Teaching Geographic Information Systems in a Soil Physics Laboratory

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ABSTRACT

Geographical information systems (GIS) are toolboxes of computer programs used to encode, display, manage, and analyze data that are georeferenced and spatially distributed in the landscape. The objective of this article is to present the use of GIS technology in the laboratory section of an upper-level college course in soil physics. The laboratory includes a lecture portion that provides an introduction to GIS and selected applications to soil science, agriculture, and environmental sciences. Emphasis is on the use of digital natural resource data such as soils to identify uses of various areas of the land. In addition to the lecture, each student chooses a topic and researches the criteria that apply to that topic. He/she meets with a mentor familiar with the GIS software and computer, and develops written reports indicating the areal extent and maps indicating the area and locations of the chosen topic within a watershed. Response of the students to GIS has been excellent with several students indicating interest in continuing their understanding of the application of GIS technology to soils, agriculture, and the environment. Several have requested that additional time be allocated for studying this technology in soil physics class.

One of the most rapidly developing technologies in the natural sciences are geographical information systems (GIS). As a technology, GIS are toolboxes of computer software programs and hardware that are used to encode, display, manage, and analyze data that are georeferenced and spatially distributed in the landscape (Arend, 1990). These geographical data include topological information and attributes about the landscape. Historical perspectives of GIS can be found in textbooks by Goodchild et al. (1993), Burrough (1986), and McGuire et al. (1991).

Informational databases such as soils, geology, roads, streams, elevations, houses, and other landscape features are manually digitized or scanned into the computer and overlaid to show geographical relationships. From overlays of these databases, mathematical and statistical relationships can be developed and the results presented in the form of two- and three-dimensional maps (Scott et al., 1992).

In a large number of GIS applications in the natural sciences, the spatial distribution of soils is included as one of the databases. Soil databases exist for a number of unit areas. Detail may be at the broad association level as in state-wide coverage, at the mapping-unit level found in county surveys, or with field-specific mapping. Soil information is used for many applications since the uses of the land are affected by soils and soil properties. For example, in agriculture, soils differ in their ability to grow plants, and in the environmental sciences, soil data can be used to show areas vulnerable to groundwater contamination.

Because GIS are increasingly used in natural resource management and research, students in soil, environmental, and earth sciences need to learn to use these tools. The objective of this article is to give our approach to presenting an introduction to GIS in the laboratory section of a senior–graduate student course in soil physics.

GIS TEACHING PROCEDURES

Course Description

The soil physics course at the University of Arkansas, designated as AGRN 4204, is taught as a combined lecture (3 h/wk) and laboratory (3 h/wk). Students taking the course are mostly graduate students in the soil, crop,

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Abbreviations: GIS, geographical information systems; GRASS, Geographic Resource Analysis Support System; CERL, Construction Engineering Research Laboratories; SCS, Soil Conservation Service; USGS, U.S. Geological Survey; CAD, computer-aided design; MLRA, major land resource area.

and weed sciences and agricultural engineering. Advanced seniors in soils also take the course. Early in the semester, students are introduced to the variability of soils and its impact on soil physical parameters in both the vertical dimension by studying horizonation and the horizontal dimension by considering a transect through a field.

In the laboratory portion of the course, the students are introduced to the various techniques for measuring soil physical parameters. Lectures are given early in the semester on the spatial distribution of soil physical parameters, including both classical and geostatistical characterization techniques. The students then sample a field for soil water content along a transect, usually down a gradient of soil mapping units. Using their own data and those obtained by their classmates, the students compute means, standard deviations, and coefficients of variation of the soil water contents along the transect. These data are later used to compute semivariograms. Toward the end of the semester, a 3-h laboratory devoted to the introduction, demonstration, and use of GIS techniques in soil science is presented. The emphasis is directed toward the variation of soils in landscapes and the impact of soils on landuse.

GIS Software and Hardware

The GIS software used is the Geographic Resource Analysis Support System (GRASS). It was developed by the Corps of Engineers (CERL) at Urbana, IL, and is a general purpose, grid-cell based, public domain geographical modeling and analysis package (CERL, 1988). GRASS has been used in numerous studies in resource management (Engel et al., 1991; Scott et al., 1992) and has been adopted by the Soil Conservation Service (SCS) and other federal agencies as the GIS software of choice. The version of GRASS used here is 4.1 and is installed on a SUN SPARCstation10. Additional equipment available for the laboratory includes a Tektronic 4697 painter and an Epson LQ-510 printer. There are other less expensive hardware and software components that could be used to set up the GIS demonstrated project. These include PC software versions of GIS such as IDRISI, MapInfo, and PCI.

Watershed Database

The GIS databases developed on the Muddy Fork Watershed in the northwest portion of Washington County, Arkansas, were selected for use by the instructor (Fig. 1). This area is one of the principal watersheds for the upper portion of the Illinois River basin and contains approximately 19 000 ha in the physiographical regions of the Boston Mountains and Springfield Plateau. The primary GIS databases, which included soils, elevation, hydrography, roads, geology, landuse, ownership, wells, springs, poultry houses, and P and NO_3 analyses of pastures, had been developed for a previously completed research project on the geographical and statistical relationships between landscape parameters and selected water quality parameters in the Muddy Fork Watershed (Scott et al., 1992).

The soils database had been digitized from a recompilation of the Washington County soil survey by the SCS on a 7.5-min quadrangle basis. Because the original soil survey of Washington County was compiled from unrectified aerial photography, soil maps had been rescaled by SCS personnel from the 1:20 000 scale found in the county soil surveys to the 1:24 000 scale used by U.S. Geological Survey (USGS) on the 7.5-min quads. Once rescaled, the maps were manually rectified with USGS topographic quads by SCS soil scientists onto a stable mylar base. The soil quads were patched together in GRASS for a seamless coverage of the entire Muddy Fork Watershed.

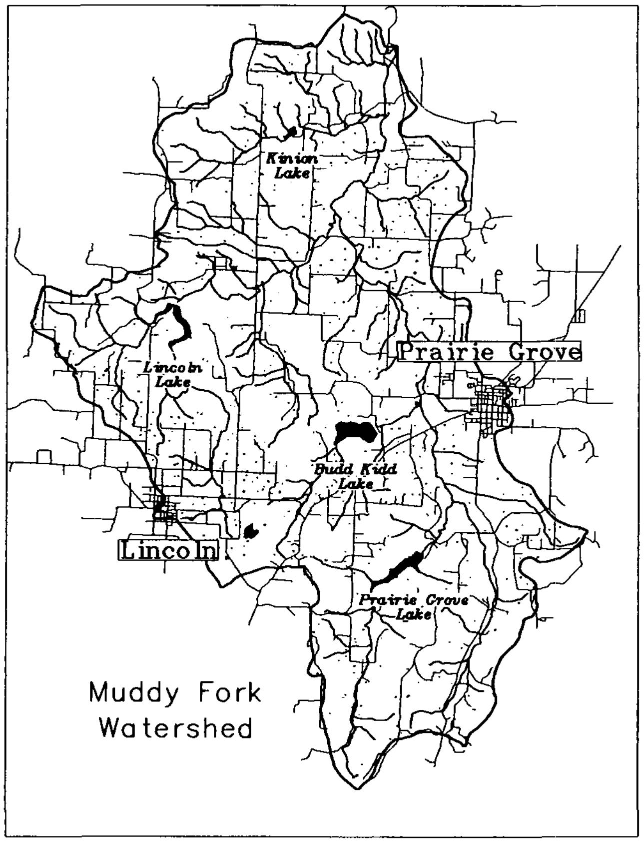

Fig. 1. Roads, streams, lakes, and towns in the Muddy Ford Watershed.

The smallest division within the primary soil data layer of an Order II County Soil Survey is the soil mapping unit, which is characterized by the dominant soil series contained with that mapping unit. Because county soil surveys attach the soil characteristics of the dominant soil series to the soil mapping unit, secondary soil data layers were generated by GRASS, indicating the location of soil characteristics such as drainage class, permeability, depth to bedrock, texture, percentage clay, and other mapping characteristics. Any soil characterization or analysis based on the soil mapping unit or secondary soil data layer characteristics was derived from the dominant soil series within the soil mapping unit. The Muddy Fork Watershed encompasses 85 soil mapping units and 32 dominant soil series.

Lecture

The introduction of GIS in the laboratory is presented in lecture format. The characteristics that distinguish GIS from computer-aided design (CAD) programs are discussed. The CAD programs are good for drawing maps, but they alone do not allow the user to combine data layers. A GIS combines a graphic program with a spatial data management system. Thus, the user of GIS is able to store discrete layers or maps in computer files along with descriptive data attributes. The map layers are in the form of points, lines, or polygons. Data attributes may be specific such as a name of a soil mapping unit, road, or landuse, or a matrix such as a farm size depending on sub-basin. Once the data layers are defined, they may be acted upon by any number of functions (reclass, filters, formulas) and combined with other layers.

The two types of GIS are discussed: raster and vector. Raster systems assign characteristics to a specific cell that represents the corresponding area of land. The landscape is divided into a grid, and for each data layer the dominant characteristic for each square or rectangular cell is determined. The same grid is placed over many maps or layers of data, and resultant fields of information are stored. The exact geopositioning of the data permits efficient data-file storage and management, plus extremely rapid manipulation of the information. Raster-based management systems are often associated with satellite data that are acquired in a raster or pixel format. In contrast, the data layers with vector GIS systems are encoded as points, lines, and areas. Lines and areas are sets of interconnected coordinates that can be linked with attributes into the computer. Map graphics and the ability of vector systems to easily do linear analyses are the two important advantages of the vector GIS.

The more important GIS concepts and terminology (Table 1) are discussed next. For most students in the agricultural sciences, these terms are unfamiliar; therefore, the students are given the definitions that summarize the most important concepts in GIS as related to the natural sciences. Emphasis is given to the definitions and examples of the following terms: database, data structure, thematic map, map scale, map coverage, and map accuracy (Reybold and TeSelle, 1989).

Brief explanations are given of the three digital soil geographic databases established by the SCS and known by the acronyms SSURGO, STATSGO, and NATSGO. These geographic databases represent different intensities of soil mapping.

The Soil Survey database, known as SSURGO, is the most detailed level of information. It can be used for farm and ranch conservation planning; range and timber management, and county, township, and watershed resource planning and management. Along with the soil attributes, these databases can be used to aid decisions on the appropriate use of lands. Maps are made at scales ranging from 1:15 840 to 1:31 680 and are collected and stored in 7.5-min topographic quads. The adjoining 7.5-min quads are matched within the survey areas.

The State Soil Geographic database, known as STATSGO, represents general soil associations, compiled at a scale of 1:250 000. Each database includes digitized soil map unit delineations linked with attribute data for that map unit, giving the extent and the properties of each soil (Lytle, 1993). The standards of the SCS as given by Fisher (1991) are presented to students.

Table 1. Glossary of terms used in geographic information systems (GIS).

Chloropleth map: A map consisting of areas of equal value separated by abrupt boundaries.
Database: A collection of interrelated information, usually stored on a disk. A GIS database includes data about the position and the attributes of geographical features that have been coded as points, lines, areas, pixels, or grid cells.
Database management systems: A set of computer programs for organizing the information in a database including data input, verification, storage, retrieval, and combination.
Data structure: Refers to the storage of geographic data as either points, lines or areas along with attributes associated with these features.
Digitizer: A device for manually tracing the spatial coordinates of mapped features from a map or document to the computer.
Grid map: A map in which the information is presented in the form of grid cells.
Map: In cartography, a document describing the spatial distribution of geographical features in terms of a recognizable and appropriate symbolism. In digital, a collection of digital information about a part of the earth's surface.
Map accuracy: Conformancy to a recognizable standard. Since maps are an abstraction of reality. Various organizations have established standards to measure the accuracy of a map.
Map coverage: Includes the area chosen for study, i.e., the Muddy Fork Watershed in this laboratory.
Map scale: Determines the smallest area that can be drawn and recognized on a paper map. Scale influences the material included on thematic maps.
Overlay: The processes of stacking digital representations of various spatial data on top of each other so that each position in the area covered can be analyzed in terms of these data.
Precision: The degree of variation about the mean.
Raster: A regular grid of cells covering an area.
Raster map: A map encoded in the form of a regular array of cells.
Scale: The relation between the size of an object on a map and its size in the real world.
Scanner: A device for automatically converting images such as maps and photographs to digital form.
Thematic map: A map displaying information of specific themes. Examples include soils, land use, streams, and suitability for arable crops.
Topographic map: A map showing the topography such as elevation, contours, roads, streams, etc. in great accuracy and detail relative to the map scale used.
Vector: A quantity having both magnitude and direction.

The NATSGO database is used primarily for national, regional, and multistate resource appraisal, planning, and monitoring. The boundaries of the major land resource area (MLRA) and land resource regions were used to form the NATSGO database. The scale of this map was 1:7 500 000.

Examples of local use of GIS and soil databases are then discussed (Scott et al., 1992; Smith and Scott, 1994; McKimmey, 1994). Maps used in this discussion show the areas most sensitive to sediment, P, or pesticide transport in the various study areas.

Assignment

For the laboratory assignment, each student chooses a topic area to apply GIS techniques within the Muddy Fork Watershed. Examples of topic areas include finding the optimal areas for crops such as soybean [*Glycine max* (L.) Merr.], corn (*Zea mays* L.), or blueberry (*Vaccinium corymbosum* L.); septic tank filter fields; landfills; and storage lagoons. Once the topic has been chosen, the student determines the criteria from the GIS databases that affect the areal extent and location within the watershed. This task usually requires them to read the Washington County soil survey for soil attribute information, cooperative extension publications, and/or state environmental regulations. Digital soil attributes available to help the students identify areas suitable from crops within the watershed include soil drainage class, flooding frequency, months flooding occurs, horizon 1 permeability, depth to bedrock, soil texture, slope class, percent slope, distance from major stream, and Horizon 1 pH.

The students are required to use at least three data layers to key their areas of interest. They usually utilize three modules in GRASS: r.reclass, r.report, and r.mapcalc. They are not, however, required to completely understand these modules.

An appointment is scheduled within 1 wk after the laboratory with a GIS technician who serves as a mentor for the student. The mentor discusses with the students his or her selections of the attributes. Then they input the computer commands that interpret the criteria based on the spatial databases in the watershed. For most topics, the GRASS module r.reclass is used to reclass the attributes, the module r.mapcalc is used to combine attributes contained in the data layers needed to define the area of interest, and the module r.report is used to provide a table of the results.

The results of the work are presented in two forms of output. First, a table is developed that presents the areal extent of each category within the watershed. Second, a map is painted of the geographic locations of the categories of the topic area within the watershed. The map shows the watershed boundaries along with the areas that meet the criteria issued by the student. Frequently, other primary attributes such as roads, rivers, and streams are overlaid on the map of the watershed. Overlaying different land features helps students locate topic area(s) within the watershed. Each student then identifies optimal areas for their specific land-use problem.

STUDENT RESPONSE

The brief introduction to GIS and the applications to soil science has been taught for the last 3 yr in the soil physics course. Students respond positively to the introduction of GIS in the soil physics laboratory. Usually they have heard about the technologies from students who are using them in thesis research or from presentations given by students and faculty. The students generally have a good background of soils, and agricultural and environmental issues. They appear to be readily able to select the criteria for their chosen topic. However, they are deficient in the understanding of the terminology used in GIS and the skills used in cartography. Students have requested that more time be allocated during the laboratory portion of the soil physics course to the presentation of GIS technologies and their use in soil science. They feel that the development of these skills can contribute to their future success. This approach to teaching of GIS could be utilized in many other natural resource courses.

REFERENCES

Arend, R.B. 1990. GIS: Useful tool or expensive toy? J. Surv. Eng. 116:131-138.

Burrough, P.A. 1986. Principles of geographical information systems for land resources assessment. Oxford Univ. Press, Clarendon, NY.

Construction Engineering Research Laboratories. 1988. The GRASS software system. CERL, Champaign, IL.

Engel, B.A., R. Srinivasan, and C.C. Rewerts. 1991. A GIS toolbox approach to hydrologic modeling. p. 41-51. *In* Proc. GRASS USERS Conf., Berkeley, CA. 4-7 Mar. 1991. Center for Environmental Design and Analysis, Univ. of Calif., Berkeley.

Fisher, P.F. 1991. Spatial data sources and data problems. p. 175-189. *In* D.J. McGuire et al. (ed.) Geographical informaiton systems. Vol. 1. John Wiley & Sons, New York.

Lytle, D.J. 1993. Digital soils databases for the United States. p. 386-391. *In* M.F. Goodchild et al. (ed.) Environmental modeling with GIS. Oxford Univ. Press, New York.

McGuire, D.J., M.F. Goodchild, and D.W. Rhind. 1991. Geographical information systems: Principles and applications (2 vol.). John Wiley & Sons, New York.

McKimmey, J.M. 1994. Predicting sediment and phosphorus sources in the Beaver Reservoir Watershed using a geographic information system. M.S. thesis. Department of Agronomy, Univ. of Arkansas, Fayetteville.

Reybold, W., and G.W. TeSelle. 1989. Soil geographic databases. J. Soil Water Conserv. 44:28-29.

Scott, H.D., P.A. Smith, A. Mauromoustakos, and W.F. Limp. 1992. Geographical and statistical relationships between landscape parameters and water quality indices in an Arkansas watershed. Arkansas Agric. Exp. Stn. Bull. 933.

Smith, P.A., and H.D. Scott. 1994. Influence of geographic database scale on prediction of groundwater vulnerability to pesticides. J. Soil Contam. 3:285-298.■