Using Aerial Imagery for Irrigation Management

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Abstract
Water, energy and labor resources are often limited and the need for improvements in irrigation management continues. Often information for irrigation may come from field sensors, crop modeling, field scouting, watching what the neighbors do or a combination of all of these. These provide value but in most commercial cases are limited in the area of the field they adequately address and/or provide any level of current detail. Another information source gaining attention is the use of aerial imagery. Aerial imagery has the advantage of providing a complete view of the field but has many challenges. This paper will review the experiences of using aerial imagery over the last three and part of a fourth growing seasons (2013 through 2015, 2016) for irrigation management. The discussion will focus on using satellite, manned planes and UAV (drones) to collect images, methods of analysis and the challenges of each. The potential application of each for management of center pivots and sub-surface irrigated fields will be presented. Included will be some examples on how each performed and their value for irrigation management.

Keywords: Aerial image, center pivot, drones, irrigation management, satellites,

Background
Irrigation management is often called irrigation scheduling which is the process of evaluating factors and determining when to irrigate and how much water to apply (Evans 1996). Farmers' approaches to irrigation management vary greatly. Commonly used methods as identified by the USDA 2013 Irrigation Survey include but are not limited to condition of the crop, feel of the soil, soil moisture sensing device, commercial scheduling service, reports on daily crop water evapotranspiration, personal calendar schedule, computer simulation models and of course when neighbors begin to irrigate (USDA Farm and Ranch Irrigation Survey 2013). The overall driving force for adopting irrigation scheduling is economics – scheduling is used because it increases profits or decreases expenses. Nonetheless, even irrigators who find scheduling profitable will discontinue its use if it becomes too burdensome (Hennegler, 2013). Methods of irrigation scheduling can be broken down into three main categories – soil, plant and climate. One tool that can help maximize a farmer's limited crop management time while improving his decision-making ability is aerial photography (Reising, 2016). In most discussions of irrigation scheduling and management no mention is made of using aerial images.

Aerial images have been used in agriculture for many years primarily for providing general information about the field and/or crop. Use of aerial images in the irrigation industry has been confined primarily to providing information on the crop condition and performance of irrigation equipment. The primary challenges with aerial images, depending on their source, have traditionally been cost, the time lag from ordering the image until delivered to the end user and resolution. A key advantage of an aerial image is it provides a ‘snap shot’ of the entire field at one instant in time.

Sources of aerial images include but are not limited to satellites such as the Landsat8 which provides a variety of spectral bands, manned planes which typically provide infrared and RGB (red, green blue) color images and most recently UAV (unmanned aerial vehicle) commonly called drones which can provide a variety of image types depending on the cameras being used.

Valmont Industries Inc. has been using aerial imagery regularly for many years to help evaluate performance of different types of irrigation equipment such as but not limited to, center pivots, center pivots with corner arms and linears. In the past the primary focus has been on evaluating the sprinkler package.

With the development of VRI (variable rate irrigation) in 2009 Valmont began to use NDVI (normalized difference vegetation index) to assist with the evaluation of the crop’s performance and response to VRI. In addition in most cases also collected were infrared and RGB images. All aerial images were collected using a manned plane. In 2010 to help better understand the performance and use of VRI Valmont added soil moisture sensing into key areas of the fields besides using aerial images. Until about 2011 all the images were collected using manned planes. In 2011 Valmont Industries tried a satellite service offering images with 5.0m resolution. Also in 2011 Valmont had aerial images collected and data provided on the chlorophyll and ground cover of a particular field. In each case the turnaround time was seven to twenty one days.

With all of the use of aerial images in the irrigation industry there has been little consideration of using the images for actual irrigation management primarily due to the lag time between when the image is scheduled for delivery and when it is delivered.

Methods

In 2013 Valmont expanded to try to make more use of aerial images for irrigation management. Due to the cost and time lag between images they were still ended up being only used to confirm what had already happened and not for making timely management decisions. One particular field called BF had two manned plane flights August 19th and then again on September 18th looking not only at the center pivot with a corner but also include a SDI (sub surface irrigation) areas of the field.

2014 saw the addition of UAV (unmanned aerial vehicle), drones for the collection of some aerial images. Valmont expanded the work to compare the information from the soil moisture sensors, the crop and aerial images in the BF field started in 2013 again both for the center pivot with the corner and the SDI. For the BF, three images were acquired the first at full canopy, second early reproduction and the third at early maturity. Again a manned plane was used to collect the images and the time lag precluded using for irrigation management.

In 2015 Valmont had the opportunity and tried satellite imagery again with the anticipation the images would be delivered timely with better resolution than had previously been experienced. This was in an attempt to truly move toward something approximating near real time irrigation management. The satellite imagery was to be delivered every seven to ten days with a resolution of 2.0m. Colorization to develop the NDVI map was done utilizing QGIS software by Valmont personnel. The newest colorized image was compared to the previous looking for change. Irrigation decisions were based on the change. Validation of the performance was based on field scouting, images taken from a plane (one image) and soil moisture sensors again for the BF field previously used. In addition crop yield based on the combine yield monitor was used to compare with the other information. The HP field was managed by the farmer using traditional methods and the BF field using the satellite imagery process. Unfortunately it was not possible to have replicated treatments within a single field due to the non-acceptance by the farmer.

For the 2016 crop season the same satellite company is being used as in 2015 with the expectation of improved delivery of images and faster turnaround of the colorization process. Valmont is continuing to use QGIS to create the NDVI information for the fields. In addition two other geographic areas were added with a variety of crops. Total included in the satellite project are three different areas of the United States with a total of thirteen fields and five crops including the BF field utilized in 2013 through 2015. Validation using field scouting, soil moisture sensors and crop yield has been expanded. An UAV company was contracted to do some work as well as a manned plane company for comparison.

Discussion

2013 Results - for the BF field the August 2013 flight NDVI indicated better crop health in the southern half of the field and poorer crop health in the northeast area of the center pivot. The NDVI also indicated areas of some uneven water distribution in the SDI fields on the east side, northwest corner and southwest corner. Adjustments were made to the SDI areas to compensate for what the August flight indicated. The September NDVI image was of no value from an irrigation management standpoint but did indicated the need to review why the patterns had developed seemly to indicate non-uniformity of the crop that could be associated with the center pivot corner. However the same non-uniformity did not show up in the yield data. The conclusion was the aerial images were helpful but the information was received too late to be of significant benefit in the short run. The information was valuable for planning for the next crop season. The NDVI images are shown in figures 1 and 2.

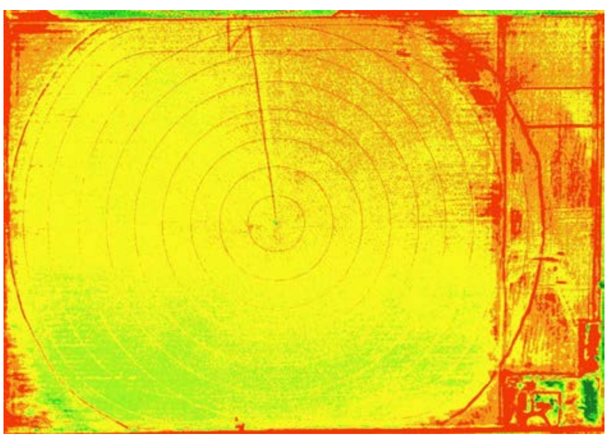


Fig 1   19/August/2013

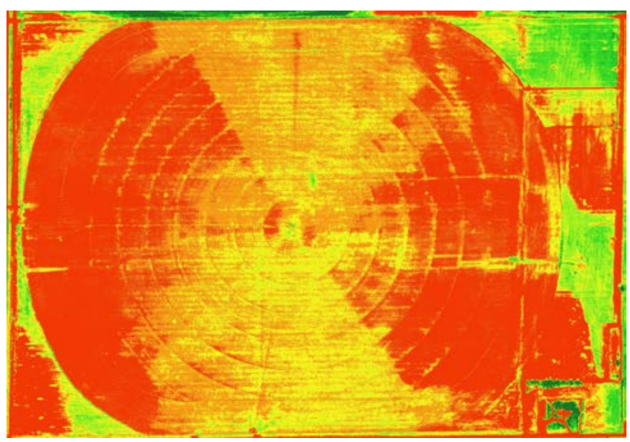


Fig 2   NDVI 18/Sept/2013

2014 information led to the following conclusions again for the BF field. Adjustments were made based on the image information but not specifically addressing weekly irrigation management. See figures 3 and 4 below. The information from the aerial images were considered valuable to the farmer but again for the longer term and not the short term. Again no non-uniformity of yield was seen that could be attributed to the center pivot corner. Scheduling of the UAV flights and the turn around to receive the NDVI images was slow. The UAV company chose to use a different colorization scheme than what was requested confusing the farmers. Also resolutions of 5cm had some interest but the file size was too large to manage easily and did not show the information most needed. The drawback of aerial images continued to be the time to receive images and the cost. Through all of this there was sufficient interest to explore if images could be used for irrigation management but needed to deliver aerial images in a more regular and routine fashion.

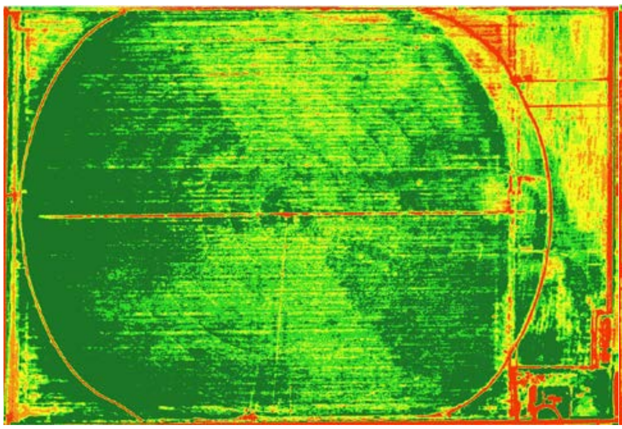


Fig. 3 NDVI 18/June/2014

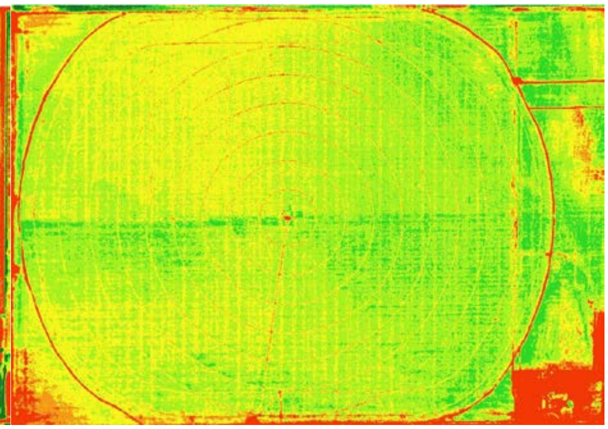


Fig 4 NDVI 22/July/2014

2015 was a difficult year for a variety of reasons. First there was a slow start using the satellite delivery of images and analysis of the aerial imagery. It was not until mid-July the image delivery began to be on a regular basis and the conversion to NDVI became a smooth process using QGIS. Second was the unanticipated amount of rainfall early in the crop season as shown in figure 5. Until there is full crop canopy it appeared aerial images providing NDVI are of limited value. A water balance was used to help manage irrigation. On at least one occasion irrigation was recommended and then the field received significant unexpected rainfall.

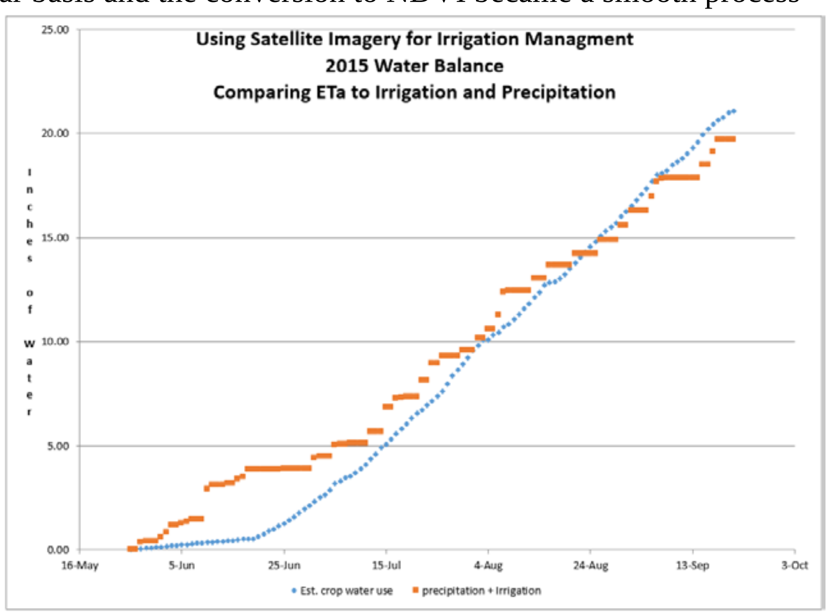


Fig. 5 Information on irrigation and weather

In review significant irrigation was not needed until later in the crop season. Figures 6, 7 and 8 are NDVI images for the BF field. In addition cloud cover was a problem during two weeks to the point no irrigation management decisions could be made based solely on aerial images and continued to operate using the water balance. Overall summation of the crop season for the BF field is shown below in table 1. In the table the BF field is called “satellite managed” and the HP field is called “farmer managed”.   All of the information displayed is on a per acre basis. While some less water was applied to the BF field, the better yield of the HP field provided more income to offset the cost of the irrigation. In a situation where irrigation water was limited the management using the aerial images could have proved to be more valuable to the overall outcome. The BF field received more irrigation later in the season than did the HP field

	satellite managed	farmer managed
irrigation:	8.2	9.2
rainfall:	10.2	10.2
overall average yield:	76.4	76.7
yield per unit irrigation:	9.3	8.3
yield per unit total water:	4.2	4.0
value of additional yield:	0	$2.58
cost to pump additional water:	0	$2.14

Table 1

Until the crop was well into the reproductive cycle neither the NDVI aerial images nor the soil moisture sensors indicated a significant need for irrigation. The NDVI generated from the manned plane aerial image matched well with the satellite aerial images. The yield maps indicated little variability across either field. After the crop season ended it was learned that historically the HP field has tended to out yield the BF field.

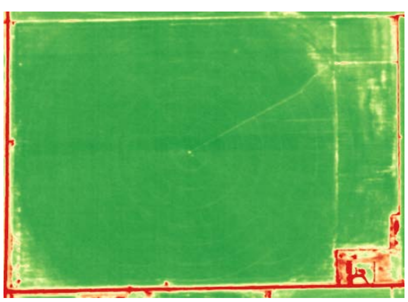


Fig. 6 NDVI 21/July/2015

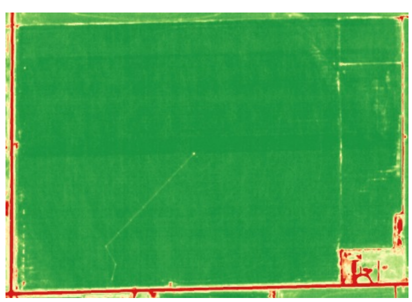


Fig. 7 NDVI 28/July/2015

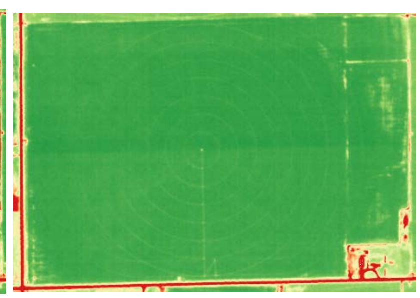


Fig. 8 NDVI 3/Aug/2015

In April of 2016 the aerial images began to be received and have been available generally in five to seven days. Valmont began to use MSAVI2 to provide better information on the crop prior to full canopy development and to avoid some of the saturation issues associated with NDVI. Cloud cover has been a problem at each of the three sites. Also a challenge is identifying if there is atmospheric water vapor in the upper deck resulting in false values.   Figures 9 and 10 are examples of what the NDVI looked like at two different atmospheric situations. Initially it was not recognized that sufficient water vapor was in the upper deck ‘sapping’ too much of the reflected energy needed to produce an accurate measure of the plant health as shown in figure 9.

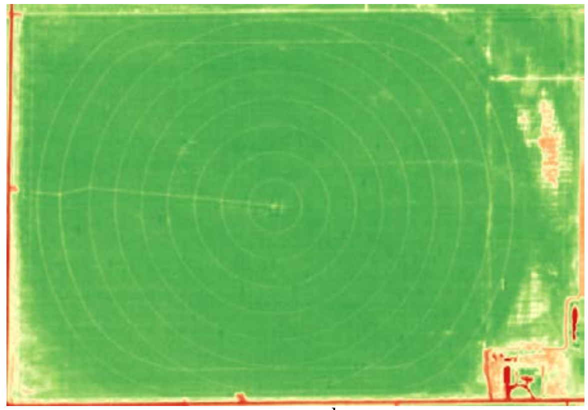
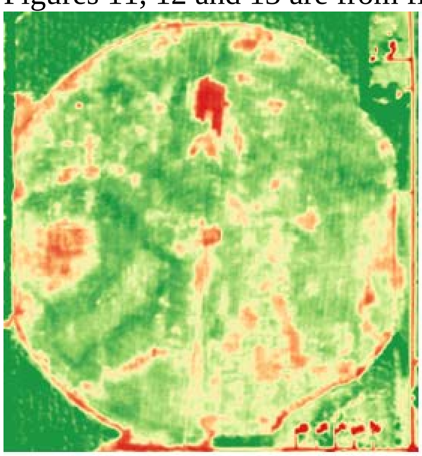
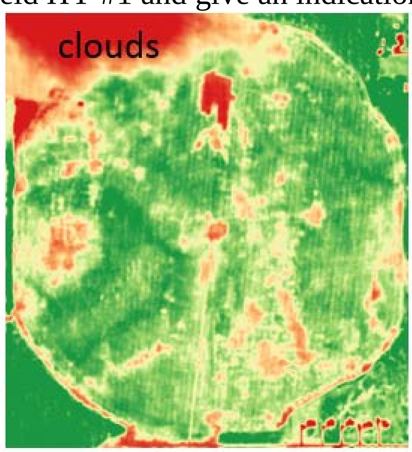


Fig 9, August 22nd   Fig. 10 September 5th

One interesting note while it was believed aerial images were of limited value prior to full crop canopy, use was made by three of the farmers to evaluate the performance of the burn down of their cover crop and status of the crop in the early season. In addition each farmer used the aerial images to evaluate early season weed pressures. The soil moisture sensor data is confirming the indications of the aerial images so far. Again the fields will be evaluated also using yield data from the combine. A 2.0m resolution can provide an indication of the stand but does not allow for individual counting of plants. The drone company contracted with went out of business before any images were delivered. Manned plane images were taken in early June and late July. Figures 11, 12 and 13 are from field HY #1 and give an indication of the information received.





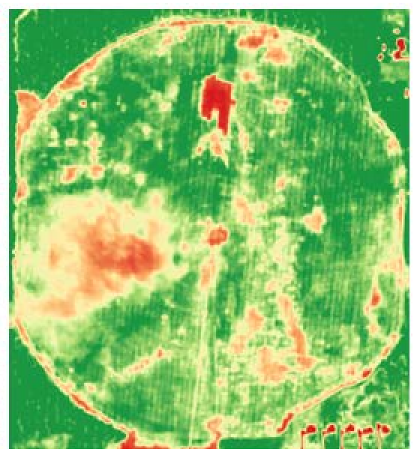


Fig. 11 28/June/2016   Fig. 12 03/July/2016   Fig. 13 05/July/2016

Summary

Many tools exist to manage irrigation. Work was done to explore the use of aerial images from satellites, manned planes and drones for irrigation management.

The common challenges of using aerial images in the past have been:

- Cost of images
- Timing of collection and turnaround time from collection to available to the farmer and/or consultant
- Resolution
- Interpretation challenges

The advantages are:

- Snap shot of the complete field
- Can see crop changes over time if collected at sufficiently close intervals during the crop season
- Automation of image management and analysis
- Minimize obstructions in the field

Work has been done with a satellite company which overcomes many of the traditional challenges of working with aerial images. In 2013 and 2014 it was obvious that receiving images every three to four weeks using manned planes or drones was insufficient to adequately manage irrigation. In 2015 due to weather conditions and slow start to image delivery and conversion the results for using satellite images was inconclusive though showed promise for dynamic irrigation management.

2016 has started well and anticipate a good test since working over a wider geographic area and with different crops. Economics of the individual fields involved are being more closely tracked. The need for solutions to automate the process of image download and analysis has become apparent as are providing irrigation recommendations.

A review of costs per aerial image seen in 2015 and 2016 indicate the following:

	$/acre/image	Minimums
Manned plane	$ 1.80	2,000 acres
UAV or drone	$ 3.80 to $ 5.40	200 to 500 acres
Satellite	Free to $ 2.48*	varies

*The cost for satellite data varies greatly due to the possibility of using public domain images such as from Landsat8, Modis, Sentinel-2 and others that are for profit companies.

The use of satellite images shows promise not only for irrigation management but can be used to identify early season field characteristics and also how the crop is maturing.

Return per acre when using aerial images also varies greatly and has been hard to determine for commercial fields. One study on remote sensing (aerial images) states “when budget assumptions are standardized the reviewed studies show that RS has the potential to improve average on-farm profit by about $12.95/acre” (Tenkorang, 2008). More work needs to be done to determine the economic value to a grower.

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