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ESRI® GIS Solutions for Production Agriculture

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1.0 Introduction

1.1 A Precision Farming Functional Description Paper

This functional description for a precision agriculture system is intended to provide the following: (1) a description of the functionality that will be in a typical precision farming system; and (2) a description of the data that will be required to make this application successful, including: sources of data, methods of automating data, and data outputs that will be generated.

1.2 Structure

This paper is composed of five parts. The first part is this Introduction. It describes the purpose and structure of this functional description paper and defines terminology used throughout this paper. The second section describes ESRI's understanding of the business model that sets the context for this application. The third section gives a general overview of the methodology for the application and identifies possible future applications. This section also identifies database and data management issues that will need to be addressed as this application is implemented. The fourth section describes the operating environment in which the application will work. It discusses the hardware, software, and connections between systems that define or influence the functionality required of the system. The fifth section describes the purpose, functional requirements, and data flow of the application.

1.3 Terms and Abbreviations

Automate

Automate means to convert nondigital data to a digital format that can be displayed on a computer. This can be accomplished through digitizing, scanning, reading coordinate information from text files, or from direct keyboard input.

Agriculture Chemical Map

An agriculture chemical map is the generic term for a grid map covering an agricultural field composed of one-tenth acre cells that shows the amount of chemical to apply to each one-tenth acre grid cell. The chemicals that will be applied initially are nitrogen, phosphorous, and potassium (N, P, K), but this system can be expanded to include additional nutrients, herbicides, and/or pesticides, and seed.

Feature

A feature is the representation of a geographic feature that has both a spatial representation (referred to as a "shape") and a set of attributes.

Heads-up Digitizing

Heads-up digitizing is automating new data by tracing map features with a cursor or mouse directly on the screen of a computer. Ancillary data may be used for orientation.

Shapefile

A shapefile stores nontopological geometry and attribute information for the features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates. Shapefiles support point, line, and polygon features.

Theme

A theme is a user-defined set of geographic features. Data sources for themes in ArcView® GIS include coverages, grids, images, and shapefiles. Theme properties include the data source name, attributes of interest, a data classification scheme, and drawing methodology.

2.0 Business Model

The business model is composed of a farm service organization delivering precision farming technical solutions to farmers. The farm service organization is the developer of this geographic information system (GIS) application, of which there are two general users. One is the farmer, or end user, who operates at the individual farm level and who utilizes maps that are produced from the application. The second is the service bureau, which may service individual farms.

2.1 Farm Service Organization

The farm service organization will develop this application, then provide this application to the service bureaus and farmers.

2.2 Service Bureaus

The service bureaus provide specialized services that are not economical or are difficult to undertake at the level of the individual farm. The service bureaus may provide technical support, recommendations, data, and training in the use of the application to the individual farm level. Service bureaus will be responsible for decision making and implementation of the functions of the map generator.

2.3 Farmers

Individual farmers function as end users; they manage the task controllers located on the application machinery. They use the data produced at the service bureau level, and they have the ability to override the application-generated chemical quantity decisions by introducing information manually at the task controller or individual farm level.

3.0 System Summary

3.1 Proposed Methods and Procedures for Initial Application

This precision agriculture application provides a new approach to agricultural chemical applications. This approach involves development of tools that will regulate the amount of crop input applied to a field based on the actual need. A key component to this approach is the utilization of GIS technology. GIS provides the visual integration of all the data sources tied to an agricultural field and allows farmers to identify the within-field variability of their systems.

This approach uses GIS to incorporate spatial information such as soil type, type of crop, and existing nutrient level of the soil with the agricultural chemical application process. The addition of spatial information to the process allows the farmer to consider within-field variation to adjust the amount of chemicals that are being applied based on what is actually needed at the subfield level. The result is a tremendous cost savings to farmers both monetarily and environmentally.

The system is based on two components: the map generator and the task controllers on the farm field machinery. The map generator is located at the service bureau; this is where the GIS software resides. The task controller electronics are located in the field on the agricultural chemical application machinery. This task controller identifies the location of each nozzle over the ground using Global Positioning Satellite (GPS) instrumentation and regulates the amount of fertilizer, pesticide, or seed distributed from each orifice.

The function of the map generator is to create agricultural chemical maps from a series of inputs. The function of the task controller is to read these maps and use the information they contain to drive agricultural chemical application equipment. The task controller also keeps a record of the amount of chemical actually applied to each unit of ground. This information can be transferred back to the map generator and used as a source for application history files. Maps are moved between the map generator and the task controller through file transfer facilitated by a portable computer.

This paper defines the functional requirements for only the map generator. It does not discuss the functions of the task controller beyond the need for file transfer between the two systems.

The precision agriculture application, running on the map generator, will utilize a simple user interface that presents the analyst with a backdrop of image data. These image data will be used as a reference for heads-up digitizing of the agriculture chemical maps. A polygon shapefile will be generated. Each polygon will be labeled by the analyst, who will make a visual determination of the amount of water or chemical to be applied to each polygon area based upon his or her interpretation of the imagery displayed on the computer screen.

The imagery displayed can be from a variety of sources, including aerial photographs, thermal images, infrared images, or images derived from soil sample data taken at known points within the field. The analyst, or farmer, determines which images will be utilized to produce each map. Data sources are discussed in **Subsection 3.3.1** of this paper.

Once the agriculture chemical map is finalized, the user will be able to convert the polygon shapefile that was digitized on the screen to a grid-based map. The user will be able to write the map to a file that can be copied onto the task controller. This map will serve as the basis for determining the amount of chemicals that will be applied by the chemical applicator machine.

In summary, this precision agriculture system will be an easy-to-use map-based interface that integrates multiple data sources, as appropriate, to produce agriculture chemical maps based on the analyst's, or farmer's, interpretation of the imagery. Some of the key points to note are

- This system is based on a visual interpretation of imagery.
- This system allows the farmer to vary the amount of fertilizer or chemicals applied within each file, based upon need at the subfield level.

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3.2 Methods and Procedures for Additional Applications

Possible enhancements for this system include automating the manual interpretation portion of the application described in **Subsection 3.1.** Rather than employing a labor-intensive, subjective method of determining the amount of fertilizer to apply to each portion of the field, an algorithm can be derived to calculate this value based on a series of known inputs.

Derivation of this algorithm is an agricultural research problem. Significant input to the algorithm will need to be identified as will the effect each has on the resultant q value. A sample function can look something like q = f (soil permeability, crop type, slope) where q is the amount of water to be applied to each one-tenth acre grid cell; soil permeability, crop type, and slope are the input maps; and the function is defined at the developer or the service bureau level.

A second potential enhancement to the application is to use image processing software to classify satellite or other digital imagery. Supervised or unsupervised classification methods can be used to identify and name portions of the image. For example, because rocks are warmer than growing crops, they will necessarily have a higher thermal reflectance value. If this information is collected digitally, image processing can be used to identify the rocks based on their thermal reflectance value. The advantage to using these image processing techniques is that once that digital value is identified through field samples, or through reference to other ancillary data, all rocks can be classified throughout the image at one time. They do not need to be delineated and identified individually, a costly and labor-intensive process.

3.3 Assumptions and Constraints

3.3.1 Database Issues

3.3.1.1 Data Availability and Content

- The first variable that the farm service organization will need to identify is the actual locations or sites where the application will be used. Once these are identified, it is possible to begin searching for additional digital data.

- Many base data layers, such as roads, public land survey boundaries, county boundaries, and hydrology to name a few, are available from public agencies such as the Department of the Interior's United States Geological Survey (USGS) or through local data providers. These data are useful as reference data; they can be drawn on the computer screen in conjunction with the imagery and used by the analyst for orientation.

  The scale and resolution of these data will vary depending on the source. For example, some data may only be available at a small scale of 1:100,000, while other data layers may have been prepared at a larger scale of 1:24,000. The large-scale data provide more detail and better accuracy and are useful for site-specific applications; the small-scale data contain less detail but are good for regional analysis.

  It will be necessary for the farm service organization to identify what, if any, base data will be required for this application, what is the best scale of base data to utilize, and where to obtain these data.

- Data collected from soil samples will also need to be integrated into the system. Soil sample data are collected at a series of known points throughout the field, and nitrogen, phosphorus, and potassium (N, P, K) concentrations are recorded. This point information can be converted into three digital maps (one map for each of the three nutrients) by first importing the (x,y) coordinate locations of each of the sample points then calculating three surfaces, one for each of the associated Z values (N concentration, P concentration, K concentration).

  ArcView GIS Version 3.0 can interpolate these surfaces with the ArcView Spatial Analyst extension. The soil survey data will need to be delivered in a predetermined format such as (ID, X,Y) with attributes associated (ID, N concentration, P concentration, K concentration) in a separate file, using the ID as a primary key.

- Crop type shapefiles will be generated within the application; they are the result of visual interpretation of imagery. Image source data and format will need to be identified and defined. Imagery may be available as photographs or as digital images obtained either by satellites or from airplane flights. Aerial photographs can be scanned into the system. All imagery will need to be preprocessed before use in the application; the preprocessing methodology will need to be defined and automated.

- A slope map will be required, particularly for fields with large variations in slope. As with the soil sample information, point data can be used as a source for a slope map, and elevations can be interpolated to derive the slope maps. Points of known latitude, longitude, and elevation distributed throughout the field can be used as the source.

- Development of a data dictionary is a necessary first step during the design phase of the application. Because information will come from a variety of sources, it will be necessary to organize the database entities, attributes, and relationships so that diverse data sources can be incorporated. The data dictionary will provide information about the data layers and data elements that are to be included in the application, and it will ensure that the application works in a consistent and predictable way. The data dictionary should include information about each data layer including the naming convention of each file, an exhaustive list of the attributes associated with each file, and the meaning of each possible value for each of the attributes.

3.3.1.2 Data Exchange

- Exchange of the grid files between the map generator and the task controllers will be accomplished through a simple file transfer mechanism. Grid files will be written from the application to an ASCII text file. This text file will be copied to a portable computer that will be taken to the task controller located in the field. A second file transfer will occur at the task controller machine. To move maps back to the map generator, the process will be reversed. ASCII files from the task controller then serve as input to the application and are displayed as maps.

3.3.1.3 Data Availability and Content—Future Applications

- Enhancements to the application may include incorporating yield monitoring information as an input map layer to produce the agriculture chemical maps. By including feedback from historical yields, it is possible to provide better estimates of fertilizer requirements across the field. This yield information can be collected during harvest and converted to a map through interpolation. The resultant derived yield map will show actual harvest variation across the field, which can then be used during the map generation process to modify the within-field applications of fertilizer and other chemicals.

- A second feedback mechanism that can be incorporated into the system involves tracking the actual applications of chemicals across the field. The task controller will track the amount of chemical applied to each grid cell during every application throughout the growing season. At the end of the season, this information can be transferred to the map generator for use as additional input to the map generation process or to produce reports or maps displaying the actual amount of chemical applied. This information can also be compared with yield maps, soil maps, imagery, and other digital data covering the field to give analysts and farmers a visual representation of these relationships.

3.3.1.4 Database Integrity

- The farm service organization will need to establish protocols to support the integrity of the database during initial creation and subsequent maintenance. Database integrity will be endangered if indiscriminate editing is allowed. It is recommended that a combination of automated and procedural steps be developed to control and validate changes made to the database.

3.3.2 Data Management

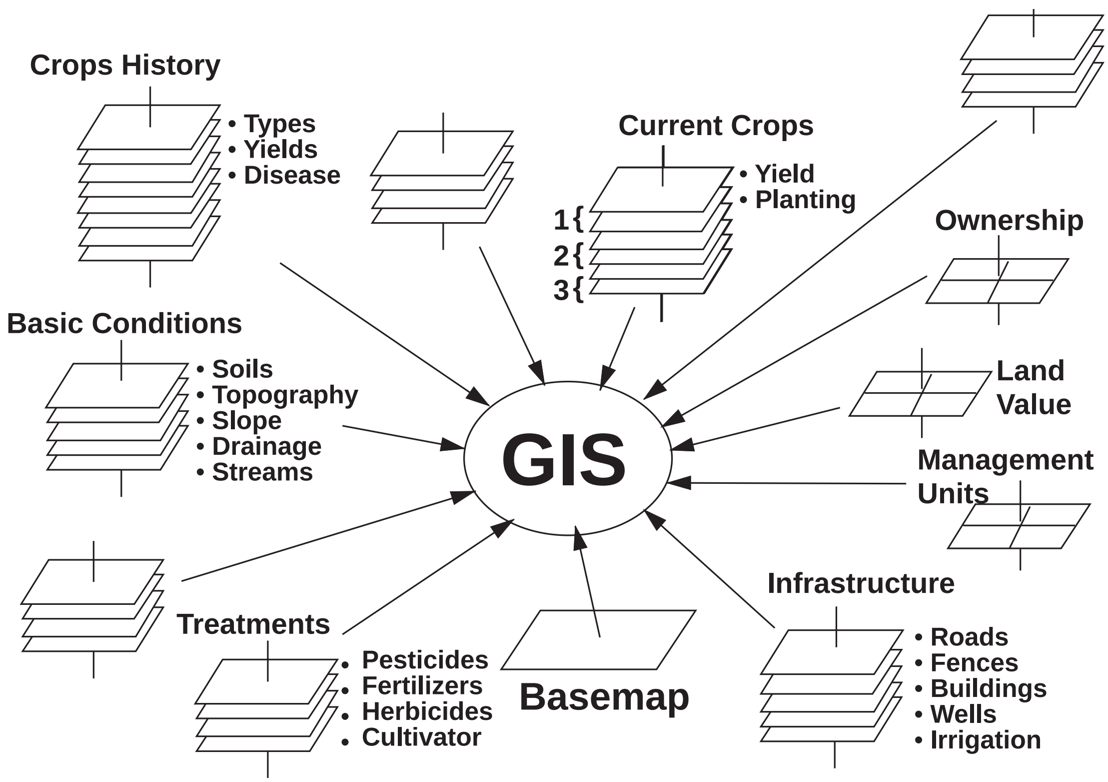
The farm service organization will need to implement a consistent, complex naming convention to all of the files that will be created by this application. This will be necessary to track and to understand the meaning and content of each of the files. See **Figure 3-1.**

Following is an example to illustrate the need for data management. Several themes will be created: crop map, N application map, P application map, and K application map. These are the polygon shapefiles that will be digitized by the analyst, or farmer, using the imagery as a reference. Each of these files will need to be identified by location or field, theme, file type (i.e., shapefile), and time/date created.

Next, each of these files will be converted to a grid-based format. In this example, the location, theme, and time/date will remain the same, but the file type becomes grid rather than shape.

Next, each of these grid files will be written to an interchange file that can be read by the task controller. Again, the file type changes.

Figure 3-1
Agricultural Data Model



This set of files is transferred to the task controller; it represents the recommended applications, not the actual applications. The actual application amounts are calculated by the task controller and written to yet another set of files. An identifier will need to be present that distinguishes these "actual" application files from the initial "prescribed" application files.

By developing a consistent, complex naming convention to identify these files, the farm service organization will be able to track and manage the data. Without this data management activity, there is a risk of data being confused or lost.

4.0 System Environment

This section describes the hardware and software environment in which the application can operate. Its purpose is to give a general overview of the hardware available to the applications, the communications environment, and the software applications from which it will be built or with which it will interact.

4.1 Hardware Environment

Processors

Personal Computer (map generator)

- Pentium 133 MHz
- 32 MB RAM (minimum of 12 MB physical memory and 17 MB virtual memory)
- A 1.2 MB or greater capacity floppy disk drive
- Ethernet card (if computer will be used on a network)
- CD–ROM

Portable Computer

- 75 MHz
- 16 MB RAM
- A 1.2 MB or greater capacity floppy disk drive

Storage Media

The disk drive for the map generator should contain sufficient space to hold input and output data for the predetermined locations. To specify the required amount of disk space, the farm service organization will need to know the extent of the data that will be required for input to the GIS as well as the number and type of output files.

Input Devices

- Keyboard and a Microsoft mouse or compatible pointing device.
- Scanner for aerial photographs.
- Applications will require GPS devices.

Output Devices

- Video graphics adapter (VGA) or better resolution monitor
- Color monitor (preferably with 256 colors) minimum of 17 inches
- Plotter or laser printer, depending on the size of the product that will be required
- External archival system (external hard drive, removable media drive, or a tape drive)

Communications Devices

Map generator connection to the portable PC and connection to the task controller can be accomplished through modem, cable connections, or over a network such as Novell. Small files can be transferred between computers using floppy diskettes.

4.2 Software Environment

- MS Windows® 95 or Windows NT
- Communications software such as LapLink™ to move data from the map generator to the portable PC and then to the task controller
- ArcView GIS for Windows with the ArcView Spatial Analyst extension

4.3 Backups

A backup schedule will need to be defined. Tape backups will need to be labeled, according to the backup date, and then stored. At least one set of full backup tapes should be stored off-site; incremental backup tapes can be reused once full backups have been created.

Backups do not prevent users from being on the system or from updating files. Updates to the data made during the backup process will not be included on the backup tapes.

Restoring data from backup may be necessary due to hardware or software failures. A process for restoring data from backup tapes will need to be defined.

5.0 Functional Details

Task controller map production in the precision agriculture system can be divided into five main functional tasks and are considered in this section. The first step is a preprocessing step. It involves the inventory and processing of source materials required to formulate the task controller maps. The second step involves the actual map generations. We have further separated map generation into automated map generation and manual delineation.

Although there is no limitation constraining the geographic coverage and details of the source materials, the output task controller maps are governed by their operational parameters and the requirements of the field task controller. Generally, each task controller map is applicable for one precision applicator machine.

After the application maps are generated, there is a review and manual adjustments tasks—the third step. After review and subsequent adjustments, the maps are exported in a suitable format for transmission to the task controller—the fourth step.

Finally, the map generation component of the precision agriculture system also maintains a feedback mechanism. The fifth step involves importing status reports or summaries from the task controller and integrating the operations reports into the map generator database.

5.1 Preprocessing

This preprocessing step is sometimes also referred to as the "data ingest" task. Data ingest covers an extremely wide range of processing and data management such as retrieval and archiving of data stored in digital form, conversion of printed documents into machine-readable form, format conversion and integration of cartographic products distributed in printed media and in film, processing of remotely sensed data from various sensing platforms, integration and harmonization of field ground truths and survey samples, and so on.

The map generation application in the precision agriculture system is developed solely as a consumer of data. These data, which are factors for the formulation of the application maps, are assumed to be in a processed form. The map generation application need not perform data format conversion, point or surface interpolation, cartographic data generalization, image interpretation and classification, spatial rectification, or georeferencing.

5.2 Map Generation

Four map types are required from the map generator application. These maps are ultimately input into the task controller of the application machinery that governs its operations.

Each task controller map is currently defined to be a regular 40x40 matrix. Each element of the matrix corresponds to an area in the field of one-tenth of an acre in size. All task controller maps should be the same dimensions.

5.2.1 Map Types

Task controller maps are, by and large, created in sets of three. These map types are (1) an agriculture chemical map that controls mainly the applications of fertilizers, (2) a crop map, and (3) a slope map.

5.2.1.1 Agriculture Chemical Map

The agriculture chemical task controller map contains numeric values that are ultimately used to regulate the flow of fertilizer through the valves.

Task controller maps for other fertilizer and chemical treatments will be included without significant structural change to the application.

The nitrogen agriculture chemical map will be identified by the code HN1 in the matrix header.

5.2.1.2 Crop Map

The crop map contains numeric values that represent the type of crop planted or scheduled to be planted.

While the crop map transmits crop type codes, the map generator and the task controller both maintain a lookup table that translates the codes to type descriptions. The descriptive text is not expected to exceed sixty characters per each dictionary entry. The precise contents of this table are determined by the capacity of the liquid crystal display (LCD) panel on the task controller.

The crop map will be identified by the code CP1 in the matrix header.

5.2.1.3 Slope Map

The slope map contains numeric values that represent the gradient classifications on the field. There are currently expected to be less than 100 slope classifications.

While the slope map transmits classification codes, the map generator and the task controller both maintain a lookup table that translates the codes to type descriptions.

The slope map will be identified by the code SP1 in the matrix header.

5.2.2 Generation Processes

The construction of the application maps described above can take one of two approaches. The first approach is an automated one. The second method uses manual delineation to create the task controller maps. With either of these approaches, the resultant task controller maps are fed to the manual adjustment module for review and final adjustments.

The map generation procedures are to be performed on maps and other cartographic products maintained in State Plane coordinates. The State Plane Coordinate System, with its accompanying Public Land Survey System (township, range, section), is the most familiar working environment to most farm operators.

Task controller map matrices are created after the alignment. This can be visualized as regular rectangular grids overlaying the field. Although the current design specifies a dimension and resolution for the eventual output matrix, the application includes additional functions for resolution control for the task controller maps.

5.2.2.1 Automated Generation

Task controller maps can be generated automatically or at least by some degree of computer-assisted methodology, as explained in **Subsection 3.2.** The two minimum prerequisites for automated generation of task controller maps are (1) adequate descriptive data having sufficient reliability, and (2) adequate models to prescribe fertilizer and chemical applications. Additional requirements before automatically generated task controller maps are accepted include (1) localization for terrain, weather conditions, crop types, and planting practices; (2) ability for personalized interventions and task controller; (3) proven performance of the model; (4) replicability of the system; and so on.

It is not expected that the two minimum prerequisites are satisfied at the initial release of the application. The following subsections describe the system's functional requirements that are likely to change as research efforts on data gathering and modeling progress.

5.2.2.1.1 Specifications

Model specification involves the definition of all the factors and the interrelationships among these factors that constitute the crop management requirements. This model is to be specified in the map algebra language and to be implemented using that specification.

Hence, the map generator must support all the local, zonal, and regional operators as defined in the map algebra. Additionally, the map generator must allow the end user ad hoc inclusion and removal of factors that make up the crop management model. Complete model definitions must be stored in or retrieved from external files.

5.2.2.1.2 Map Generation

Once the factors in a model are enumerated fully and their relationships specified, the application processes the model as specified and constructs the appropriate task controller maps. This procedure is called "overlay analysis" in map algebra.

The overlay analysis process is essentially a systematic evaluation of all contributing factors, as defined in the model specification, for every location within the area of interest. Crop management requirements for each of these points are derived from the factors as specified. These points are then grouped into zones; all locations within a zone would have similar crop management requirements. These zones are irregular polygonal areas with recognizable boundaries. **Figure 5-1** describes the overlay analysis procedure. It shows a model in which the output map, D, is constructed from the formula 2(A) + (B/C).

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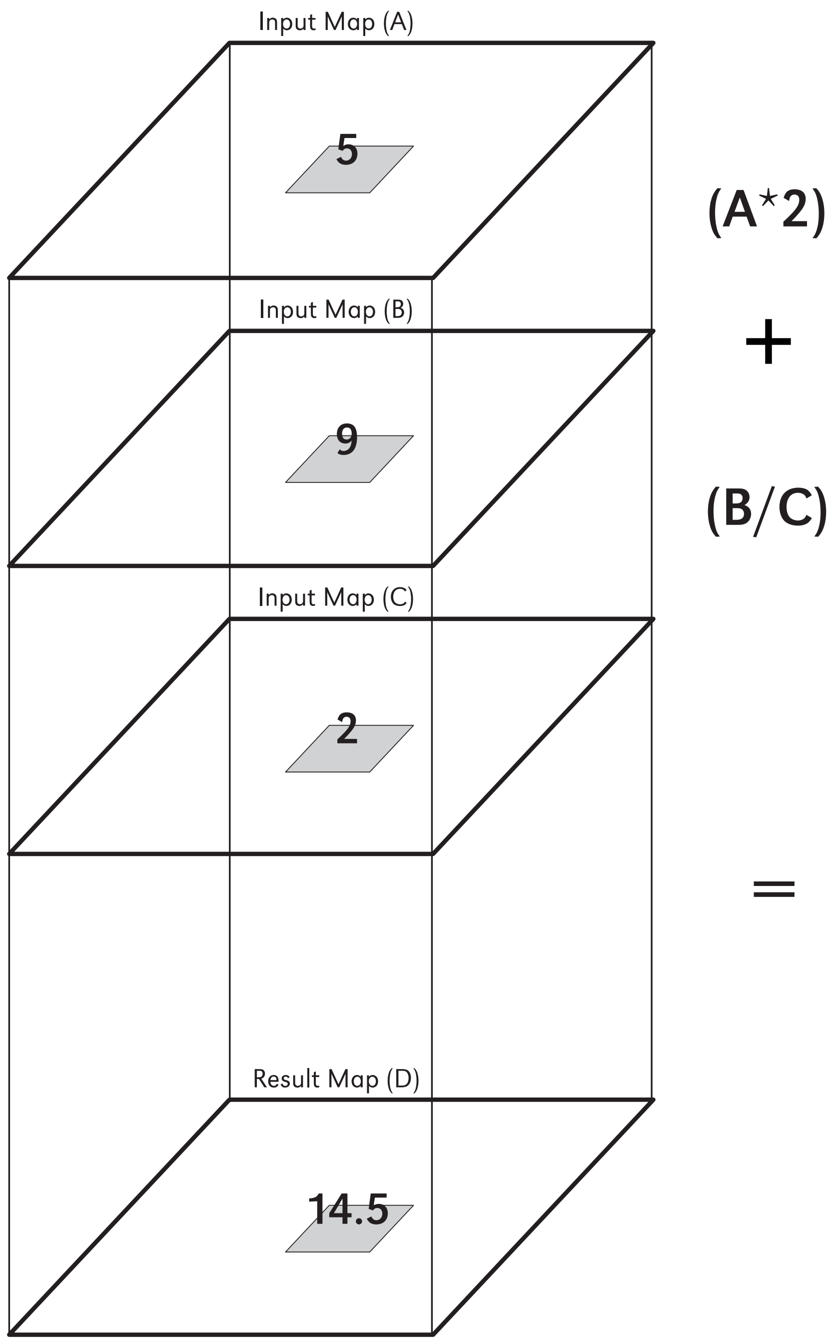
Figure 5-1
Map Algebra Example



The map generator, therefore, must support overlay analysis as defined in the map algebra.

5.2.2.1.3 Calibrations

Factors in a model contribute differently to crop management requirements and exert different influences as the modeled condition changes. In map algebra, these are represented by "weights." Model calibrations in the map generator application involve adjusting the weights, or coefficients, in a model specification.

Calibrations are iterative processes. Generally, a new set of coefficients is applied to a model and, consequently, a new set of task controller maps is constructed. Coefficients are refined further and new maps generated. Sensitivity analyses are constantly performed as new coefficients are input into the model.

The map generator must support the use of coefficients in a model without structural changes to the underlying model specifications. Model coefficients must be stored in, and retrieved from, external files. Sets of calibrated coefficients must be assigned "names" with associated information about the author, the calibration methods, and other relevant assumptions made in deriving those calibrations.

5.2.2.2 Manual Delineation

Whereas automated generation is parametric and model driven, the manual delineation method is dependent upon the experience and expertise of farm operators and service providers.

The manual delineation approach being developed here aims to construct a crop management scheme based on visual interpretations of source materials, principally topographical maps, soil and terrain data, planting plan, and so on. The process is highly interactive and is graphical in nature (see **Subsection 3.1**).

During the manual delineation procedure, the end user would show background reference layers on a map display; these give the user a spatial reference for the area of interest. Using the interpretation skills and local knowledge of the field and planting practices, distinct subfield zones within an area of interest are differentiated and their boundaries drawn. These areas are thus defined and labeled for their specific crop management requirements.

5.2.2.3 Georeferencing to Crop Management Systems

The design of the map generator intentionally separates the task controller map construction procedures with respect to the exact physical locations of crop management systems for which the maps are intended.

This approach is particularly attractive to service providers such as the farm service organization or other independent service bureaus. It is especially advantageous in the automated generation methodologies. The separation means a service provider can process a larger volume of data at once than the volume dictated by the coverage of a single crop management system; hence, it achieves a significant degree of economy of scale. For example, a farm that utilizes five farms under individual crop management systems can be modeled using a single database, and summary statistics are readily available for the entire farm as well as for individual farms.

5.2.2.4 Resolution Control

However the task controller maps are defined, either manually or by automated methods, the sole purpose of these maps is to identify zones in a field that require differentiated applications of fertilizer or chemical treatments. On the one hand, to provide an intuitive representation and ease of use, these zones are represented as polygonal areas with recognizable boundaries. On the other hand, to support the operations of the task controller, these maps must be translated into arrays of numeric control values. This process is called rasterization or gridding. A graphical explanation of this process is shown in **Figure 5-2.**

The rasterization process involves overlaying a regular grid onto the map containing the polygonal areas and then sampling the underlying assigned values at regular grid intervals. The sampling density is governed by a resolution parameter. This resolution is, in turn, determined by the eventual consumer of the output, in this case, the task controller.

The Resolution Control module provides a parametric control to the rasterization process in the application. As the system evolves, higher resolution task controller maps and corresponding larger volumes of data are transmitted to the task controller without change to the map generator.

- Provide default value for the cell size for task controller maps.
- Modify the default cell size for task controller maps.
- Create grid cell boundaries within selected task controller map bounding rectangles.
- Display grid cell boundaries for selected task controller maps on map displays.
- Display task controller zones generated either by the automatic map generation procedures or by manual delineation as backdrop.
- Display any of the source (factor) layers as backdrop.
- Display any of the source reference layers as backdrop.

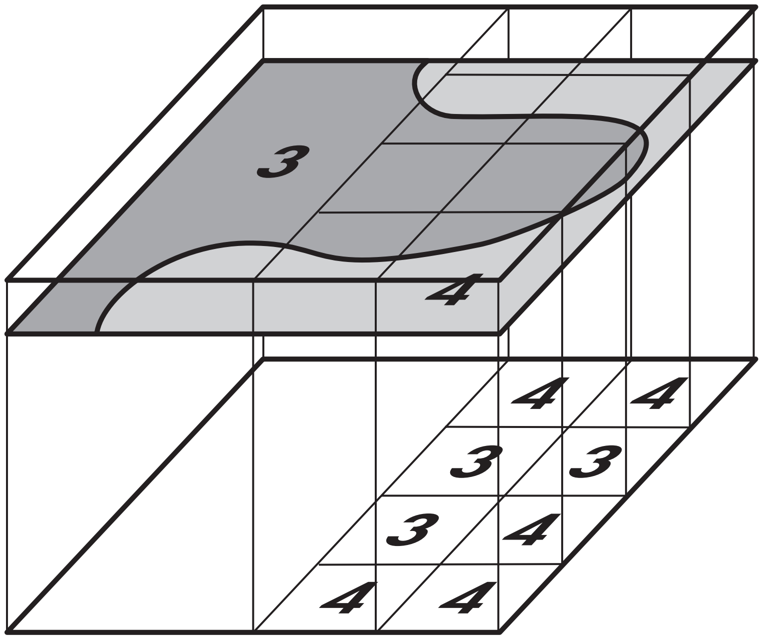
5.3 Manual Adjustments

The Manual Adjustment module allows direct end user access to the output maps. It allows the end user to review the map before it is transmitted to the task controller, and it allows the end user freedom to modify and finalize the maps. Adjustments are done on individual cell elements or on groups of selected cells.

5.4 Export Matrix

Once a map is generated and additional adjustments, if necessary, have been completed, the map (matrix) is written out in an ASCII text file. The file is transmitted to the task controller via a separate communication software on a portable computer. The Export module provides the user an interface to browse and select maps generated from the application and to export the selected maps and suitable text files.

Figure 5-2
Task Controller Map Rasterization



The text file must contain the following items:

- A unique identifier for the farm field
- A time stamp to indicate when the map was created
- A code to identify the type of task controller map
- The latitude and longitude coordinates for the upper left corner of the map
- The number of rows and columns in the matrix
- A number representing the dimension of the (square) cell
- One numeric string for each of the cell elements in the matrix

To optimize the flexibility of the system, the text file should be free-formatted, with each value string separated by a "white space character." It is envisioned that the communication software on the portable computer, which actually performs the downlink operations to the task controller, would perform other data packaging required by the software running on the task controller. The coordinate pair defined for the task controller maps should be transmitted in latitude and longitude decimal degrees. This approach is deemed most suitable in GPS-based operations.

Appendix A—Tools for Agricultural Science and Production

ArcView GIS Version 3.0 lets the researcher perform GIS queries and analysis, and display tabular data visually.

The GIS is the single, most critical component of a precision agriculture system that will ensure long-term success for the user. Remote field research desktop GIS sites are easily networked together as more and more organizations reorganize their databases by using UNIX® and PC servers. An important advantage of these reorganized databases is that data collections become accessible for users within and outside the centralized computing site. A comprehensive system uses ARC/INFO® software by a central group, while ArcView GIS is used as a desktop GIS by researchers. This desktop GIS tool makes it possible to collect data of different origins on one platform, allowing data to be shared and used mutually. The sharing of data and knowledge between different projects and researchers can now be performed to a much larger extent than ever before.

The introduction of ArcView GIS Version 3.0 offers a very powerful tool to global agriculturists. ArcView GIS Version 3.0 lets the user combine vector and raster data for analysis, which makes it an excellent front-end tool in site-specific agriculture and agricultural research.

The field desktop GIS sites can be considered as a frame that contains data related to the research fields. ArcView GIS is used as a front-end tool for the scientist, whereas ARC/INFO is used as a high-end tool for more complicated analysis. Feature data, such as soil properties, treatment, crops, climatic data, land cover, land use, and topographical data, are stored inside the frame of the field GIS for every research field. The field data are supplemented with research-specific data and the results are displayed in ArcView GIS.

Yield Monitors

ArcView GIS Version 3.0 can be used not only in research but also in traditional farming. Data downloaded from a combine's yield monitor are interpolated in ArcView GIS using inverse distance weighting (IDW). A histogram is displayed to show the distribution. Similarly, detailed investigations can be made by doing analysis at field collection points of physical, chemical, and biological data.

Biomass Production Analysis

Basic data on the interactions between growth factors, environment, and productivity, such as fertilization levels, row space distance, and irrigation, are collected for analysis. Plant parameters relating to harvesting technologies and quality can be evaluated. Nutrient leaching and nutrient balances can be calculated for each research plot.

Appendix B—ESRI GIS Software for Agriculture

ArcView GIS Version 3.0

ArcView GIS Version 3.0 is a powerful desktop GIS for the agriculturist!

ArcView Spatial Analyst Extension

ArcView Spatial Analyst is ideal for mapping an analysis of crop production management plans for agronomists, crop consultants, and agricultural production service organizations. Search for crop agronomic data. Query the relationships between the action exchange capacity, organic matter, yield map, and slope to create new management maps. Point and click to derive nutrient contour values for farm field prescription maps.

ArcView Network Analyst Extension

ArcView Network Analyst is useful for organizations that move harvests from fields to inland grain elevators to export terminals. Manage the commodity flow through trucks, trains, and ships. Calculate routes for distribution of wholesale and retail seed, fertilizer, and agricultural chemicals to lower costs. Custom applicators can schedule equipment to arrive "just in time" at farm sites.

ArcView 3D Analyst

ArcView 3D Analyst software helps users integrate three-dimensional data into their farm analysis. You can create and modify surface models of spatial maps of crop production data. Create three-dimensional shapefile themes, and edit triangulated irregular networks (TINs) of crop production management plans.

ArcView Image Analyst

ArcView Image Analyst complements the existing raster-based spatial analysis of ArcView Spatial Analyst of agricultural data. ArcView Image Analyst provides a simple and intuitive extension to ArcView GIS for accessing a wide range of image data types. ArcView Image Analyst does image visualization and enhancement, map registration, feature extraction and image categorization, and simple change detection.

MapObjects

MapObjects™ software is for application developers. MapObjects lets developers add mapping and GIS capabilities to applications. Use MapObjects in development frameworks such as Visual Basic®, Delphi®, PowerBuilder®, Visual C++®, Access, and others.

Internet Map Server Technology

ESRI has two products to provide solutions for Internet and Intranet applications.

ArcView Internet Map Server

The ArcView Internet Map Server (IMS) extension makes publishing a map on the Web almost as easy as printing a map on a printer. No programming is required. All you need is ArcView GIS Version 3.0, the ArcView IMS extension, a connection to the Internet or your Intranet, and Web server software (or access to another machine already running Web server software). The ArcView IMS extension provides a ready-made, generic front end, MapCafé, which allows visitors to your site to view, browse, explore, and query your maps on the Web.

MapObjects Internet Map Server

MapObjects Internet Map Server (IMS) is an extension for MapObjects that makes it easy for application developers to serve dynamic maps and data on the Web. MapObjects IMS gives Web authors a completely customizable, Windows-based Web mapping solution.

Spatial Database Engine (SDE)

Spatial Database Engine™ (SDE™) software lets you query, warehouse, and analyze millions of crop acres (spatially) for your agribusiness organization. Take advantage of advances in client/server computing and database management technologies that allow you to query and analyze enormous volumes of digital spatial data and deliver them anywhere on your network using SDE.

Appendix C—Precision Agriculture

Gridded Soil Sampling Methodology

Field problems: Sampling the farmlands, at points that represent the farm fields adequately, may not conform to a regularly spaced grid. For example, if you have a forty-acre homogenous tract, you may only require samples every ten acres (or whatever you deem randomly representative). However, if you have a twenty-acre field with five different soils and other important factors, such as slope, you may require much more intensive soil sampling. If you are looking for an alternate methodology, assume the restrictions of a grid based on two and a half acre squares limits your management techniques for fertility analysis.

ArcView GIS Version 3.0 with the Spatial Analyst extension is an excellent tool for this application. If you are looking for a way to interpolate point values where the points are randomly located in the field, then you may be interested in some of the functions of the Spatial Analyst for your fertility analysis, such as kriging and/or IDW, as well as other spatial statistical functions. The following will give you an idea of how the functions are applied.

MakeKriging/ MakeFrom Variogram Discussion

Kriging is an advanced interpolation procedure that generates an estimated surface from a scattered set of points with z values. Unlike the other interpolation methods supported by the Spatial Analyst, kriging involves an interactive investigation of the spatial behavior of the phenomenon represented by the z values before you select the best estimation method for generating the output surface.

The following is an introduction to the procedure of using kriging to produce an estimated surface. Kriging is a complex procedure that requires adequate knowledge about spatial statistics. Before using the Interp.MakeKriging request, you should have a thorough understanding of the fundamentals of kriging.

The spatial variation is quantified by the semivariogram. The semivariogram is computed from the input point data set.

The Grid.MakeKriging request offers two types of surface estimators: ordinary kriging and universal. Ordinary kriging is represented by the SPHERICAL, CIRCULAR, EXPONENTIAL, GAUSSIAN, and LINEAR methods. With these options, kriging uses the mathematical function specified with the method argument to fit a line or curve to the semivariance data in the semivariogram.

Universal kriging assumes that the spatial variation in cell values is the sum of three components: a structural component (drift), a random but spatially correlated component, and random noise representing the residual error.

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IDW Discussion

IDW interpolation determines cell values using a linear weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

IDW allows you to control the significance of known points on the interpolated values, based on their distance from the output point. The interpolation can be shifted from local to global by changing the power. A larger power will result in less influence from surrounding points. In other words, nearby data will have the most influence and the surface will have more detail (be less smooth).

The characteristics of the interpolated surface can also be controlled by limiting the input points used to calculate each interpolated point. The input can be limited by the number of sample points to be used (specified as a variable radius object), or by a radius (specified as a fixed radius object), within which all points are to be used in the calculation of the interpolated locations. The radius object to be used is identified through the aRadius argument.

The output value from a cell using IDW is limited to the range of values used to interpolate. Because the IDW is a weighted distance average, the average cannot be greater than the highest or less than the lowest input.

Frequently Asked Questions

Q. Will your software also allow you to choose the semivariogram model that most fits the data?

A. Yes, you can choose one of six methods, SPHERICAL, CIRCULAR, EXPONENTIAL, GAUSSIAN, LINEAR, or a UNIVERSAL KRIGING method. We provide limited tools for variogram calibration. If you want to have full control over the variogram model, you should use a full statistical package like S-PLUS®.

Q. Is your program limited by the number of samples in the data set (only 16 samples in a 40-acre field)?

A. No, the software is not limited by the number of sample points in the interpolation. If you use twenty points, it will be noticeably slower than using six points, but it works nonetheless.

At this time, there is no distinct advantage in map development using kriging over inverse distance squared. The bottom line is that although the maps will not appear square unless you use inverse distance to the fourth power, by using either kriging or inverse distance, the information within them is no more valid than the square maps. The most important factor in good map representation is the sample density or the validity of the "smart" sampling method used to draw fertility lines, such as remote imaging, digital aerial cameras, or topographic boundaries. A quarter-section sampled in a ten-acre grid and then contoured using a kriging program will look great, but may have little relationship to a more densely sampled rendition of the same field.

There is much debate and, sometimes, more art than science in determining the best interpolation method and parameters. It is critical to obtain a sampling density suitable to represent the variation of the phenomena being modeled. In doing interpolation of the points, this sampling distribution should still be somewhat random. It's okay to make sure that certain phenomena are sampled, but to specifically sample certain areas in a systematic manner will bias the resulting map. If you oversample one area too close to its edges, that area will appear larger than it really is in the resulting interpolated map.

Capturing soil variation as polygons and modeling similar combinations of soil, slope, etc., is done in hydrology by creating what are referred to as hydrologic response units (grouping areas of the landscape that have similar characteristics.) This can be done manually or by using some type of statistical clustering algorithm, such as the ISOCLUSTER function in ARC GRID™. This type of solution is useful when mapping manually or with vector data. With the ability to map soil and landscape characteristics as continuous phenomena and combine all those maps seamlessly to create a resulting prescription map, however, aggregating data into response units is no longer very common.

If you require a nongrid-based approach, another possibility is using an ARC TIN™ component or the ArcView 3D Analyst extension to represent the data, instead of the two and one-half acre cells. The end result would most likely be very similar but you could contour along a surface rather than a grid. Ultimately, the analysis would be done in ARC GRID but then you could do some contour generation and possibly slope analysis with ARC TIN.

The more variables you utilize on a map, the less likely you are to improve over grid sampling. Dividing a field into "hydrologic response areas" makes sense if you are interested in hydrology alone, but if your map is to represent variation in N, P, K, lime, pests, etc., the chance of choosing any predetermined mapping pattern that does not bias the results for at least one of these variables is not very good.