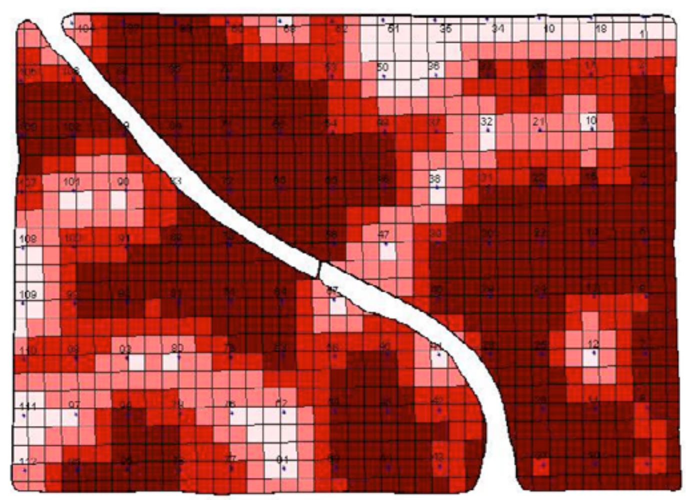
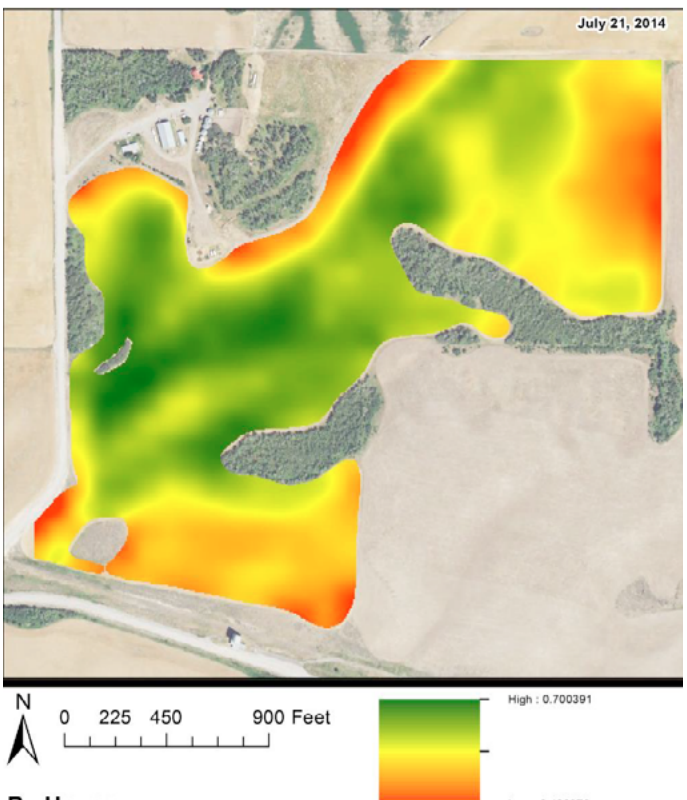
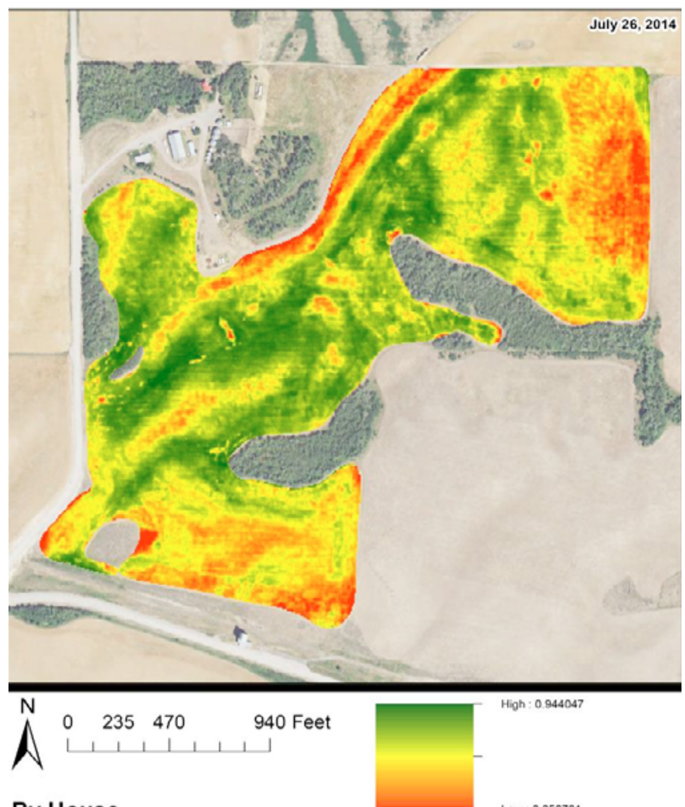


Image 13 and Image 13.1: Satellite imagery the Lamont Farm field, "West of House," with the GIS grid points and the 3 color ramp overlaid. Below in Image 13.1, the corresponding VRN application map.

Appendix B: Satellite Imagery on July 21 (Landsat 8) and July 26 (GeoEye)

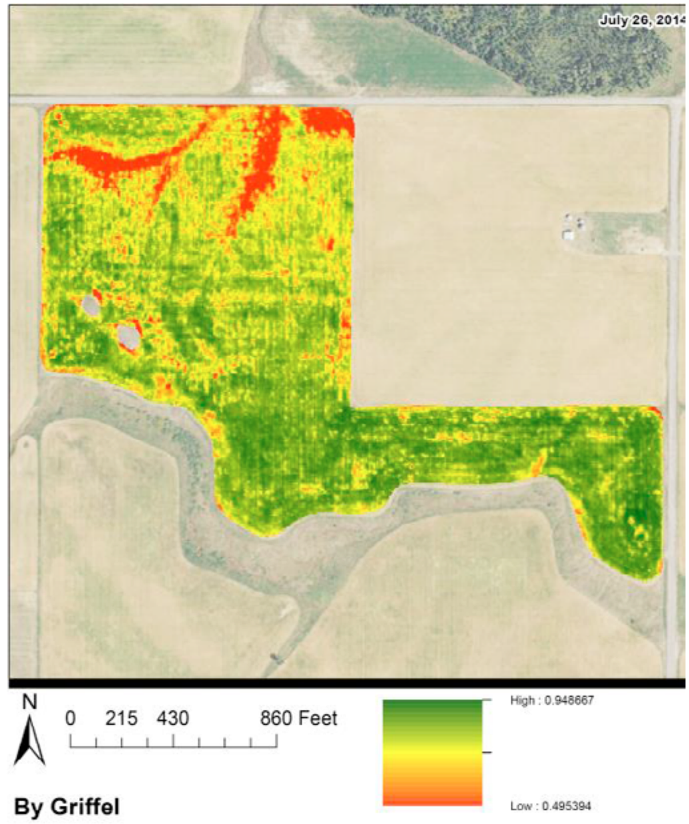


Landsat 8—Smoothed (by Home)

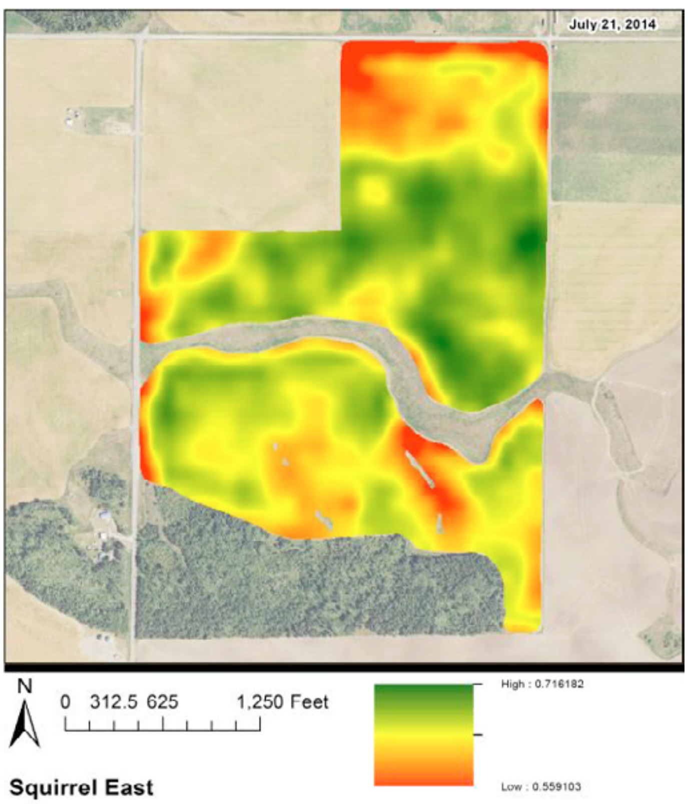


GeoEye (by Home)

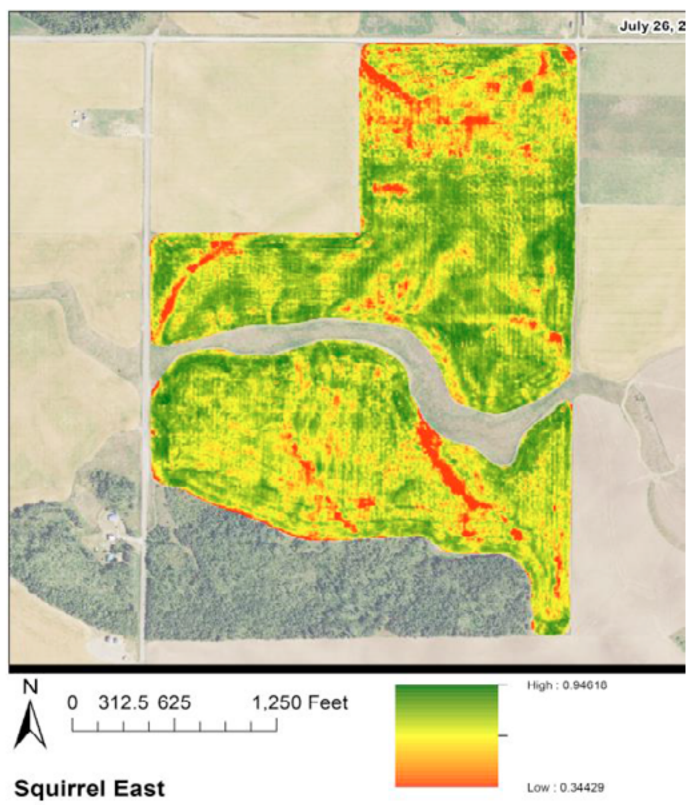
Landsat 8—Smoothed (by Griffels)



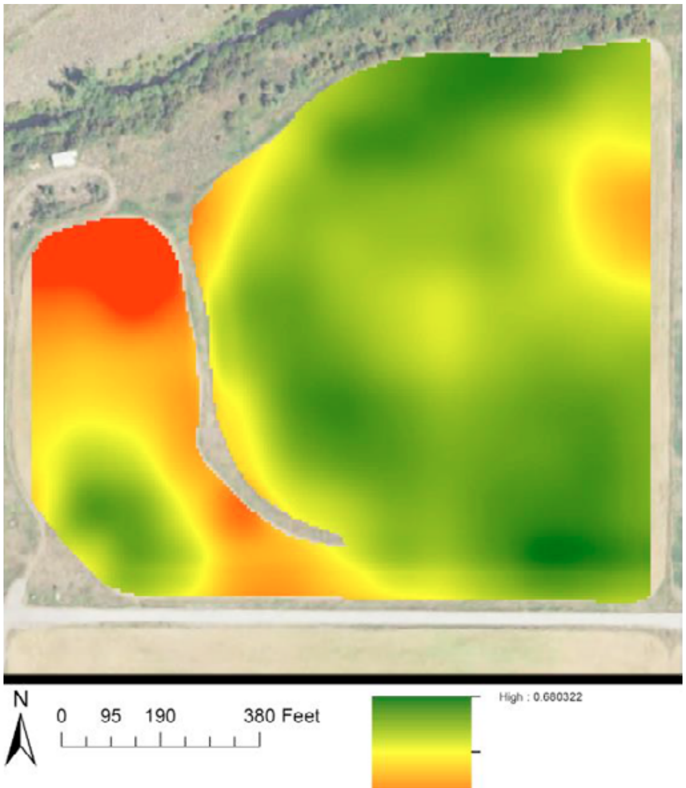
GeoEye (by Griffels)



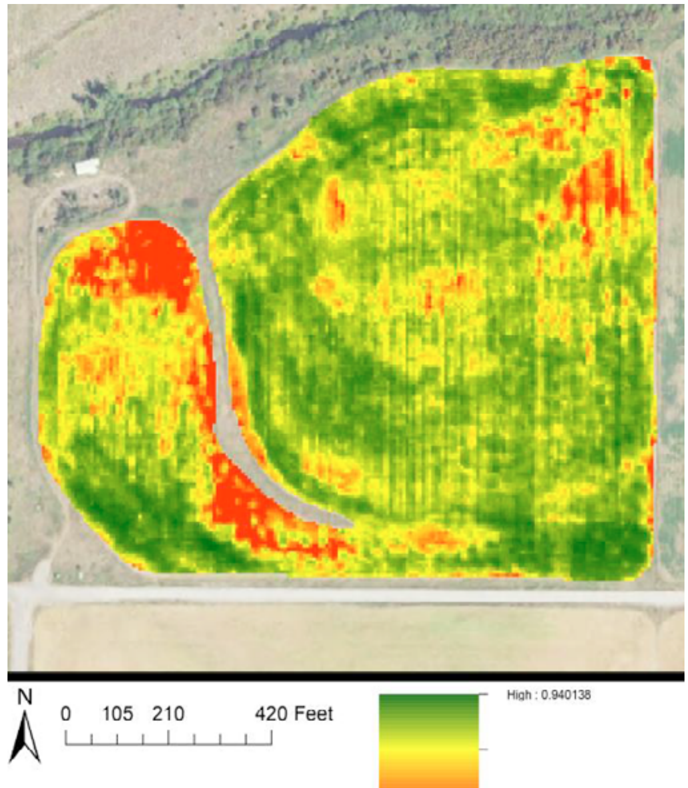
Landsat 8—Smoothed (Squirrel East)



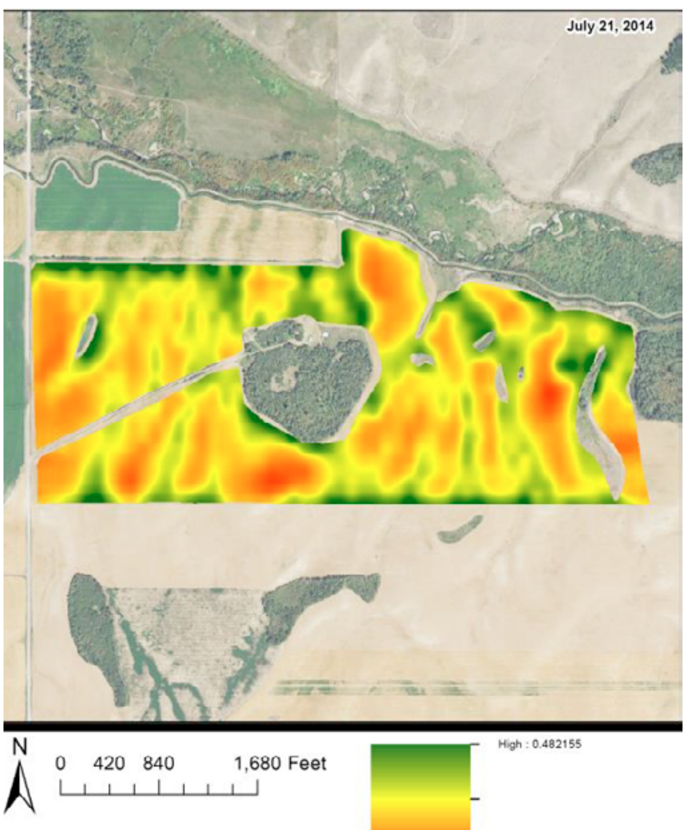
GeoEye (Squirrel East)



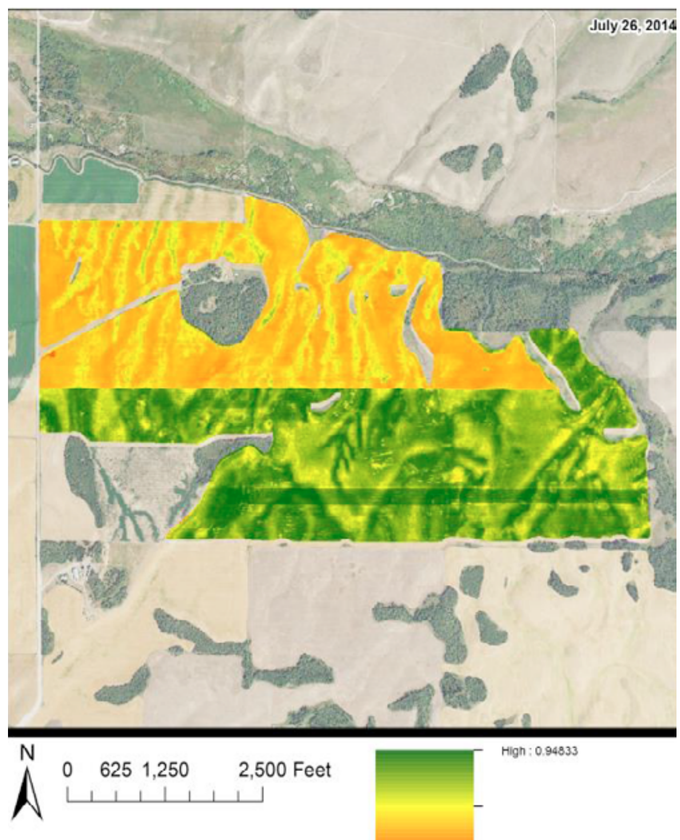
Sharp North
Landsat 8—Smoothed (Sharpe 26)



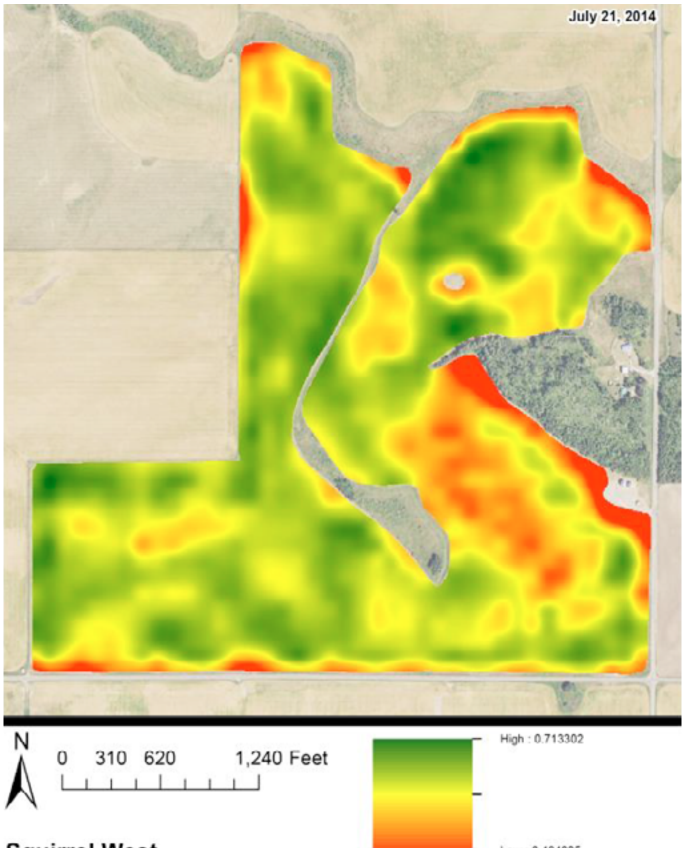
Sharp North
GeoEye (Sharpe 26)



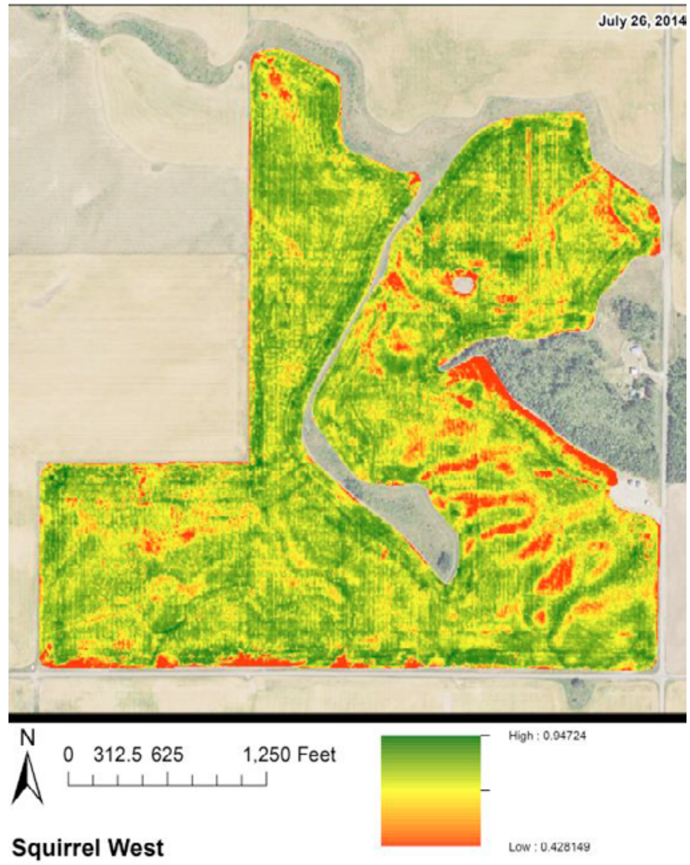
Mom's Place
Landsat 8—Smoothed (Moms)



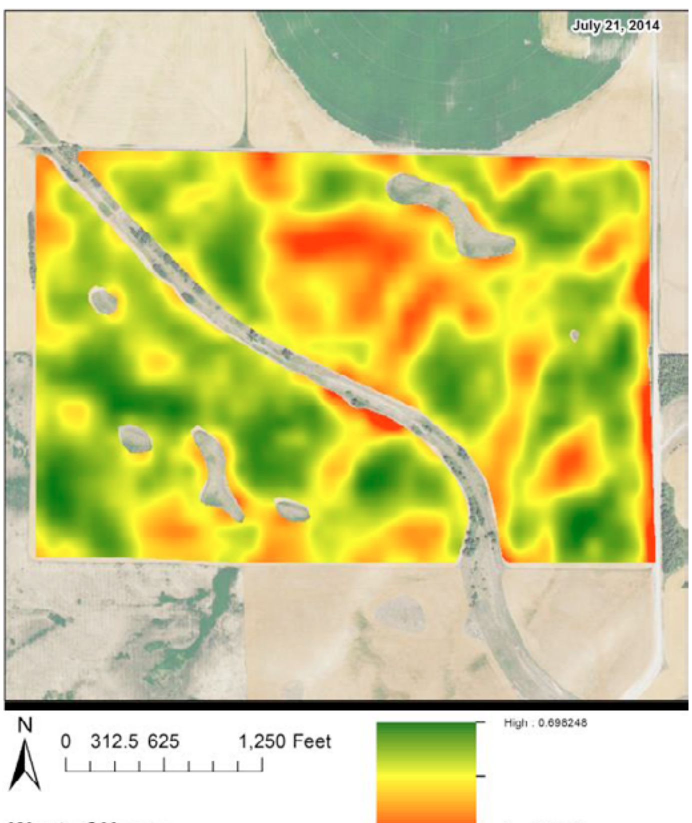
Mom's Place
GeoEye (Moms, an extra image to south)



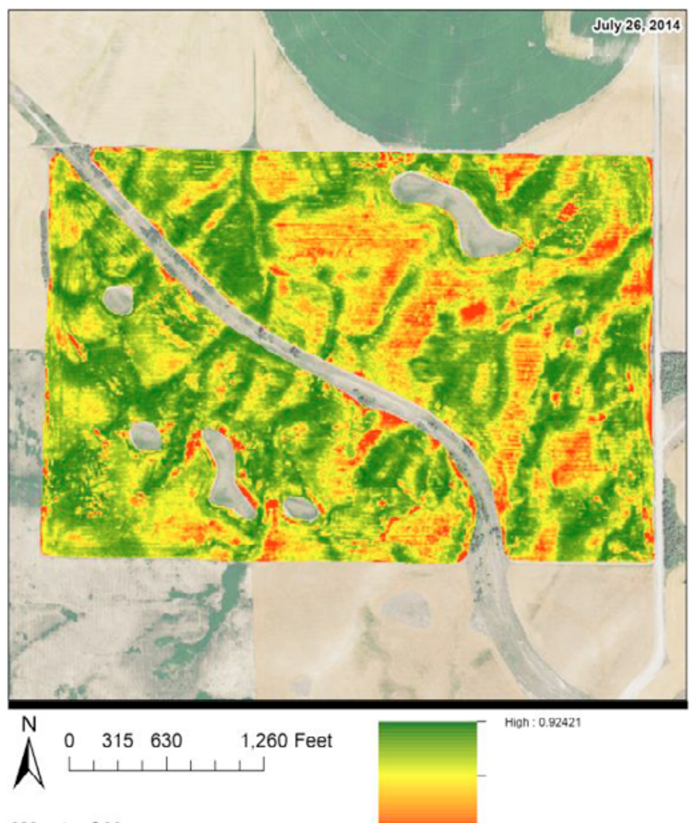
Squirrel West
Landsat 8—Smoothed (West of House)



Squirrel West
GeoEye (Squirrel West)



West of Home
Landsat 8—Smoothed (West of House)



West of Home
GeoEye (West of House)