PROGRESS ON USING REMOTE SENSING FOR CROP MANGEMENT[1/]

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Introduction

Remote sensing has been available for decades but continues to become more available and useful to crop producers in managing their field. Remote sensing data provides assessment of crop production fields during the growing season when some management decisions may be made to address the problem as it is occurring. Coupled with other field information, the remote sensing data may be used to identify the cause of the anomaly which may be problems such as soil moisture, weeds or fertility. Also it can increase the efficiency of crop scouting by locating anomalies in the production fields for focused ground evaluation.

Since 1997 remote sensing data have been collected on three production fields north of Madison, WI, while ground data were collected including yield monitor, plant population and plant height. Four fields have been added since the start of the study. Numerous anomalies were identified in the remote sensing data and related to ground data collected. As in the past, many anomalies were due to operator error and changes in management. In addition to the discussion of the field results, some background information on remote sensing will be provided.

Remote Sensing Background

The definition of remote sensing is the acquisition of information about the surface of an object without contacting the object. The distance between the object and the sensor could be from less than an inch to thousands of miles. The sensor is measuring the energy reflected and emitted from the object surface. In these field studies, this energy is dependent on the sun's electromagnetic energy striking the surface. This electromagnetic energy from the sun ranges from ultraviolet to visible to infrared and is either absorbed, conducted or reflected when striking an object. The percent of sun's electromagnetic energy that is reflected is measured by the sensing system and is dependent surface characteristics of the object.

Systems have been developed where the energy such as radar (microwave) comes from the system and the sensor picks up the radar energy that is reflected by the surface. These systems are referred to as active versus those systems utilizing the sun's electromagnetic energy are called passive systems. These systems were not used in this study.

Fundamentals of Remote Sensing

The electromagnetic energy from the sun is characterized on the basis of wavelength which ranges from about 0.300 micrometers (*u*m) to 3.000 *u*m. Electromagnetic energy with a wavelength less than 0.400 *u*m is defined as ultraviolet while the energy is the 0.400 to 0.700 *u*m

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is defined as the visible range. The visible range is further broken down in to blue (0.400 to 0.500 *u*m), green (0.500 to 0.600 *u*m) and red (0.600 to 0.700 *u*m). Beyond the visible range is the infrared range. Within the electromagnetic range from 0.700 to 3.000 um, it is called the near-infrared range.

The remote sensing systems when directed at the earth's surface are sensing the energy reflected and emitted which is in the visible and infrared range (0.400 to 14.000 *u*m). In addition to near infrared energy (0.700 to 3.000 *u*m), some of these sensors are capable of thermal infrared, 3.000 to 14.000 *u*m. The energy emitted in the thermal range is related to the temperature of the surface which may indicate the health of a growing crop. During a sunny day the evapotranspiration rate will have a cooling effect on the plant. Healthy crops have higher rates.

The majority of the energy that is sensed by the human eye is in the visible range. On a growing and healthy crop much of the energy in the green visible range is reflected and much of the energy in the blue and red ranges is absorbed. Therefore, a green color is seen in a growing crop.

Although the wavelengths listed above imply a precise cutoff from one band to another, there is a transition. For example going from green to red, the visible transition is red to orange to yellow to green. A sensing system will have a camera that covers a number of specific wavelengths such as blue, green, red and infrared. Some cameras will cover the full range of each band while others will cover a portion of the band width.

Performance criteria

When evaluating sources of remote sensing data, the characteristics of the equipment of the supplier should be evaluated to ensure the data quality is appropriate for the intended purpose. The primary characteristics are spectral resolution, spatial resolution and temporal resolution.

The spectral resolution is the quality of data being collected with respect to wavelengths of the energy signal being processed. Most sensor systems used in agriculture will provide visible, near infrared and thermal infrared. The minimal wavelengths that should be collected for production fields are three in the visible, usually red, green and blue and one in the near infrared. Also the width of each band being collected and the sharpness of the wavelength cutoff for bandpass filters is important when evaluating this data. Many providers of this data have calibration data available to the user. If the bands are too narrow the energy received by the system will be smaller and more susceptible to noise errors. If the bands are too wide, the unique characteristics of each band will degrade the results of vegetative index computations.

Spatial resolution is the area represented by each pixel (picture element) of data being collected. These pixels are square and the resolution indicates the length of the area represented by each pixel. The resolution depends on the sensor and the distance from the sensor to the surface being studied. The resolution for handheld units can be as small as several inches while some satellites have resolution near thirty feet. For an agriculture field the spatial resolution will be dependent the purpose of the data and on the width of the machinery used. If large geographic areas are being evaluated, storm damage and flooding, then a larger resolution such as 30 feet may be acceptable. If the purpose is to analyze field problems such as weeds and machine malfunctions, a spatial resolution approaching three feet is excellent. Note, as the spatial resolution decreases the size of the data set increases. For example a remote sensing data set with a pixel representing a square yard (9 square feet), the number of pixels (data points) is 5000 for each acre.

Temporal resolution refers to the timing and frequency of data collection during the growing season. If data are going to be collected once during the growing, it should be done when the crop is likely to demonstrate the highest level of stress, usually near flowering. If multiple dates are being used then, excellent times to consider are bare soil, early crop stage (crop canopy closure), near flowering and as crop is maturing (dry-down difference may be visible). Data should be collected during the middle of the day.

For multiple dates, it is very difficult to maintain a planned schedule. Problems that occur are clouds and availability of the systems. The best results are obtained a clear days. The clouds create a problem when between the sensor and target and when casting a shadow on the field. Aircraft mounted cameras provide good flexibility but often have difficulty maintaining a planned schedule due to weather.

Sources of Data

Sensors for collecting remotely sensed data are transported by satellites, low flying aircraft, ground transport equipment such as irrigation equipment or other machinery, or person walking through a field. For the handheld, the sensor may be stationary when the data are collected. Some handheld sensors are held stationary just above the crop canopy collect multispectral data or a very specific band such as chlorophyll meters and thermal infrared thermometers.

Since the start of this study numerous data sources have been used including satellite, low flying aircraft and hand held. In 1997,1998 and 2000, the remote sensing data were collected by Airborne Data Systems, Inc. with their instrument known as SPECTRA-VIEW. The multi-spectral data are collected with CCD cameras with the appropriate filtering. The particular spectral coverage they provided is listed in Table 1. In 2000 only the visible range and the first near infrared bands were collected. The data were transferred to CD-ROM and processed by Environmental Remote Sensing Center staff. The spatial resolution was three to six feet depending on the band.

Table 1. Airborne Data Systems spectral coverage for the remote sensing data (*u*m).

Visible Range					
	Wavelength	0.4-0.5	0.5-0.6	0.6-0.7	
	Color	Blue	Green	Red	
Infrared					
	Wavelength	0.7-0.8	0.8-2.2	2.4-4.5	8.0-14
	Type	Near	Near	Thermal	Thermal

*u*m – micro-meter

In 1997 and 1998, US-NASA provided remote sensing data with a resolution of eight to sixteen feet. With their airborne terrestrial applications sensor their spectral coverage included four wavelengths in the visible range, four in the near-infrared and six in the thermal infrared, Table 2.

In 1999, Spectro Visions provided hyperspectral remotely sensed data having 120 bands in the visible and near-infrared ranges. The interval between the bands was 0.003 *u*m and the spatial resolution was four feet.

In 2001, 3di LLC provided remotely sensed using a sensor processing sixteen bands of data, eight bands in the visible range and eight in the near infrared range. Each with a bandwidth of

Table 2. NASA Airborne Terrestrial Applications Sensor spectral coverage for the remote sensing (*u*m).

Visible Range				
Wavelengths	0.45-0.52	0.52-0.60	0.60-0.63	0.63-0.69
Color	Blue	Green	Orange	Red
Infrared(Near)				
Wavelengths	0.69-0.76	0.76-0.90	1.55-1.75	2.08-2.35
Infrared(Thermal)				
Wavelengths	8.20-8.60	8.60-9.00	9.00-9.40	9.60-10.2
	10.2-11.2	11.2-12.2		

*u*m – micro-meter

0.0097 to 0.0106(*u*m), Table 3. Although their data normally has a spatial resolution of about three feet which was better than they normally obtain. The altitude of their flights was 200 to 250 feet less than planned resulting in some missing data.

Table 3.3diLLC Sensor spectral coverage for the remote sensing (*u*m – center of 0.010 *u*m band).

Visible					
Wavelengths	0.530	0.554	0.580	0.605	0.634
	0.649	0.675			
Infrared(Near)					
Wavelengths	0.700	0.725	0.750	0.780	0.800
	0.824	0.850	0.880		

*u*m – micro-meter

In 2001, Ikonos satellite data were obtained three times during the growing season in two fields and during the 2002 season, data was collected twice on the same two fields. The bands for the Ikonos satellite are listed in Table 4.

Table 4. Ikonos spectral coverage for the remote sensing data (*u*m).

Visible Range			
Wavelength	0.445-0.516	0.506-0.595	0.632-0.698
Color	Blue	Green	Red
NIR Infrared			
Wavelength	0.757-0.853		
Panchromatic			
Wavelength	0.450-0.900		

*u*m – micro-meter

In 2002, Precision Aviation Inc. provided remote sensing data using a low flying aircraft having two sets of instrumentation. On two dates they provided multispectral data having four bands similar to the Ikonos data except there was no panchromatic data. On one date they provided data using the same system used by Spectral Visions which the 120 band hyperspectral data. It would have been more desirable to have the same source remote sensing data throughout the study. But the demands on the suppliers during this time which created an availability issue. One source received some contracts mapping forest fire in the western U.S. and was not available in later years.

In addition a handheld radiometer was used to collect data for 2000-2002. To obtain more timely data, a Cropscan handheld radiometer was used in 2001 and 2002 seasons. This unit provided eight bands of data from 460 to 810 *u*m at 50 *u*m intervals. This radiometer provided five bands were in the visible and three bands were in the near infrared range. Table 5 lists the center wavelength of each band recorded.

Table 5. Cropscan handheld radiometer spectral coverage for the remote sensing data (*u*m).

Visible Range					
	Wavelength	0.460	0.510	0.560	0.610
	Color	Blue	Green	Green	Red
	Wavelength	0.660			
	Color	Red			
NIR Infrared					
	Wavelength	0.710	0.750	0.810	

*u*m – micro-meter

Field Studies

Seven crop production fields, 40 to 105 acres, were identified for intensive geo-referenced data collection. These fields are located north of Madison, WI on what is commonly referred to as the Arlington Prairie, primarily a silt loam soil. Data collection was started on three fields in 1997. Three more fields were added in 1999 and one more field was added in 2000. One-acre soil grid sampling was done at the beginning of the growing season when the fields joined the study. During the 1997-2002 growing seasons, the fields were in corn or soybean production having a two-year rotation of corn and soybeans or three-year rotation of two years corn and one year of soybeans. Although extensive crop and soil data were collected, the discussion in this paper will focus on remote sensing data and other geo-referenced data that was used to ground truth the remote sensing data. Also crop yield data were also collected.

As the field data were colle cted several observations were made with respect to impact of equipment, disease infestations and high density weed areas. Examples of equipment effect included planter skips, sprayer skips and wheel traffic during a late herbicide application. Using a global positioning system, these areas were mapped for later analysis. Over the years of the project several sources of remotely sensed data were used and in several cases the data were processed by the Environmental Remote Sensing Center UW-Madison staff.

Observations

The observations for the 1997 growing season were reported in the 1998 Proceedings of the Wisconsin Fertilizer, Aglime and Pest Management Conference. At that time one growing season of results was reported for three fields. Since that time four more fields have been added to study and data collection on the three initial fields continued. At the conference in 2002, additional observations were reported.

Most observations reported are based on comparisons of images from the various sources of data and a brief summary of these observations is provided. No extensive statistical analysis was done to determine the degree of correlation between the various data sets. Many of the same observations persist and are divided between operator, equipment, or management induced effects and natural induced effects. Many of these observations were seen in the remote sensing data and then followup field observations were made to identify the cause of the difference in the image.

Only one field which is referred to as field A will be discussed extensively here. Images for field A include Figure 1 for May 30 before no-till planting and covered with corn residue (Ikonos), Figure 2 for August 29 with field in soybeans (Ikonos) and Figure 3 for August 20 with the field in soybeans (3diLLC).

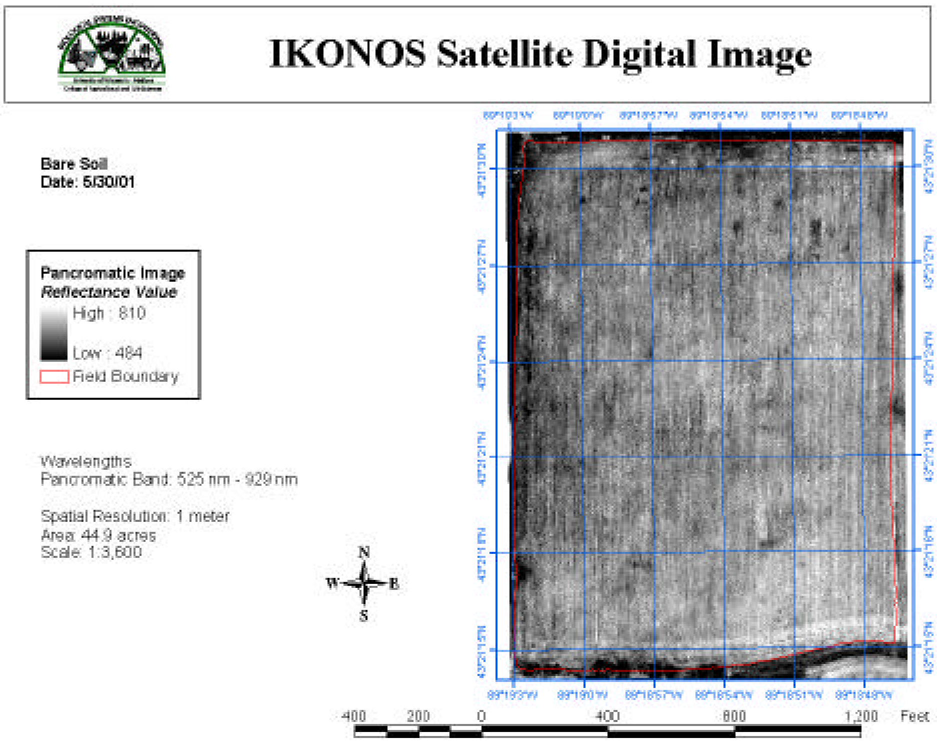

Figure 1. Ikonos panchromatic data for field A before no-till planting into corn stalks.

An image developed before planting can be very useful in developing management zones, Figure1. But if large quantities of residue it is difficult to obtain an image of the bare soil. The dark areas in Figure 1 are areas of early weed development.

In Figure 2, the dark area at the south end of the field are trees while the small light areas at the north and south ends of the field are drill skips caused by delayed seeding the soybean drill started planting at the beginning of the pass.

The drill skips are very apparent in the 3diLLC image in Figure 3. The dark irregular shaped area in the center of the field resulted from the pilot flying too low (200 feet) resulting in missed data. The drill skips also show in the yield data, Figure 4. Also some low yielding strips, toward the east side of the field, show which resulted from less than a full width being harvested.

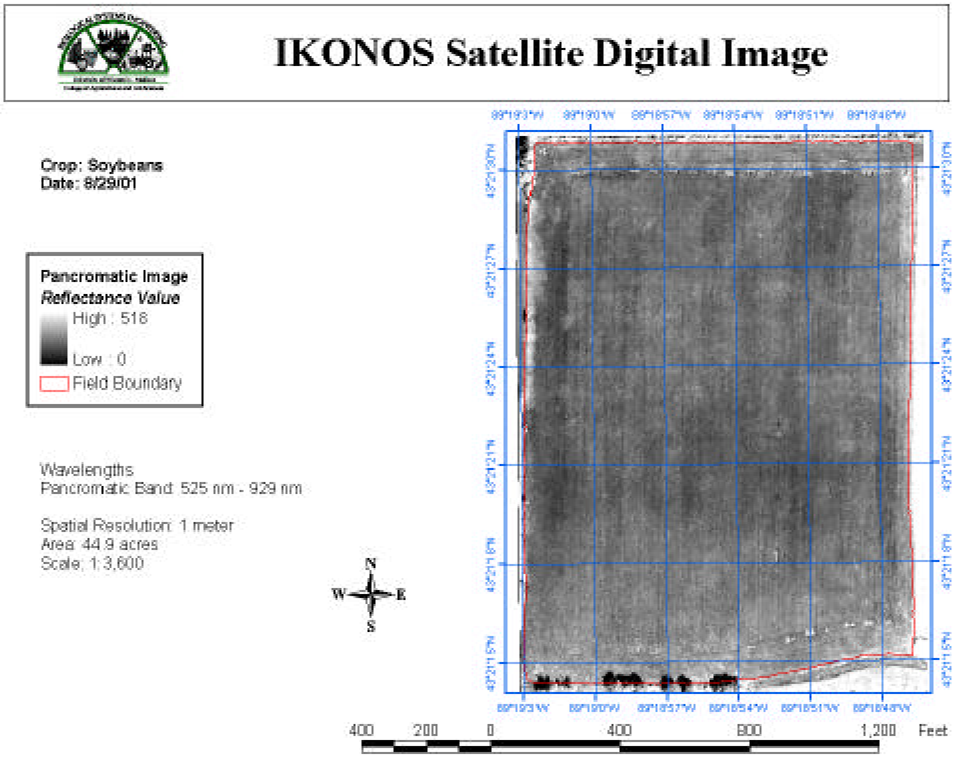

Figure 2. Ikonos panchromatic data for Field A

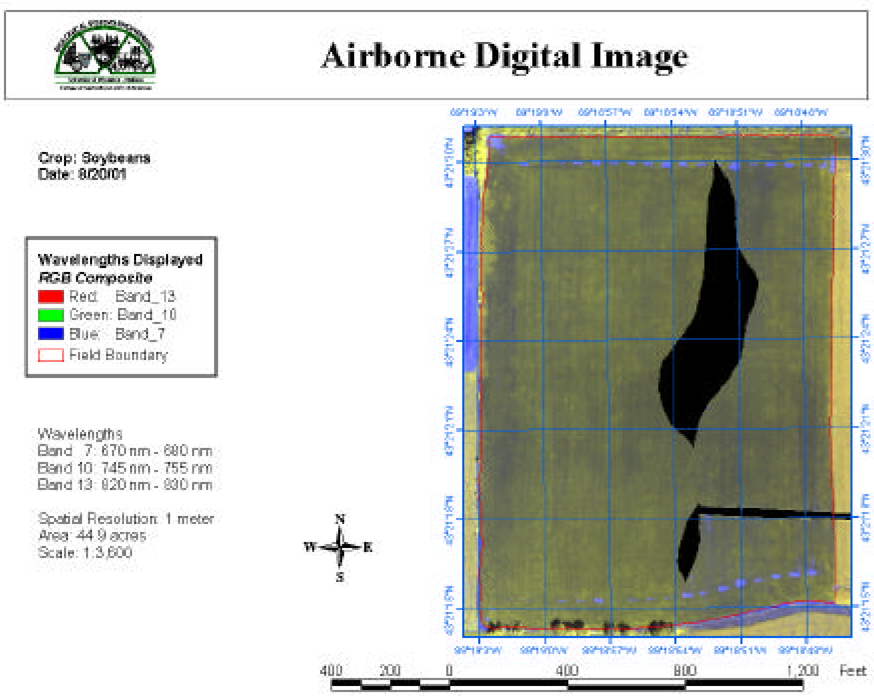

Figure 3. 3diLLC remote sensing data for field A.

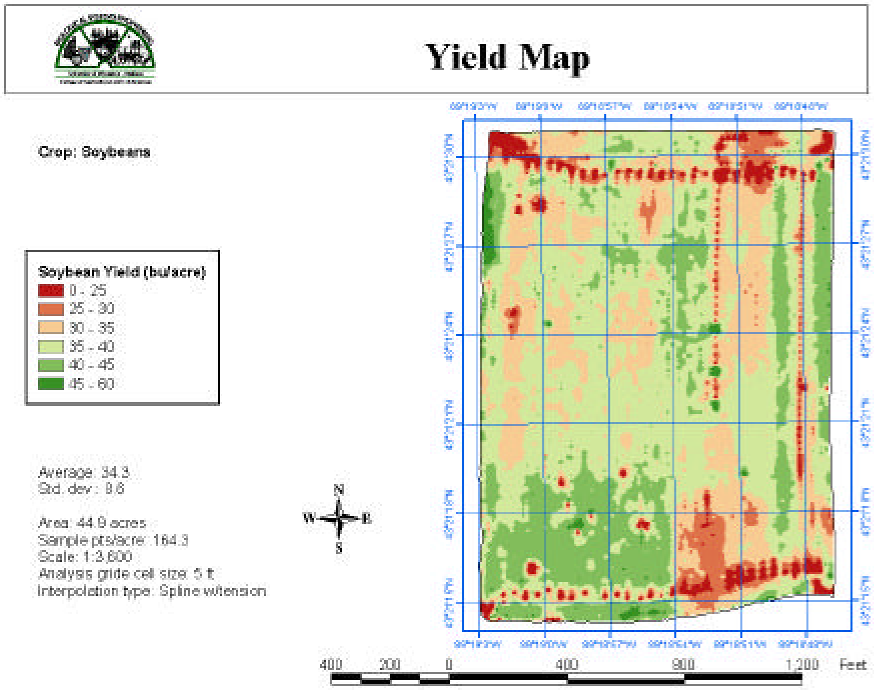

Figure 4. Soybean yield for field A.

In the other fields, equipment malfunctions or operator errors continue to be present in the data. Highly compacted areas of fields were identified in several fields especially in areas of high machine traffic, often near field entrances. Tillage practices and previous cropping practices create observable differences in the remotely sensed data.

Soil characteristics such as soil type and depth and influence the moisture availability which was observed in the remote sensing images. Several fields have eroded areas that have a coarse textured soil with a poor water holding capacity. Also topsoil depth variation was observed in the remotely sensed data of the growing crop in higher elevations of the field. Also lower elevations of the fields were observed where drainage ditches are present with a greater topsoil depth.

Currently remotely sensed data provides information on anomalies in crop production fields. Additional data and field observations are needed to further identify the problems. Also spatial statistical analysis will be done to relate the remote sensing data to other variables.