

# Precision Farming and Precision Pest Management: The Power of New Crop Production Technologies<sup>1</sup>

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*Abstract:* The use of new technologies including Geographic Information Systems (GIS), the Global Positioning System (GPS), Variable Rate Technology (VRT), and Remote Sensing (RS) is gaining acceptance in the present high-technology, precision agricultural industry. GIS provides the ability to link multiple data values for the same geo-referenced location, and provides the user with a graphical visualization of such data. When GIS is coupled with GPS and RS, management decisions can be applied in a more precise "micro-managed" manner by using VRT techniques. Such technology holds the potential to reduce agricultural crop production costs as well as crop and environmental damage.

*Key words:* agriculture, geographic information systems, GIS, global positioning system, GPS, management, nematode, remote sensing, review, RS, variable rate technology, VRT.

Persons involved with production agriculture today encounter myriad new technologies which generate information that may enhance management decisions. Such technology generates large amounts of data. The ability to manage and correctly interpret these data are critical to their use and adoption. In this paper we provide a basic description of the technologies available for production agriculture in the categories of the Global Positioning System (GPS), Geographic Information Systems (GIS), Remote Sensing (RS), Variable Rate Technology (VRT), and Precision Farming (PF).

## GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS) is a network of satellites, controlled by the U.S. Department of Defense, designed to help ground-based units determine their real-time location using latitude and longitude coordinates. For agricultural applications, GPS is being used for machine guidance and control (variable-rate-input applications, described later) and data collection during harvesting operations, soil sampling, and field scouting (Morgan and Ess, 1997).

The GPS consists of three segments. The

first is composed of 24 satellites (21 operational, 3 spares) orbiting 20,200 km above the Earth and providing line-of-sight signals and 24-hour coverage. The satellites travel in one of six orbital planes and make complete orbits in slightly less than 12 hours. Each satellite transmits a Pseudo Random Noise (PRN) code that tells precisely where it was when it sent the signal and the precise time the signal was sent. The second segment of the system consists of ground-based control centers that calculate the orbit of each satellite a week or so into the future, predict ionospheric conditions over that time, and upload the data to each satellite's computer. By consulting its clock and the ephemeris, the satellite determines and transmits its location continuously. The third segment of the GPS is a signal receiver that typically sees three to eight satellites at any instant, determines their positions, then calculates distances to the receiver based on the time difference between signal transmission and reception. The receiver requires a minimum of 3 satellites for two-dimensional (latitude and longitude) positioning and 4 for three-dimensional (latitude, longitude, and altitude) positioning. The antenna for a GPS receiver needs a clear line of sight. Any field obstruction that can block sunlight (trees, buildings, steep slopes, etc.) can also block a GPS signal (Lange, 1996). Equipped with a GPS receiver, an observer can navigate or collect positional information while stationary or moving.

Sources of error in a GPS position estimate may include one or more of the fol-

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lowing factors: (i) atmospheric-ionospheric effects that may delay radio transmissions; (ii) multi-path error due to signal reflections from nearby objects; (iii) ephemeris, defined as orbital position in relation to time; and (iv) Selective Availability (S/A)—a Department of Defense-induced clock shift. For most applications in agriculture it is necessary to correct for S/A and other error factors to reduce the position error from 100 m or more to somewhere in the 1-to-5-m range. Differential GPS (DGPS) accomplishes this task by using two or more GPS receivers working together simultaneously. One reference receiver is located at a precisely known location (base station) and computes a continuous stream of position data. Differences between the actual and computed position can be determined to produce a corrected data set (the differential correction). The second receiver (mobile unit) is used to compute position data in the field. Most of the error in the position estimation of the mobile unit can be removed by applying the differential correction transmitted to it from the base station because the two receivers will experience essentially identical errors for any given moment in time. A mobile DGPS unit must have two receivers—one for GPS signals, one for differential correction data.

It is possible for end users to set up, operate, and maintain their own differential correction base station. However, because of the high initial cost, most choose to use one of three services currently available. Systems that utilize U.S. Coast Guard (USCG) Beacon correction signals cost \$1,500 to \$5,000, with no annual fee. Characteristics of this system include: free correction signal, lower-frequency signals that travel outward as ground waves to a 320-km (200-mile) radius, the digital frequency-modulated (FM) signal that is less sensitive to noise than AM radio, service areas near coastal and inland waterways, and signal outages controlled by USCG. A second service option is subscription to an FM sub-carrier. Such systems cost \$1,500 to \$3,500, with a \$75 to \$900 annual fee. Characteristics of FM sub-carrier systems include: a correction signal that must be

purchased, higher-frequency signals that travel as space waves to an 80-km (50-mile) radius, the FM-band signals that are less susceptible to atmospheric interference, and signal outages controlled by the local FM station. The third option is a satellite-based system, with a cost of \$3,000 to \$7,000 and an annual fee of \$600 to \$1,500. Satellite-based system characteristics include: a correction signal that must be purchased; wide-area coverage, including the continental United States, Mexico, and much of Canada, that is not affected by obstructions as are radio links; and signal outages controlled by the satellite operator.

#### GEOGRAPHIC INFORMATION SYSTEM

A Geographic Information System (GIS) is a collection of computer hardware, software, and procedures designed to support the compilation, storage, retrieval, analysis, and display of spatially referenced data that can assist planning and management decisions (Aronoff, 1989). A GIS for crop production might include information from various sources pertaining to field history, input operations, GPS-based yield maps and soil surveys, aerial photography, satellite imagery, and pest or pathogen scouting data. The data are shown spatially (geo-referenced) on top of a base map of the field, allowing layers to be combined to provide accurate analysis of crop health and maturity. Once the base map is in place, the farm manager can collect and input data (e.g., weather, insect and weed problems, nematode densities, seed varieties, and planting populations) to provide information about the current crop, assess treatments, and potentially generate projected harvest maps.

All GIS packages have a user interface, database management-creation-data entry capabilities, spatial data manipulation, analysis tools, and display-product generation functions. A GIS can integrate geo-referenced data and perform complex spatial queries and analyses of spatial features with attribute data (seed cultivar, population rate, etc.). A system has topological capabilities and can define the locations of data elements in

space with respect to one another but without reference to actual distances. A GIS also can be used to relate new geographical information by integrating data layers to show the original data in different ways and from different perspectives. A GIS can combine both vector and raster data and related attributes, which greatly expands its power and utility.

It is important that end users understand any limitations associated with GIS data before incorporation into a management plan. Some factors to consider are: (i) method of data collection, (ii) accuracy of the data, (iii) intended purpose of the data, (iv) meaning of the attributes, and (v) the person who collected or compiled the data. With the implementation of GIS-related technologies, it is anticipated that end users should be able to improve yields, lower production costs, improve the quality of the crop, and more accurately forecast yields.

#### REMOTE SENSING

Remote Sensing (RS) is the act of detection and(or) identification of an object, series of objects, or landscape without having the sensor in direct contact with the object (Frazier et al., 1997). Agricultural applications of remote sensing generally involve detection of electromagnetic energy phenomena, such as light and heat. Sensors can measure energy at wavelengths that are beyond the range of human vision (ultra-violet, near infrared, or thermal infrared) and thus can provide information about subtle changes within a field or crop that could not otherwise be detected or quantified.

Digital imagery for RS may be obtained from either an orbiting satellite or from an airplane fly-over, depending on the location, type of crops being grown, and desired use of the information. Currently, satellites have the potential to obtain images of a given area of interest (field) approximately five to seven times in a 3-week period, with a resolution of 10 m or less at a cost of \$1.25/ha per time period. There can be wide variation in results and performance among satellites, and usefulness may be limited by

cloud cover. Airplanes can provide images based on the specific needs of the producer, typically at a cost of \$15 to \$37/ha for 16 to 36 images. Airplane imaging can be timed to coincide with critical periods of crop development and can be scheduled around bad weather. Imagery from airplane fly-overs is limited to areas where such technology is available.

Three types of resolution (spatial, spectral, and temporal) need to be considered when discussing digital imaging. Spatial resolution is the distance between data points (e.g., a resolution of 10 m would give 100 data points/ha). Improvements in spatial resolution have paralleled improvements in satellite technology. Spectral resolution is the variation of light energy and the measurement of the portions of such energy reflected, absorbed, and transmitted from an object or location. These differences permit the user to distinguish between different features on an image. Understanding what those differences depict is the critical part. Temporal resolution refers to repeated imaging of the same field or crop on successive dates, thereby providing a record of changes over time. How often remotely sensed images are needed varies greatly with the type of crop grown and how often the grower plans on performing a field operation based on the data received. Therefore, another important factor to consider when deciding on an imagery service provider is the time required before the images are available for use (e.g., a 1-week delay may be acceptable for some crops, but not for others).

Remote Sensing has a wide range of potential applications including detection of crop stress; monitoring variability in crops, soils, weeds, insects, and plant disease; detection of unusual conditions, such as broken drainage tiles or crop injury during cultivation; yield estimation, which is highly dependent on the type and variety of crop; and GIS applications. Digital imagery provides access to repeated observations of a field during the growing season to help explain changes as they happen and while the grower has time to respond.

### VARIABLE RATE TECHNOLOGY

Variable Rate Technology (VRT) refers to the instrumentation used for regulating application rates of fertilizer, lime, pesticides, and seed as an applicator travels across a field, based on a decision support system and/or management plan. VRT resembles a back-to-basics approach to farming, with varying inputs across a field depending on a number of field and production variables. The information needed to support VRT may come from several sources such as GPS-referenced data, RS images, and GIS-generated maps. All of the data are used to produce a site-specific application plan based on sound agronomic principles.

Current VRT equipment allows the user to monitor machine functions as mechanical applicators quickly react to changes in field conditions and make adjustments to field operation (seeding rates, fertilizer and chemical application rates, etc.). When coupled with a GPS receiver, VRT provides the controlling mechanism to make adjustments based on the location of invisible lines predetermined by the farm manager or equipment operator. VRT provides the opportunity to manage production based on soil type, soil texture, organic matter, nutrient levels, soil pH, weed and insect populations, disease, spatial pattern of nematode populations, desired yield, and other factors.

### PRECISION FARMING

Precision Farming (PF) combines the best available technologies to provide the information needed to make soil and crop management decisions that fit the specific conditions found within each field. Precision Farming, also called Site-Specific Farming, uses GPS, GIS, and RS to revolutionize the way data are collected (at resolutions of 1 to 5 m) and analyzed to enable more informed management decisions. Today, the potential exists to have detailed records covering every phase of the crop production process, thus enhancing sound business decisions. The cost of adopting the new technologies, and the time required for their implementation and use, are two factors that need to

be considered when judging the added benefits for decision making.

The use of PF can provide numerous benefits: (i) greatly improved ability to identify, diagnose, and communicate crop and field problems; (ii) improved equipment efficiency through better scheduling, sequencing of equipment, planning of field operations, equipment movement, etc.; (iii) risk reduction through reduced variability in growing conditions, improved varietal choices, crop rotation, etc.; (iv) improved monitoring and supervision, including better records of field operations, location of equipment, production output, and employee performance; (v) improved records pertaining to production processes, crop conditions, and required inputs; (vi) increased documentation of food safety; and (vii) enhanced environmental stewardship through more accurate and precise application of chemicals and fertilizer to reduce the potential for leaching and runoff. This last benefit, environmental stewardship, is perhaps the most important factor of the group. Such stewardship does not happen automatically but must be incorporated throughout the PF decision support system.

### CONCLUSIONS

GIS, GPS, and RS can provide producers with the management tools to reduce risk. Producers now have simultaneous access to the numerous types of data needed to make more informed management decisions. To better utilize the precision graphical maps that can be generated today, producers must understand the information contained in the images and be able to use that information to change the way fields are managed. The ability to use such information is more a function of agronomic skills than of limitations imposed by technology. There may be practical limits regarding location size that influence whether changes in management are justified in terms of economic or environmental returns.

Some Internet sites with relevance to topics discussed in this article include:

GIS: (<http://wwwscas.cit.cornell.edu/landeal/gis.htm>) and (<http://www.usgs.gov/research/gis/work1.html>)

GPS:<<http://www.unavco.ucar.edu/>> and  
<<http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html>>  
RS:<<http://www.geo.mtu.edu/rs>>  
VRT:<<http://nеспal.cpes.peachnet.edu/pf/vrt.stm/>>

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