INTEGRATING SITE-SPECIFIC AND PUBLIC DOMAIN DATA IN A GEOGRAPHIC INFORMATION SYSTEM TO FACILITATE AGRICULTURAL PRODUCERS' DECISION-MAKING

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NOMENCLATURE

ASCS	Agricultural Stabilization and Conservation Service
AVHRR	Advanced Very High Resolution Radiometer
bu/A	bushels per acre
K	potassium
K_2O	potash, a form of potassium fertilizer
lbs/A	pounds per acre
MIADS	Machine Input And Display System
N	nitrogen
NO_3	nitrate, a form of nitrogen fertilizer
P	phosphorus
P_2O_5	phosphate, a form of phosphorus fertilizer
PLSS	Public Land Survey System
SCS	Soil Conservation Service
SO_4	sulfate, a form of sulfur fertilizer
SPOT	French polar-orbiting satellite
TIGER	Topographically Integrated Geographic Encoding and Referencing System
USDA	United States Department of Agriculture

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CHAPTER I

INTRODUCTION

Spatial analysis tools have many potential applications to modern agriculture. Agricultural producers have recently begun to make use of site-specific maps to show localized conditions and variability, but in general geographical tools are still greatly underutilized. As Fenneman observed in his 1918 presidential address to the Association of American Geographers,

> "Agriculture is now so specialized and so firmly entrenched that crops and their distribution, and their relation to all manner of factors, are studied without concern for geography" (Fenneman, 1918, p.4).

Modern agriculture has certainly become increasingly specialized, but implicit in Fenneman's statement is the recognition that many aspects of agriculture are inherently geographical. Agricultural geography has traditionally addressed topics such as changing crop and livestock distributions, loss of farmland to urban and other uses, and water resources issues, but has rarely focused on farm or field-level studies.

The development of geographic information systems (GIS) has resulted in many useful methodologies that can aid agricultural producers in their decision-making processes. GIS is of increasing importance to the discipline of geography because it provides the capability to overlay maps of different themes, often obtained from different sources, and to analyze their relationships. GIS is a system for the support of spatial analysis, not an electronic filing cabinet, an automated drafting system, nor a technical fad (Crisman et al., 1989).

GIS has great potential to assist farmers with some of their most important production decisions, especially those which attempt to account for spatial and temporal differences within specific agricultural fields. According to Jeff Jacobsen, Montana State Extension soil scientist, "Traditional approaches to farming, where large fields are managed as one unit, are becoming obsolete. Most fields contain several soils with different crop production potential" (Reichenberger and Russnogle, 1989, p.11).

Agricultural producers must often deal with the variability of soil characteristics and fertility within fields. Excess application of fertilizer and chemicals is costly for the producer and increases the potential for negative environmental impacts. Insufficient nutrients not only reduce crop yields, but also retard plant development and thus the root zone's ability to hold soil in place, increasing the potential for erosion (Richter and Tank, 1991). Geotechniques can considerably enhance a producer's ability to determine and quantify the extent and nature of variability so that different areas within fields can be treated differently.

The benefits of site-specific management in agriculture are many. The reduction of fertilizer and pesticide inputs can let the producer realize cost savings without sacrificing crop yields. Reduction of inputs also has positive environmental considerations by decreasing chemical applications where they are not needed, especially in light of growing concerns regarding nonpoint-source pollution from agricultural sources. When site-specific management does not call for reduced inputs, such as when areas of nutrient deficiency are detected, the producer can gain increased confidence that fertilizer is applied only where it is needed to produce a planned crop at a specified yield goal.

Information relating to the spatial distribution of agricultural production can be difficult to incorporate into management systems because of problems associated with the handling of large amounts of spatially distributed data. Efforts by a producer to assemble data describing all the relevant factors such as physical and chemical characteristics of the soil, topography, yields, crop history, weeds, insects, and disease can quickly become unwieldy, cumbersome, and overwhelming. Even the most sophisticated agricultural producers use spatial data that is "externally referenced" from computer databases or on paper which must be related to a physical location or to a map. GIS provide capabilities to encode, store, analyze, manipulate, and display spatial data in a flexible and intuitive manner, and in a way that the data may be "internally referenced" with respect to geographic location by the system. The characteristics, traits, and properties "associated with any geographical location can be organized as a set of spatially registered overlays which can be combined analytically in a modelling context to accommodate a variety of scenarios" (Smith et al., 1991, p.188). It is this capability of GIS, to view many variables and factors in combination with each other and in their correct spatial context, that potentially offers great utility to agricultural producers for day-to-day as well as year-to-year decision-making on a field-level basis.

Many farmers are beginning to recognize that GIS can be used as a tool to improve production decisions, but there is a general feeling that GIS adoption is time consuming and difficult. Also, many possibilities exist regarding the the variables and factors which could be considered for site-specific management. For example, fertilizer applications may be tailored to different soil types. Herbicide rates may be adjusted to match varying levels of organic matter. Different seed varieties may be selected based on soil pH and cation exchange capacity (Reichenberger and Russnogle, 1989). These are all good examples of spatially related agricultural operations that would be appropriate for, and within the capability of, GIS analysis and display, and they serve to point out that the possible uses of GIS in agriculture are far greater than the scope of this paper. For the purposes of this study, the focus is on fertility management and the variables selected for examination are nitrogen (N), phosphorus (P), and potassium (K). Fertility recommendations for these nutrients were derived from soil tests.

The use of soil testing as a guide to the application of agricultural chemicals in crop production continues to increase in Oklahoma (Johnson, 1985), but there are many different ways to take soil samples and to use the results. One way is to take several samples from random locations within the field and mix them together to obtain an average soil sample for the field, and then treat the field uniformly. The design of this whole-field approach does not lend itself to the detection of within-field variability. Another way is to separate the field into smaller areas and to obtain a representative sample from each, and then to treat these subfield areas uniformly. Depending on the size of these areas and the criteria by which they were delineated (soil types, cropping history, etc.), this method may detect and help to account for some variability. A third approach is to divide the field into a grid so that samples can be taken systematically at regular intervals. This grid sampling approach requires a greater number of samples at a finer spatial resolution, and thus offers a better opportunity to detect variability and to improve the efficiency of fertilizer applications.

Objective

The objective of this study is to evaluate the fertility recommendations derived from the three different soil sampling techniques described above--whole field, subfield, and grid sampling--to show how agricultural producers can more efficiently manage within-field nutrient variability. These fertility recommendations are represented as layers of an ARC/INFO (Environmental Systems Research Institute, Inc., 1992) database. The database includes other site-specific layers such as soil series and production data, as well as regional layers including satellite imagery, soil classifications from the Soil Conservation Service (SCS) Machine Input And Display System (MIADS), transportation and hydrography from the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing system (TIGER) files, the Public Land Survey System (PLSS) grid, and meteorological data interpolated from the Oklahoma MesoNetwork.

Study Area

The study area is in Caddo County in west central Oklahoma, where center-pivot irrigation is widely used to grow peanuts, corn, and watermelons. Operational GIS has the potential to be especially beneficial to producers who cultivate these high-value crops because they make extensive use of irrigation, fertilizer, and pesticides in fields with variable soil types. These characteristics call for intensive field-level management.

Two quarter sections have been selected for site-specific study. They are: (1) the southwest quarter of section 10, township 9 north, range 13 west, designated as Agricultural Stabilization and Conservation Service (ASCS) tract number 4807, and (2) the southwest quarter of section 31, township 9 north, range 12 west, designated as ASCS tract number 702. These two quarter sections will be referred to by their ASCS tract number throughout this paper. Tract 4807 is located approximately three miles south of Eakley, Oklahoma; tract 702 is located approximately eight miles south-southeast of Eakley on the west side of Fort Cobb Reservoir (Figure 1). The portions of these tracts included in the study are the fields that were in production of irrigated, high value crops in 1993. Identified by their ASCS field numbers, they are fields 2B, 2C, and 2D in tract 4807 and fields 2A and 2B in tract 702 (Figure 2).

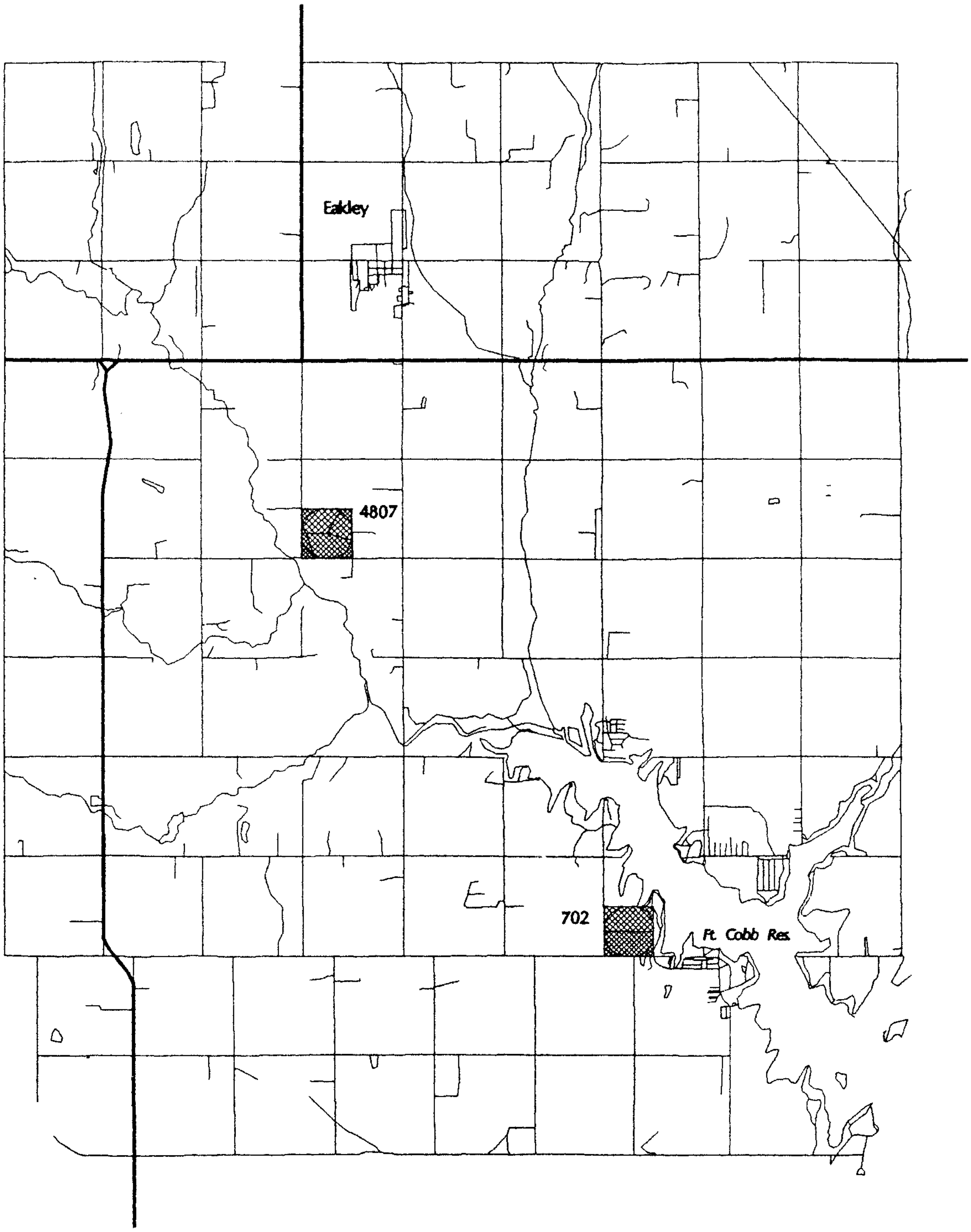

Figure 1. Location of Tracts in Caddo County

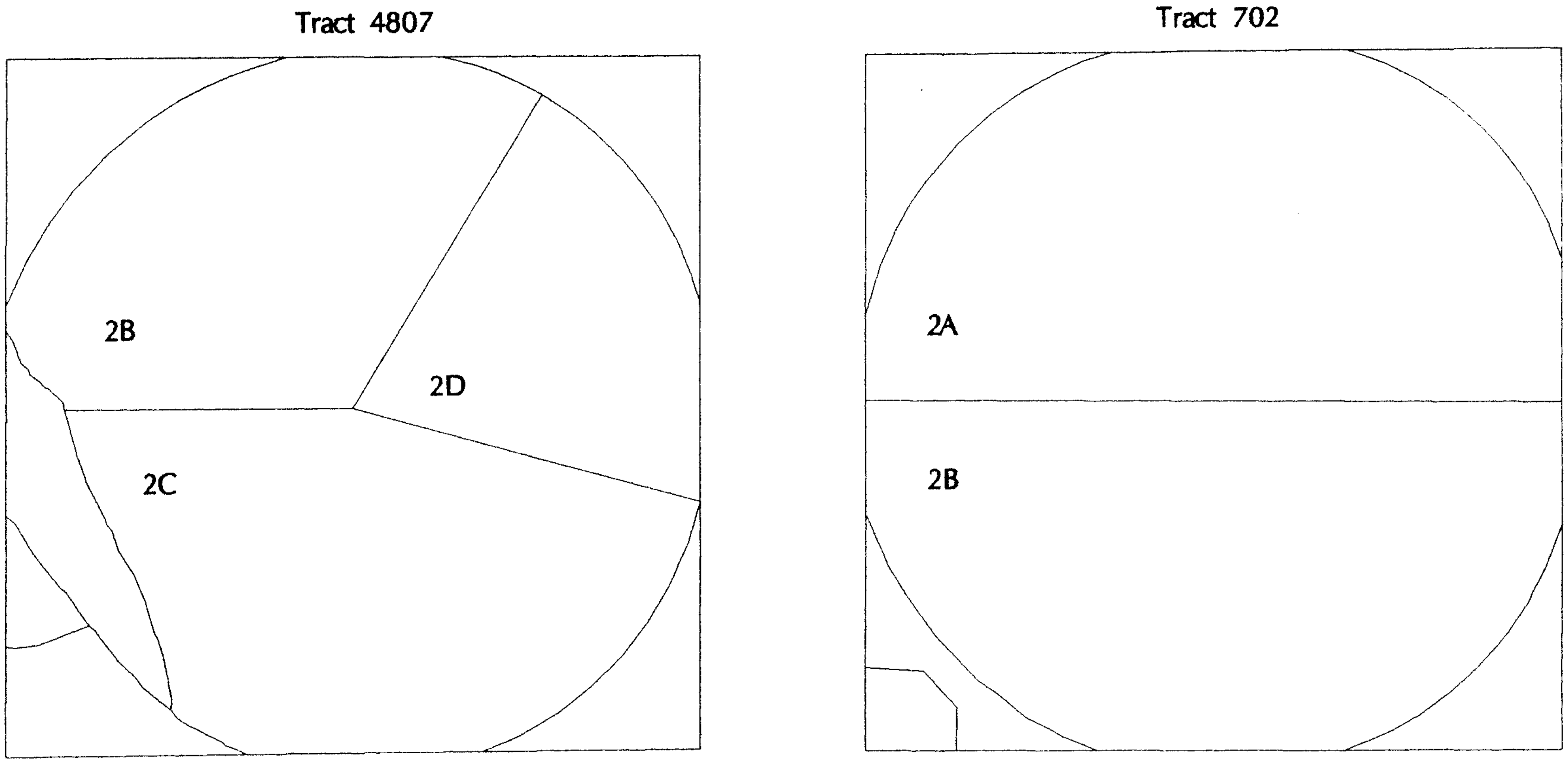

Figure 2. ASCS Field Number Designations within Tracts

CHAPTER II

LITERATURE REVIEW

The applications of GIS technology to agriculture have been very limited to date. Efforts to integrate remotely sensed data typically involve coarse resolution image data of over large areas and are used either to display vegetation indices or for crop inventory, rather than for farm level management. When computer technology has been employed to create site-specific maps showing localized conditions and variability, the applications do not take full advantage of GIS's analytical capabilities. Literature dealing with the use of geotechniqes for site-specific management can be more often found in agricultural trade journals and magazines (e.g. Farm Journal, Progressive Farmer) rather than in academic or professional journals. This chapter will first review articles dealing with the integration of remotely sensed data, and then several concerning site-specific applications.

Remote Sensing Applications

Teng (1990) demonstrated that vegetation index numbers derived from Advanced Very High Resolution Radiometer (AVHRR) data could be useful for large area crop monitoring. The interpretation included consideration of factors such as crop stage, mix, and distribution;

precipitation and temperature; and soil moisture. These were not incorporated into a system for analysis purposes. Instead, Teng pointed out the constraints concerning the application of remotely sensed data on large areas in comparison with traditional controlled, small plot studies, and recognized the need for more work on linking the two types of approaches.

Manore and Brown (1990) described the integration of AVHRR imagery of the grain-producing regions of western Canada into a GIS for the Canadian Crop Information System. This enabled the overlay of administrative units such as Crop Reporting Districts and physiographic units such as agricultural land use onto the processed image, providing information on vegetation condition during the crop growing season to assist in forecasting potential yield and production.

Eckhardt et al. (1990) described a GIS constructed and maintained by the Bureau of Reclamation being used to calculate previous maximum irrigation water demand (MIWD) for the Newlands Project, which consists of approximately 25,000 hectares of irrigated lands in west-central Nevada. Data layers in the GIS include land ownership, sections and quarter-quarter sections of the U.S. Public Land Survey System (PLSS), agricultural fields, water rights, and bench- and bottom-land soil designations. Each agricultural field has an "irrigated" or "non-irrigated" attribute which must be updated annually because irrigation patterns within the project change from year to year. SPOT multispectral imagery was used to update this attribute and to locate new agricultural fields brought into production since the original mapping. Although SPOT data were used in the Newlands Project, it is important to note that the methods developed are applicable to data acquired by other spaceborne sensors.

Site-Specific Agricultural Applications

Reichenberger and Russnogle (1989) summarized several of the earlier attempts to implement site-specific management. Some of these efforts examined yield and fertility variation based on soil types from SCS soil survey maps; others tried intensive soil sampling on different sized blocks or grids. Soil test results from each grid sample were used to represent the values for the corresponding grid area.

Reichenberger (1991) described the use of aerial infrared photography to divide a spring wheat field near Westhope, North Dakota, into three soil sampling areas. The results indicated that one of the areas representing about 25% of the area of the field would benefit from additional nitrogen. This was compared with the result of a conventional single composite sample, which indicated no additional nitrogen would be recommended for the yield goal of 45 bushels per acre (bu/A). By adding more nitrogen to the deficient area, farmer Ron Wyman said, "The field made 45 bushels an acre, and the crop was far more consistent than in other years" (Reichenberger, 1991, p.3).

Keller (1991) summarized a project in which the results of grid soil sampling were used to make detailed fertility maps, enabling the producer to significantly reduce inputs without sacrificing yield.

Stafford and Miller (1993), at the Silsoe Research Center in Bedford, U.K., developed a system for targeting herbicide applications to weed patches in arable crops, recognizing significant spatial variability in weed plant density and in weed type. They noted that the normal practice of farmers is to spray an entire field at a uniform rate, although some farmers exercise a small measure of manual control by turning off the spray boom in areas where they know there are no weeds. Critical to the implementation of selective application was weed detection, location, and mapping, realizing that weeds tend to occur in patches which remain relatively stable in size and location from year to year. Methods of weed detection that were explored included: (1) the examination of differences in spectral reflectivity during periods of the growing season when the differences between weeds and crops were most pronounced; (2) also imagery from aerial photographs;

(3) detection by manual surveying on foot or from field vehicles. Weed patches were also located on maps using field tramlines as a reference system.

Stafford and Miller used a differential Global Positioning System (GPS) to investigate a possible method of determining within-field location, but sufficient resolution could not be achieved with the available systems. A UK ordnance survey 1:2500 scale map was used to input a base field map including field boundaries into an IDRISI GIS. The weed patch locations and tramlines were overlaid on the base map to produce the weed control map. The sprayer control system which could apply the herbicide in three levels of concentration was linked to a laptop PC mounted in the sprayer cab. The PC also contained the weed treatment map. The location of the sprayer, either from tramline number and position or from x,y position from a GPS receiver, was input into the PC. Different rates could then be applied according to the location on the weed map.

The authors emphasized the most difficult part of the project was the detection of weed patches because of the similarities between weeds and crops, and noted that the map-based approach was appropriate for the treatment of grass weeds in cereal crops. The weed patches tend to be stable in size and location over time, allowing multitemporal weed maps to aid in the assessment of the effects of patch spraying on the presence or absence of weed patches over a number of crop production cycles and growing seasons (Stafford and Miller, 1993).

Smith et al. (1991) demonstrated how GIS can provide useful tools for farm management by displaying the spatial distribution of key soil and foliar parameters, examining spatial variability within and between harvests, and by querying the database to determine possible causes of deficiencies in forage quality and yield. The study was conducted in British Columbia on a five hectare forage field of orchard grass and white clover. The forage crop was harvested five times during the year. The field was stratified into a 20m X 20m grid and soil samples were taken from randomly selected sites within each grid cell. Crop samples were taken immediately prior to harvest five times during the growing season and analyzed for nutrients and quality parameters. GIS-generated maps showed the significant spatial variation in feed quality for different cuts over the growing season, indicating that higher quality feed occurred in different areas of the field at different times. Important implications were that the awareness of the spatial patterns of crop yield and quality enabled the producer to target fertilizer applications and to apply irrigation water with reference to soil characteristics.

Bradley (1993) described the British national land information system (LandIS) which contains soil, climate, and environmental data for England and Wales, and how it was used in two case studies to aid in farm management decisions. In one case study, the LandIS was used to look at varying soil properties to select land most suitable for particular crops. LandIS was also used to develop a strategy for subdividing fields into soil sampling areas. The other study was done on a designated "Nitrate Sensitive Area" (where water sources had a high and/or rising nitrate level). Its purpose was "to examine the practical implementation of controls on nitrate leaching from agriculture in potable water catchment areas" (Bradley, 1993, p.104). The soil series were mapped and assigned a nitrate leaching risk class. This risk class was examined in combination with land use and precipitation data to determine a nitrate leaching rate. The result was the suggestion that the land use be limited to agricultural practices that produce lower leaching rates such as permanent grassland or forest.

Bauer and Schefcik (1994) cooperated on a project in which herbicide application rates were varied based on soil characteristics in a 130 acre irrigated sugar beet field in western Nebraska. An aerial photograph of the field was imported as an image into a Computer Aided Design (CAD) system. Areas of coarse-textured sandy soils, which were to receive lower rates of herbicide, were identified on the aerial image and delineated on the computer representation as management zones. The computer was installed in the cab of a tractor which also carried a Global Positioning System (GPS) receiver. In the field, the image was georeferenced using locations determined by the GPS receiver. As the operator moved through the field, his location was tracked and displayed on the monitor screen. As he moved in and out of the management zones, he could select a high rate or low rate of herbicide by throwing a manual switch.

Mulla (1991) described how a GIS was used to aggregate and map soil fertility patterns. Soil test data were analyzed to derive nine soil fertility categories which were grouped into three fertilizer management zones and then mapped. A 56 hectare irrigated potato field near Quincy, Washington, was sampled on a regular grid at spacings of 61m. At each sample location three soil cores 46cm deep were collected within a circle of 4.6m radius, placed in a bucket, and mixed to give a composite sample. The samples were analyzed for phosphorus (P) and potassium (K). The P and K soil test levels were mapped using the interpolation method of kriging to estimate values between measured data points. Kriging is essentially a method of estimation by local weighted averaging. Soil test cutoff levels were defined to indicate regions having low, medium, and high fertility based on the appropriate fertilizer guidelines for irrigated potatoes with a yield goal of 67+

tons per hectare. The fertility categories were aggregated into management zones representing areas receiving low, moderate, and high rates of fertilizer. Recommendations were then made for each management zone by calculating the average of the interpolated soil test values for P and K, and then obtaining the recommended rate from the fertilizer guide. It is important to note that the rates for each zone were derived from an average of the soil test values.

Summary

The use of GIS as a tool to assist in agricultural decision-making at the field-level is a relatively new subject for study, and so the literature about it is not extensive. The articles from professional literature (Mulla, 1991; Smith et al., 1991; Bradley, 1993) were written by soil scientists. The articles from the agricultural trade magazines, for the most part, describe efforts by producers or chemical dealers to reduce costs or increase yields. The literature provides a starting point for future researchers in that it raises questions about how to proceed, what variables should be considered, and what areal units are appropriate. Methodologies for data collection, interpretation, analysis, and mapping are not well defined and established, but are emerging and being developed.

CHAPTER III

METHODS

The spatial database described below was created using ARC/INFO GIS software. Coverages were then accessed with ArcView v. 2.0, a companion product which provides a graphical user interface along with display and query capabilities.

Regional Data

Although the specific objective of this study focuses on site-specific data, it is essential to understand the importance of displaying the sites in their regional setting. The regional database not only allows the examination of the fields under study in their correct spatial context, but also shows that the field-level analysis is applicable to any of the producer's fields in the area, and to other producers' fields as well. The regional database also demonstrates that as new data become available in the future, such as new soils data or imagery from video or satellite, they can be incorporated into the system. The layers included as regional data are: agricultural census data, Landsat imagery, TIGER/Line census files, Public Land Survey System (PLSS) grid, United States Department of Agriculture (USDA) Soil Conservation

Service (SCS) Machine Input And Display System (MIADS) soil associations, and meteorological data. These data layers which serve as separate themes are described below.

County boundaries for Caddo county and nine surrounding counties were imported and built as ARC/INFO polygon coverages. County data from the agricultural census were then linked to the corresponding counties as polygon attribute data. The agricultural census contains figures on the number, type, and size of farms; the number and type of livestock; and the acreage and harvested amount of different crops. These data reveal many important characteristics of agricultural activity in the region.

A Landsat Thematic Mapper image was acquired for August 1992 and imported into the image processing system in the Center for Applications of Remote Sensing at Oklahoma State University, and a subset containing the study area was extracted. The image was then geocorrected so that locations represented on the image would correspond to geographic coordinates on the earth's surface. The corrected image was used as a base layer for the regional GIS database. Thematic Mapper imagery contains data from six distinct reflective bands at a 30m spatial (ground) resolution. By employing image processing techniques, these data can be manipulated to detect differences in various biophysical land surface parameters which might be used, for example, to locate areas of crop stress (Waits, 1993).

The Topographically Integrated Geographic Encoding and Referencing system (TIGER) is the U.S. Census Bureau's digital map database. TIGER/Line files for Caddo County were converted into an ARC/INFO coverage. Each line segment has a census feature class code attribute which may be referenced to determine what type of feature the line segment represents. By selecting data records based on this feature class code, individual features including highways, secondary roads, streets, railroads, county and city boundaries, rivers, streams, and waterbody boundaries were extracted to create separate line coverages for each feature.

A section grid representing the Public Land Survey System was incorporated as an ARC/INFO polygon coverage enabling the display of sections in Caddo County, with the corresponding township, range, and section numbers linked as polygon attribute data. This layer offers great utility in that it permits the user to locate a parcel of land easily by querying on the legal description only, and then quickly highlight or zoom in to the selected section.

MIADS soils data for Caddo County, indicating the soil associations at 200m resolution, were acquired from the SCS in raster format and converted into an ARC/INFO polygon coverage.

The Oklahoma MesoNetwork consists of 111 stations across the state which record and transmit meteorological data at fifteen minute intervals. The types of measurements taken include solar radiation, relative humidity, temperature, wind speed and direction, and precipitation. Weather data collected from the MesoNetwork were used to calculate reference evapotranspiration at each station. These evapotranspiration values were used to create an ARC/INFO point coverage and the point values were interpolated to a one kilometer output resolution (Yuen, 1994). A portion of the resulting coverage encompassing the study area was extracted and converted to a polygon coverage, enabling the overlay and display of estimated reference evapotranspiration.

Site-Specific Data

Public Domain Data

SCS soil series were digitized from SCS soil survey maps for both tracts. The soil series is the most detailed level of classification below the more general soil association level used for the MIADS data. These were built as ARC/INFO polygon coverages and the corresponding soil series, symbol, and slope range were assigned as polygon attribute data. Tract 4807 contains six different soil types: Noble fine sandy loam, Cobb fine sandy loam, Shellabarger fine sandy loam, Dougherty loamy fine sand, Eufaula fine sand, and Dougherty and Eufaula loamy fine sands. Tract 702 contains four soil types: Dougherty loamy fine sand, Eufaula fine sand, Konawa loamy fine sand, and Dougherty and Eufaula loamy fine sands. Both of the quarter sections have been classified as highly erodible land by the Soil Conservation Service.

Elevation contours at ten foot intervals were digitized as ARC/INFO line coverages from USGS 7 1/2 minute quadrangle maps for both tracts. Tract 4807 ranges in elevation from 1373 feet in the southwest to 1440 feet in the northeast. Tract 702 ranges from 1350 feet in the north to 1400 feet in the southwest.

Aerial photographs of both quarter sections taken in 1966 were obtained from the OSU Library Map Room. These photos were scanned and imported as image data for display in ArcView2 showing the land use has changed dramatically since the photos were taken. For example, the center pivot irrigation systems were not in operation in 1966. The ability to easily incorporate data such as aerial photography into the GIS was a good demonstration of the system's usefulness and flexibility.

The coverage of estimated reference evapotranspiration derived from the MesoNetwork data was overlaid on the study area so that the evapotranspiration for individual agricultural fields could be identified. By multiplying this value by the crop coefficient for the particular crop at the proper growth stage, the producer can obtain the crop evapotranspiration for the specific field.

Operator Data

Cropping data were obtained from the Caddo county SCS office in Anadarko. These data consisted of photocopies of aerial photographs with the field boundaries delineated and identified by ASCS tract and field numbers, showing the number of acres in each field and crop types planted in each field for the years 1991, 1992, and 1993. The field boundaries were digitized as ARC/INFO line coverages and built as polygon coverages. The ASCS tract and field numbers, area in acres, and crops planted were linked to the corresponding fields as polygon attribute data.

Fertilizer and pesticide data were obtained from the operator, consisting of the name of the chemical applied and the date of application for each field as delineated in the crop layer. These data were linked as polygon attributes to the corresponding fields in the cropping coverage. Data on tillage operations and crop yields were not included.

Soil Test Data

Data Collection

Soil samples were collected from tract 4807 on October 12, 1993, and from tract 702 on October 14, 1993. In order to evaluate the results and implications of the different sampling techniques, the different fertility recommendations derived from each technique were compared. For the whole field and subfield methods, the sampling areas were first defined based on 1993 cropping practices and then the fertility recommendations based on the soil test data for that area were examined. These areas are referred to by their designated ASCS field numbers (Figure 2). Using the grid sampling method, however, the soil test data were interpolated to determine areas for which different fertilizer recommendations would be made, based on nutrient variability. These areas were then overlaid with the identified ASCS fields so that the results from the grid method would correspond to the same field boundaries for comparison.

Whole field method. Four cores were taken from random points in each 160 acre field, comprising a simple random point sample (McGrew and Monroe, 1993). In tract 4807, the "whole field" consists of the combined areas of ASCS field numbers 2B, 2C, and 2D; in tract 702, the "whole field" consists of the combined areas of ASCS field numbers 2A and 2B. These were mixed to obtain a sample representing an average of the soil in the entire field. Interviews with several producers indicated that the typical method they have used in the past when having their soils tested is as follows: drive through the field, stop a few times to get soil samples, mix them up and send in one sample. Johnson (1985) cautions that since the sample represents an average of the soil in the field, treatment based on the soil test will likely exceed the level needed on some parts of the field and be too little on other parts. It has been stated that "locational or spatial unevenness is a natural consequence" of random sampling, with different parts of the field not being equally represented (McGrew and Monroe, 1993, p. 107).

Subfield method. The soil samples for the subfield method comprise a disproportional stratified point sample. This sampling method requires that the area to be sampled first be separated into subareas or strata from which simple random point samples are taken. It is disproportional because an equal number of cores were taken from each stratum without regard to its areal extent as a proportion of the entire field (McGrew and Monroe, 1993).

The fields were first divided into subfield sampling areas, based on recent crop history and identified by ASCS field number, and then simple random point samples were taken from each subfield sampling area or stratum.
Tract 4807 was divided into three sampling areas reflecting 1993 cropping:

field 2B - 40 acres - watermelons

field 2C - 52.6 acres - potatoes
field 2D - 30 acres - peanuts.

Tract 702 was divided into two sampling areas:
field 2A - 59.4 acres - corn
field 2B - 59.3 acres - watermelons.

A minimum of twenty cores were taken at random from each subfield area and mixed in a plastic bucket to obtain a sample representing an average of the soil in the sampling area. This procedure is in accordance with that described in _OSU Extension Facts No. 2207_, "How to Get a Good Soil Sample" (Johnson, 1985).

Grid sampling method. Each 160 acre field was intensively sampled on a regular grid at a distance interval of 330 feet for a total of 64 sampling locations. Samples for the grid method represent a systematic aligned point sample.

> "This approach offers representative, proportional coverage of the sampled area" and "avoids problems possible with an uneven distribution of points across a study area. Systematic point sampling is widely used in geographic research, particularly when geographers deal with environmental and resource problems where data are continuously distributed across an area" (McGrew and Monroe, 1993, p. 107).

At each sampling location, five soil cores were collected within a circle of a fifteen foot radius to a depth of six to eight inches using a soil tube. The five cores were placed in a plastic bucket and mixed thoroughly by hand. A sample bag was filled from the mixture (Johnson, 1985).

Soil Testing and Interpretation

All soil samples were delivered to the Soil, Water, and Forage Analytical Laboratory at Oklahoma State University where the soil testing was performed. Results of the soil tests were returned as a fertility listing for each sample giving test values for each of these soil test variables: soil acidity (pH), buffer index (BI), nitrate (NO_3), phosphorus (P), potassium (K), sulfate (SO_4), calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn).

Fertilizer requirements can be determined from tables published in OSU Extension Facts No. 2225, "OSU Soil Test Interpretations" (Allen and Johnson, 1993). These tables are reproduced in the 1993 Oklahoma Soil Fertility Handbook (Johnson, 1993). Since fertilizer requirements may vary for different crops and yield goals, corn with a yield goal of 160 bushels per acre (bu/A) was selected for this study.

The nitrate soil test measures the actual amount of nitrate (NO_3) available to plants. The nitrogen fertilizer requirement is determined by subtracting the pounds of nitrate in the soil from the total nitrogen requirement for the selected crop and yield goal.

The phosphorus and potassium soil tests estimate the amount of these nutrients available, listed in the soil test interpretation table as a "percent sufficiency" supplied by the soil. Requirements listed in the table are annual amounts that must be applied each year to prevent deficiencies.

In this study, requirements for nitrogen (N) and phosphorus (P) were taken from the tables. Phosphorus index values indicated great variability but seldom fell below the 100% sufficiency level. For areas where the P index was less than 65 (below 100% sufficiency), a requirement of 20 pounds per acre (lbs/A) was assigned.

Potassium index values also showed great variability ranging to below 75% sufficiency. Since some values were between those listed in the table, requirements were estimated from the table as described in the 1993 Oklahoma Soil Fertility Handbook (Johnson, 1993).

Data manipulation

Whole field method. ARC/INFO polygon coverages representing the whole field for each quarter section were created and georeferenced. The fields were digitized as polygons representing the ASCS field numbers. Items were created in the polygon attribute tables for each soil test variable (pH, BI, etc.) and the values from the soil test results were input as values for the corresponding items.

Soil test values were linked to each field as polygon attribute data. Since one composite sample was used to represent an average of the soil for the whole field, the values of each soil test variable, represented as attributes of the separate ASCS fields, are the same for all fields within each tract and each soil test variable contains only one value per field. Specifically, soil test results from the whole field method are the same for fields 2B, 2C, and 2D in tract 4807, and for fields 2A and 2B in tract 702.

Items were added to the polygon attribute tables for N, P and K--recommended material and amount per acre, acres, total material, unit cost, total cost--so that recommended amounts could be indicated and costs could be calculated. The recommended amounts per acre were read or estimated from the tables in _OSU Extension Facts No. 2225_, "OSU Soil Test Interpretations" (Allen and Johnson, 1993). The amounts per acre were then multiplied by the area of each field to give total recommended application amounts per field. Costs can be similarly calculated which would yield coverages enabling the producer to easily see the fields with the corresponding soil test results, as well as the calculated recommendations.

Subfield method. The same ARC/INFO polygon coverages representing the identified ASCS fields were used as the base coverages for the data from the subfield sampling method. The soil test values were linked to each area as polygon attribute data. Since separate composite samples were taken from each ASCS field, the soil test values from the subfield sampling method were assigned to the corresponding fields, and each soil test variable contained only one value per field.

As with the whole field method, items were added to the polygon attribute table for N, P and K--recommended material and amount, acres, unit cost, total cost--so that recommended amounts could be indicated and costs could be calculated.

Grid method. The locations of the grid sample points for each tract were digitized as ARC/INFO point coverages, and the soil test values for each sampling location were linked to the corresponding points as point attribute data.

For each soil test variable, values for semivariance were computed and fit with an authorized spherical semivariogram model. The semivariogram indicates that the pattern of variation is nonrandom up to a distance called the range, beyond which the variance is not spatially dependent. It also supplies estimates of the nugget (the portion of the variance which can be attributed to random error), and the sill (maximum variance where the semivariogram may level off) (Mulla, 1991; Burrough, 1986; McBratney and Webster, 1986).

The test values for each variable were interpolated at 45 foot intervals using kriging, which uses the parameters of the semivariogram model and the measured soil test values to estimate data at locations where no measured data exists. All neighboring values within a search radius of 518 feet were used for interpolation. This distance was selected because it included the nearest eight sample points. Where this radius did not include at least eight sample points (such as at field edges) the radius was expanded until it included eight points (Mulla, 1994). The use of this interpolation method is well documented and explained for use with soil data (Mulla, 1991; Burrough, 1986; McBratney and Webster, 1986).

The next step involved the aggregation of the interpolated values to delineate areas for which a range of soil test values and a recommended amount could be assigned. This was done by generating isolines from the interpolated values. The base and interval values used to generate isolines for the variables N, P, and K were determined by examining the nutrient requirement tables from the <u>OSU Soil Test Interpretations</u> (Allen and Johnson, 1993). Recommended amounts for unlisted values were estimated from the tables as described (Johnson, 1993). Values which indicated very high fertility on the soil test interpretation table were aggregated and assigned a uniform high value. (For example, K values greater than 250 were aggregated and assigned a value of 251. Isolines were then generated from a base of 125 at an interval of 6.25).

The isoline coverages were then edited to remove lines with intermediate values (not corresponding to the recommendation table). The tract outline was then added, polygon topology was created, and the appropriate value ranges were assigned to the polygons resulting in several "fertility maps" of the tracts. Each of these contains multiple polygons representing different fertility levels for one soil test variable. Each fertility map was overlaid with the ASCS field boundaries, enabling the examination of the different fertility levels in their proper spatial context within the ASCS fields.

As with the other methods, items were added to the polygon attribute tables--recommended material and amount, acres, unit cost, total cost--to create the final coverages representing recommended amounts and cost. The resulting coverage enables the producer to view the locations and areas within each field where different amounts have been recommended, as well as to produce recommendation summaries at the field level for the grid method results.

CHAPTER IV

RESULTS AND DISCUSSION

To evaluate the fertilizer recommendations derived from the different soil sampling techniques, the recommended rates for corn and a yield goal of 160 bu/A were read directly from the nutrient requirement tables in OSU Soil Test Interpretations (Allen and Johnson, 1993) or estimated from the tables as described in the Oklahoma Soil Fertility Handbook (Johnson, 1993).

The rates (lbs/A) of each recommended fertilizer for the two tracts as determined by the subfield and grid methods are presented by the Figures in this chapter, referred to later in the text. The presentation of results in this manner is perhaps the most revealing for comparison purposes because it shows how the results of the grid sampling method enable the producer to account for within-field nutrient variability. While the subfield method, by design, represents a composite estimated value for the field, the grid method may detect areas of high fertility that would be over-fertilized compared to the subfield results, as well as areas that are deficient which were not detected by the subfield method.

Tract 4807

The rates (lbs/A) of recommended nitrate (NO_3), phosphate (P_2O_5), and potash (K_2O) for each sampling method for tract 4807 were multiplied by the areas of each field to denote the total recommended amounts per field. The rates and totals are presented in Table I.

The rates (lbs/A) of recommended NO_3 for the subfield and grid methods are displayed in Figure 3. The display of the grid method results indicates areas with recommended rates ranging from 170 to 190 lbs/A and their locations within the fields. The results of the subfield method indicate a recommendation of 180 lbs/A NO_3 for field 2B, 190 lbs/A for fields 2C and 2D. The results of the whole field method indicate a recommendation of 190 lbs/A NO_3 for the three fields in tract 4807. Note that the subfield and whole field methods represent a uniform rate of application for each field.

The comparison of the maps of the subfield and grid results in Figure 3 reveals areas in all three fields for which NO_3 inputs might be varied, especially in fields 2B and 2C. In field 2B the recommended total from Table I is 7592.15 lbs compared to 8870.4 lbs (subfield) and 9300 lbs (whole field). The grid total is less because it reflects a lower rate of 170 lbs/A on 14.42 acres. In field 2C, the grid total is 9371.13 lbs (reflecting a lower rate of 170 lbs/A on 12.76 acres) compared to 9923.7 lbs (subfield and

		Recommended Fertilizer					
		NO_3		P_2O_5		K_2O	
	Method	lbs/A	total	lbs/A	total	lbs/A	total
Field 2B 42.98 acres	Grid.	170-190	7592.15	0-20	27.63	0-60	407.56
	Subfield	180	8870.4	0	0	0	0
	Whole Field	190	9300.2	0	0	0	0
Field 2C 52.23 acres	Grid	170-190	9371.13	0-20	348.15	0-60	615.14
	Subfield	190	9923.7	0	0	0	0
	Whole Field	190	9923.7	0	0	0	0
Field 2D 27.07 acres	Grid	170-190	5086.91	0-20	406.37	0-70	1443.9
	Subfield	190	5143.3	0	0	50	1353.5
	Whole Field	190	5143.3	0	0	0	0

Table I. Tract 4807 Fertilizer Recommendation Summary

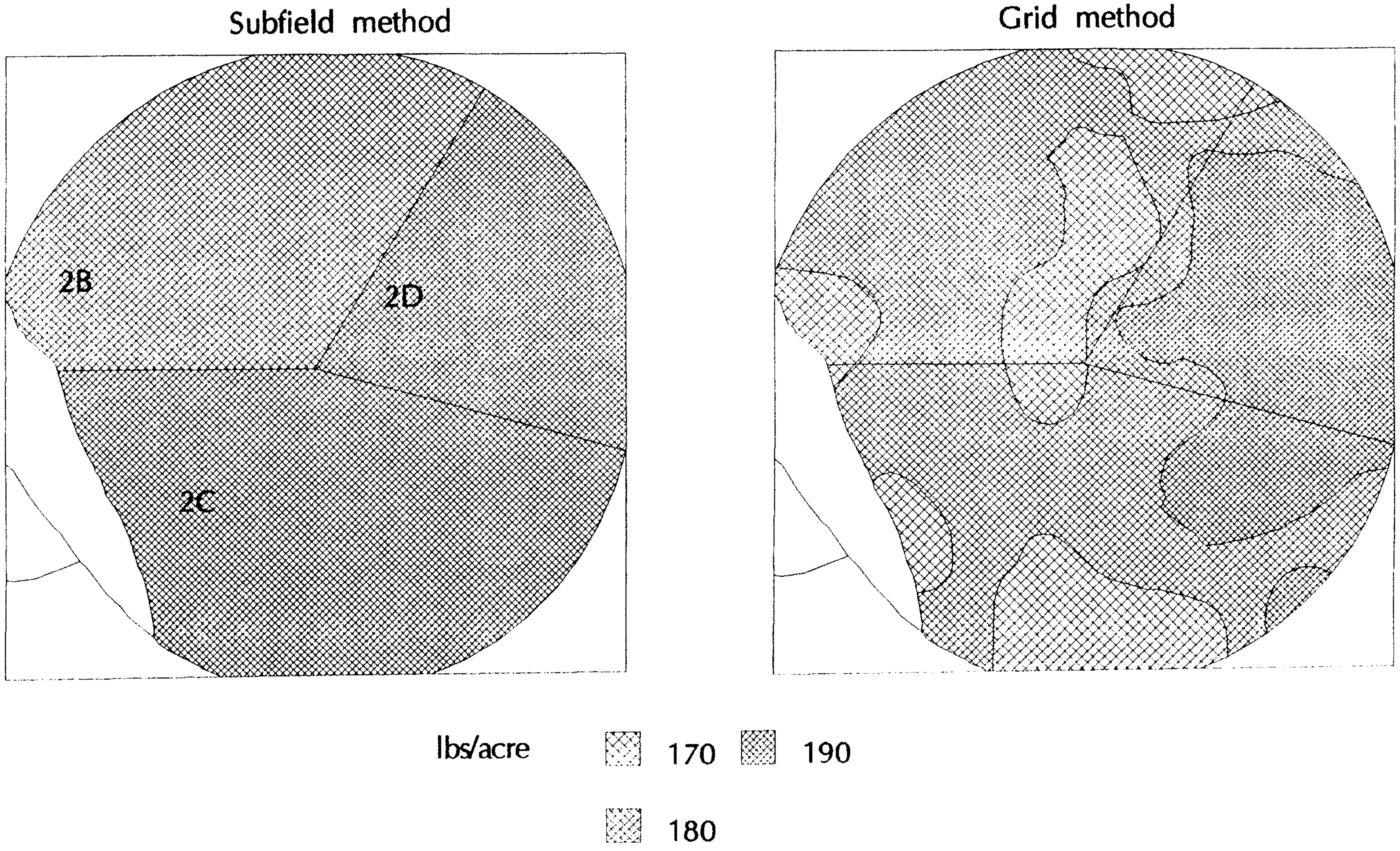

Figure 3. Tract 4807 NO_3 Recommendation Comparison

whole field). In this case, the producer might be able to reduce inputs without sacrificing yields.

The rates (lbs/A) of recommended P_2O_5 for the subfield and grid methods are displayed in Figure 4. The display of the grid method results indicate areas with recommended rates of 0 and 20 lbs/A and their locations within the fields. The results of the subfield and whole field methods indicated high phosphorus levels and no additional P_2O_5 recommendation for any of the three fields in tract 4807. The comparison of the maps in Figure 4 reveals 17.42 acres in field 2C and 20.32 acres in field 2D where additional P_2O_5 may be beneficial as determined by the grid method which were not detected by the other methods. In this case the grid method calls for increased inputs, and most importantly, shows the producer the location of the deficient areas.

The rates (lbs/A) of recommended K_2O for the subfield and grid methods are displayed in Figure 5. The display of the grid method results indicate areas with recommended rates ranging from 0 to 70 lbs/A and their locations within the fields. The results of the subfield method indicate no additional K_2O recommendation for fields 2B and 2C, and 50 lbs/A for field 2D. The whole field method indicated high fertility and no additional K_2O recommendation for any of the three fields in tract 4807.

The comparison of the subfield and grid results in

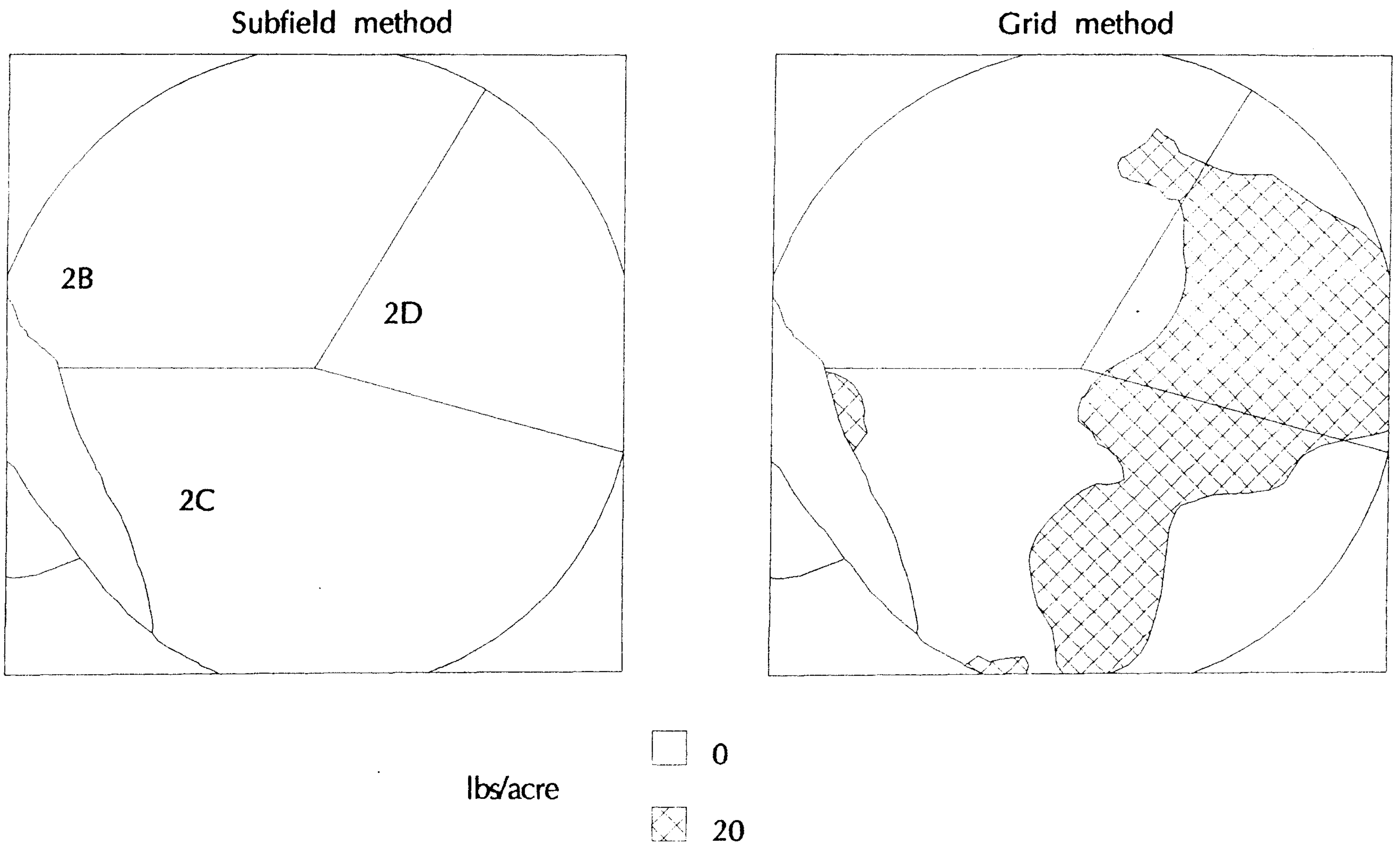

Figure 4. Tract 4807 P_2O_5 Recommendation Comparison

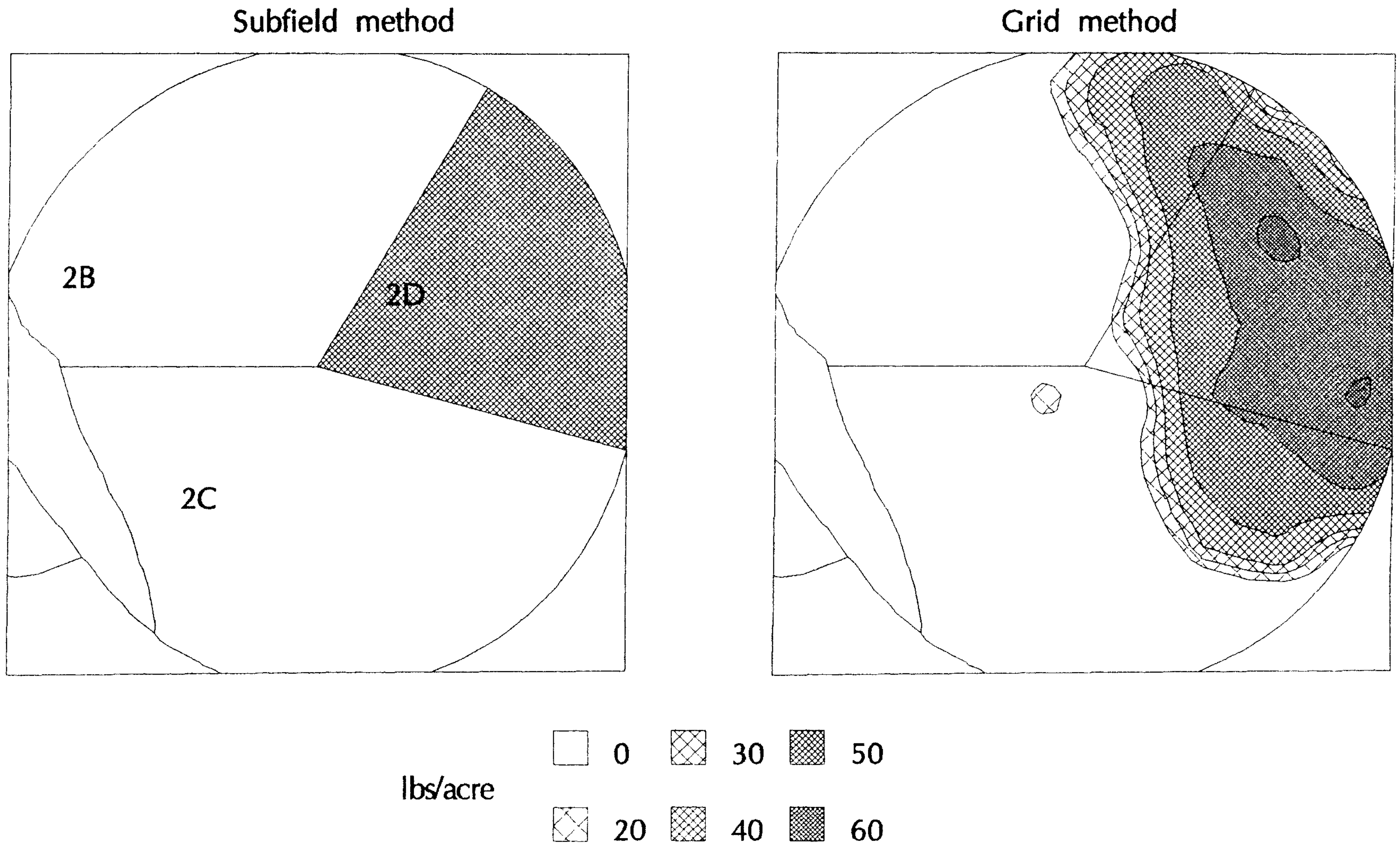

Figure 5. Tract 4807 K_2O Recommendation Comparison

Figure 5 shows 10.11 acres in field 2B and 14.18 acres in field 2C that have various levels of potassium deficiency as determined by the grid method which were not detected by the subfield method, as well as 10.3 acres in field 2D that would be over-fertilized and 16.77 acres that would be under-fertilized in comparison with the 50 lbs/A indicated by the subfield method. This case illustrates how the results from grid sampling can be much more useful to the producer because the comparison map shows the extent and magnitude of variability within the field. Knowing where different rates may be applied offers much more utility than the totals from Table I--1443.9 lbs (grid) and 1353.5 lbs (subfield).

Tract 702

The rates (lbs/A) of recommended NO_3, P_2O_5, and K_2O for each sampling method for tract 702 were multiplied by the areas of each field to denote the total recommended amounts per field. The rates and totals are presented in Table II.

The rates (lbs/A) of recommended NO_3 for the subfield and grid methods are displayed in Figure 6. The display of the grid method results indicates areas with recommended rates ranging from 140 to 190 lbs/A and their locations within the fields. The results of the subfield method indicate a recommendation of 180 lbs/A NO_3 for field 2A and

		Recommended Fertilizer					
		NO_3		P_2O_5		K_2O	
	Method	lbs/A	total	lbs/A	total	lbs/A	total
Field 2A 67.98 acres	Grid	140-190	12104.5	0-20	203.26	0-60	2290.34
	Subfield	180	12236.4	0	0	50	3399
	Whole Field	150	10197	0	0	40	2719.20
Field 2B 67.15 acres	Grid	150-180	11220.83	0-20	42.50	0-60	1916.52
	Subfield	160	10744	0	0	20	1343
	Whole Field	150	10072.5	0	0	40	2686

Table II. Tract 702 Fertilizer Recommendation Summary

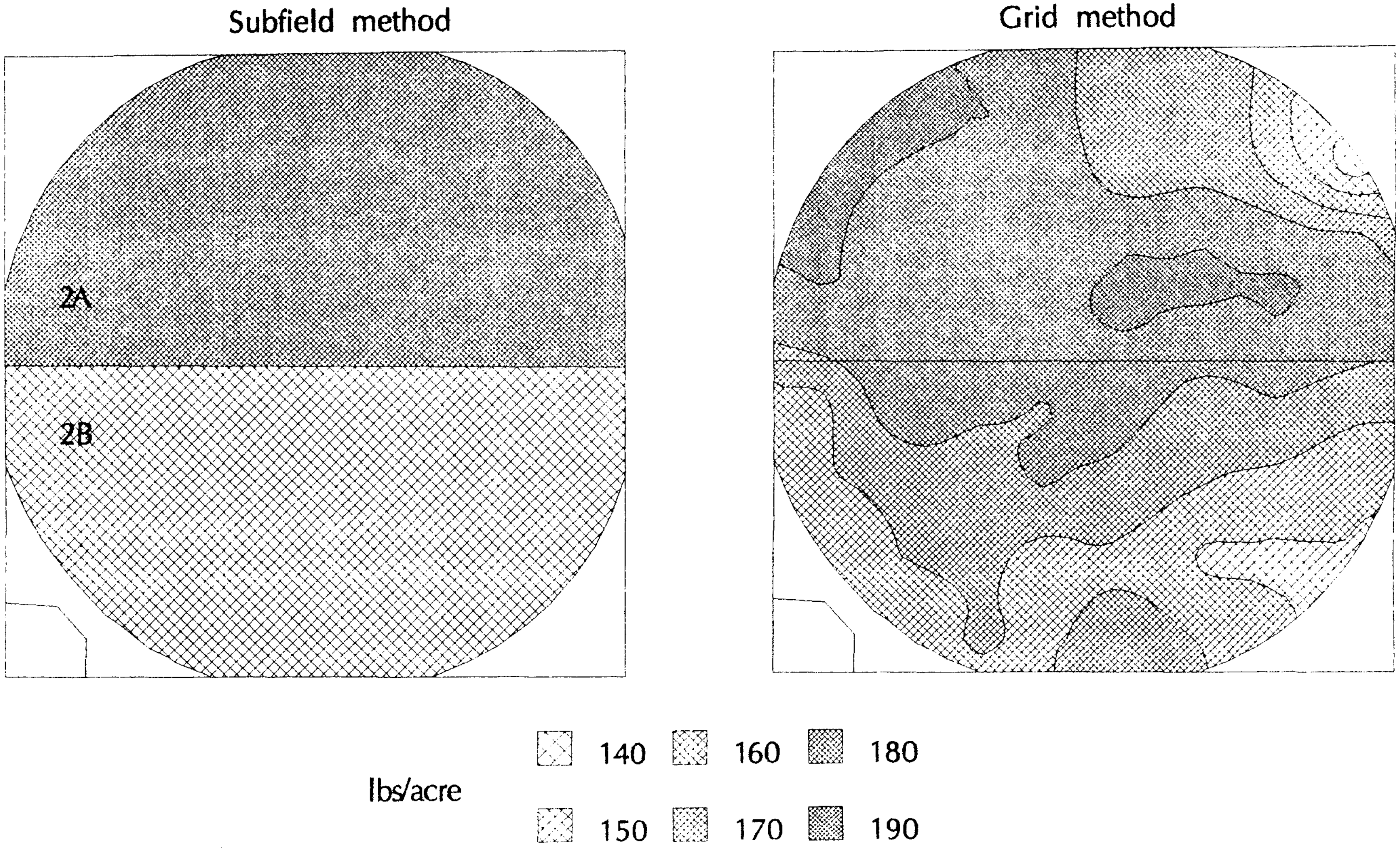

Figure 6 Tract 702 NO_3 Recommendation Comparison

160 lbs/A for field 2B. The results of the whole field method indicate a recommendation of 150 lbs/A NO_3 for the two fields in tract 702.

The comparison of the subfield and grid results in Figure 6 reveals areas in both fields for which NO_3 inputs might be varied. In field 2A the grid results show 9.71 acres that would be under-fertilized and 16.25 acres that would be over-fertilized compared to the uniform application of 180 lbs/A recommended by the subfield method. The grid results allow the producer to make more efficient use of inputs by more precise placement, even though the totals from Table II--12104.5 lbs (grid) and 12236.4 (subfield)--are essentially the same.

In field 2B the grid results show a recommendation of 170 lbs/A on 27.17 acres and 180 lbs/A on 11.6 acres, areas where additional NO_3 may be beneficial that would be under-fertilized by the 160 lbs/A recommended by the subfield method.

The rates (lbs/A) of recommended P_2O_5 for the subfield and grid methods are displayed in Figure 7. The display of the grid method results indicate areas with recommended rates of 0 and 20 lbs/A and their locations within the fields. The results of the subfield and whole field methods indicated high phosphorus levels and no additional P_2O_5 recommendation for either field in tract 702. This comparison reveals 10.16 acres in field 2A and 2.13 acres

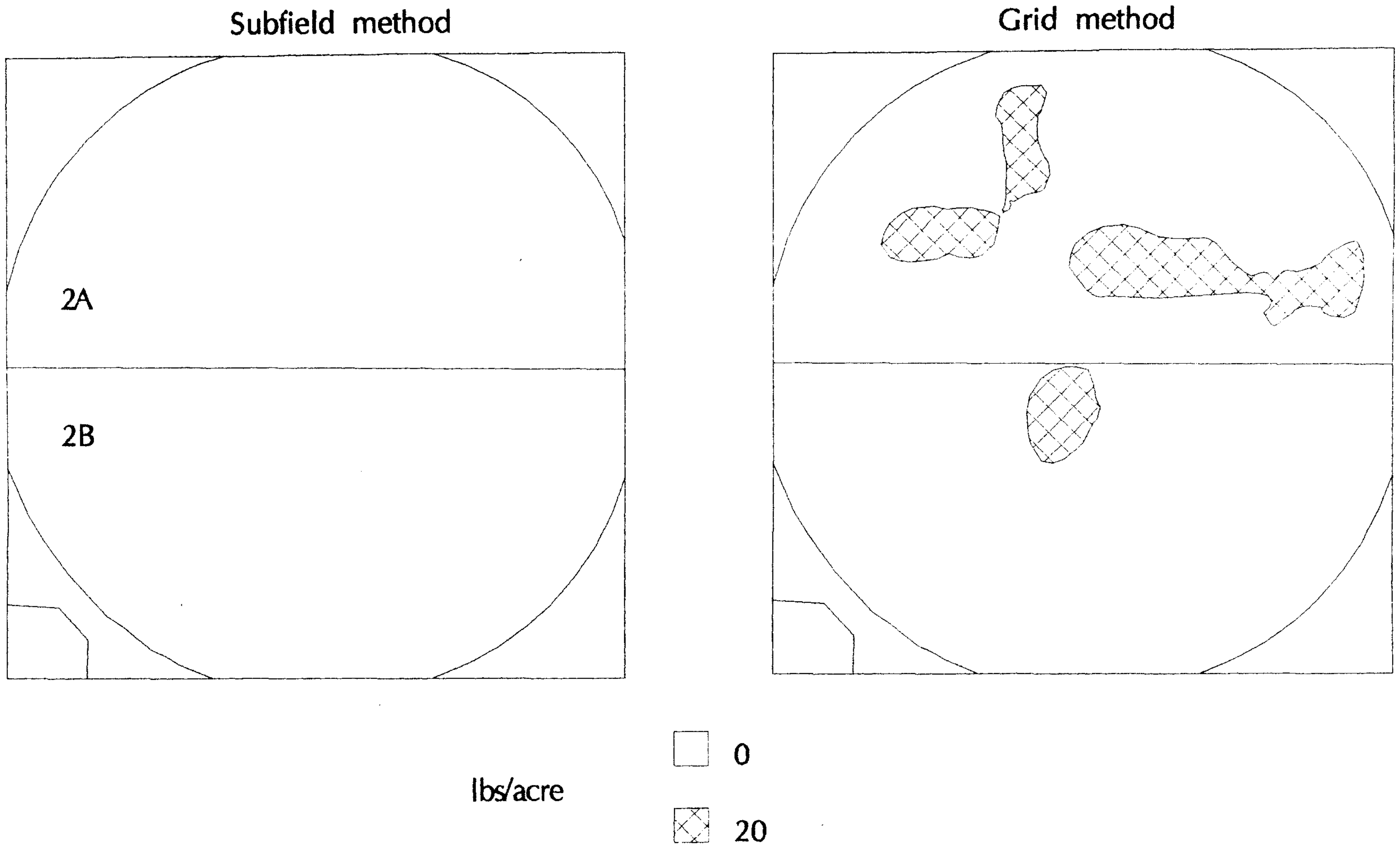

Figure 7. Tract 702 P_2O_5 Recommendation Comparison

in field 2B where additional P_2O_5 may be beneficial as determined by the grid method which were not detected by the other methods.

The rates (lbs/A) of recommended K_2O for the subfield and grid methods are displayed in Figure 8. The display of the grid method results indicate areas with recommended rates ranging from 0 to 60 lbs/A and their locations within the fields. The results of the subfield method indicate a recommendation of 50 lbs/A K_2O for field 2A and 20 lbs/A for field 2B. The whole field method indicated a recommendation of 40 lbs/A K_2O for the two fields in tract 702. The comparison in Figure 8 shows the areas of fields 2A and 2B where the potassium deficiency as determined by the grid method is greater than that detected by the subfield method, as well as areas of high potassium levels which would be over-fertilized in comparison with the recommendation indicated by the subfield method.

In field 2A the subfield total is 3399 lbs (Table II), representing a uniform application of 50 lbs/A over the 67.98 acres. The grid total was 2290.34 lbs, representing amounts ranging from 60 lbs/A on 9.76 acres to no additional K_2O on 17.43 acres. The grid total for field 2A is less than the subfield total even though areas of deficiency were detected, because areas of high fertility were also located.

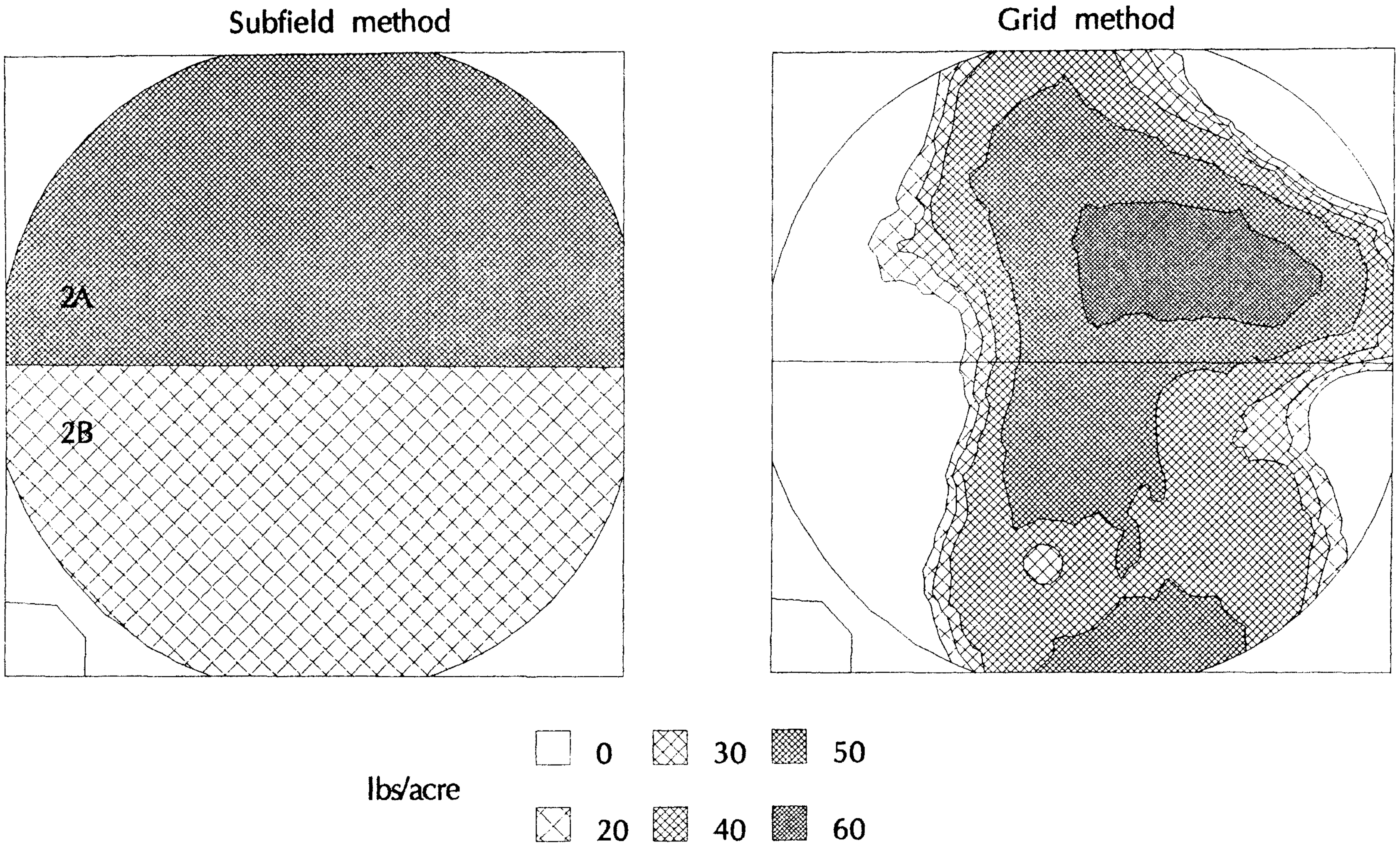

Figure 8. Tract 702 K_2O Recommendation Comparison

In field 2B the subfield total is 1343 lbs (Table II), representing a uniform application of 20 lbs/A over the 67.15 acres. The grid total was 1916.52 lbs, representing amounts ranging from 50 lbs/A on 15.16 acres to no additional K_2O on 20.31 acres. In field 2B the grid total was greater because it identified areas of greater deficiency that were not detected by the subfield method, even though areas of high potassium levels were also located. In both fields, results of the grid method enable the producer to account for within-field variability, so that K_2O could be applied only where needed. The K_2O recommendations for the two fields in tract 702 are perhaps the best examples of the superiority of grid sampling over averaging to achieve the optimal placement of inputs. The point is that the totals do not tell us very much, the maps do. Geography makes all the difference.

SUMMARY AND CONCLUSIONS

By combining various types of site-specific data (soil types, fertility, landuse) with regional data (PLSS grid, meteorological observations, TIGER files, Landsat imagery) to create a comprehensive database, agricultural producers can satisfy a variety of decision-making objectives by viewing and evaluating many different variables in combination. This project, which has focused on fertility recommendations, was not intended to be only a case study of these two particular tracts, but an example of a methodology using the site-specific approach that may be applicable to many fields in the region. The ability to view individual fields in the regional context greatly adds to the power and usefulness of the database. Fields can be seen in their proper spatial relationship to each other, to highways and secondary roads, and to streams and waterbodies. Site-specific layers can be overlaid on satellite imagery or aerial photographs, combined with regional soils data, and located by legal description.

Fertility Recommendations

As the fertility recommendations derived from the different sampling methods are compared, it becomes increasingly clear that the results of grid sampling give a more accurate dataset illustrating the variability of within-field nutrient conditions, potentially guiding the producer to more efficient fertilizer use either by the reduction of inputs or by the improved placement of inputs. While this is to be expected because of the nature of the sampling methods (the grid method being more intensive and more proportionally representative), it is in line with the objective--to show how producers can more effectively manage for within-field variability. The other methods are conventional and established because they are practical in the sense that farmers can implement and use them. If a producer wishes to use grid sampling, it is the GIS that enables him to handle the greater amount of spatial data, and that provides the tools for the interpolation, aggregation, and mapping. Without a GIS it is impractical.

The key advantage is the geographical perspective. The values of the soil test results can be preserved as characteristics of places. The fertility maps showing <u>where</u> different rates should be applied have much more practical meaning and significance than the total recommended amounts from the tables. The different fertility levels can be determined by the grid method as attributes of locations independent of pre-defined field boundaries, and then overlaid with the field units under study for use by the producer as a management tool. This is in contrast to the conventional methods for which the area is defined first and then fertility values are combined to represent an average.

It should be noted that the derived recommendations will not necessarily be applied by the producer, but should be used as input factors for decision-making. Looking at the P_2O_5 recommendations, for example, where only a slight deficiency is indicated, the producer can evaluate the added economic and environmental costs of the application and the expected marginal benefits, and act accordingly. He may decide that additional costs associated with the application of additional P_2O_5 would not be justified when compared to the anticipated resulting yield increase.

Suggestions for Further Study

From the results of this study it cannot be concluded that grid sampling is the best method in all cases, but in cases where significant variability does exist, the results suggest that grid sampling is superior to more conventional sampling methods. If the results of grid sampling indicate fairly uniform fertility within a field, the more intensive sampling accomplishes little except to increase costs. One of the most important areas for future study is the development of a methodology for the identification of fields with highly variable conditions so that producers can target appropriate areas for more intensive sampling.

The improvement of intensive within-field yield monitoring may offer one way to identify and assess variability, and also would be useful in evaluating the effectiveness of variable-rate applications. There is also great potential for the use of remotely sensed data to identify variable conditions by estimating such biophysical surface parameters as biomass and vegetative moisture.

Many questions exist regarding the use and manipulation of measured point data that call for further investigation. The spatial resolution for systematic aligned sampling is often arbitrarily selected. How can the proper intensity for soil sampling be determined? Should point data represent values for grid cells? Should they be interpolated? If so, by what interpolation method and to what resolution?

There is a trade-off in trying to define areas of a size suitable for management without losing the depiction of variability. At what intervals and levels should data be aggregated, if at all? Should a range of values be used to delineate management zones?

The Oklahoma MesoNetwork offers an exciting opportunity to develop applications for the unique meteorological dataset that continues to be generated. Further studies incorporating MesoNetwork data into an agricultural GIS may help to develop new methods for irrigation scheduling. These data might also be used as inputs for modelling efforts to reduce nonpoint-source pollution from agricultural chemical runoff to surface water or leaching to groundwater. Meteorological data might also be important inputs for the modelling of nutrient and fertility changes in the soil over time.

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