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EC03-702 Precision Agriculture: Applications of Remote Sensing in Site-Specific Management

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Precision AGRICULTURE

Applications of Remote Sensing in Site-Specific Management

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Precision farming is an emerging agricultural technology that involves managing each crop input on a site-specific basis to reduce waste, increase profits, and maintain the quality of the environment. Remote sensing is a technology that can be used to obtain various spatial layers of information about soil and crop conditions. It allows detection and/or characterization of an object, series of objects, or landscape without having the sensor in physical contact. A simple classification of remote sensing systems is shown in *Figure 1*.

Typically remote sensing is conducted by positioning a sensor above the object (target) being observed. Platforms that support the sensors vary, depending on the altitude above the target. Today two main observation platforms are used to collect remote sensing data: aircraft-based (aerial) and satellite-based. Ground-based sensors also have been used for certain specific applications and research studies.

Sensors commonly used for remote sensing are part of either passive or active systems. Active systems, such as radar, supply their own source of energy to illuminate target surfaces. Passive systems, like a common photo camera, detect reflected solar energy. Although several concepts involving active systems have been developed at the research level, primarily passive systems are used in commercial applications related to site-specific management.

The objective of this publication is to review some remote sensing systems and their application in site-specific management.

Current Aerial and Satellite Systems

Initial research involving remote sensing in agriculture can be traced back to the middle 1950s, when aerial imagery was used to detect diseases in wheat. Application of aerial and satellite remote sensing to monitor soil and crop conditions has progressed to offer valuable quantitative and near real time information over large areas and, most

RESOURCES

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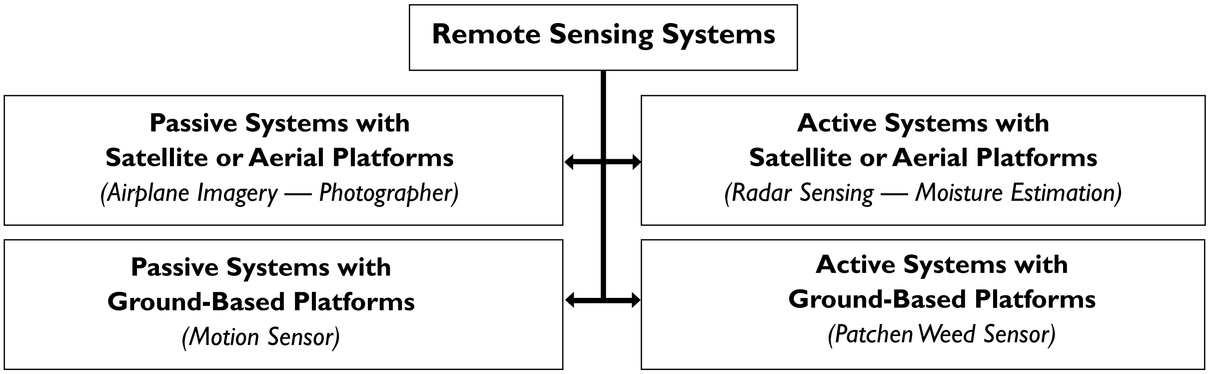

Figure 1. Variety of remote sensing systems.

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importantly, without destruction. However, the reliability and timely delivery of data have been major concerns.

During the last half of the century, remote sensing instrumentation developed from simple optical systems into complex digital sensors, allowing rapid and high quality scanning of the Earth's surface. Computation algorithms have been developed to process remotely sensed data and to produce different types of images. Spatial, spectral, temporal, and radiometric resolutions are the main characteristics of any remote sensing system.

Spatial resolution refers to the smallest area (pixel) that can be distinguished in the image. Each pixel becomes a data point. As with photography, the distance between the sensor and the target, as well as the viewing angle, defines the field of view (i.e., size of the area represented by a single image or scan). Most images and data sets used in site-specific management have spatial resolutions ranging from less than 1 meter to 20 meters or more. Smaller pixel size usually is more expensive and requires more storage space and computation power.

Spectral resolution defines the ability of the system to differentiate between levels of electromagnetic radiation across different wavelengths (portions of spectrum). The visible/near-infrared range of the spectrum (400-700 nanometers) provides the greatest insight into crop conditions. Useful information also can be obtained from other portions of the spectrum such as the mid-infrared and thermal. The number of sensed portions of the spectrum (bands) and their width also characterize the spectral resolution of the system. Some sensors (especially photographic) produce only black and white, color, or color infrared images, while others allow recording multi-spectral (typically less then 10) or hyper-spectral responses (can be more than a hundred). Panchromatic images also can be used to represent total reflectance combined from visual and near-infrared bands.

Temporal resolution refers to the time between sequential data collection events using the same source. This is especially important while studying crop growth conditions. The schedule of orbiting satellites and planned aircraft missions does not always allow obtaining data in favorable weather conditions and at the desired times. Delays in data delivery also have been a limiting factor in the past.

Radiometric resolution is a term used to describe a remote sensing instrument's sensitivity. Most current systems produce 8-bit data. In other words, each picture element of an image (pixel) can have a range of 0 to 255 possible data values. The same pixel examined with a 10-bit instrument can produce 1024 gradations and a 16-bit instrument can produce 65,536 possible data values.

The above considerations are important when comparing alternative sources of aerial or satellite data. Some of the most popular aerial and satellite services are listed in *Tables I* and *II*.

Potential Applications

Most remotely sensed data can be imported into Geographic Information System (GIS) software to overlay with other layers of information such as yield maps, field boundaries, soil sampling locations, and analytical results. A hard copy of obtained imagery (like from 35 mm film) also can be produced to visually compare observed field patterns and to identify field anomalies.

Table I. Selected aerial imagery data sources.

Service/Detector	Type	Spectral Range	Number of Bands	Band Width
Duncan Tech	Multi-spectral	400-1100 nm	3-5	40-65 nm
ADAR	Multi-spectral	450-860 nm	4	50-110 nm
AISA	Hyper-spectral	400-900 nm	Up to 288	3-10 nm
CASI	Hyper-spectral	400-1000 nm	288	1.9 nm
35 mm color film	Broadband	400-700 nm	3	100 nm
35 mm color infrared film	Broadband	500-900 nm	3	2 @ 100 nm 1 @ 200 nm
Black and white film	Panchromatic	400-700 nm	1	300 nm

Table II. Selected satellite imagery data sources.

Service	Type	Spectral Range	Number of Bands	Spatial Resolution	Revisit
AVHRR	Multi-spectral	580-1250 nm	5	1 km	Daily
SeaWIFS	Multi-spectral	402-885 nm	8	1 km	Daily
Landsat	Multi-spectral	450-1250 nm	7 + Pan*	30 m	16 Days
Spot	Multi-spectral	500-890 nm	4 + Pan	20 m	26 Days
IRS	Multi-spectral	450-900 nm	4	72 m	22 Days
IKONOS	Multi-spectral	445-853 nm	4 + Pan	4 m (1 m Pan)	2-3 Days
QuickBird	Multi-spectral	450-900 nm	4 + Pan	2.5 m (0.6 m Pan)	2-5 Days

**Pan refers to panchromatic (black and white) images.*

Figure 2. Background image of University of Nebraska Rogers Memorial Farm, Eagle, Nebraska.

Various GIS and mapping software packages have different analytical capabilities to process digital and scanned images. However, in every case it is necessary to make sure that remotely sensed data are rectified using proper geographic coordinates. In other words, each image should be scaled and oriented according to true geographic coordinates of every pixel. Once the data are in digital format, various analytical algorithms can be applied.

The most common indirect use of remote sensing images is as a base map onto which other information can be layered using GIS software. A georeferenced image provides a background for ownership boundary, yield, and fertility maps. *Figure 2* illustrates a remote sensing image used as a background for different spatial data layers. It is important to note that when considering the use of any imagery or image-based products as a layer in a GIS package, all layers must be georeferenced to the same geographic projection in order to display properly. Other applications include: use of derived vegetation parameters in crop simulation models, defining soil and plant parameters to improve soil sampling strategies, and discovering and locating crop stresses such as weeds, insects, and diseases.

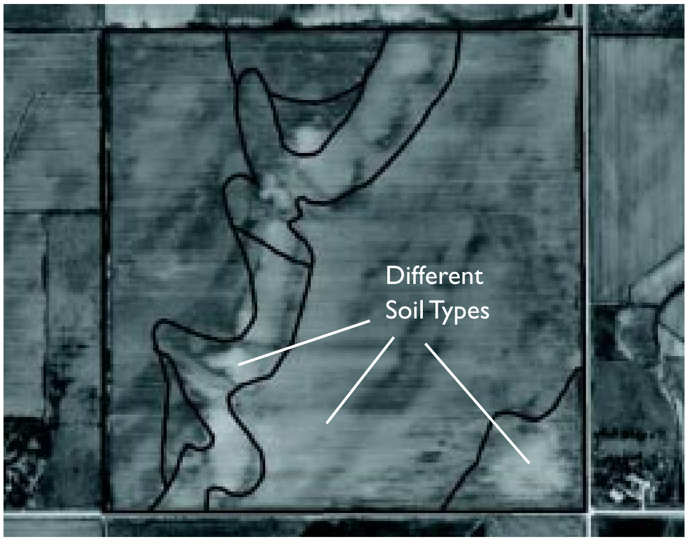

Figure 3. USDA soil survey boundaries superimposed on a bare soil image.

Soil Characteristics. Remote sensing images obtained when vegetative field coverage is not significant often are called "bare soil images" *(Figure 3)*. These data can be used to identify areas of the field with similar physical soil properties. This method has not been widely accepted as an adequate method of soil mapping because the reflectance characteristics of the desired soil properties often are affected by variability in soil moisture content, crop residue coverage, surface roughness, atmospheric conditions, solar zenith angle, and view angle. However, the patterns of bare soil images in many instances reproduce soil type survey maps and are often more accurate. Digital Orthophoto Quadrangles (DOQ) are the most popular examples of imagery that can be downloaded from various data bank web sites.

Alternatively, bare soil images can be used as a key element in prescribing adaptive soil sampling that provides a cost efficient alternative to conventional grid sampling. Homogeneity of bare soil reflection in certain areas of the field (in practice represented by management zones) usually suggests similarities in organic matter content and some other key soil properties causing variable soil fertility and moisture holding capacity. The management zone approach can be significantly enhanced when productivity factors derived from ground-based soil maps and crop related information are integrated.

Yield Prediction. Yield estimation by means of remote sensing data is not new. Experimentation in this area has been ongoing since before the launch of NASA's first Earth Resources Technology Satellite (ERTS-1, now known as Landsat) in 1972. Currently, remotely sensed imagery is being applied to predict yield in two ways. The first, focused on crop-growth models, uses remote sensing as a calibration tool for a particular model. Some of these, process-oriented physiological crop growth models, could be used to accurately predict yield under well-managed conditions. However, the models require agronomic

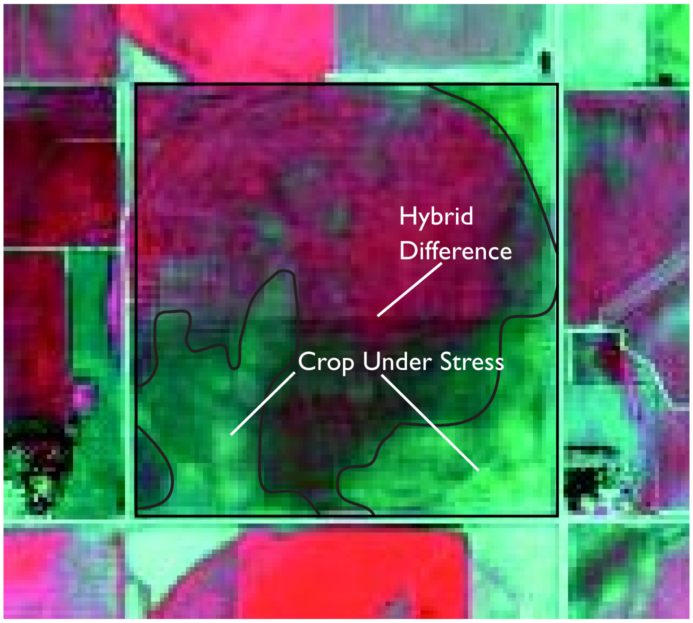

Figure 4. Visual-NIR image showing end-of-season crop performance.

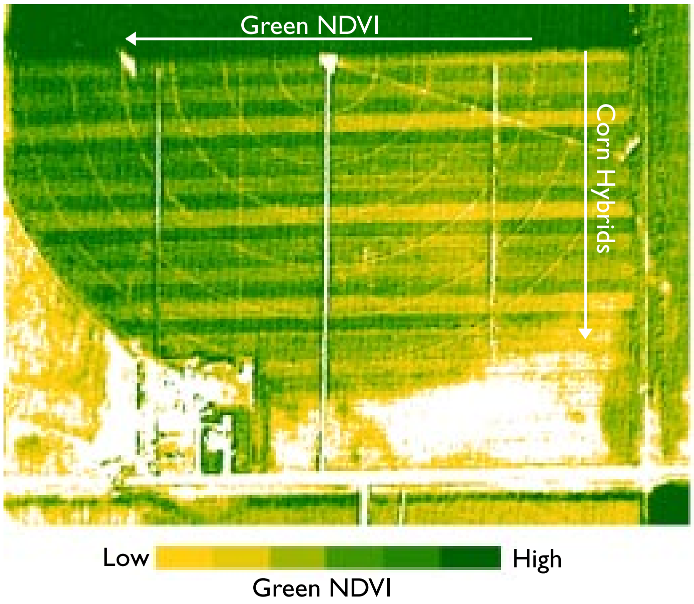

Figure 5. Results from a study on performance of several hybrids under different levels of nitrogen availability.

and meteorological data that generally are not available at desired spatial resolution. Current physiological crop growth models appear to be primarily intended for research purposes and input requirements are numerous and complex.

The second approach involves estimating yield based on vegetative indices such as the Normalized Difference Vegetation Index (NDVI). The Red NDVI, commonly referred to as NDVI, is calculated as (NIR-Red)/(NIR+Red) while the Green NDVI, or GNDVI, is calculated as (NIR-Green)/(NIR+Green). It has been demonstrated that there is a high correlation between yield of corn and soybean crops and respective NDVI calculations. Research studies revealed that yield could be best estimated by NDVI calculations during the grain filling stage.

Crop Monitoring. Remote sensing images generated from vegetative indices, like NDVI and GNDVI, throughout the growing season are becoming common. These products (often referred to as "Crop vigor" or "Vegetation status" maps) can be used to guide nutrient management, weed control, and irrigation.

Remotely sensed crop vegetation data also can be used to identify crop stresses and injuries due to abnormal soil and weather conditions (drought, weed patches, soil erosion, nutrient deficiency, hail storms, flooding, etc.). These data can help identify field areas that are most susceptible to poor crop performance *(Figure 4)*.

Nutrient Management. Knowledge of plant growth, nutrient uptake patterns during the growing season, and deficiency symptoms have prompted researchers to acquire imagery during key growth stages. Crop reflectance varies with: 1) genetic varietal differences in corn and soybean cultivars, 2) leaf structure, growth stage, soil color, and nutrient/moisture content, and 3) environmental stress factors. Therefore, relative vegetation condition cannot be directly compared between fields (i.e., hybrid to hybrid). However, it is possible to assess relative health within one field. As with most crop tests, there is a need for on-site calibration with a reference strip (also referred to as normalization). The crop reference strip is given excess nitrogen fertilizer to ensure a no-stress condition for comparison purposes. With the use of an on-site crop calibration strip, relative health within a field can be assessed with imagery as shown in *Figure 5*. The image map shows the "Green" NDVI of an irrigated (center pivot) cornfield in eastern Nebraska. A number of corn hybrids were planted, each occupying several consecutive rows. A nitrogen gradient was established from east to west. Differences among hybrids and along the nitrogen gradient are conspicuous. Additionally, it can be seen that some hybrids are more sensitive to a nitrogen deficit than others.

Weed Detection. Competition from weeds is a major source of yield loss in row crop production. During most years, weed populations in row crops will require some form of weed management to reduce the impact on both quality and quantity of yield. A grower's ability to use site-specific technologies to reduce the quantity of herbicide applied would be recognized economically. This reduced application would, in turn, markedly reduce the filtration of chemicals into surface and groundwater supplies.

Weed populations often are aggregated in fields. The following characteristics of weed populations in row crops were reported: 1) typical field level studies identify a small number of sites having densities of 60-200 seedlings per square meter; and 2) a four-year study revealed stable spatial distribution, especially for large seeded annuals and perennials.

Imagery may be used to separate weeds from bare soil by taking advantage of the increase in near-infrared reflectance during early season development. This is about the time that post-emergence herbicides are applied.

Irrigation. To help reduce the time required and spatial uncertainty associated with irrigation scheduling, remote sensing can be used to help automate and perhaps more accurately schedule irrigation. Research to improve irrigation scheduling with remote sensing technologies has been conducted using on-site, airborne, and satellite sensors to accurately detect canopy temperature, pigment content and composition, vegetation indices, leaf cell structure, canopy architecture, and leaf-water content. Each of these research efforts has enhanced our understanding of crop growth, but at this time none has produced a viable product to be used for irrigation scheduling.

One technique for detecting crop stress (including that due to a water deficit) is fluorescence. As plants become stressed, the photosynthetic process begins to slow down. When this happens, plants are unable to fully utilize all of the solar radiation that is captured via photosynthesis. Most of the unused energy is converted to heat, but a small portion is emitted as red light (chlorophyll fluorescence). Infrared sensors (infrared thermometers referred to as IRTs) are available to monitor canopy temperature. Medium to low spatial resolution visible and thermal data are available from Landsat Thematic Mapper and can be used to determine net irrigated acreage and cropping patterns. It also can help assess evaporation at scales from the field to irrigation system level.

Vehicle-Based Optical Sensors

Close range optical sensors also qualify as remote sensing tools. In this case, instead of providing field scale information about the crop canopy, the information is limited to a few plants or leaves. Several researchers have mounted sensors on the end of a boom that extends up to 30 feet above the crop. These instruments usually are used to provide crop canopy reflectance data that is used to calibrate satellite and aerial imagery.

Some vehicle-based optical sensors have been incorporated into closed-loop, real-time, variable rate application systems. These sensors play the role of a "seeing-eye". The main components of such variable rate applicators are irradiance and/or radiance sensors, a master control unit, and nozzles with solenoid valves. As the implement travels through the field, the irradiance/radiance detector data is interpreted by a microprocessor that controls the corresponding solenoid valves, thus turning the spray nozzles on and off. Real-time systems can make necessary adjustments to application rates of crop amendments on the go.

Nitrogen deficiencies within a given hybrid can be detected through corn canopy color (reflectance levels), and yield can be corrected using crop reflectance as a guide for nitrogen application. Such equipment reads canopy colors directly and applies the appropriate amount of nitrogen fertilizer based on the color of well-fertilized standard plots.

Herbicide application to selected areas can be conducted by application systems capable of weed identification based on leaf patterns or reflectance. Success with these techniques has been limited; cost and developing technology have prohibited large-scale inception. However, new algorithms with improved weed and crop characterization capabilities using technology called "Machine Vision" are being developed.

Another opportunity for vehicle-based systems are optical sensors targeting subsurface soil reflectance. These sensors are not sensitive to crop residue coverage and may improve quality of information about spatial and depth variation of selected soil properties. Research and limited commercial applications are available at this time.

Summary

Remote sensing can provide valuable information about soils and vegetative coverage for a relatively large area without physical contact. Several commercial vendors offer aerial and satellite imagery that can serve as one of key GIS layers for making decisions related to site-specific management. Some vehicle-based concepts have been found suitable for real-time control of agricultural chemical application rates. Difficulties related to data quality and timely deliveries are two major concerns that have emerged from past experience. Numerous research efforts are currently directed to development and validation of various applications of remotely sensed data to support precision agriculture.

The strength of remote sensing is the opportunity to learn more about crop performance variability while the crop is still growing. Benefits can be realized by combining this information with soil, yield and other maps in developing an integrated crop production program.

Acknowledgements

The data illustrated in *Figure 2* were provided by Paul Jasa, Biological Systems Engineering Department, University of Nebraska-Lincoln.

Remote sensing imagery used in *Figures 3* and *4* was generated through a research project sponsored by USDA/NASA program on Application of Geospatial and Precision Technologies (AGPT).

The image shown in *Figure 5* was provided by UNL-NASA Affiliated Research Center/Wilson Genetics, the Center for Advanced Land Management Information Technologies, University of Nebraska-Lincoln.

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