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# GIS, GPS, and Remote Sensing Technologies in Extension Services: Where to Start, What to Know

**Abstract**
The rapid development and integration of spatial technologies such as Geographic Information Systems, the Global Positioning System, and remote sensing, have created many new tools for Extension professionals, but have also widened the "digital divide," leaving many with little understanding of the technology and potential applications. This article presents examples of Extension-related applications of GIS-GPS-RS technologies and discusses how to go about learning more and determining if these technologies would be useful. Examples and recommendations are taken from the literature and from the authors' own experience.

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## Introduction

The rapid development of spatial technologies in recent years has made available new tools and capabilities to Extension services and clientele for management of spatial data. In particular, the evolution of geographic information systems (GIS), the global positioning system (GPS), and remote sensing (RS) technologies has enabled the collection and analysis of field data in ways that were not possible before the advent of the computer.

How can potential users with little or no experience with GIS-GPS-RS technologies determine if they would be useful for their applications? How do potential users learn about these technologies? Once a need is established, what potential pitfalls or problems should the user know to avoid? This article describes some uses of GIS-GPS-RS in agricultural and resource management applications, provides a roadmap for becoming familiar with the technologies, and makes recommendations for implementation.

## Spatial Technologies

### Geographic Information Systems

GIS applications enable the storage, management, and analysis of large quantities of spatially distributed data. These data are associated with their respective geographic features. For example, water quality data would be associated with a sampling site, represented by a point. Data on crop yields might be associated with fields or experimental plots, represented on a map by polygons.

A GIS can manage different data types occupying the same geographic space. For example, a biological control agent and its prey may be distributed in different abundances across a variety of plant types in an experimental plot. Although predator, prey, and plants occupy the same geographic region, they can be mapped as distinct and separate features.

The ability to depict different, spatially coincident features is not unique to a GIS, as various computer aided drafting (CAD) applications can achieve the same result. The power of a GIS lies in its ability to analyze relationships between features and their associated data (Samson, 1995). This analytical ability results in the generation of new information, as patterns and spatial relationships are revealed.

### The Global Positioning System

GPS technology has provided an indispensable tool for management of agricultural and natural resources. GPS is a satellite- and ground-based radio navigation and locational system that enables the user to determine very accurate locations on the surface of the Earth. Although GPS is a complex and sophisticated technology, user interfaces have evolved to become very accessible to the non-technical user. Simple and inexpensive GPS units are available with accuracies of 10 to 20 meters, and more sophisticated precision agriculture systems can obtain centimeter level accuracies.

### Remote Sensing

Remote sensing technologies are used to gather information about the surface of the earth from a distant platform, usually a satellite or airborne sensor. Most remotely sensed data used for mapping and spatial analysis is collected as reflected electromagnetic radiation, which is processed into a digital image that can be overlaid with other spatial data.

Reflected radiation in the infrared part of the electromagnetic spectrum, which is invisible to the human eye, is of particular importance for vegetation studies. For example, chlorophyll strongly absorbs blue (0.48 mm) and red (0.68 mm) wavelength radiation and reflects near-infrared radiation (0.75 - 1.35 mm). Leaf vacuole water absorbs radiation in the infrared region from 1.35 - 2.5 mm (Samson, 2000). The spectral properties of vegetation in different parts of the spectrum can be interpreted to reveal information about the health and status of crops, rangelands, forests and other types of vegetation.

## Applications

The uses of GIS, GPS, and RS technologies, either individually or in combination, span a broad range of applications and degrees of complexity. Simple applications might involve determining the location of sampling sites, plotting maps for use in the field, or examining the distribution of soil types in relation to yields and productivity. More complex applications take advantage of the analytical capabilities of GIS and RS software. These might include vegetation classification for predicting crop yield or environmental impacts, modeling of surface water drainage patterns, or tracking animal migration patterns.

### Precision Agriculture

GIS-GPS-RS technologies are used in combination for precision farming and site-specific crop management. Precision farming techniques are employed to increase yield, reduce production costs, and minimize negative impacts to the environment (Zhang et al., 1999). Using GIS analytical capabilities, variable parameters that can affect agricultural production can be evaluated. These parameters include yield variability, physical parameters of the field, soil chemical and physical properties, crop variability (e.g., density, height, nutrient stress, water stress, chlorophyll content), anomalous factors (e.g., weed, insect, and disease infestation, wind damage), and variations in management practices (e.g., tillage practices, crop seeding rate, fertilizer and pesticide application, irrigation patterns and frequency) (Zhang, Wang, & Wang, 2002).

Site-specific data, such as soil characteristics, fertility and nutrient data, topographic and drainage characteristics, yield data, harvester-mounted yield sensor data, and remotely-sensed vegetation indices, are collected from different sources and stored and managed in a spatial database, either contained within the GIS or connected to the GIS from an external source. The analytical power of a GIS is applied to the data to identify patterns in the field (e.g., areas of greater or lesser yield; correlations between yield and topography or characteristics such as nutrient concentrations or drainage) (Zhang et al., 1999).

Once patterns and correlations are elucidated, management practices can be modified to optimize yield and production costs, and minimize environmental impacts caused by excessive applications of fertilizers and pesticides. Site-specific applications of fertilizers, pesticides and other applications can be implemented by dividing a field into smaller management zones that are more homogeneous in properties of interest than the field as a whole (Zhang et al., 2002).

### Forest Management

Spatial technologies are well suited for applications to resource management issues. The ability to interface GIS with relational databases enables integration of large data sets and many variables to support management decisions (e.g., Arvanitis, Ramachandran, Brackett, Rasoul, & Du, 2000). One example is the Florida Agroforestry Decision Support System (FADSS) (Ellis, Nair, Linehan, Beck, & Blance, 2000). FADSS is a GIS application that integrates geographically linked data on climate and soil characteristics in the state of Florida with a database of over 500 trees and 50 tree attributes. FADSS enables landowners, farmers and extension agents to make management decisions based on site-specific and tree-specific information.

### Habitat Analysis

The modeling capabilities of GIS can be combined with remotely sensed landscape imagery to evaluate the effects of management practices and to assist resource managers and public decision makers in making informed decisions. For example, a GIS-enabled program, VVF, was developed to assess the suitability of a landscape as a species habitat (Ortigosa, De Leo, & Gatto, 2000). VVF integrates user-selected environmental variables to produce habitat suitability maps, and enables the user to create habitat suitability models for a specified area. Another model, LEEMATH (Landscape Evaluation of Effects of Management Activities on Timber and Habitat), evaluates both economic and ecological effects of alternative management strategies on timber production and habitat quality (Li, Gartner, Mou, & Trettin, 2000).

### Data Analysis and Display

The spatial visualization capabilities of GIS technology interfaced with a relational database provide an effective method for analyzing and displaying the impacts of Extension education and outreach projects. This application was demonstrated in the Florida Yards & Neighborhood (FY&N) program developed by the University of Florida Extension to teach homeowners and landowners how to reduce non-point source pollution and storm water runoff and protect the environment through landscape practices they exercise in their own yards.

Homeowners filled out surveys both before and after receiving training in landscaping methods. Responses to questions concerning landscape practices were rated as good, fair, or poor, and statistical analysis was conducted on before and after scores for each landscape practice using a relational database interfaced with GIS software. Geospatial analysis of the extent of homeowner/landowner adoption of these best management practices taught by the program enabled assessment of impact by acreage and location, identification of areas needing greater emphasis, tracking of change, and the ability for policymakers to see impacts in map format.

## Where to Start

To the uninitiated Extension specialist, the complexity and vast array of potential applications can be confusing and intimidating. Because the applications of GIS-GPS-RS cut across a great many disciplines, chances are good that these technologies can be beneficial in your own area of expertise. How do potential users with little prior knowledge identify specific ways in which they can be useful in their own work?

The decision must begin with a process of self-education. This includes gaining an understanding of the basic concepts of the technologies and doing a careful evaluation of your own needs and the needs of your clientele. A good place to start is at http:www.digitalgrove.net/. This Web site is a mapping gateway for resource managers and provides information on the fundamentals of GIS-GPS-RS technologies and data and provides numerous links to other sources of information, tools, utilities, data, and software applications. Another useful resource is ESRI's Virtual Campus online education and training Web site (http://campus.esri.com). This site offers course both free and inexpensive modules on the use of ESRI's GIS software, as well as a courses on how to go about planning and implementing a GIS.

An Internet search on uses of GIS, GPS, and RS in your field is a good way to start. Many agencies already using these methods post project reports, research results, and information on specific applications. Good sources include the USDA-ARS Hydrology and Remote Sensing Laboratory at the Beltsville Agricultural Research Center (http://hydrolab.arsusda.gov/) and the U.S. Fish and Wildlife Service GIS home page (http://www.fws.gov/data/gishome.html). Many online tutorials and educational materials are also accessible through the worldwide web. Two excellent tutorials are the National Center for Geographic Information and Analysis GIS Core Curriculum (http://www.ncgia.ucsb.edu/pubs/core.html) and the Remote Sensing Core Curriculum (http://www.r-s-c-c.org/).

Once you have researched the potential for GIS-GPS-RS technologies in your field, it is important to become familiar with the workings and capabilities of different software applications and equipment technologies before a decision is made about implementation. A number of software companies have free data readers and browsers that provide an opportunity to examine and use some of the functionality of their software packages. Some examples include ESRI's Arcexplorer (http://www.esri.com/) and Leica Geosystems' ViewFinder (http:www.leica-geosystems.com). Many software companies will also provide time-limited trial copies of software packages to allow the user to evaluate the applications before purchasing. If your needs are limited to obtaining and viewing images and GIS data layers and performing simple analysis functions, then one or several of these free data viewer programs may be sufficient for your purposes. Using ESRI's ArcExplorer, for example, you can view, identify, locate and query geographic and attribute data; create thematic maps; and perform basic statistical analysis.

If you need to create or edit new data layers, or perform some basic analysis and data conversion functions, several freeware applications are available that may fulfill your requirements. One of these applications, Forestry GIS (fGIS$^{TM}$), was developed for operational field managers in the natural resources by the University of Wisconsin. fGIS is freely downloadable (http:www.digitalgrove.net/fgis.htm) and can be used to edit existing GIS data, digitize new data layers, query and search spatial data, build customized data views and create maps. The application also includes utilities for working with database tables, transforming spatial data to different coordinate systems, and designing diagrams. Another freeware GIS application, DIVA-GIS (http:www.diva-gis.org/) was designed for mapping and analyzing the distributions of species. DIVA-GIS can create, edit, and transform GIS data files, and has capabilities for various statistical and biological modeling functions.

If you need to perform more sophisticated spatial analytical functions, then you will most likely need to purchase commercial software with more functionality. A number of different GIS and RS software packages are commercially available, each with different features and functionality. Some of these applications can be expensive for organizations with a limited budget. If your organization is affiliated with an educational institution, then a special educational price may be available. Although ESRI GIS software products and file formats are probably the most common for manipulating and distributing GIS data, most other GIS software applications can translate data from and to these file types. For reviews and discussions and downloads of different GIS software products, see http://software.geocomm.com/.

## GPS Equipment Selection

Recent advances, refinements, and expansion of GPS technology have provided a broad array of choices to users. The Global Positioning System was developed by the U.S. Department of Defense for military applications and consists of a number of continuously orbiting satellites that transmit low power radio signals. Ground-based receivers can use these signals to calculate a location on the surface of the Earth with a high degree of accuracy and precision. In general, obtaining higher degrees of accuracy requires the use of more complex, and therefore more expensive, equipment.

The type of equipment selected depends on a number of considerations, including the degree of accuracy required by the user, budget considerations, ease of use, and working conditions (e.g., is waterproof equipment required?). The issue of instrument accuracy is one that appears to cause some concern among new users. Many users seem to assume that an inexpensive ($100-$200) handheld unit is not able to deliver the necessary accuracy and precision. The fact is that even inexpensive units are capable of attaining good accuracies.

This has not always been the case. Prior to May, 2000, the horizontal accuracy of locations from non-corrected data obtained using the Global Positioning System was limited to at least 100 m. This limited accuracy was due to the effects of selective availability (i.e., artificial signal degradation) applied by the US Government. On May 1, 2000, selective availability was turned off by Presidential order, and greatly improved accuracies are now possible from even inexpensive handheld GPS units. Studies have demonstrated that accuracies on the order of 10-20 m can be obtained from typical stand-alone GPS units (Ochieng and Sauer, 2002; Adrados, Girard, Gendner, & Janeau, 2002).

If accuracies less than 10 meters are needed, then differential correction of data (DGPS) is required. There are several ways of obtaining differential corrections. One method requires a base station receiver or beacon placed at a known location, which then transmits corrections in real time to a roving receiver via a ground- or satellite-based radio signal. Another method is to obtain pre-recorded correction files for post processing. Files can be obtained from commercial and governmental agencies. The increased accuracy of DGPS data comes at an increased cost, and the user can expect to pay significantly more for equipment. A good overview of GPS can be found on The Geographer's Craft Web site (http://www.colorado.edu/geography/gcraft/contents.html), developed by the University of Colorado at Boulder.

## Things to Keep in Mind

From our collective experience in using and teaching GIS and remote sensing for agricultural sciences, landscape design, urban forestry, geology, and Extension services, we have prepared a list of guidelines that may be helpful when considering or implementing spatial technologies for your program.

- Educate Yourself: GIS-GPS-RS technologies have rapidly become more accessible, less expensive, and more sophisticated. As a result of the relatively fast evolution of geospatial technologies, many professionals may either be unaware of their capabilities or may have an obsolete understanding of their potential and current implementation. It is important for potential users to educate themselves before investing in equipment and software.
- Clarify Your Needs: Make sure there is a clear need for GIS-GPS-RS technologies. Lack of understanding can lead users to overestimate the usefulness of geospatial technologies.

Using these technologies requires a broad understanding of many different concepts, including map projections and coordinate systems, data types and formats, computer literacy, and proper documentation of data. If all you require is the ability to make maps or locate features, and don't need sophisticated spatial analysis capabilities, then you may not need a full-featured GIS package. In many instances, conventional methods of data collection, analysis, and presentation are more appropriate and efficient

- Know Your Users: Carefully consider the needs of the intended users. Do you need technical support for your own staff, or do you want to create deliverables for your clientele? Do the intended users have a high or low degree of technical savvy? Are they teachable or not? Applications should be kept as simple as possible for your needs.
- Be Realistic in Your Expectations: It has been our own experience that it is impractical to expect all members of your staff or faculty to learn to use GIS-GPS-RS technologies. Workshops we have held for this purpose have been poorly attended, despite enthusiasm expressed by the would-be attendees. Before investing in infrastructure, it may be wise to consider if your work could be farmed out to a consulting agency. There are now many commercial and independent contractors doing geospatial consulting work. In the long run, hiring a consultant may be more cost efficient.
- Maintain Spatial Integrity of Your Data: One of the most frustrating aspects of working with geospatial data is dealing with different geographic coordinate systems and map projections. Because the Earth is not a perfect spheroid, numerous different projection systems have been devised to transfer points from an irregular curved surface to a plane surface. Different projections and coordinate systems are used for different purposes. For example, the State Plane coordinate system is used for many surveying applications, whereas a Transverse Mercator projection is useful for showing equatorial and mid-latitiutde continental regions. When data are stored and distributed in different projections, they must be reprojected so that all layers will plot in the same coordinate space. It is extremely important to carefully keep track of both the original and reprojected systems.
- Document Your Data: Developing metadata documentation of your spatial data cannot be emphasized enough. Without proper documentation of coordinate and projection systems your data may be useless to both you and others. A commonly used method for preparing metadata documentation has been developed by the Federal Geographic Data Committee (FGDC) and is described in the Content Standard for Digital Geospatial Metadata (http://www.fgdc.gov/). It is very important that users of GIS data understand the documentation procedure *before* using and creating data.
- Organization Is Key: Another important point to keep in mind before establishing and working with a GIS database is that your data can quickly become very disorganized. You will find that you will accumulate a large number of files as well as different versions of the same data (for example, in different projections systems). It is vitally important to establish a system for organizing data from the beginning.

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