8-1999

Soil resource evaluation using precision farming techniques for selected sites in Tennessee

Ronald J. Gehl

Recommended Citation

Gehl, Ronald J., "Soil resource evaluation using precision farming techniques for selected sites in Tennessee. " Master's Thesis, University of Tennessee, 1999.
https://trace.tennessee.edu/utk_gradthes/6694

To the Graduate Council:

I am submitting herewith a thesis written by Ronald J. Gehl entitled "Soil resource evaluation using precision farming techniques for selected sites in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Donald D. Tyler, Major Professor

We have read this thesis and recommend its acceptance:

H. Paul Denton, John B. Wilkerson, Michael D. Mullen

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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John Wilkerson

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M D Mullen

Michael D. Mullen

Accepted for the Council:

C W Minkel

Associate Vice Chancellor and
Dean of The Graduate School

SOIL RESOURCE EVALUATION USING PRECISION FARMING TECHNIQUES FOR SELECTED SITES IN TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ronald J. Gehl
August, 1999

DEDICATION

This thesis is dedicated to my parents, Philip and Ruth Gehl. The only way I can ever repay you for all you've done is to strive to do my best with the knowledge and abilities you have given me. I also dedicate this work to my brother Daniel F. Gehl, an inspiration in everything I do.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to the following persons:

Dr. Donald D. Tyler, major professor, for his guidance, advice, and assistance throughout the course of this study.

Drs. Michael D. Mullen, H. Paul Denton, and John B. Wilkerson for serving on my graduate committee, the assistance they provided for both field and computer tasks completed during this study, and for their advice and suggestions in preparing this thesis.

Dr. Arnold M. Saxton, for his assistance with spatial data analysis and interpretation.

Jason Goodwin and the Agricultural Engineering Department for providing equipment, assistance, and advice without which this project would not have been possible.

Plant and Soil Science graduate students who I have come to know in my time here, Edwin Ritchey, Sloane Smith, Jeff Scott, Andrew Price, John Wah, Steve Komar, Eric Walker, Cheryl Ashburn, Susan Matthews, Anthony Ohmes, and all the others who have provided the friendship, advice, and encouragement necessary for handling everyday stresses associated with writing a thesis.

Tony and Ann Gehl, for allowing me to live in their house, and for their guidance and encouragement they have provided for as long as I can remember. Also to the rest of my family, especially my parents Philip and Ruth Gehl, for the support and love they have given me through the many trials of life.

Kathy Bryant, for all the love, encouragement, support, and friendship she has dedicated to me in the time we have been together.

And most of all God, for providing me with the gifts that make the life I live possible.

ABSTRACT

Crop yields have been shown to vary both between and within fields. Current technology allows for an accurate measurement of yield variability using Global Positioning System (GPS) and yield monitoring equipment. However, determination of the source of this variability is complicated by spatial differences in soil fertility, soil series, slope, and past management practices.

This statewide study was designed to test the effectiveness of conventional soil survey maps against an intensive soil map created for various sites in Tennessee. Field-specific soil maps were developed using intensive soil sampling, incorporated with GPS and Geographic Information System (GIS) software. Relationships between soybean yield and soil mapping units were then statistically compared using spatial correlation models and SAS proc mixed procedures. Intensive soil maps better explained soybean yield variation ($\alpha = 0.05$) although neither mapping technique was strongly related to yield. The site-specific maps were also better at distinguishing distinct yield groups by individual soil mapping unit.

Specific properties of the soil and crop landscape were also investigated to determine their affect on soybean yield. Properties that had a significant affect on yield included subsoil texture, slope, and pH. Slope and subsoil texture interactions and drainage and effective rooting depth (ERD) interactions also showed yield differences. Soil properties that did not affect yield included soil drainage class, ERD, available phosphorous, and available potassium. Interactions of ERD and subsoil texture, ERD and slope, drainage and subsoil texture, and drainage and slope also showed no yield differences.

Results of this study indicate that conventional mapping methods may not provide the necessary detail for use in today's precision farming applications. When investigating specific properties within soil units, a limit is set in explaining yield variation by the soil unit boundary and further variability related to the soil unit cannot be explained. Although site-specific maps are better than conventional mapping methods at predicting yields, an investigation into specific soil properties within a field may be necessary in providing a useful tool for producers implementing precision farming crop management.

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Ad	Adler SiL
Ar	Arrington SiL
BdC	Baxter cherty SiL, 5-12% slopes
BdC2	Baxter cherty SiL, 5-12% slopes, eroded
BdD2	Baxter cherty SiCL, 12-25% slopes, eroded
Bo	Bowdre SiC
BrE2	Bodine cherty SiL, 25-60% slopes, eroded
Bw	Bewleyville SiL
C	clay
Ca	Calloway SiL
Ca2	Calloway SiL, eroded
Ca3	Calloway SiL, severely eroded
CaB	Calloway SiL, 2-5% slopes
CaB2	Calloway SiL, 2-5% slopes, eroded
Ce	Center SiL
CeB	Center SiL, 2-5% slopes
CeB2	Center SiL, 2-5% slopes, eroded
CL	clay loam
Cm	Commerce SiL, frequently flooded
Cn	Convent SiL

Co	Collins SiL, occasionally flooded
Cr	Crider SiL
CrB	Crider SiL, 2-5% slopes
CsC2	Cumberland SiCL, 5-12% slopes, eroded
DGPS	differential global positioning system
Dk	Dekoven SiL
dpi	dots per inch
Ds	Dickson SiL
Ds2	Dickson SiL, eroded
Ds3	Dickson SiL, severely eroded
DsB	Dickson SiL, 2-5% slopes
DsB2	Dickson SiL, 2-5% slopes, eroded
DsC	Dickson SiL, 5-12% slopes
ERD	Effective Rooting Depth
Fa	Falaya SiL, rarely flooded
Fb	Falaya SiL, occasionally flooded
Fn	Fountain SiL
GaB	Greendale cherty SiL, 2-5% slopes
Gb	Greendale SiL
GIS	geographic information system
GPS	global positioning system

GrB	Grenada SiL, 2-5% slopes
GrB2	Grenada SiL, 2-5% slopes, eroded
GrC2	Grenada SiL, 5-8% slopes, eroded
GrC3	Grenada SiL, 5-8% slopes, severely eroded
Gu	Guthrie SiL
He	Henry SiL
He2	Henry SiL, eroded
Ib	Iberia SiL
Ie	Iberia SiCL
La	Lawrence SiL
Ld	Lindside SiL
Lo	Loring SiL
Lo2	Loring SiL, eroded
LoB	Loring SiL, 2-5% slopes
LoB2	Loring SiL, 2-5% slopes, eroded
LoC3	Loring SiL, 5-8% slopes, severely eroded
LoD2	Loring SiL, 8-12% slopes, eroded
LoD3	Loring SiL, 8-12% slopes, severely eroded
LoE2	Loring SiL, 12-20% slopes, eroded
LoE3	Loring SiL, 12-20% slopes, severely eroded
Mf	Memphis SiL
MfB	Memphis SiL, 2-5% slopes

MfB2	Memphis SiL, 2-5% slopes, eroded
MfC	Memphis SiL, 5-8% slopes
MfD/E	Memphis SiL, 8-20% slopes
MfE	Memphis SiL, 12-20% slopes
MfE2	Memphis SiL, 12-20% slopes, eroded
MfF2	Memphis SiL, 20-30% slopes, eroded
Mo	Mountview SiL
MoB	Mountview SiL, 2-5% slopes
MoC	Mountview SiL, 5-12% slopes
MoC2	Mountview SiL, 5-12% slopes, eroded
Ne	Newark SiL
PeB	Pembroke SiL, 2-5% slopes
PeC	Pembroke SiL, 5-12% slopes
PeC2	Pembroke SiL, 5-12% slopes, eroded
Re	Reelfoot SiL
Rt	Routon SiL
RtB	Routon SiL, 2-5% slopes
SiC	silty clay
SiCL	silty clay loam
SiL	silt loam
Ta	Taft SiL
Vk	Vicksburg SiL

Wa	Waverly SiL, rarely flooded
WcB	Waynesboro SiL, 2-5% slopes
WcB/BwB	Waynesboro L/Bewleyville SiL, 2-5% slopes
WR	Waverly and Rosebloom SiL, frequently flooded

1. INTRODUCTION

Traditional farming practices result in variable crop yields both between and within fields. This yield variability is a function of many sources that may include soil profile characteristics, erosion, past management practices, pressure from weeds, insects, and animals, or an interaction of these factors (Jaynes and Colvin, 1996). The crop yield patterns seen in a field under uniform management practices often reflect the pattern of soil conditions in which the crop is grown. Large yield differences have been observed over relatively short distances and areas of consistently high, consistently low, or erratic yields have been discovered (Bruce et al., 1990; Cambardella et al., 1994;). Several of the soil properties that will influence crop productivity exhibit high spatial and temporal variability. The measurement of this variability is complicated by the traditional practice of arbitrarily delineating boundaries of fields with little regard for variation in soil type, landscape position, or drainage class (Cambardella et al., 1996).

Productivity of soils may be defined as the rate at which a particular land area can fix accumulated energy as measured by cumulative biomass of a particular crop. Variables associated with crop productivity at a particular site are classed into two categories: inherent and cultural (Bruce et al., 1991). Inherent variables include those that are associated with climate, soil, and hydrological characteristics of the site. These variables are essential for evaluating the productive potential of any site. Cultural variables are those that include selection among a range of crop, nutrient, energy and crop biomass levels that constitute the cropping system. Productivity potentials of any given site can only be determined when cultural decisions are made based on characterization of the inherent variables (Bruce et al., 1995).

Soil properties have been shown to vary across landscapes due to differences in topography, parent material, and soil development. This systematic variation in soil properties across landscapes is controlled by hydrologic and geomorphic processes acting across a continuum of spatial and temporal scales and is inherently scale dependent (Parkin, 1993; Khakural et al., 1996). Solum thickness, thickness of the A horizon, organic matter content, soil pH, cation exchange capacity, bulk density, soil water content, and plant nutrient distribution have all been shown to vary with landscape position (Kleiss, 1970; Malo et al., 1974; Stone et al., 1985; Buol et al. 1989; Brubaker et al., 1993; Cambardella et al., 1994;).

Several studies have shown that relative soil thickness is often directly correlated with crop yields. Rhoton (1990) found that soybean yield correspondingly decreased with a decrease in soil depth above a fragipan. His study concluded that erosion of soils with limited profile thickness can reduce soil productivity to the point where crop yields are no longer profitable. Khakural et al. (1996) concluded that greater crop yields were obtained in footslope positions compared to backslope and sideslope positions due to the relatively deeper soil profile in the footslope. These findings are supported by the previous research completed by Power et al. (1981) showing an increase in yields as total soil thickness increased.

Soybean yield levels are primarily determined by the amount of water available to the plant during flowering and pod-filling stages (Rhoton, 1990). Thus the available water-holding capacity of a soil influences yield directly by reducing the soil's ability to store water for crop use between significant precipitation events (Nizeyimana and Olson, 1988). A limited soil profile restricting the amount of water available can therefore greatly influence crop productivity. This fact is especially pertinent when a fragipan, clay pan, or sand layer exists in the soil profile. Increased soil water storage capacity may be the primary factor influencing crop yields on soils where fertility is not a limiting factor (Rhoton, 1990).

A variety of studies have described the relationship between degree of soil erosion and several soil properties that influence productivity and potential yields (Frye et al., 1982; Stone et al., 1985; Nizeyimana and Olson, 1988; Rhoton and Tyler, 1990; Cihacek and Swan, 1994; Bruce et al., 1995; Lowery et al., 1995). Soil thickness influences plant rooting depth and the amount of soil water available for plant growth, thus influencing total crop productivity. Power et al. (1981) found this relationship especially important on soils with underlying materials that consisted of a poor medium for plant root activity. Other studies have also shown that the plant available water is directly related to thickness of the soil and has a strong influence on yield variability seen across soil landscapes (Khakural et al., 1996).

Other soil characteristics influencing crop productivity are also influenced by soil depth. Rhoton (1990) showed that soil organic matter, soil organic carbon, and pH at the soil surface decrease with decreasing profile depth above a fragipan. The increase in acidity in the soil surface in turn increases the availability of some toxic elements that stunt root growth and reduce opportunities for the uptake of additional water (Nizeyimana and Olson, 1988). Whether the relationship between these factors and soil depth is due to erosion class or a function of landscape position has been disputed (Rhoton, 1990).

Soil texture and structure also contribute to crop yield variability. Bruce et al. (1990), Khakural et al. (1996), and Cambardella et al. (1996) all showed a negative correlation between soybean yield and surface clay content, while surface silt content and soil organic matter content were positively correlated with soybean production. Bruce et al. (1990) showed that as surface clay content increased from three to 18%, soybean yield greatly decreased and the yield response to pH, rainfall, and soil water tension was reduced. The importance of soil structure in defining water relations in the soil-plant system is seen by the significant contribution of aggregate size distribution, surface coarse fragments, and bulk density to yield variability (Cambardella et al., 1996; Khakural et al.,1996). Soils exhibiting relatively higher bulk densities and stronger aggregation limit the abilities of plant roots to explore the subsoil for additional water needed in times of moisture stress (Nizeyimana and Olson, 1988).

Many soil properties that affect crop yield are spatially distributed over a landscape. This soil spatial variation has a strong influence on the productivity variation found in these areas. Cambardella et al. (1994) presented data on the spatial distributions of several soil properties at the field and watershed level. Soil organic carbon, total N, pH, and macroaggregation were all shown to be strongly spatially dependent variables. Biomass C and N, bulk density, and denitrification were properties that reflected a moderate spatial dependency, and NO_3^- N, mineral N, Ca, and Mg were not spatially dependent (Rhoton, 1990; Khakural et al., 1996). Non-normal distributions of organic C and pH were determined by Miller et al. (1988) while Young et al. (1992) reported non-normal distributions of particle size fractions of both surface and subsurface horizons, pH, organic C, and epipedon thickness (Young et al., 1999). Although spatial changes in soil fertility have shown little effect on yield variation, many of the previously mentioned spatial chemical and physical properties can strongly influence yield (Rhoton, 1990; Khakural et al., 1996).

Levels of variability associated with estimates of any given soil property require an associated estimate of the variability of that property for a scale that is pertinent to the research question(s) being considered. Soil classification and survey have been the most common methods used for partitioning variation at the field and watershed scale. Soil class maps are generated from soil surveys, where the average values of soil properties are estimated within a defined region or mapping unit. These values are often predicted for the majority of locations in the region and are not actually field-measured values (Cambardella et al., 1994). This method of delineating soil boundaries may lack the necessary detailed information required for use in many of the soil analyses and procedures used today. A more accurate and objective method for improving and supplementing existing soil maps is needed in meeting the precision farming requirements currently being implemented. (Indorante et al., 1996; Young et al., 1998; Ahn et al., 1999)

Detection of spatially variable yields and soil properties has in the past been difficult but can now be aided by technological advances that have evolved in recent years. These advances have provided accurate, relatively inexpensive equipment for precision farm applications. Crop yield monitors, Global Positioning System (GPS) technology, and Geographic Information System (GIS) software have allowed researchers and producers alike to micro-manage on even a large scale (Cambardella et al., 1996; Morgan and Ess, 1997). The overall agricultural objective of increasing crop yield per unit of input energy for a field requires favorable soil conditions across the entire field during critical times of the crop season. Soil situations that are depressing yield must therefore be identified, and methods for predictable improvements of these low-yielding areas must be formulated in an acceptable time frame. This can be done when important soil characterization factors are known, and the available or readily attainable data concerning crop yield can be easily interpreted (Bruce et al., 1990).

Soil property variability within fields is often described using classical statistical methods, where the variation is assumed to be randomly distributed within mapping units. However, parametric statistics are often inadequate for analysis of spatially dependent yields and soil properties because they assume that measured observations are independent despite their distribution in space (Cambardella et al., 1994; Young et al., 1999). Several methods of both parametric and nonparametric analysis for field experiments have been proposed (Littel et al., 1996; Gilmour et al., 1997; Young et al., 1999). Geostatistical analyses involving various spatial models have been used as an alternative for estimating spatial variability of soil physical properties (Viera et al., 1981; Lascano and Hatfield, 1992), biochemical properties (Bonmati et al., 1991; Sutherland et al., 1991), and microbiological properties (Aiken et al., 1991; Rochette et al, 1991) that may have direct influence on yield (Cambardella et al., 1994).

The goal of spatial statistics is to model and estimate the patterns that often exist in spatial variability. The relationship among observations in proximity to each other, or small-scale dependence, is of particular interest in designed field studies. The tendency of close observations to be more alike than observations farther apart results in a positive small-scale spatial dependence, or positive spatial correlation. Due to this correlation and the spatial heterogeneity often seen in field experiments, the use of statistical methods that do not account for spatial dependence can result in erroneous results and conclusions (Littell et al., 1996).

The growing interest in precision agriculture led to the 1997 initiation of a Tennessee statewide research project, aiming to assist producers in locating site-specific areas within soybean fields that produce both high and low yields. This study was a cooperative effort involving University of Tennessee soil scientists, agricultural engineers, and agriculture extension service agents, the Tennessee Soybean Promotion Board, and several soybean producers throughout the state. Precision farming techniques and technologies, including yield monitoring, GPS equipment, and GIS software, were implemented to collect and handle field data for analysis and interpretation.

The overall objectives of this research project were to determine variables that contributed to in-field soybean yield variability and to propose a strategy for managing this variability. The specific objectives of the research presented in this thesis were to (i) evaluate possible sources of yield variation within selected soybean fields, (ii) determine field scale soil mapping units by studying profiles intensively sampled at each site, and (iii) determine effectiveness of intensive soil maps vs. conventional USDA-SCS[1] soil survey maps for explaining and predicting soybean yield variability.

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[1] United States Department of Agriculture, Natural Resources Conservation Service-formerly Soil Conservation Service. Reference in this text will be presented as SCS documentation.

2. MATERIALS AND METHODS

Site Description

Study sites were chosen to represent various soil landscapes throughout the state, with consideration given to the yield potential of the site. All sites were located in fields that were in no-till soybean crop management and were chosen with preference to producers currently using yield monitors in their combines. An attempt was made to include as many of the state's soil series typically used for soybean production as would be economically feasible for the project. Five privately-owned farms and a total of nine producer fields were selected as sites in five counties of the state, including: Franklin County, Montgomery County, Obion County, Weakley County, and Lake County. A map of the general site locations can be found in Appendix A. Taxonomic classifications for the soil series referred to in this study are included in Appendix B (http://www.statlab.iastate.edu/soils/sc/).

Franklin County

Three field sites were located in this county, which is located in south-central Tennessee on the Eastern Highland Rim physiographic region (Springer and Elder, 1980). The soils at these sites formed from limestone bedrock and thin loess and are identified within the Dickson-Baxter-Greendale and Bodine-Baxter-Ennis soil associations. Site F1 (35°16'10"N, 86°13'55"W) included 22.5 acres of primarily Dickson and Lawrence soils on an undulating landscape. This site is cropped as full season soybeans. Site F2 (35°18'00"N, 86°15'05"W) encompassed 29 acres of rolling landscape with mostly Dickson and Baxter soils. Site F3 (35°15'55"N, 86°12'50"W) contained 40 acres of undulating landscape with predominantly Dickson and Lawrence soil series (Soil Survey Staff, 1958; Soil Survey Staff, 1975). Sites F2 and F3 were managed in a corn-soybean-wheat rotation.

Lake County

One field was used as a site in Lake County. Lake County is in the northwestern corner of Tennessee, bound on the west by the Mississippi River. Site L1 (36°17'30"N, 89°31'30"W) consisted of 180 acres of generally level landscape in the Mississippi River alluvial flood plain in the Reelfoot-Tiptonville-Adler soil association. The primary soils located at this site included the Bowdre, Commerce, and Iberia series (Soil Survey Staff, 1969). The western border of the site was bound by a levee and the site was frequently flooded. The field was managed as full season soybeans.

Montgomery County

One project field site was used in this county, located in the north-central part of the state. Site M1 (36°35'55"N, 87°11'05"W) is found on the Western Highland Rim (Springer and Elder, 1980) in the Pembroke-Crider soil association and contains 68 acres of gently rolling landscape. Dickson, Taft, and Pembroke are the principal soils found throughout the site area. These generally loamy soils were formed by a layer of loess over an alluvial layer covering limestone bedrock (Soil Survey Staff, 1975). A corn-soybean-wheat rotation was used to manage this site.

Obion County

Obion County is located in the northwest corner of Tennessee on the Silty Uplands physiographic region (Springer and Elder, 1980). Site O1 (36°21'15"N, 89°06'10"W) was located in a gently rolling bottom land area with 100 acres of mostly Grenada, Adler, and

Falaya soils in the Falaya-Waverly-Collins soil association. Site O2 (36°22'10"N, 89°05'40"W) was located on a steeply rolling upland with primarily Memphis and Loring soils and contained 65 acres. This site fell into the Grenada-Loring-Memphis association which formed from silty loess deposits (Soil Survey Staff, 1973). Corn-soybean-wheat rotations were used to manage each of these sites.

Weakley County

Two fields were used as sites in Weakley County, located in the northwestern part of the state. Site W1 (36°26'35"N, 88°43'20"W) was cropped with full season soybeans and was located on a generally flat bottom land site of 53 acres in the Waverly-Falaya-Rosebloom soil association. Soils in this association are alluvial soils and the major series found at the site were Collins, Waverly, and Falaya. Site W2 (36°28'10"N, 88°43'50"W) was a gently sloping upland site in the Loring-Grenada-Collins soil association. This site contained 110 acres and was in a corn-soybean-wheat rotation. Soils in this area predominantly formed from loess and alluvial deposits and common soils at this site included Routon, Calloway, and Grenada (Soil Survey Staff, 1992).

Field Scouting

Each of the research sites was scouted during the 1997 growing season to identify areas that may have specifically caused yield variation within the site. Problem areas that were investigated included insect damage, weed pressure, poor plant stand, moisture stress, and wildlife damage. These areas were identified by field researchers with assistance from county extension agents and producers. All boundaries of fields being used were recorded by driving the boundary on a Kawasaki Mule[2] all-terrain-vehicle using a Trimble AgGPS 132[3] GPS receiver. Once a problem area was identified, it's location in the field was recorded using a hand-held Trimble GeoExplorer II GPS receiver. The data collected during the growing season by scouting was downloaded and differentially corrected using Pathfinder Office[4] software and was later managed using ArcView[5] GIS software.

Yield Measurements

Producers involved in this study had previously installed instantaneous yield monitors on their combines. Those producers using a yield monitor without a differentially corrected GPS (DGPS) unit to geo-reference the data were provided either Trimble AgGPS 122 DGPS or AgGPS 132 DGPS receivers for use during harvest of the research fields. The yield monitors in the combines used were calibrated on-site by project staff prior to harvest of the research fields. During the harvesting of the soybeans, each producer was assisted by at least one research cooperator. This provided a reliable source of data with as few errors as possible and ensured that data was collected properly.

Following completion of harvest of the research fields, yield data was compiled and yield maps were printed for each field. Using these maps, accurate representations of high,

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[2] Kawasaki Motors Corp., U.S.A., 9950 Jeronimo Road, Irvine, CA 92618-2084.

[3] Trimble Navigation Limited, 645 N. Mary Avenue, Sunnyvale, CA 94086.

[4] Pathfinder Series Post-Processing Utilities, Trimble Navigation, Sunnyvale, CA 94088-3642.

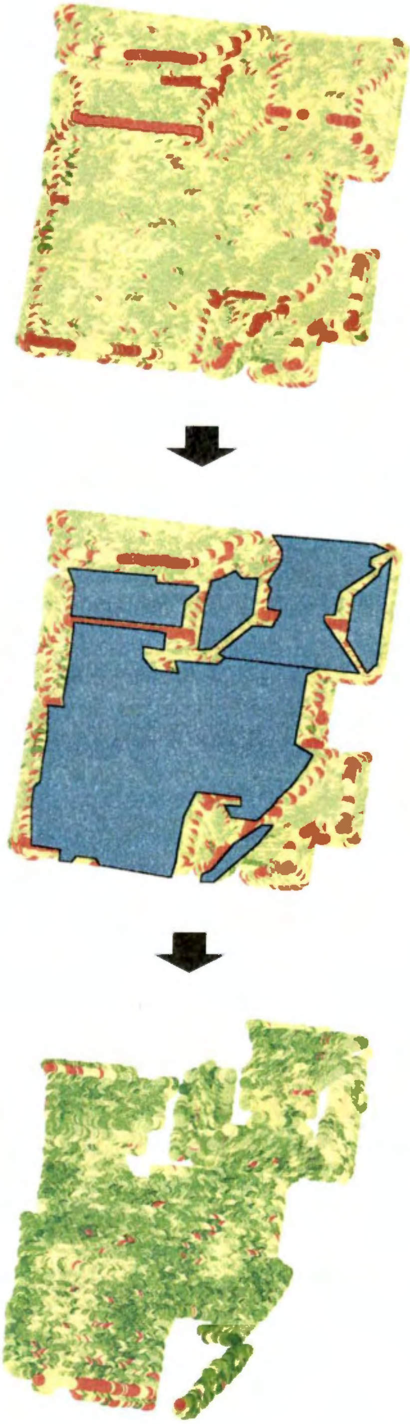
[5] Environmental Systems Research Institute, Inc., 380 New York Street, Redlands, CA 97373-8100.

low, and average production could be identified in each field. Fields showing defined patterns of yield variation were further investigated. Selected locations within these fields were intensively studied to determine levels of soil nutrients, nematodes, soil type, surface erosion, rooting depth, and pest problems.

Yield data were exported from the yield monitors to a common text format. These data were then imported into ArcView where yield maps were created and modified as needed. Since raw yield data is often found to be highly variable and can contain misleading points, it was necessary to eliminate as many erroneous yield data points as possible (Blackmore and Marshall, 1996). All field boundaries were clipped to remove edge effects, point rows, and areas where the combine stopped or turned around. Yield measurements less than 5 bushels/acre (bu/ac) or greater than 75 bu/ac were discarded. Any points taken while the combine ground speed was less than 1 mile per hour (m.p.h.) or greater than 7 m.p.h. were also discarded. Areas within sites that had been identified during site scouting as probable low-yield areas for reasons other than soil properties were also eliminated (Figure 1). Corrected yield maps for each of the sites are included in Appendix C.

Field Sampling

The research areas were soil sampled following harvest to evaluate the soil conditions and measure possible characteristics that may influence crop yield. Samples for nutrient analysis were taken on 2.5 acre grids with a sampling radius of approximately 100 feet around the grid center. The areas that showed distinct yield patterns were re-sampled at a smaller grid size of 110 feet within a thirty-foot radius around the grid center. All nutrient



Original yield map collected in the field.

Highlighted area included in analysis.

Area remaining following clipping.

Figure 1. Site O1 yield maps illustrating the removal of erroneous points due to factors other than those directly related to soil mapping units. Selection and elimination of points was completed using ArcView GIS software.

samples were taken to a depth of 6 inches. Samples were analyzed by the Tennessee State Soil Testing Laboratory[6] for pH, phosphorous (P), and potassium (K) levels. Soil pH was determined using a glass electrode, a potentiometer, and a 1:1 soil to water ratio. Extractable P and K values were obtained using a Mehlich I (0.05 N HCl in 0.025 N H_2SO_4) extracting solution (Hanlon, 1998).

An intensive soil characterization and mapping was also completed at each site. This characterization was strongly influenced by individual site landscapes and the existing USDA-SCS soil surveys. This method was used based upon previous research showing that soil type patterns often follow changes in landscapes and changes in soil types often occur at breaks in the landscape (Buol et al., 1989; Bruce et al., 1990; Khakural et al., 1996). Topographic elevation maps created from yield monitor GPS data were used as aids in determining landscape breaks and relative elevations.

A soil bucket auger was used to sample selected locations at each site. Each sample profile was then examined for identifiable features and characterized. The profiles were examined to various depths at each sampling location. Sampling depth was determined by depth to identifiable profile characteristics as described in the respective county soil surveys. The number of auger samples taken was determined at each site individually and varied between the sites. Typically, the number of observations varied from about one to two per acre. Slopes at each sample location were determined using a clinometer and were assigned into respective classes (0-2% A, 2-5% B, 5-12% C, 12-25% D, 25+ % E). Erosion class was

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[6] Tennessee Agriculture Experiment Station, University of Tennessee, Knoxville, TN 37901

determined based upon depths to root restrictive horizons (0-12" IV, 12-20" III, 20-30" II, 30+" I).

Each auger sample location was flagged and labeled in the field and its position was logged into a Trimble AgGPS 132 DGPS unit. Following sample completion at each individual site, the soil boundaries were drawn on the landscape by driving the ATV along the boundaries while being logged on the DGPS unit and recorded into a palm-top computer. This method resulted in a more precise estimation of the soil mapping units than could be obtained from county soil surveys. Following the field collection of the soil data, any necessary corrections or changes were made and the maps adjusted as needed. Units of less than one acre in size were delineated where they had landscape expression.

The intensive soil map positional data were imported into ArcView where maps were created and each soil map unit was assigned a label in its attribute table. These maps can be found in Appendix D. Each site was located in its respective county soil survey and scanned into a 75-dots per inch (dpi) bitmap format. The bitmap images were imported into ArcView and geographic coordinates were assigned to the images with the ArcView Warp Environment extension using reference points recorded near each site. Polygons representing the various soils within each field were then traced to create a referenced soils map within ArcView representing the USDA-SCS Soil Surveys for each of the sites. Soil units were then assigned appropriate labels. These maps can be found in Appendix E.

Statistical Analysis

Influence of Soil Mapping Units on Yield

ArcView attribute tables for each yield map and its corresponding intensive soil map and soil survey map were joined based on geographic coordinates. Each yield point recorded was therefore assigned a respective soil mapping unit for both the intensive and SCS soil survey soil maps for each site. In order to satisfy computational constraints with one gigabyte of memory using the SAS (1999) PROC MIXED procedure, adjacent yield points were averaged so that approximately 2200-4000 points per site remained for analysis (A. Saxton, personal communication). Semivariograms were then produced using the SAS 7.0 PROC VARIOGRAM procedure to determine whether exponential, gaussian, or spherical correlation models fit the yield data. For each site, the exponential model fit the data best as was visually evident by a pattern that most closely matched the observed variogram. Spatial analyses relating soil mapping units to yield were then performed using the SAS PROC MIXED procedure with nugget, sill, and range values that were obtained from each semivariogram (Littel et al., 1996; [SAS] Statistical Analysis Systems, 1999). Yield point numbers used for analysis of soil data and nugget, sill, and range values used for each site can be found in Table 1. Soil mapping units were compared with an LSD mean separation on the yield least square means at $\alpha = 0.05$ (Saxton, 1998).

Soil Property Variables Affecting Crop Yield Pattern

An investigation into specific soil properties within intensive survey soil mapping units was completed using SAS statistical procedures. This analysis followed the same procedures as previously mentioned. However, a combination of all site yield results versus

Table 1. Yield points number (N) used to compare with soil data for each site. Nugget, sill, and range values estimated visually from semivariograms.

Site	Survey Method	Size (ac)	Original N	Adjusted N	Nugget $(bu/ac)^2$	Sill $(bu/ac)^2$	Range (m)
F1	Intensive	22.5	6955	2400	10	65	25
	Conventional		6955	2385	10	65	25
F2	Intensive	30.0	7751	2719	10	150	15
	Conventional		7751	2702	10	150	15
F3	Intensive	40.0	25704	2365	10	25	30
	Conventional		25704	2296	10	25	30
L1	Intensive	196.0	40279	3926	10	65	50
	Conventional		40279	3897	10	65	50
M1	Intensive	68.0	26265	2324	10	55	80
	Conventional		26265	2407	10	55	80
O1	Intensive	80.0	17491	2352	10	10	40
	Conventional		17491	2330	10	10	40
O2	Intensive	65.5	10703	2260	10	21	20
	Conventional		10703	2282	10	21	20
W1	Intensive	53.0	7781	2674	2	18	85
	Conventional		7781	2659	2	18	85
W2	Intensive	77.0	12514	2308	2	13	65
	Conventional		12514	2323	2	13	65

soil properties was analyzed using the PROC MIXED model and a randomized block design blocked on individual field. Several analyses were initially run to determine the model which best explained yield variation. The analysis that is reported in this paper was determined to be the best model.

Soil properties of interest to this study included soil drainage, slope, effective rooting depth (ERD), subsoil texture, and P, K, and pH levels. Soil drainage classes and predominant subsoil textures were obtained from each site's respective SCS county soil survey. Effective rooting depth and slopes were determined during field sampling of soil units.

In order to evaluate fertility effects within soil mapping units, soil nutrient data results from both the 2.5 acre and 110 foot grids were initially combined into one data set. A correlation model was then run on the nutrient data of each site using PROC VARIOGRAM (SAS) to determine whether the grid sample points were spatially related. The resulting semivariograms indicated spatial correlations existed between the nutrient sample points. This allowed for spatial smoothing of the nutrient data. The nutrient data for each site were then interpolated using inverse distance weighted procedures in ArcView, based on the four nearest neighbors with a weighted coefficient inversely proportional to the square of distance. This resulted in a continuous nutrient data layer with nutrient values estimated across every 1.5 meter grid cell for each site. Average nutrient values for each intensively-mapped soil unit were then obtained using the Summarize Zones procedure in ArcView (Environmental Systems Research Institute, Inc., 1998). Tables of summarized nutrient results for each site can be found in Appendix F.

3. RESULTS AND DISCUSSION

Effect of Soil Mapping Unit on Soybean Yield

Yield data were normally distributed in all tests. Initial PROC GLM procedures of SAS indicated that soil units explained no greater than 15% of the soybean yield variation for any site or mapping technique. In addition, SAS analysis of variance (ANOVA) results indicate that the majority of variation in yield data was not statistically affected by soil mapping unit at the $\alpha = 0.05$ level (Table 2). This was especially true when considering soil units that were mapped in the SCS soil surveys. Only one SCS soil survey map of the nine sites was statistically related to yield variation. Soil units mapped intensively at each site were better at explaining yield variation. Four of nine sites showed statistical significance ($\alpha = 0.05$) for explanation of yield variability by soil mapping unit.

Site F1 in Franklin County was the smallest project site (22.5 acres) and was the only location in which both the intensive and SCS soil map were closely related to yield. The site-specific maps for field sites in the same county (sites F2 and F3) as well as site L1 in Lake County also contained soil units that explained yield variation, while no other site maps contained soil units that significantly explained yield. This may be an indication that the variable separating the soils mapped in these two counties are more closely related to yield than was the case with the soils found in each of the other counties.

The fact that the soil maps used for this study did not effectively explain yield patterns within a field may be due to other soil property factors overwhelming those that were investigated. It may also have been due to a failure of the soil mapping, even at this

Table 2. Summarized analysis of variance for soil mapping unit versus soybean yield for each site and soil survey method. Pr > F values less than 0.05 indicate significance.

Site	Survey Method	Type III F	Pr > F
F1	Intensive	5.47	< 0.0001
	Conventional SCS	10.14	< 0.0001
F2	Intensive	2.04	0.0313
	Conventional SCS	2.20	0.1115
F3	Intensive	6.47	< 0.0001
	Conventional SCS	0.80	0.3697
L1	Intensive	10.19	< 0.0001
	Conventional SCS	1.47	0.2299
M1	Intensive	0.41	0.8938
	Conventional SCS	0.91	0.5102
O1	Intensive	1.41	0.1877
	Conventional SCS	0.87	0.4837
O2	Intensive	1.42	0.2256
	Conventional SCS	0.49	0.8129
W1	Intensive	0.14	0.9837
	Conventional SCS	0.48	0.7505
W2	Intensive	0.54	0.8640
	Conventional SCS	0.46	0.8353

intensity, to accurately separate landscape areas of differing productive potentials. Soil properties within a unit itself may have a more specific influence on yield than the soil unit viewed as a whole. The variability may occur over smaller distances than can practically be delineated by the methods commonly used in mapping. The intensive maps, though more specific to the field scale, were often times not different enough from the original soil maps to be a better predictor of crop yield within a site. Other variables may have possibly overwhelmed the effect of soil physical properties and landscape characteristics. It is also possible that in a good production year, soil differences which often relate to water-supplying differences did not express themselves as they would in a drier year. It is interesting to note that soil units did the best job at separating yield in lower yielding fields.

The scale used to complete the SCS soil surveys is a determining factor for map accuracy when examining soil patterns at the field scale. Soil maps that were created on a larger scale would provide less accurate information than those created on a smaller scale size. The Montgomery and Obion County soil surveys were completed at a scale of 1:15,480, while Franklin and Lake County surveys were done at a scale of 1:20,000. The Weakley County survey was completed on a scale of 1:24,000. The differences in these scales indicate that when examining the effects of soil unit versus yield, the Montgomery and Obion county surveys would provide the most accurate results, followed by Franklin, Lake, and Weakley counties.

Yield Variation Between Soil Units

Intensive soil mapping resulted in a larger number of soil units mapped at six of nine sites. Fewer units were mapped in only two locations while the remaining site had an equal number of units. In all cases, soil unit areas were adjusted and soil boundaries were moved. This method of mapping thus produced both areas in which new soil units were introduced and areas in which soil units were found in the same general locations within a site as were found in the SCS soil surveys (Table 3).

Mean estimates of average soybean yield for each soil unit varied both between and within sites. Intensive soil mapping at the field level resulted in statistical differences (α = .05) in yield between soil units within a field at six of nine sites. The conventionally-mapped units showed statistical yield differences between map units within a field in only two of the nine project sites.

Differences in yield between soil units were seen in both the intensive and SCS maps for site F1. The intensive map for this site consisted of seven soil units split into three yield groups (Figure 2) while the SCS map consisted of four units in two yield groups (Figure 3). The yield differences seen at this site were overall as expected, with deep, well-drained soils on A slopes yielding higher than shallow, more poorly drained soils on steeper slopes. An exception is the Guthrie unit mapped intensively, which yielded higher than many of the other units despite its poor drainage.

Site M1 was the only other location in which yield variation was seen within soil map units for the SCS soil maps, in which nine soil units resulted in three distinct yield groups (Figure 4). A deep, well-drained Arrington SiL unit contained higher yields than the other units mapped at this site. Slope appeared to have little effect on yield at this site since many

Table 3. Soil units mapped by both the intensive soil survey and the conventional SCS survey.

Site	Survey Method	Soil Units Included in Yield Area
F1	Intensive	Bw, Ds, DsB, Gu, Ta, WcB, WcB/BwB
	Conventional	BdC2, DsB2, Gb, La
F2	Intensive	BdC2, Ds, Ds3, DsB, DsB2, GaB, Mo, MoB, MoC, Ta
	Conventional	BdC2, DsB2, Gb
F3	Intensive	BdC, Ds, Ds2, DsB2, MoB, MoC2, Ta
	Conventional	DsB, La
L1	Intensive	Bo, Cm, Ie
	Conventional	Bo, Cm, Ie
M1	Intensive	Cr, CrB, Ds, DsB, DsB2, Gu, PeC2, Ta
	Conventional	Ar, DsB, DsC, Ld, MoC2, Ne, PeB, PeC, Ta
O1	Intensive	Ad, CaB2, Ce, CeB2, Dk, Fa, Fn, Rt, RtB
	Conventional	Ad, Fa, Fn, GrB, GrC2
O2	Intensive	CeB, MfB, MfC, MfD/E, MfE
	Conventional	Ad, Cn, LoD2, LoE2, MfB, MfE2, MfF2
W1	Intensive	Ca3, Ce, Co, Fa, Rt, Wa
	Conventional	Ca, Co, Fb, Rt, WR
W2	Intensive	CaB, Co, GrB2, He, He2, Lo, Lo2, LoB, LoB2, LoC3, Rt
	Conventional	Ca, GrB2, GrC3, LoB2, LoD3, MfB2, Rt

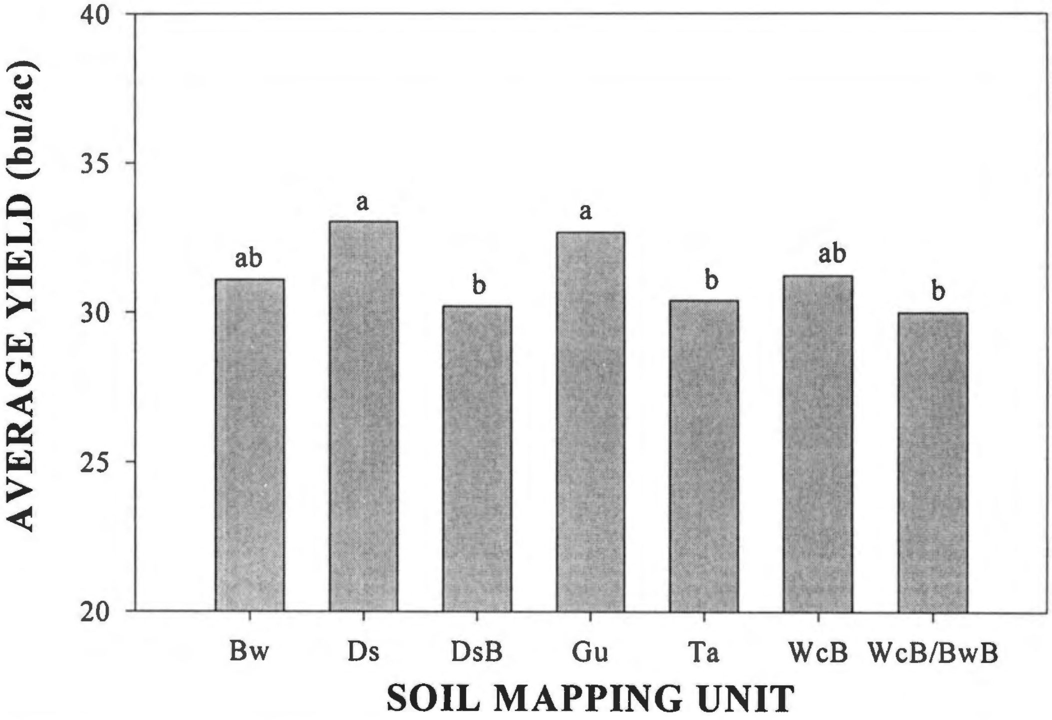

Figure 2. Average yield values by intensive soil mapping unit for site F1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

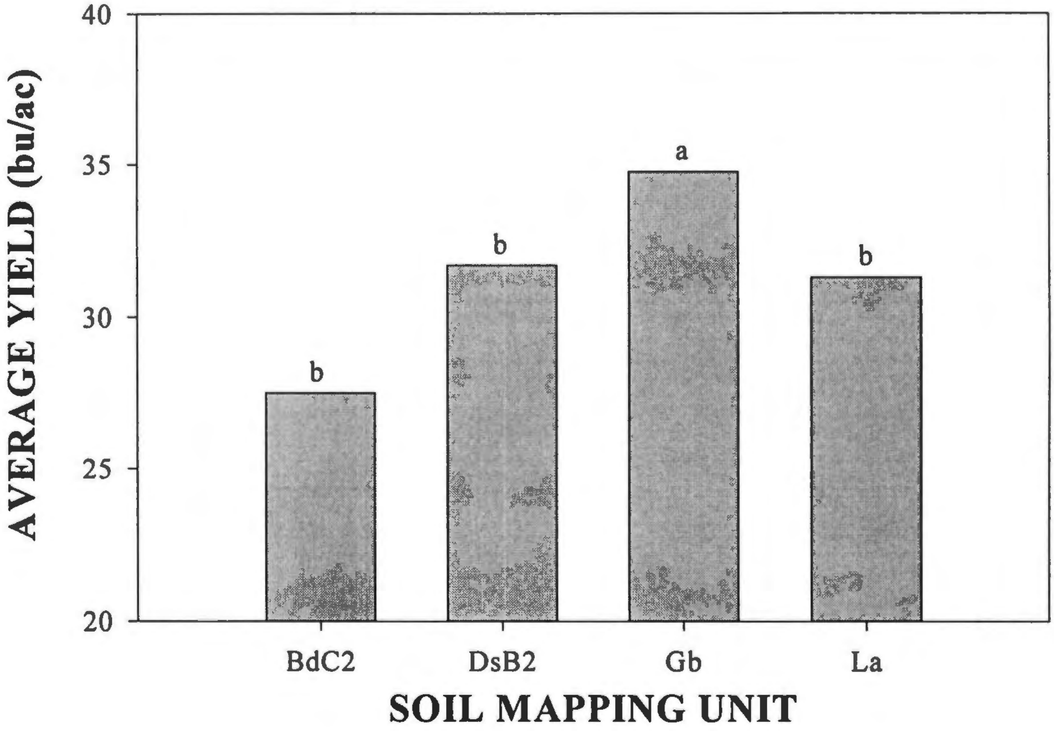

Figure 3. Average yield values by SCS soil mapping unit for site F1. Means labelled with the same letter are not different as determined by LSD at $\alpha = 0.05$.

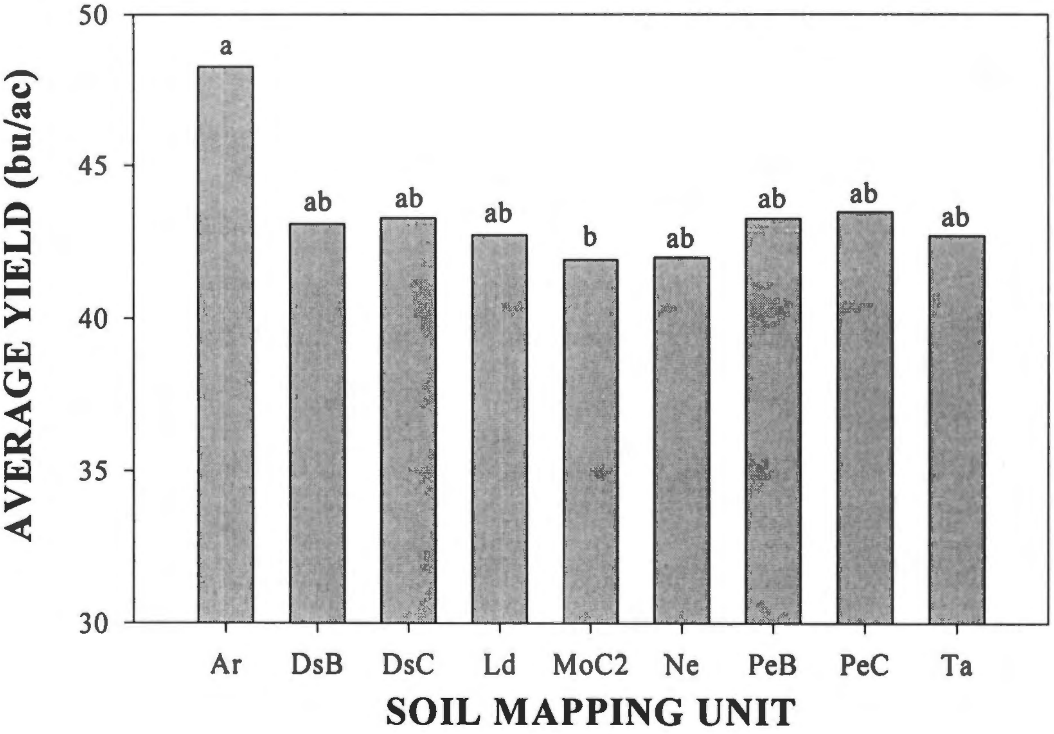

Figure 4. Average yield values by SCS soil mapping unit for site M1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

soil units on steeper slopes had similar yields to units on found on A slopes. However, the more eroded Mountview unit did contain lower yields than soil units with deeper profiles. Since the intensive soil map for this site did not show yield differences between eight soil classes (Figure 5), this was the only location in which the conventional soil map was a better predictor for yield patterns within a field. An improperly-functioning moisture sensor component of the yield monitoring unit used at this site could be a possible source for the differences seen in the data at this location.

The other sites in Franklin County (F2, F3), showed yield differences among soil units based on the intensive soil map, while no differences were seen using the SCS soil survey maps. Three yield classes were evident resulting from analysis of the ten intensive soil units at site F2 (Figure 6) while the three soil units from the soil survey showed no yield differences (Figure 7). The differences seen in the intensive mapping yield groups were not as expected in that eroded Bowdre and Dickson soils on C and B slopes were among the highest yielding soil units, while a deep, well-drained Mountview unit contained statistically lower yields. The seven intensive soils mapped at site F3 split yield into two distinguishable groups (Figure 8). In this case a small unit of Taft SiL contained lower yields than the other soil units within the site. Although lower yields were expected in the poorly-drained Taft, other units found on B and C slopes with eroded profiles were also expected to have lower yields. However, the results at this site showed no yield differences between those units and any of the others. The soil survey for the same site consisted of only two soil units and one yield group (Figure 9).

Sites L1, O1, and O2 showed similar results as were found in sites F2 and F3. The

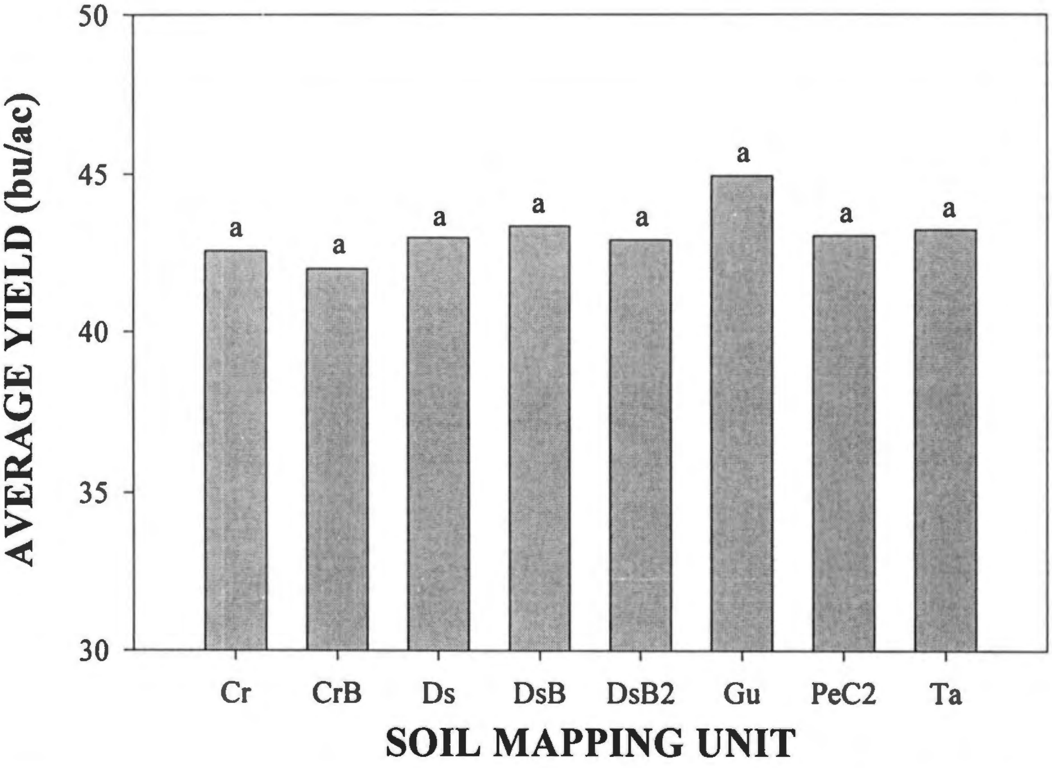

Figure 5. Average yield values by intensive soil mapping unit for site M1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

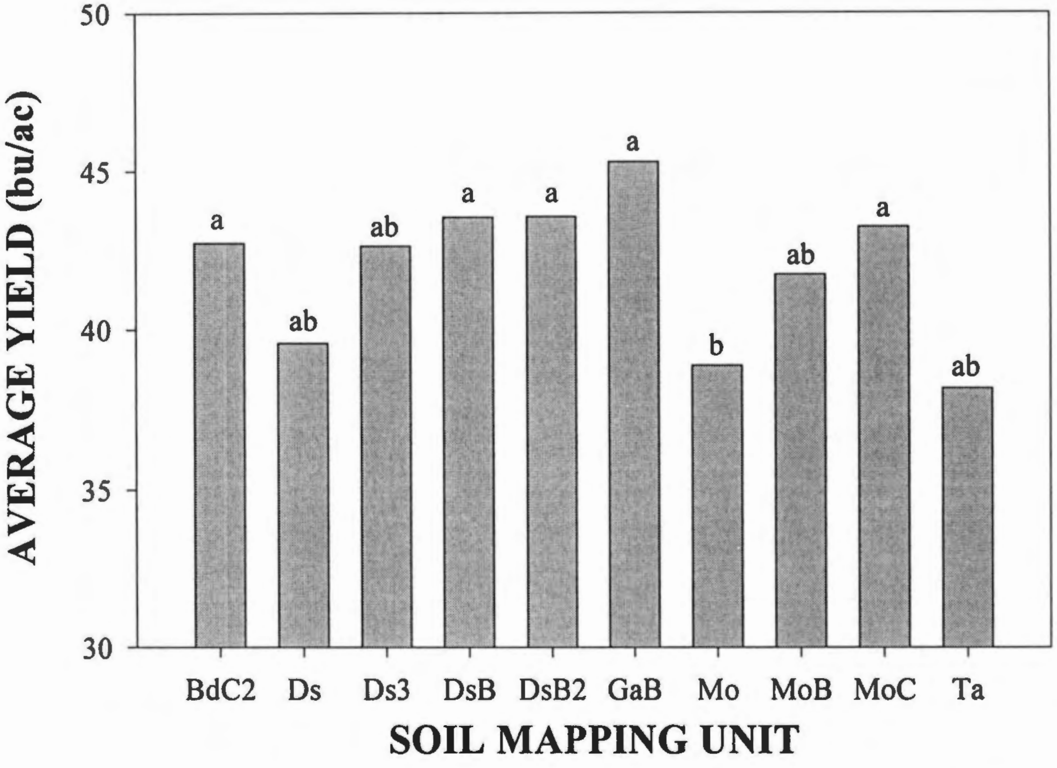

Figure 6. Average yield values by intensive soil mapping unit for site F2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

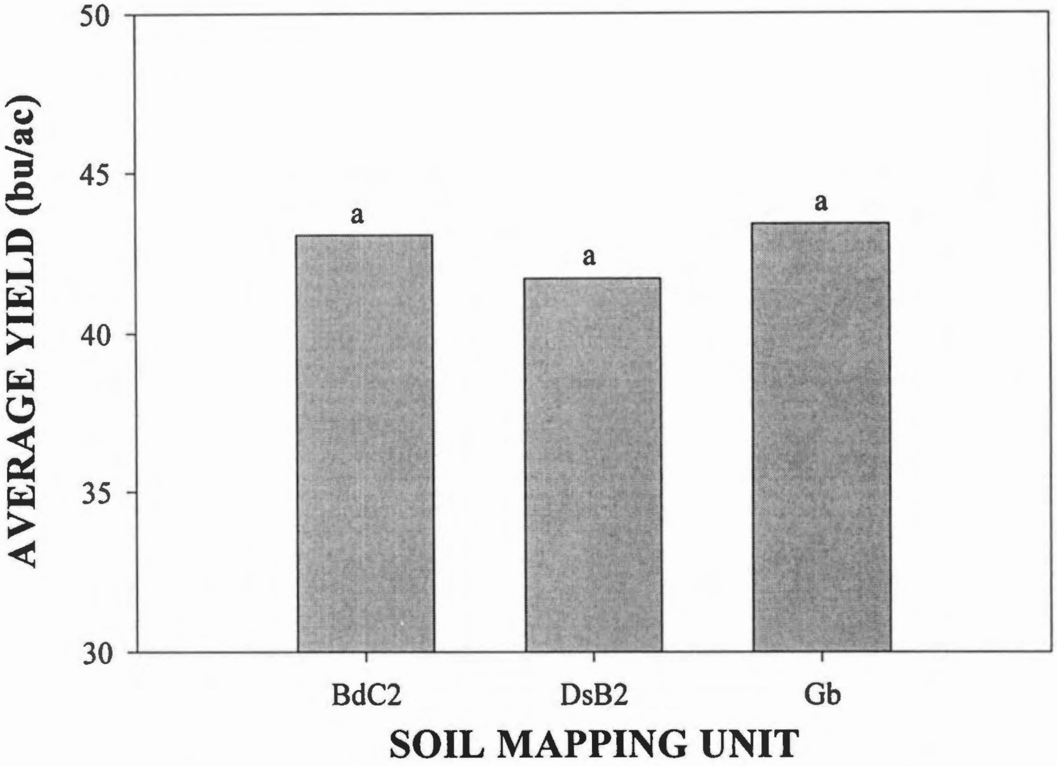

Figure 7. Average yield values by SCS soil mapping unit for site F2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

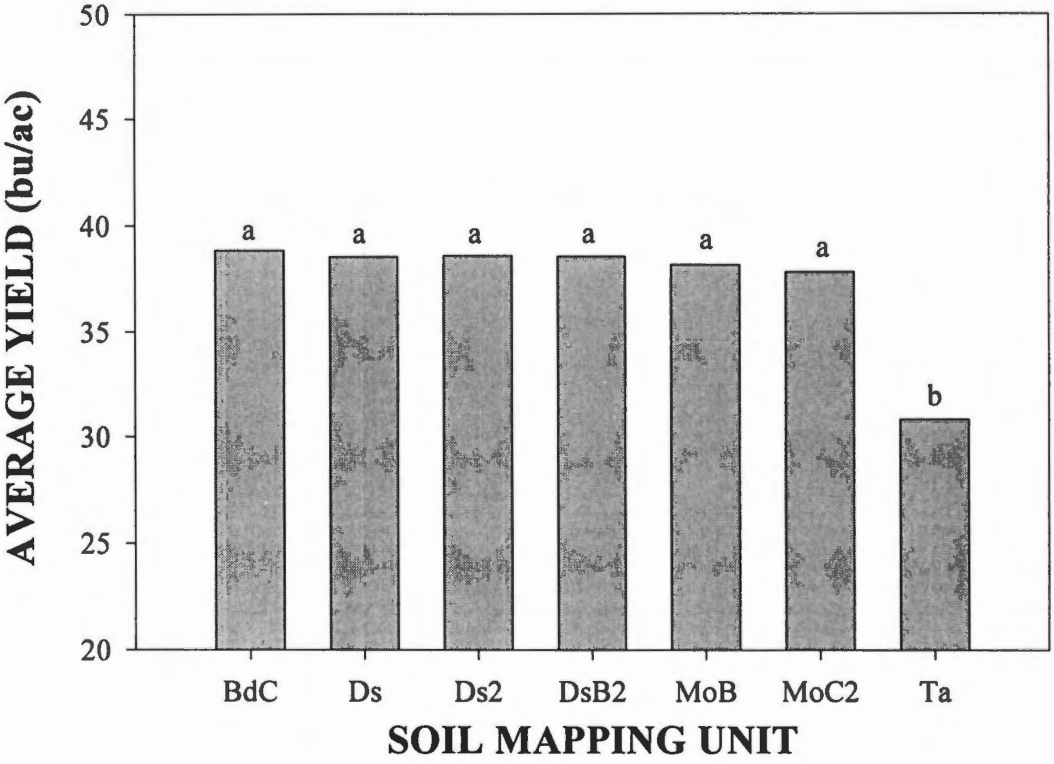

Figure 8. Average yield values by intensive soil mapping unit for site F3. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

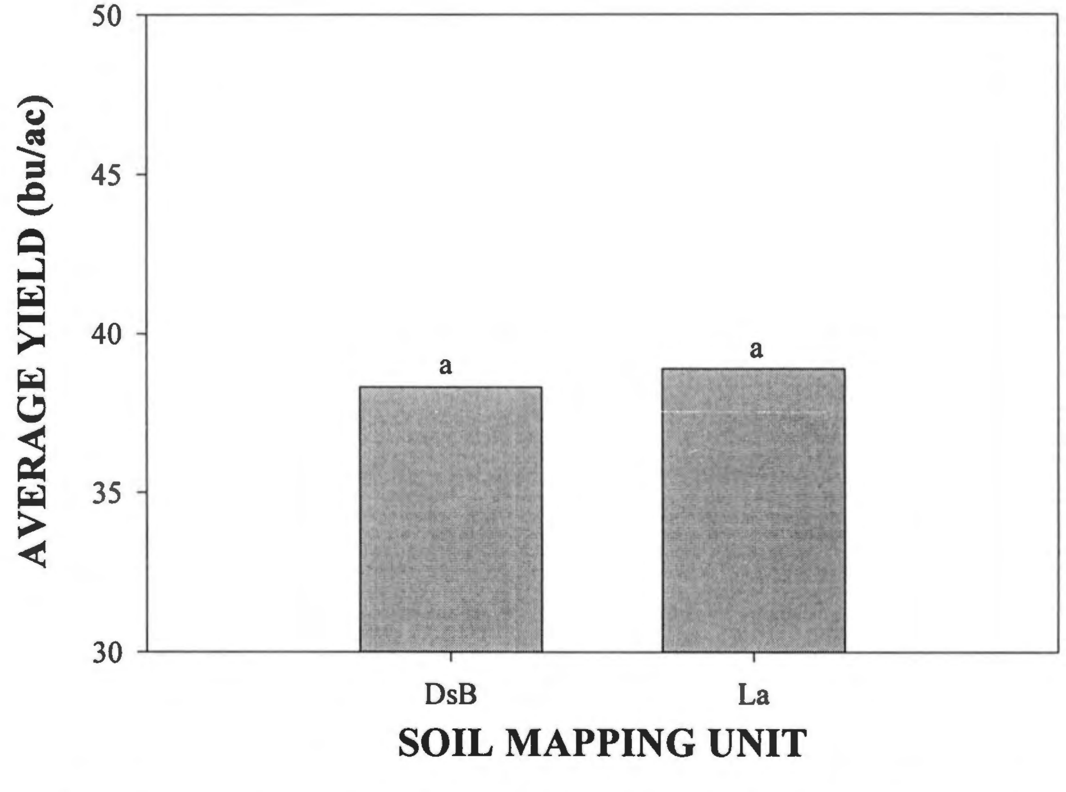

Figure 9. Average yield values by SCS soil mapping unit for site F3. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

intensive soil mapping done at site L1 produced three soil units that were divided between two yield groups (Figure 10). The clayey Bowdre and Iberia units yielded lower than the silt loam Commerce unit at this site. The soil survey for this site also consisted of three soil units. However, these units did not result in yield differences (Figure 11). The intensive soil maps for sites O1 and O2 contained nine and five soil units, respectively. Yield differences were seen between units at each of these sites with five yield groups resulting at site O1 (Figure 12) and three at site O2 (Figure 13). Neither of the SCS maps for these sites were sufficient for distinguishing variation in yield (Figures 14, 15).

Sites W1 and W2 in Weakley County showed no yield differences between soil units for either of the mapping methods. The SCS W1 site map contained five soil units and the W2 site map was made up of seven total units (Figures 16, 17). The intensive maps showed W1 divided into six units, while eleven units were found in site W2 (Figures 18, 19).

Effect of Soil Mapping Unit Properties on Soybean Yield

Less than half of the soil properties and property interactions that were investigated had a significant effect ($\alpha = 0.05$) on soybean yield (Table 4). Varying subsoil texture had an impact on yield as shown by the decrease in yield with an increase in subsoil clayey textures (Figure 20). This may be due to the decrease in available water content in the soils containing a larger percentage of clay (Nizeyimana and Olson, 1988; Rhoton, 1990).

Spatial changes in slope class, as well as an interaction between slope and subsoil texture, also demonstrated importance in determining yield patterns. In many instances the data indicated higher yields occurred on steeper slopes (Figure 21, Table 5). The results seen

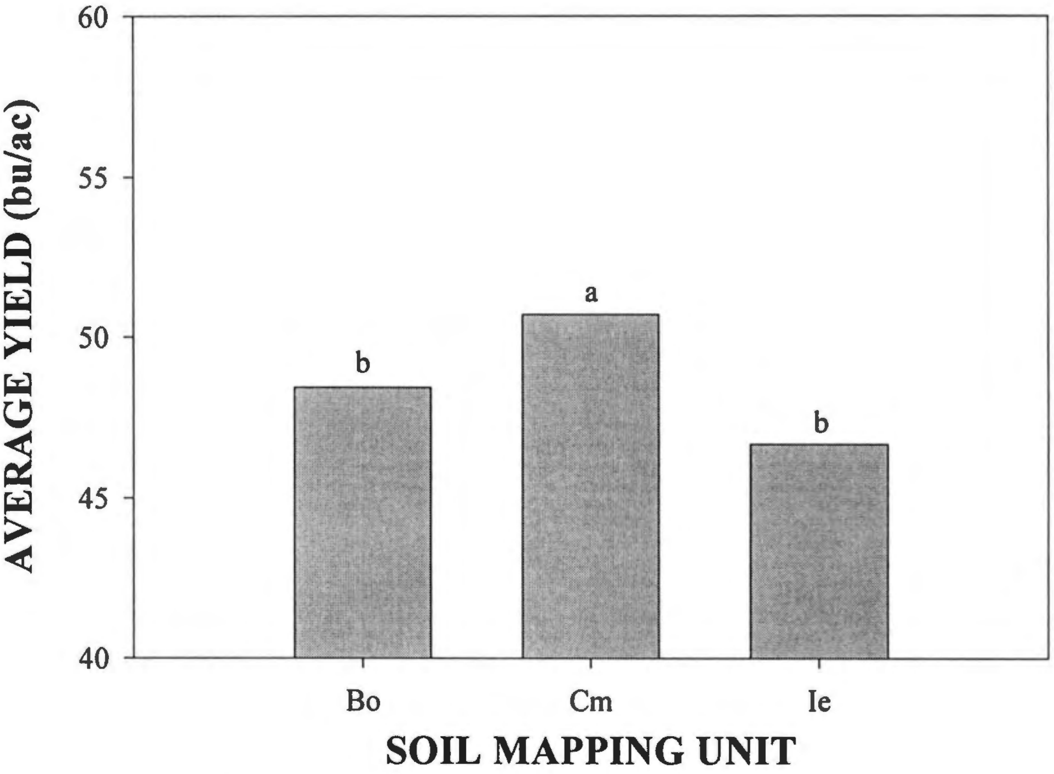

Figure 10. Average yield values by intensive soil mapping unit for site L1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

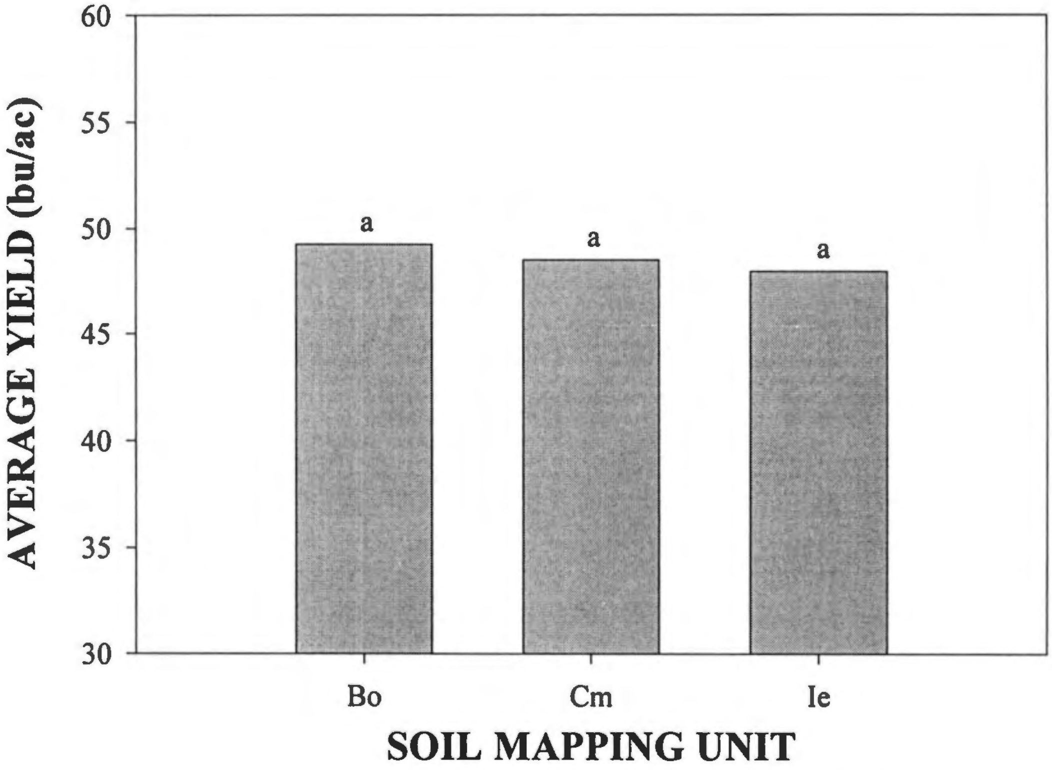

Figure 11. Average yield values by SCS soil mapping unit for site L1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

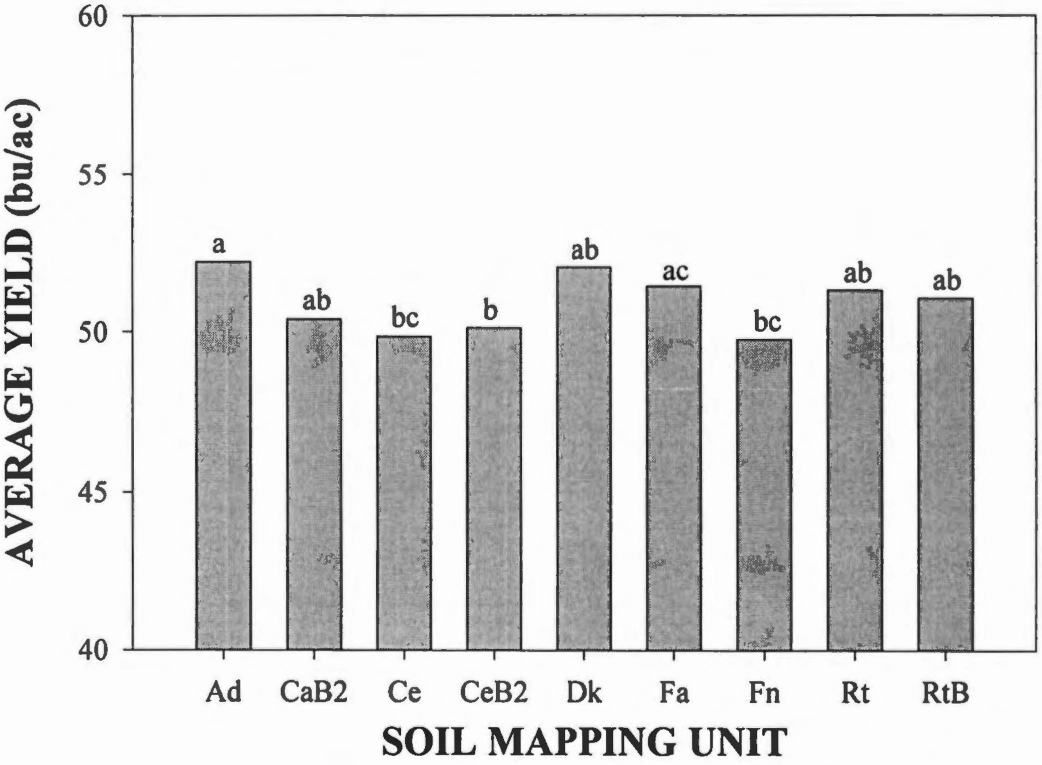

Figure 12. Average yield values by intensive soil mapping unit for site O1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

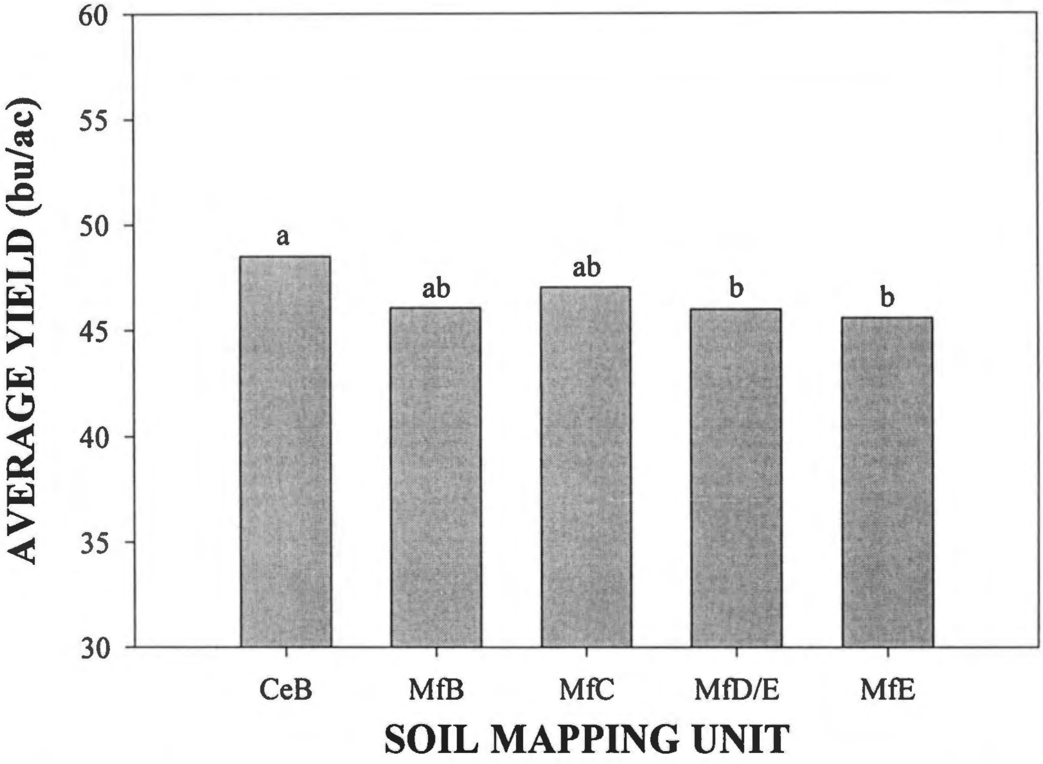

Figure 13. Average yield values by intensive soil mapping unit for site O2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

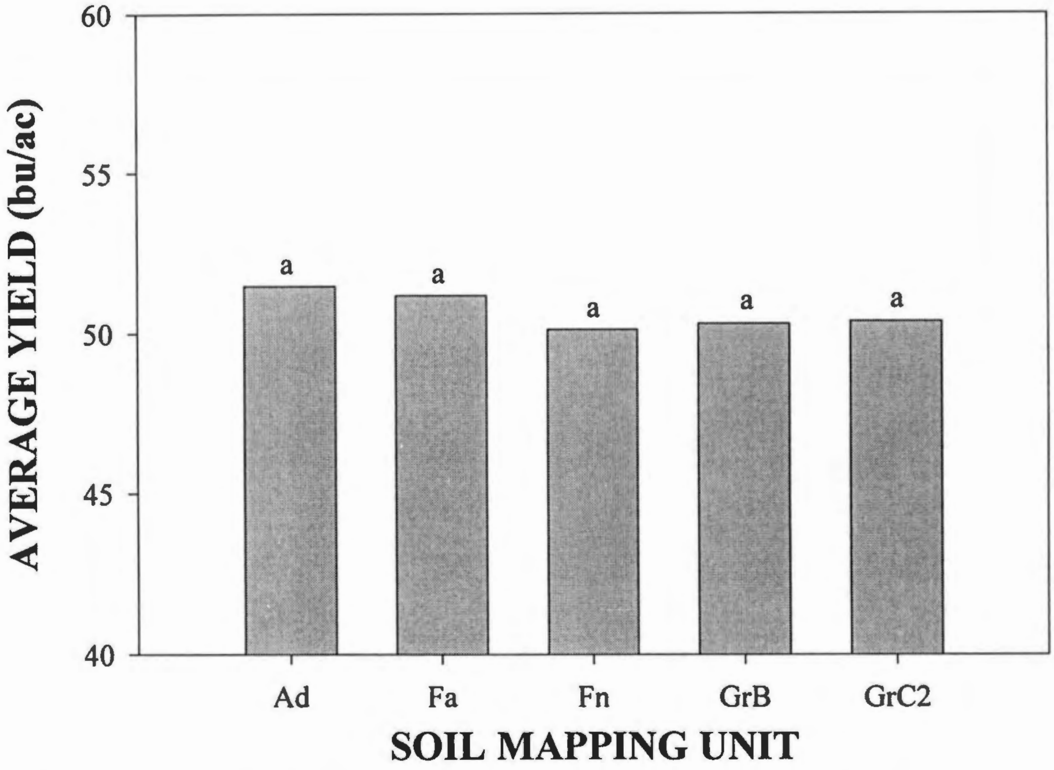

Figure 14. Average yield values by SCS soil mapping unit for site O1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

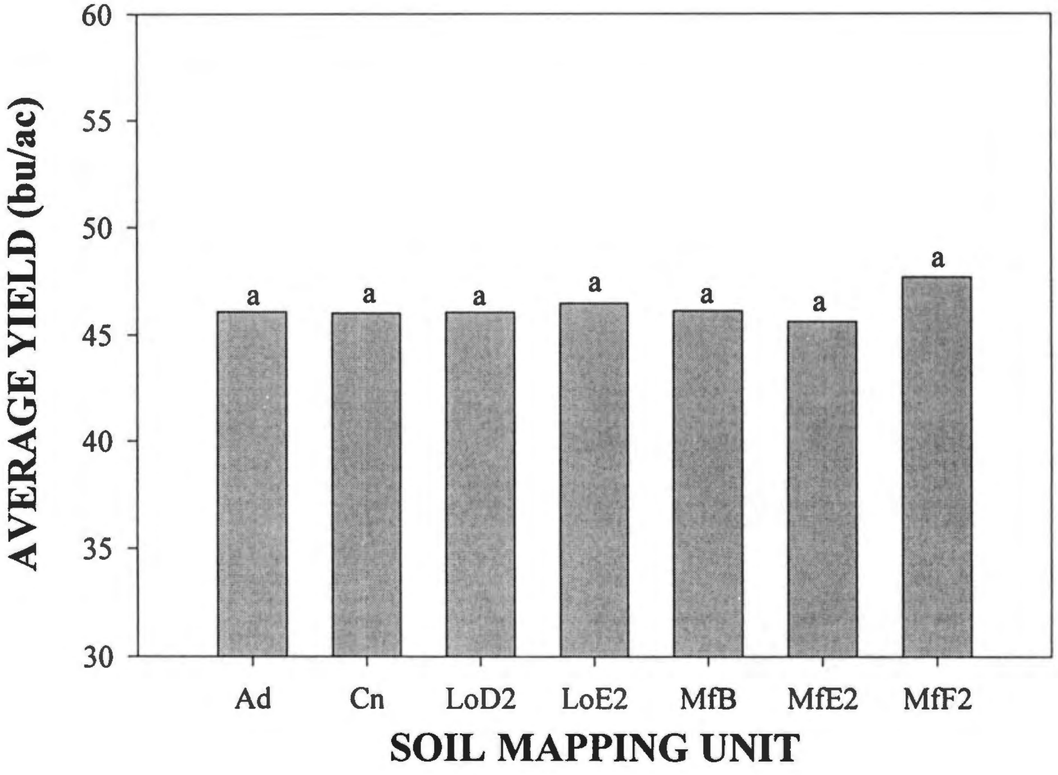

Figure 15. Average yield values by SCS soil mapping unit for site O2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

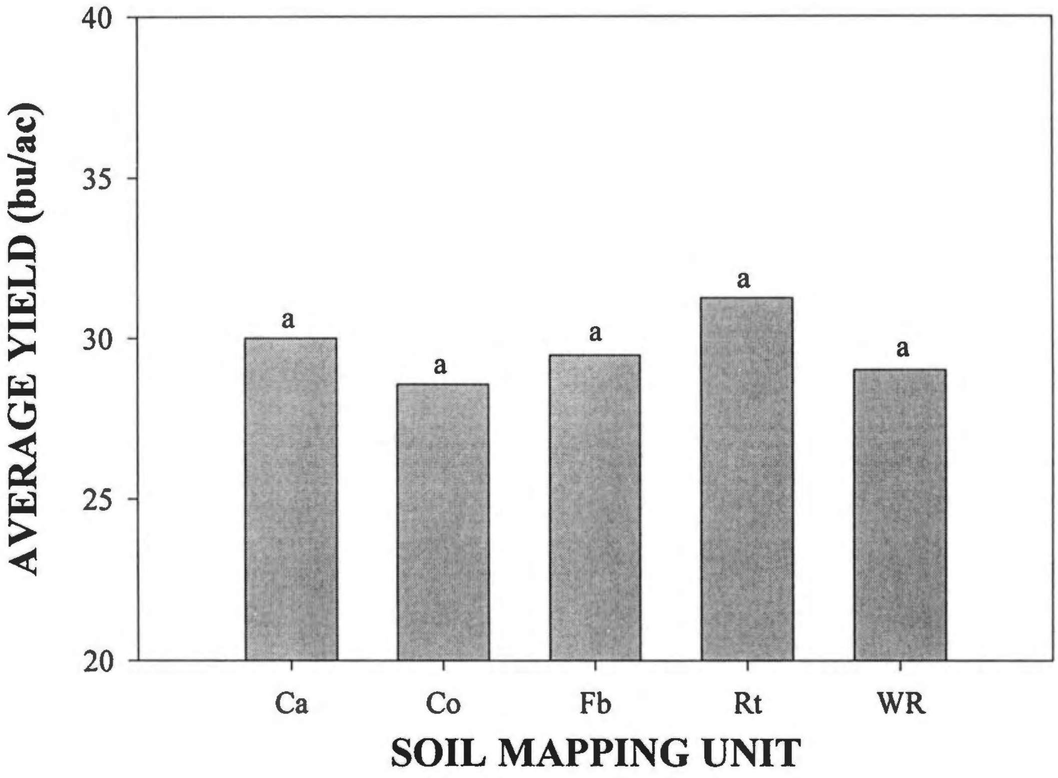

Figure 16. Average yield values by SCS soil mapping unit for site W1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

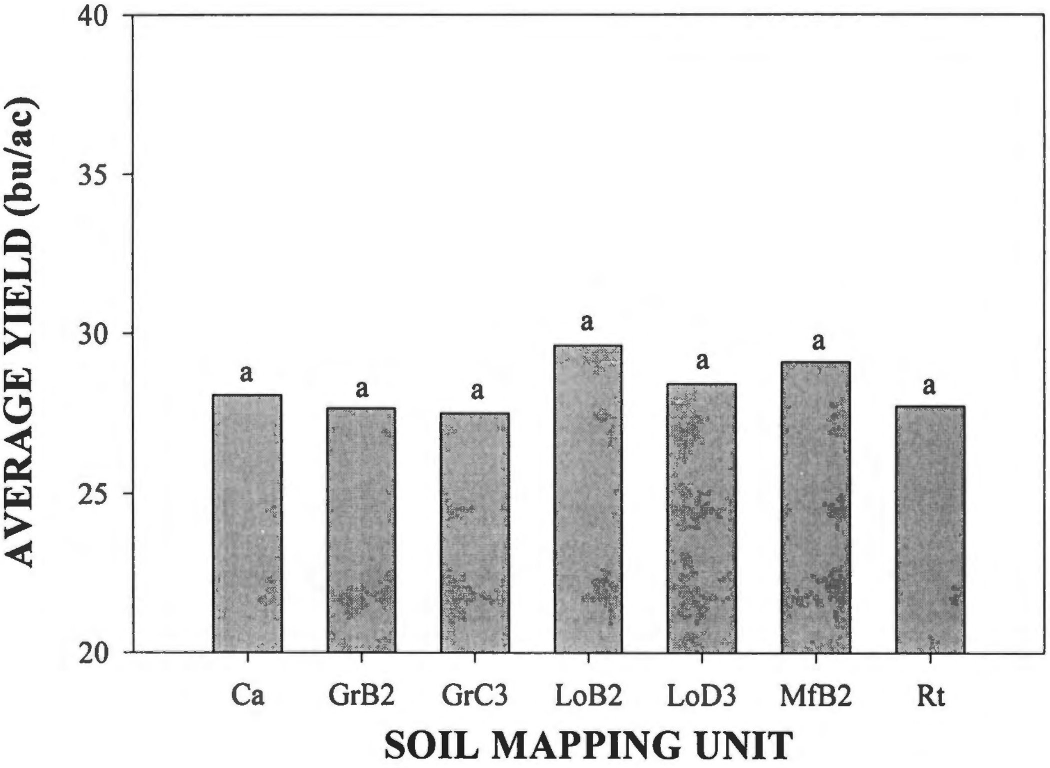

Figure 17. Average yield values by SCS soil mapping unit for site W2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

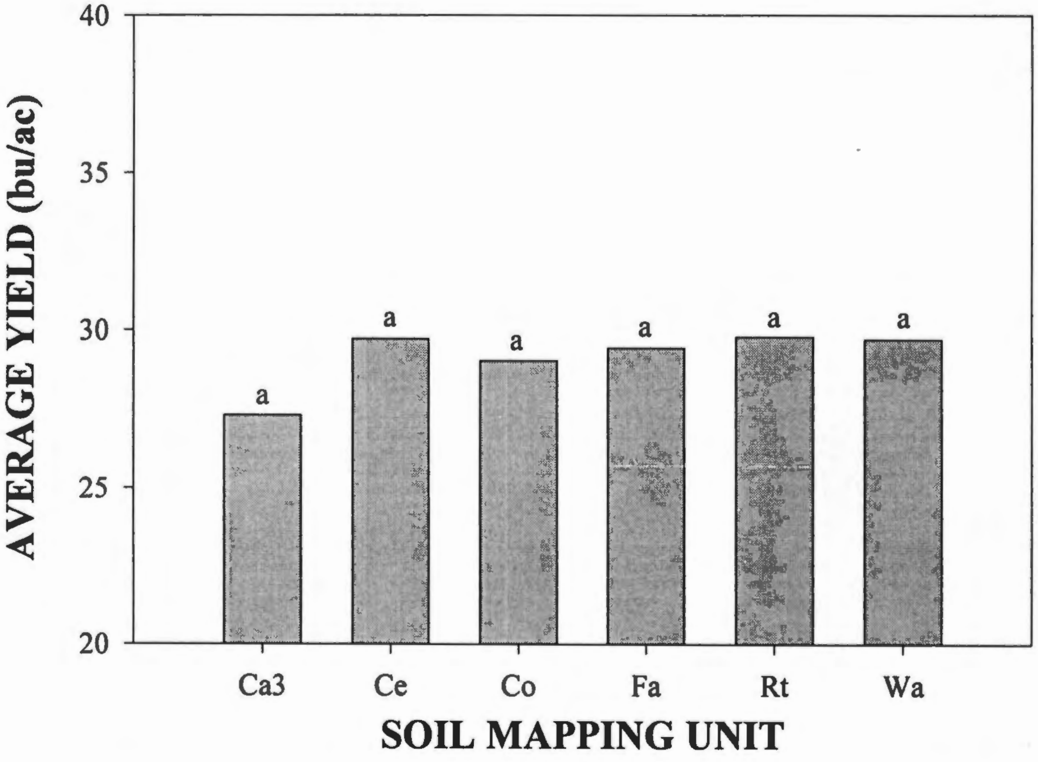

Figure 18. Average yield values by intensive soil mapping unit for site W1. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

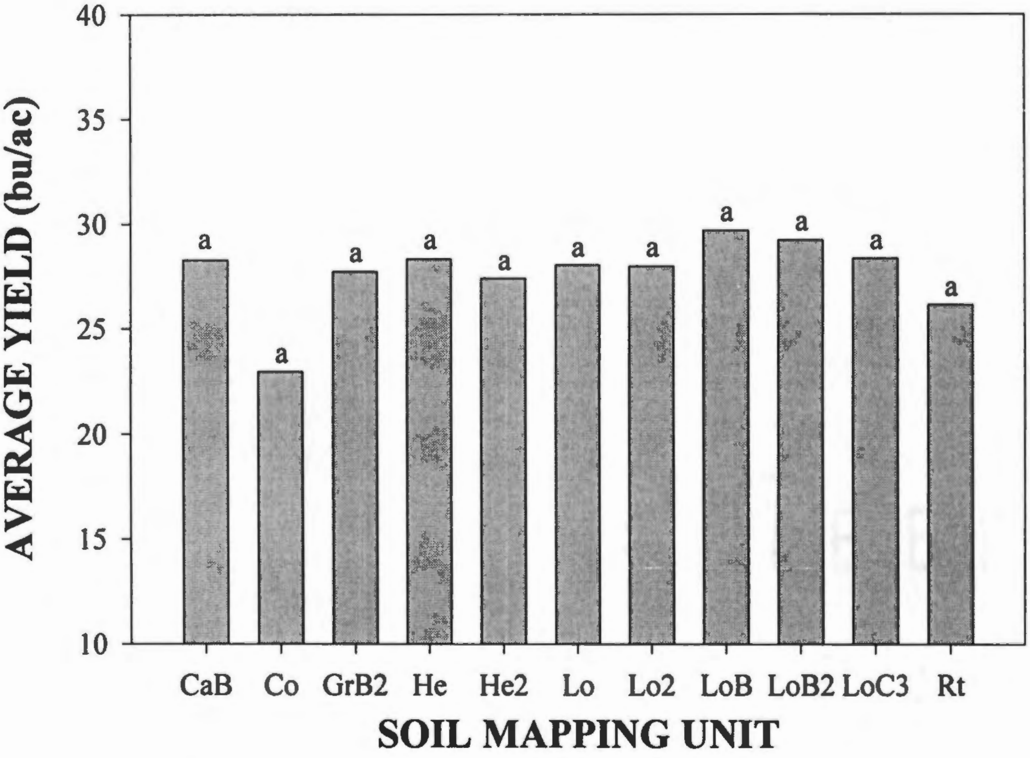

Figure 19. Average yield values by intensive soil mapping unit for site W2. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

Table 4. Summarized analysis of variance for intensive soil mapping unit properties versus soybean yield across all sites. Pr > F values less than 0.05 indicate significance.

Source	Type III F	Pr > F
Subsoil Texture	2.16	0.0346
Slope	4.65	0.0009
Slope * Subsoil Texture	5.41	0.0002
Effective Rooting Depth (ERD)	1.99	0.1365
ERD * Subsoil Texture	0.83	0.4379
Slope * ERD	2.61	0.1060
Drainage	1.58	0.1910
Drainage * ERD	3.29	0.0198
Drainage * Subsoil Texture	0.69	0.5034
Drainage * Slope	1.20	0.3018
Phosphorous	0.97	0.3248
Potassium	0.09	0.7631
pH	20.39	< 0.0001

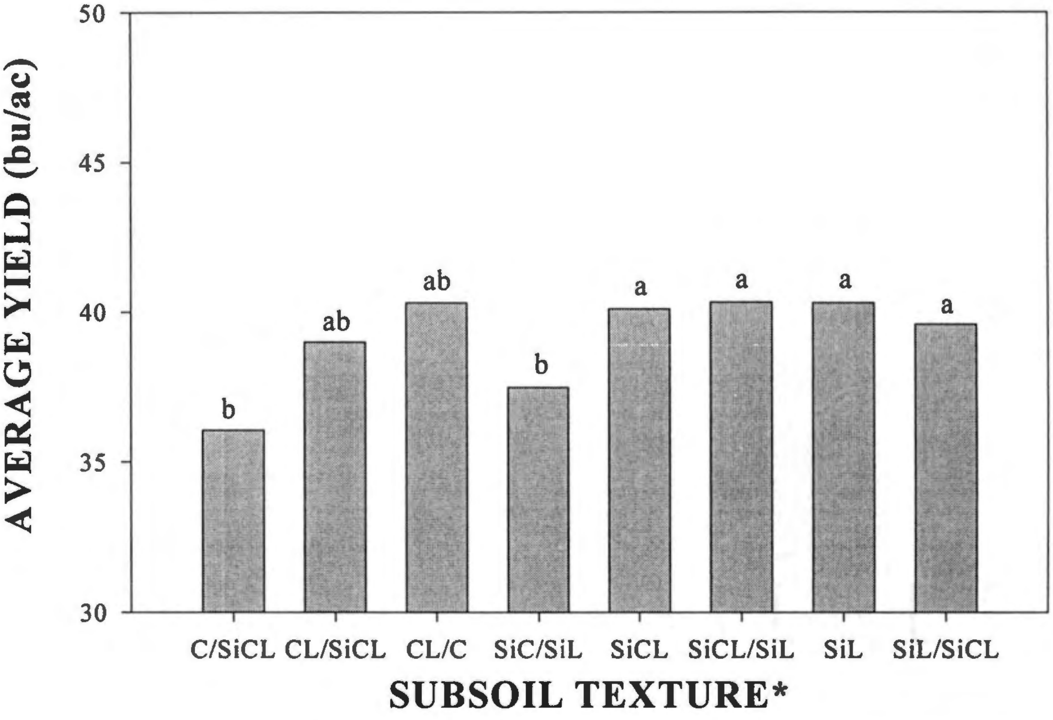

Figure 20. Average yield values by subsoil texture for all sites. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$. *Predominant subsoil texture followed by secondary texture.

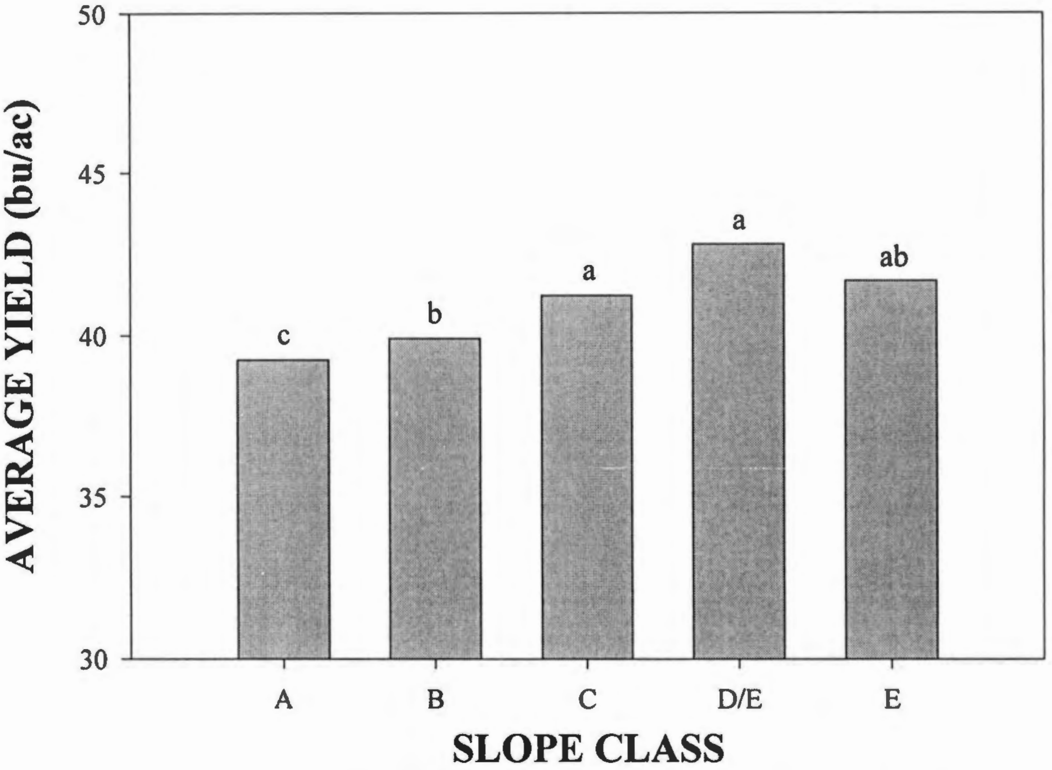

Figure 21. Average yield values by slope class for all sites. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

Table 5. Table of mean separations for intensive soil mapping unit slope by subsoil texture versus soybean yield across all sites. Means labelled with the same letters are not different as determined by LSD at $\alpha = 0.05$.

Slope	Subsoil Texture	Mean Yield (bu/ac)	Std. Error	Group
A	C/SiCL	35.44	6.58	I
A	SiC/SiL	37.16	6.47	GI
A	SiCL	39.19	6.47	DEFG
A	SiCL/SiL	41.15	6.46	BCDF
A	SiL	39.95	6.43	DEF
A	SiL/SiCL	39.90	6.45	DEF
B	CL/SiCL	38.46	6.54	FGHI
B	CL/C	39.62	6.65	BCDEFGI
B	SiCL	36.56	6.50	I
B	SiCL/SiL	41.36	6.48	BCDF
B	SiL	39.68	6.43	EH
B	SiL/SiCL	41.28	6.44	C
C	SiCL	41.19	6.47	BCDF
C	SiCL/SiL	40.96	6.46	BCDEF
C	SiL	40.05	6.55	BCDEFG
C	SiL/SiCL	44.43	6.53	A
D/E	SiL/SiCL	42.81	6.48	AB
E	SiL/SiCL	41.69	6.51	BCDE

here are of particular interest in that the negative effects of steep slopes would normally indicate that yields should actually be higher on more undulating slopes (Power et al., 1981; Rhoton, 1990; Khakural et al. 1996). However, the results seen in the study may have been influenced by the large area of 0-2 % slopes found at site L1 which consisted of subsoil textures of clay and silty clay.

Effective rooting depth (ERD), which is an indicator of degree of erosion, did not have show significant yield differences. This result contrasts past studies that have shown several soil properties that may influence potential crop yields are directly influenced by soil profile depth (Frye et al., 1982; Stone et al., 1985; Nizeyimana and Olson, 1988; Rhoton and Tyler, 1990; Cihacek and Swan, 1994; Bruce et al., 1995; Lowery et al., 1995). Relative soil thickness influences the amount of plant available water as well as limiting the actual depth of root penetration. This point is especially true when underlying soil materials consist of poor mediums for plant growth. In contradiction, results of this study indicated that the interaction between ERD and subsoil texture did not affect soybean yield. The relationship between slope and erosion would also indicate that lower yields would be expected on steeper slopes with thinner soil profiles. However, the interaction between slope and ERD examined in this study showed no affect on yield.

The drainage characteristics of a soil have been shown to be directly related to the soil's texture and structural properties. Drainage of a soil is also directly related to the available water holding capacity of the soil, which has been shown to have an effect on crop yields (Nizeyimana and Olson, 1988; Bruce et al., 1990; Cambardella et al., 1996, Khakural et al., 1996). However, results of this study show that soil drainage properties did not have a significant impact on soybean yield. In addition, the interactions of drainage with neither subsoil texture nor slope appeared to affect soybean yield significantly. In contrast, the interaction of drainage and ERD demonstrated importance in determining crop yield. With a decrease in ERD an increase in surface clay would be expected, which would result in lower amounts of plant available water and lower crop production (Frye et al., 1982).

Mixed results were found when comparing soil fertility to yield. Plant available phosphorous and potassium levels were not closely associated to total production. The result seen here may stem from the fact the nearly all of the sites had fertility levels in the high or very high range. Thus, variation in yield would not have been expected due to changes in fertility levels. Soil pH, however, did have a highly significant negative relationship to yield. This result supports other studies that have shown a negative correlation between surface pH and crop productivity. A decrease in acidity has been shown to restrict the solubility of several elements important to plant growth, while an increase in acidity at the surface increases the availability of some toxic elements that stunt root growth and reduce the opportunities for the uptake of water (Nizeyimana and Olson, 1988; Rhoton, 1990; Khakural et al., 1996).

4. CONCLUSIONS

This study was designed to test the effectiveness of conventional soil maps for predicting soybean yield patterns at the field scale. Detailed soil maps were created to compare a more site-specific method of delineating soil boundaries than has been traditionally used. The use of GPS technology and GIS software was essential in creating accurate representations of these soil maps for use in comparisons with soybean yields.

Yield monitors, when incorporated with GPS technology, provide an accurate and efficient means for measuring yield at specific locations within a field. Using this yield data it is possible to distinguish differences between crop yield and various soil properties and soil units as a whole. Soil mapping techniques of the past may not be specific or descriptive enough to be of practical use in determining crop yield patterns within a field. When viewed as a whole, the adequacy in crop yield prediction of a standard soil survey may be limited to simply understanding the general soils found within an area and not for making site-specific management decisions. While an intensive soil survey at the field scale is a slightly more adequate tool for predicting yield patterns, it may still not be an efficient means for which to base specific management decisions, without first investigating other soil variables within the unit itself.

Several soil variables demonstrated importance in affecting soybean yield. However, to determine how these variables effectively explain yield patterns they must be sampled independently of soil map unit boundaries. By investigating properties within soil units, a limit is set by the soil unit boundary and yield variation outside that limit cannot be explained. Therefore, specific measurements of various soil properties must be taken to compare with crop yields without regards to individual soil units.

The current use of modeling applications such as GIS at both the research and producer level requires a soil map with effective accuracy in terms of scale and cartographic quality. This accuracy could be achieved if an efficient method of intensively mapping soils can be developed and implemented. While soil maps as a whole may not be an indicator of crop yield pattern directly, it may be possible to intensively map soils in a manner so that differences in crop yield may become evident. It is only then that a map of various soils within a given area can become an effective tool for managing crops site-specifically.

The research methods presented here are continuing at these and other field sites throughout Tennessee. The method of intensively mapping soil units within fields is being revised in order to achieve a more efficient, yet useful, means to delineate soil boundaries at the scale desired. A comparison of these mapping techniques may be necessary to determine the consistencies of results in obtaining the best possible soils information for use in precision agriculture management decisions.

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LITERATURE CITED

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APPENDICES

APPENDIX A. PROJECT SITE MAP

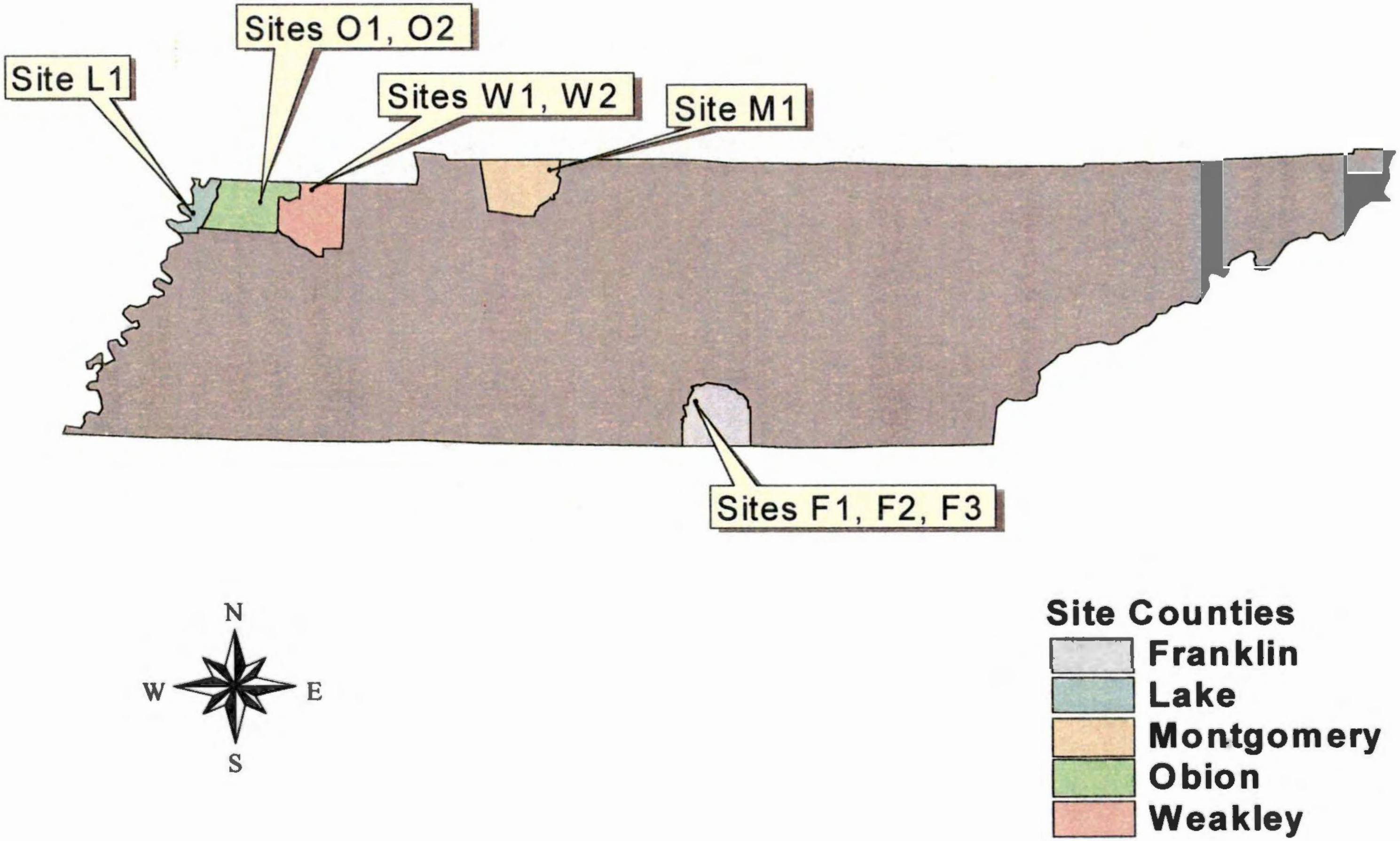

Figure A.1. Map representing project site locations in Tennessee.

APPENDIX B. SOIL CLASSIFICATIONS

Soil Series	**Classification**
Adler	*coarse-silty, mixed, active, nonacid, thermic Aquic Udifluvents*
Arrington	*fine-silty, mixed, superactive, thermic Cumulic Hapludolls*
Baxter	*fine-clayey, mixed, semiactive, mesic Typic Paleudalfs*
Bewleyville	*fine-silty, siliceous, semiactive, thermic Typic Paleudults*
Bodine	*loamy-skeletal, siliceous, semiactive, thermic Typic Paleudults*
Bowdre	*clayey over loamy, smectitic, thermic Aquic Fluvaquentic Hapludolls*
Calloway	*fine-silty, mixed, active, thermic Glossaquic Fragiudalfs*
Center	*fine-silty, mixed, thermic Aquic Hapludalfs*
Collins	*coarse-silty, mixed, acid, thermic Aquic Udifluvents*
Commerce	*fine-silty, mixed, nonacid, thermic Aeric Fluventic Haplaquepts*
Convent	*coarse-silty, mixed, nonacid, thermic Aeric Fluvaquents*
Crider	*fine-silty, mixed, active, mesic Typic Paleudalfs*
Dekoven	*fine-silty, mixed, thermic Fluvaquentic Endoaquolls*
Dickson	*fine-silty, siliceous, thermic Glossic Fragiudults*
Ennis	*fine-loamy, siliceous, thermic Fluventic Dystrochrepts*
Falaya	*coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents*
Fountain	*fine-silty, mixed, thermic Typic Glossaqualfs*
Greendale	*fine-loamy, siliceous, semiactive, mesic Fluventic Dystrudepts*
Grenada	*fine-silty, mixed, active, thermic Glossic Fragiudalfs*
Guthrie	*fine-silty, siliceous, thermic Typic Fragiaquults*
Henry	*coarse-silty, mixed, active, thermic Typic Fragiaqualfs*

Iberia	*fine, smectitic, thermic Vertic Haplaquolls*
Lawrence	*fine-silty, mixed, semiactive, mesic Aquic Fragiudalfs*
Lindside	*fine-silty, mixed, active, mesic Fluvaquentic Eutrudepts*
Loring	*fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs*
Memphis	*fine-silty, mixed, active, thermic Typic Hapludalfs*
Mountview	*fine-silty, siliceous, semiactive, thermic Typic Paleudults*
Newark	*fine-silty, mixed, active, nonacid, mesic Aeric Fluvaquents*
Pembroke	*fine-silty, mixed, active, mesic Mollic Paleudalfs*
Reelfoot	*fine-silty, mixed, thermic Aquic Argiudolls*
Rosebloom	*fine-silty, mixed, active, acid, thermic Typic Fluvaquents*
Routon	*fine-silty, mixed, thermic Typic Epiaqualfs*
Taft	*fine-silty, siliceous, thermic Glossaquic Fragiudults*
Tiptonville	*fine-silty, mixed, thermic Oxyaquic Argiudolls*
Vicksburg	*coarse-silty, mixed, acid, thermic Typic Udifluvents*
Waverly	*coarse-silty, mixed, acid, thermic Typic Fluvaquents*
Waynesboro	*fine, kaolinitic, thermic Typic Paleudults*

APPENDIX C. YIELD MAPS

Figure C.1. Corrected soybean yield (bu/ac) map for site F1.

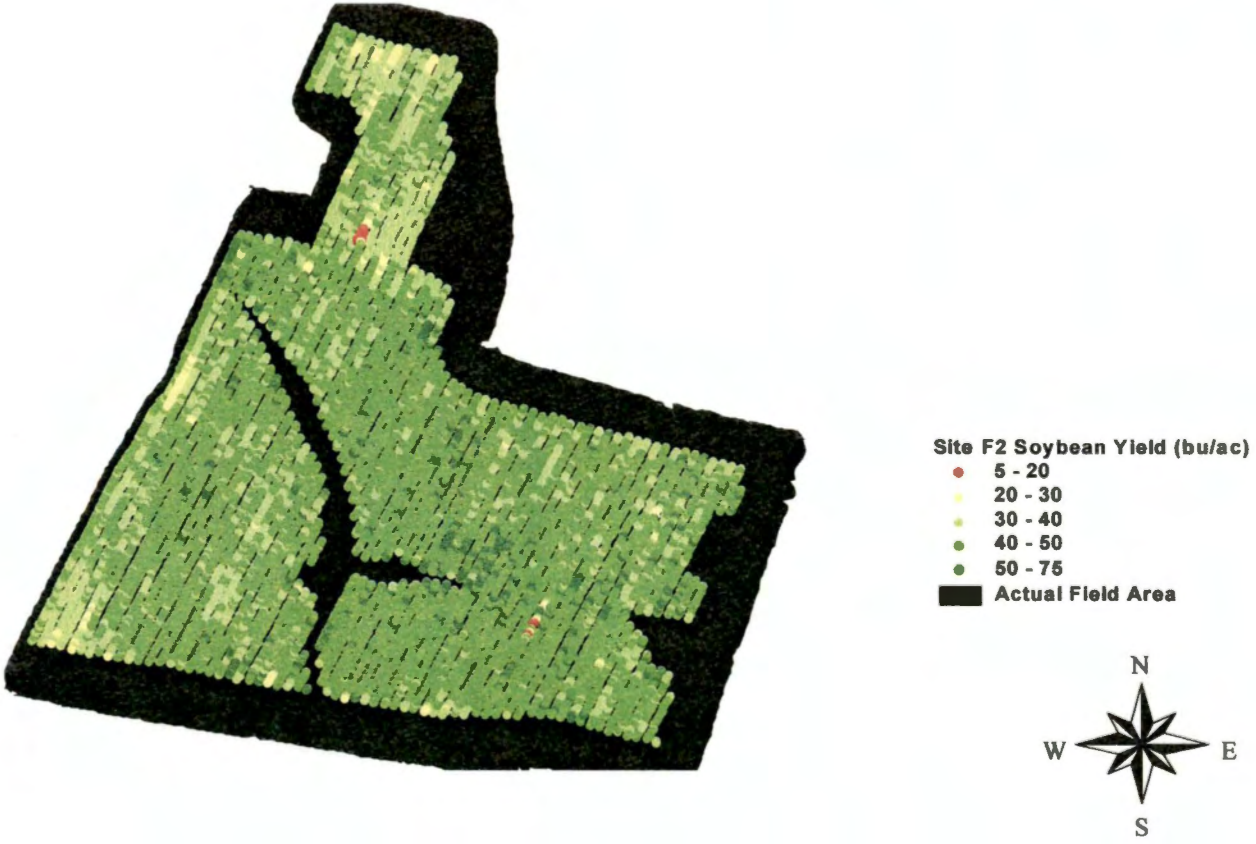

Figure C.2. Corrected soybean yield (bu/ac) map for site F2.

Figure C.3. Corrected soybean yield (bu/ac) map for site F3.

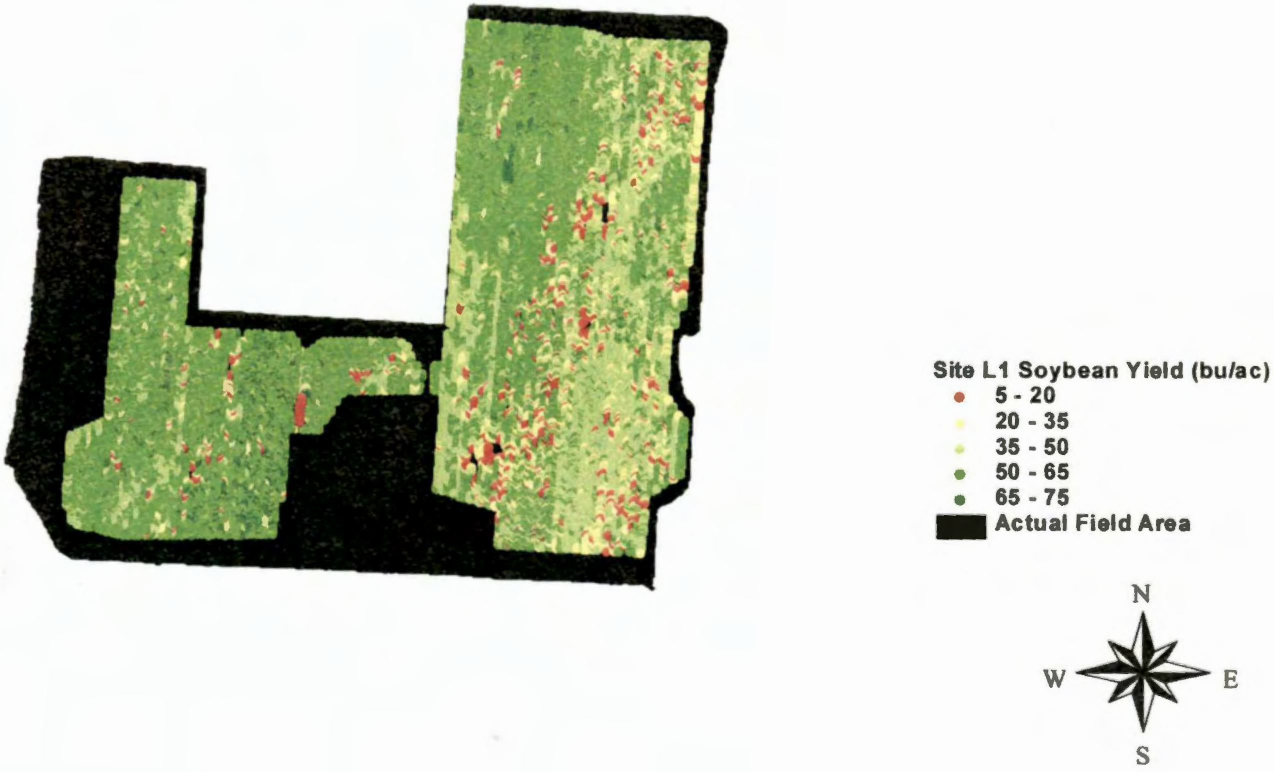

Figure C.4. Corrected soybean yield (bu/ac) map for site L1.

Figure C.5. Corrected soybean yield (bu/ac) map for site M1.

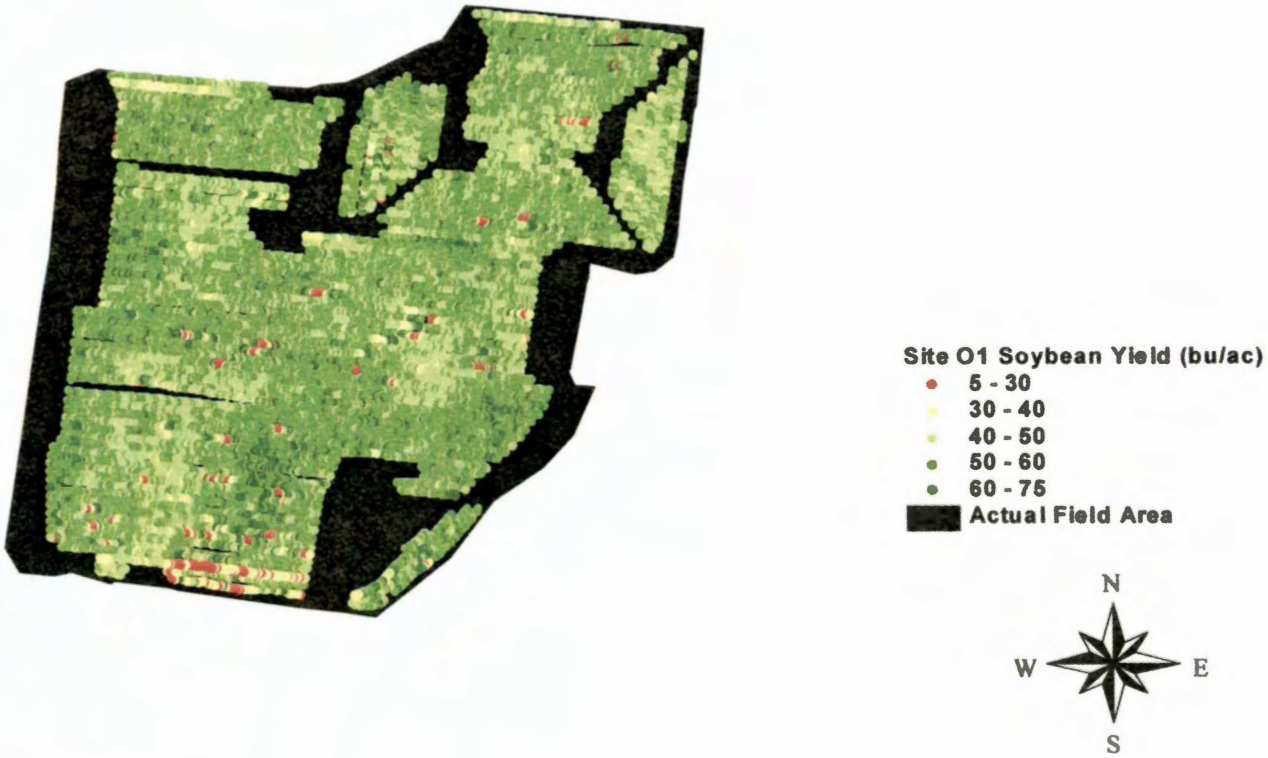

Figure C.6. Corrected soybean yield (bu/ac) map for site O1.

Figure C.7. Corrected soybean yield (bu/ac) map for site O2.

Figure C.8. Corrected soybean yield (bu/ac) map for site W1.

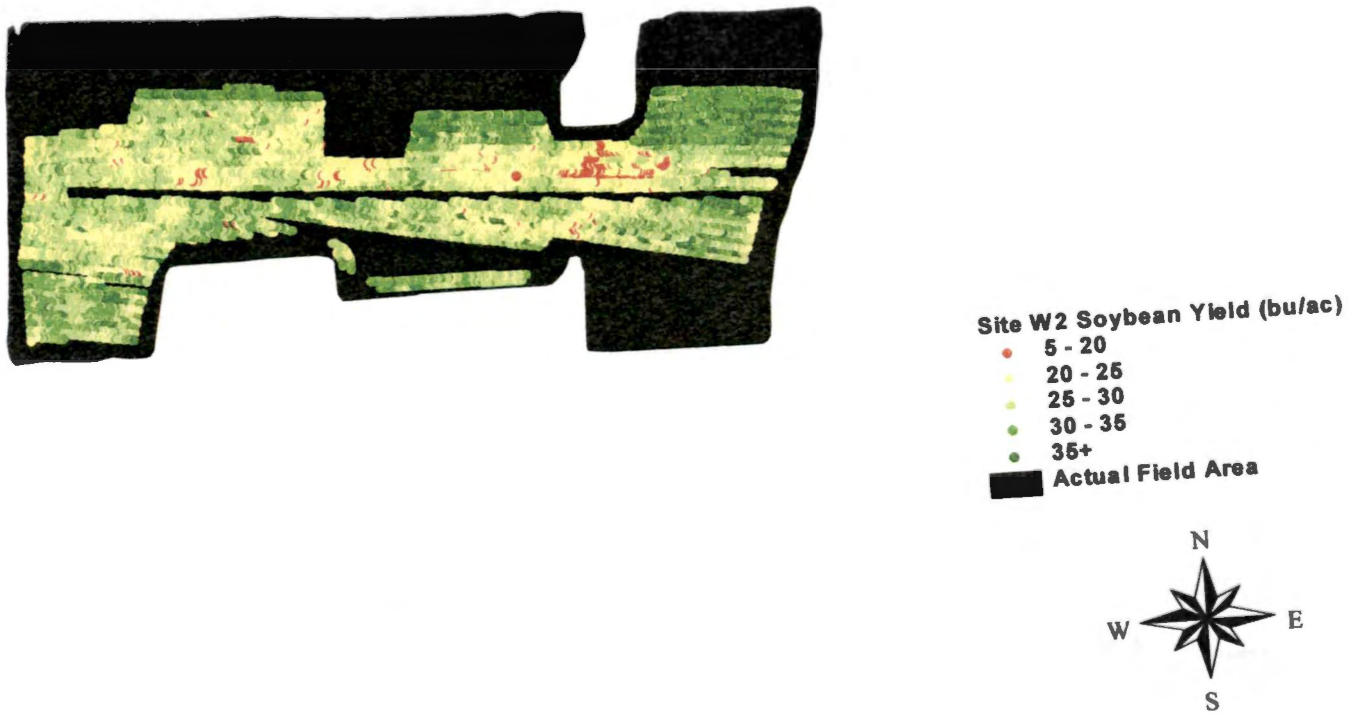

Figure C.9. Corrected soybean yield (bu/ac) map for site W2.

APPENDIX D. INTENSIVE SOIL MAPS

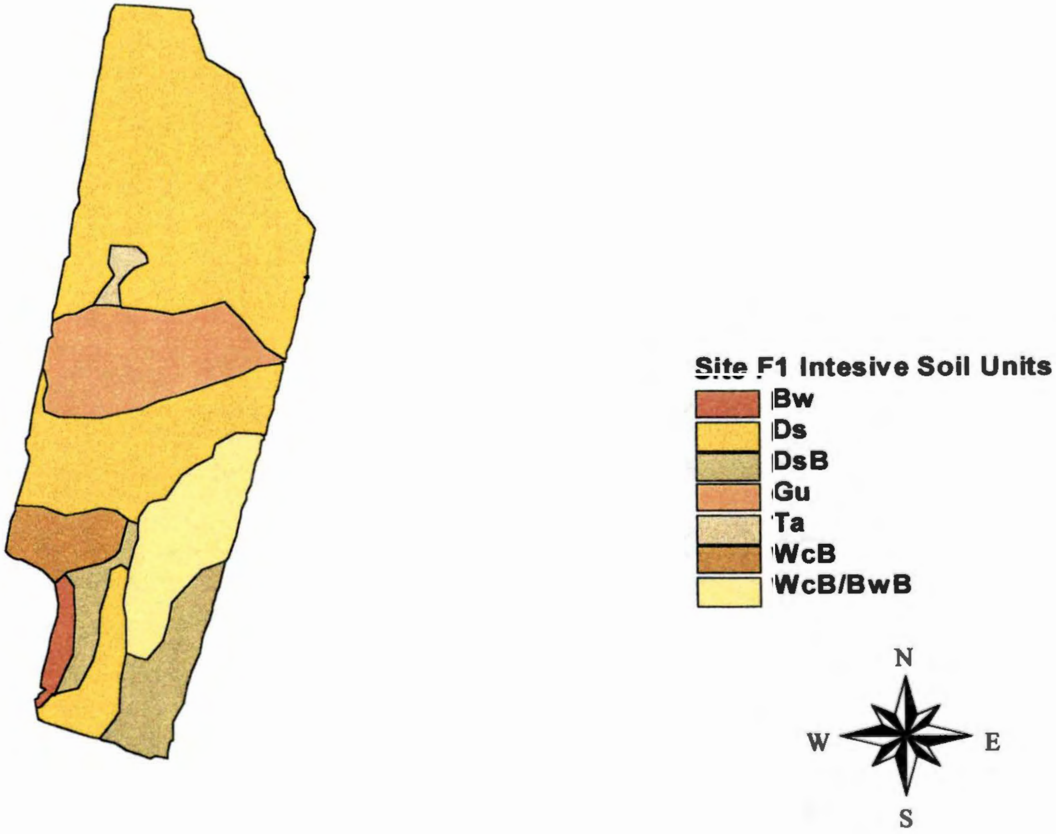

Figure D.1. Intensive soil map produced from field sampling positional data for site F1.

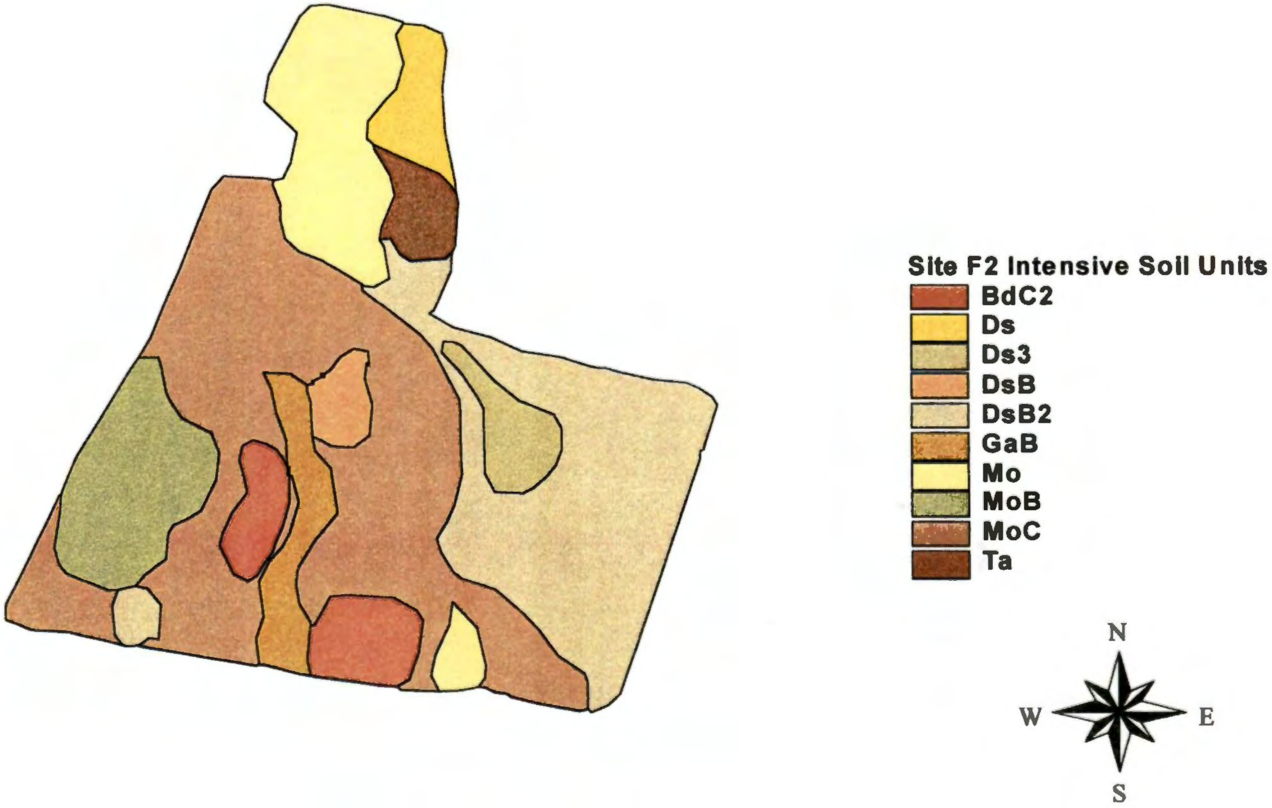

Figure D.2. Intensive soil map produced from field sampling positional data for site F2.

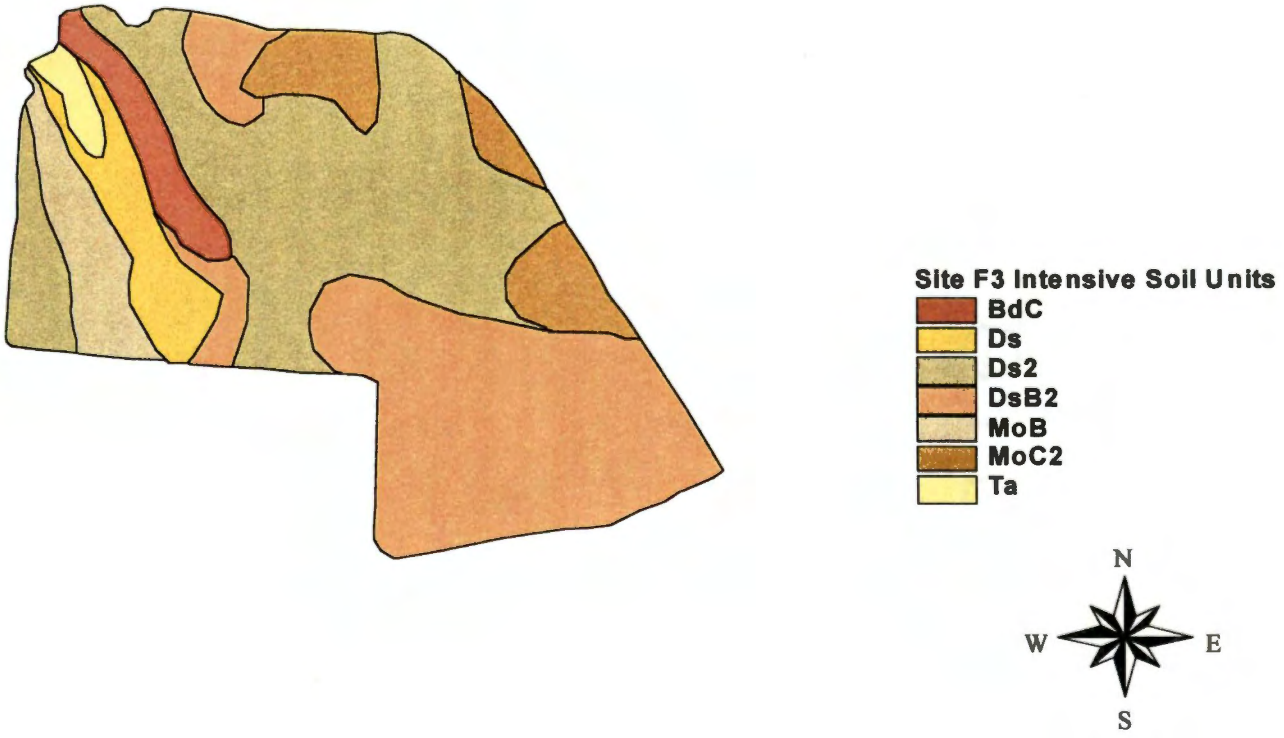

Figure D.3. Intensive soil map produced from field sampling positional data for site F3.

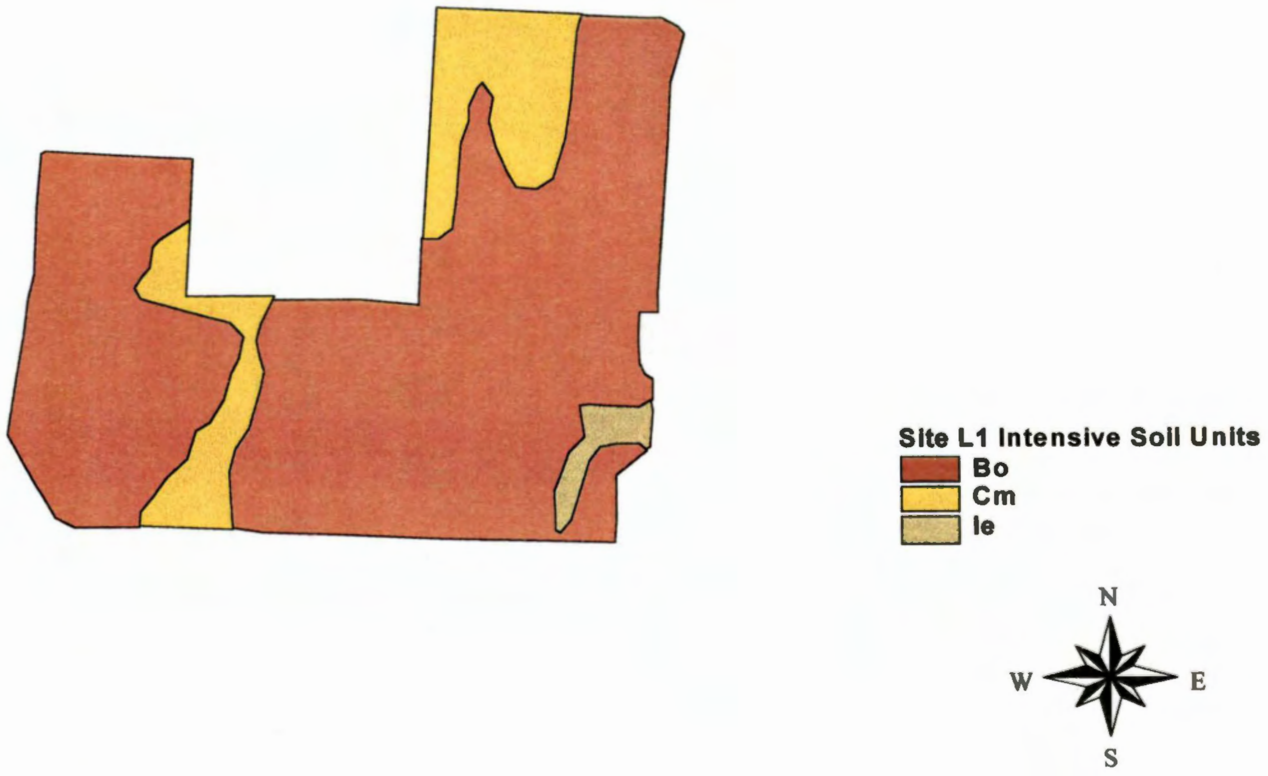

Figure D.4. Intensive soil map produced from field sampling positional data for site L1.

Figure D.5. Intensive soil map produced from field sampling positional data for site M1.

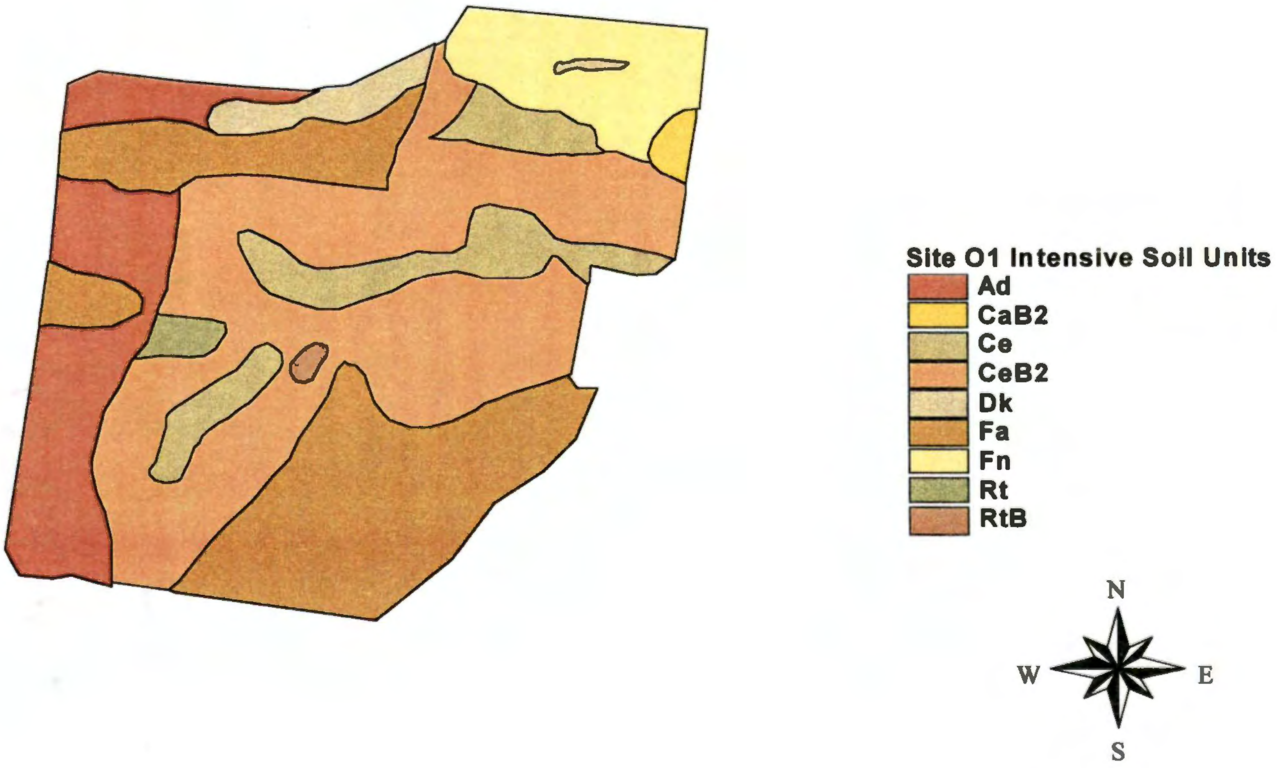

Figure D.6. Intensive soil map produced from field sampling positional data for site O1.

Figure D.7. Intensive soil map produced from field sampling positional data for site O2.

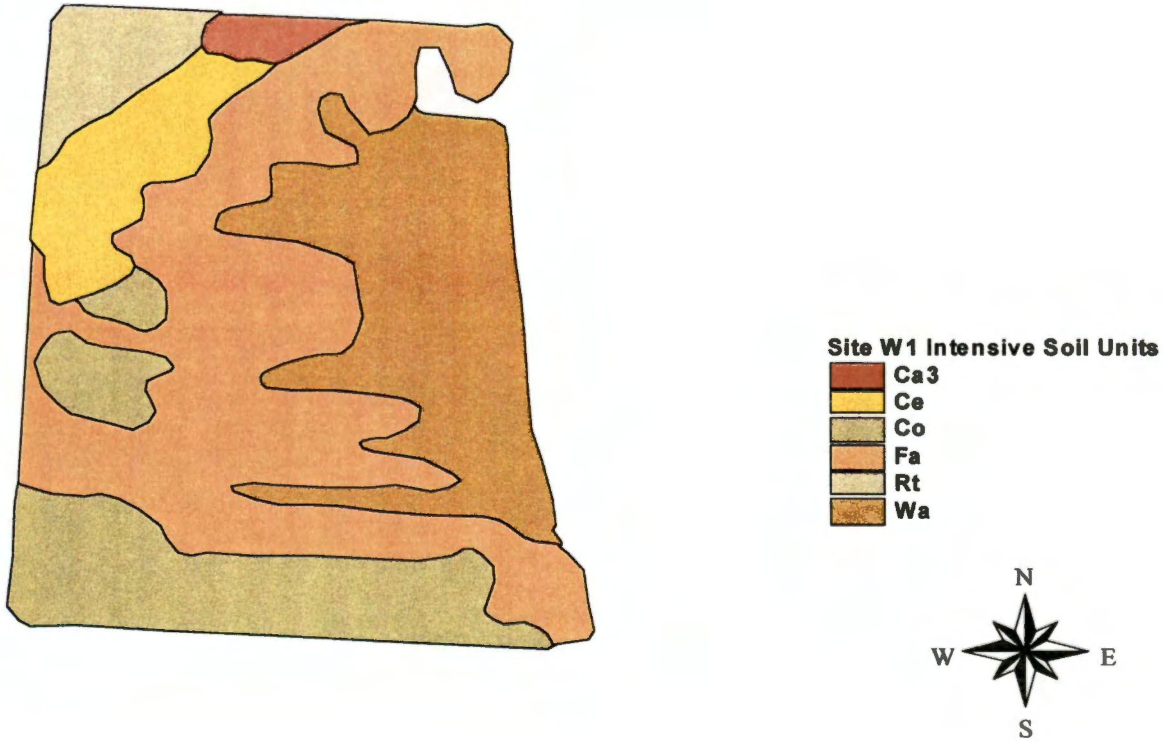

Figure D.8. Intensive soil map produced from field sampling positional data for site W1.

Figure D.9. Intensive soil map produced from field sampling positional data for site W2.

APPENDIX E. USDA-SCS SOIL SURVEY REPRESENTATIVE MAPS

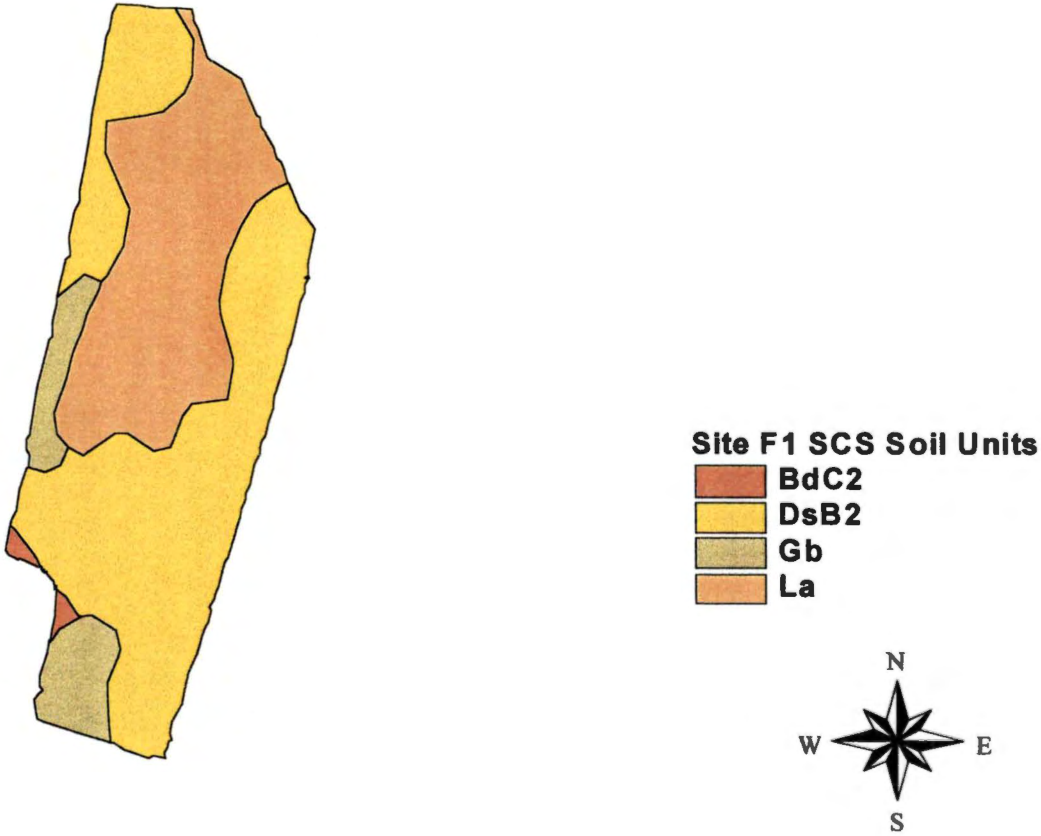

Figure E.1. Soil map reproduced from USDA-SCS county soil survey for site F1.

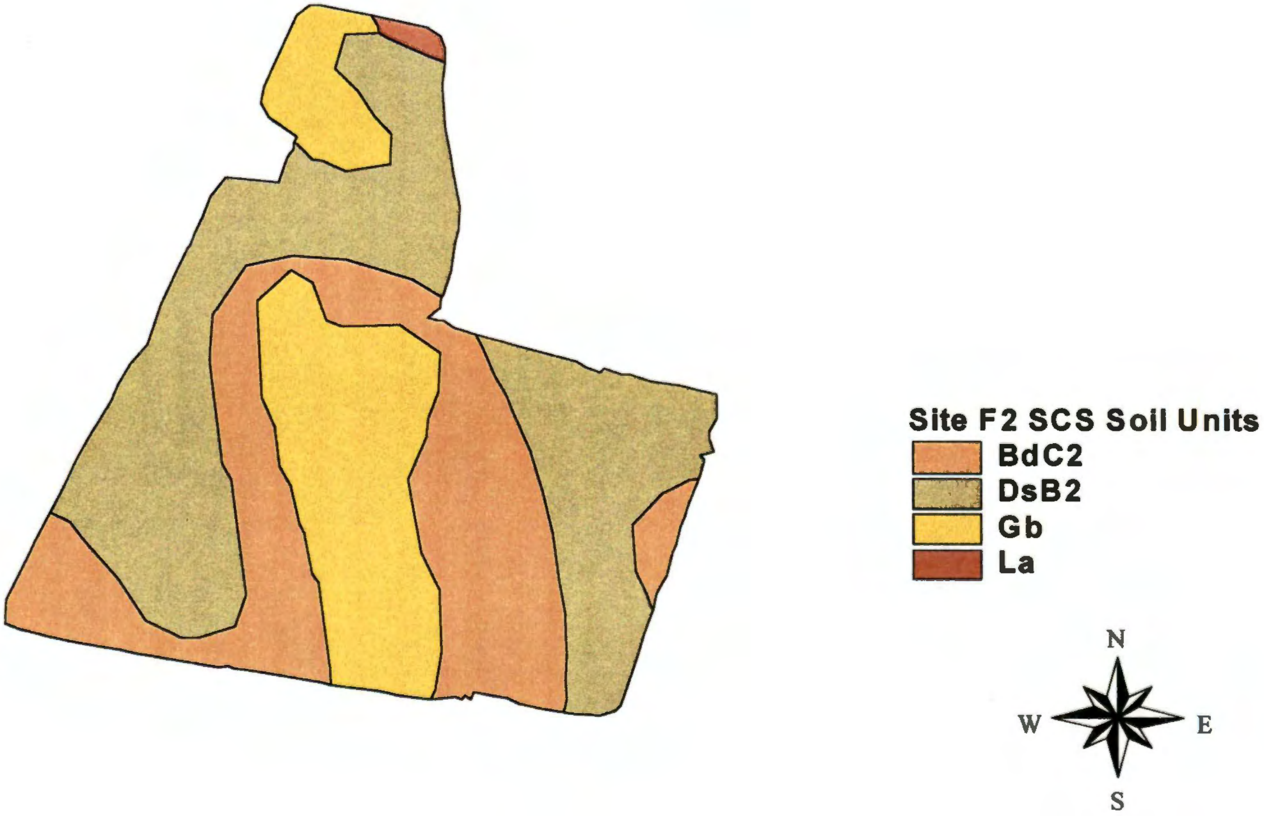

Figure E.2. Soil map reproduced from USDA-SCS county soil survey for site F2.

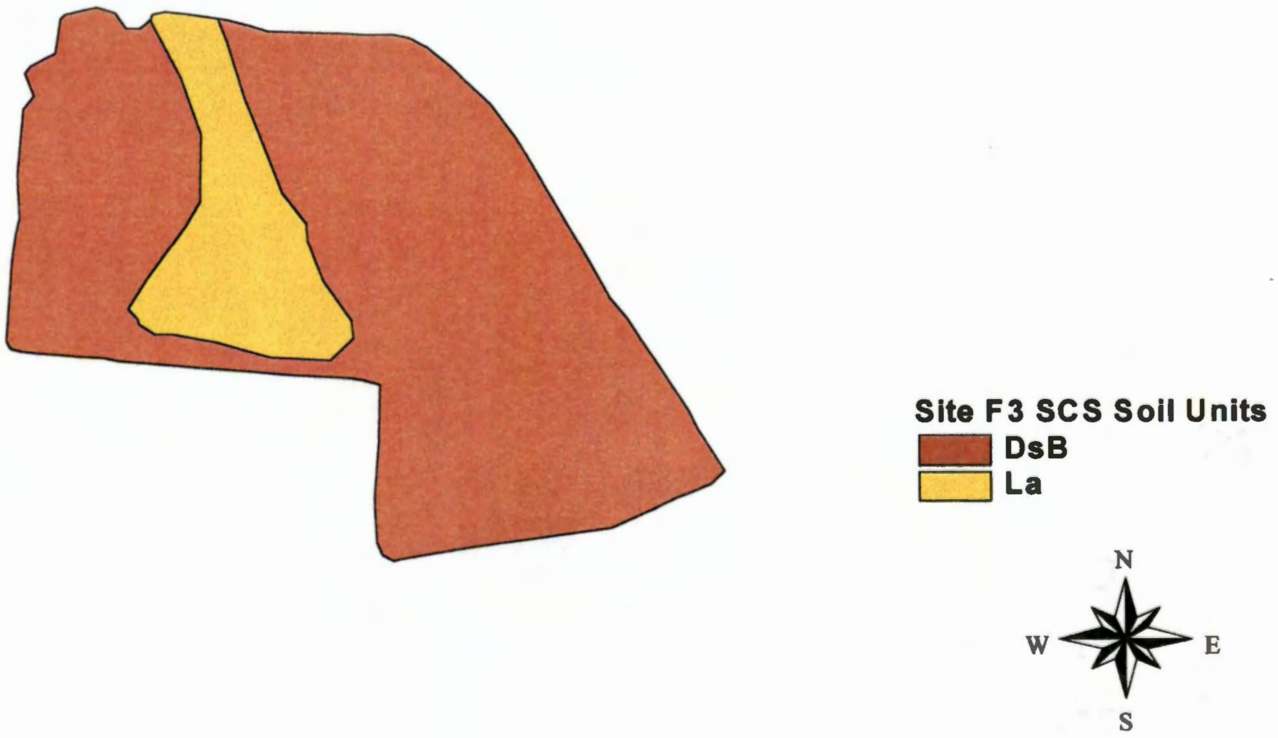

Figure E.3. Soil map reproduced from USDA-SCS county soil survey for site F3.

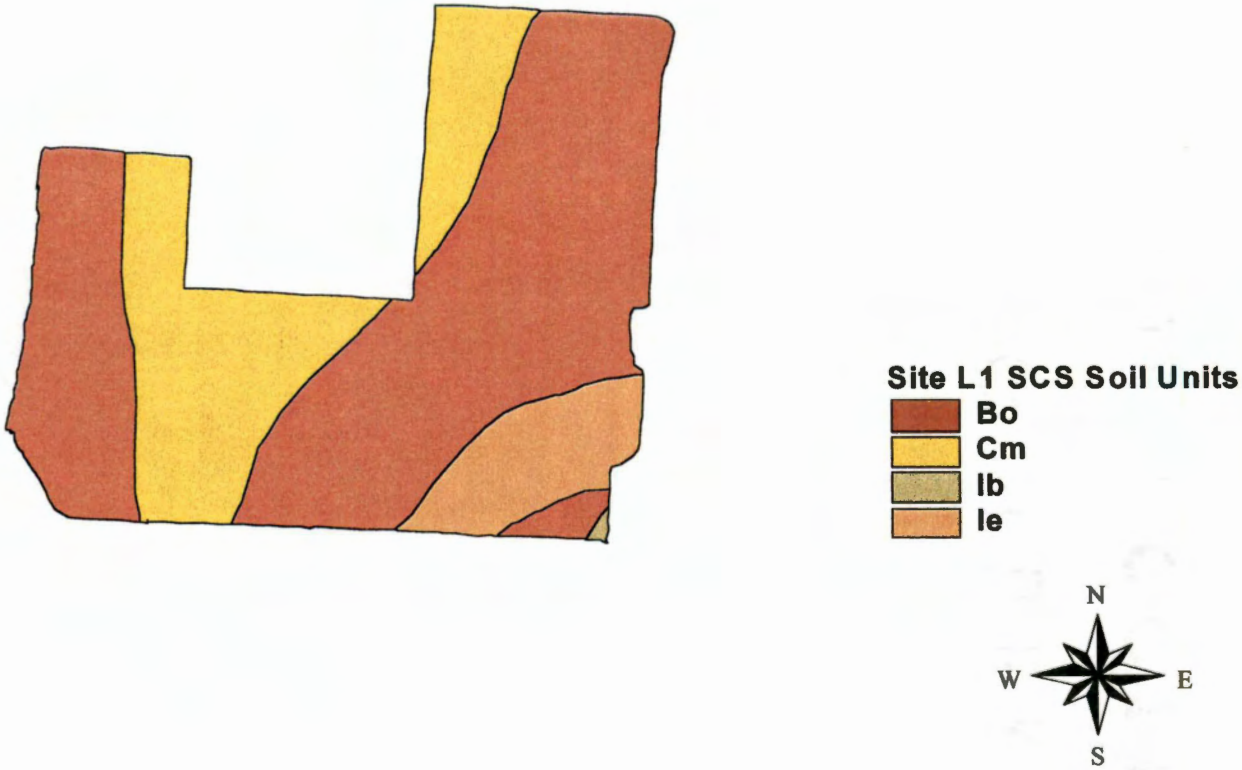

Figure E.4. Soil map reproduced from USDA-SCS county soil survey for site L1.

Figure E.5. Soil map reproduced from USDA-SCS county soil survey for site M1.

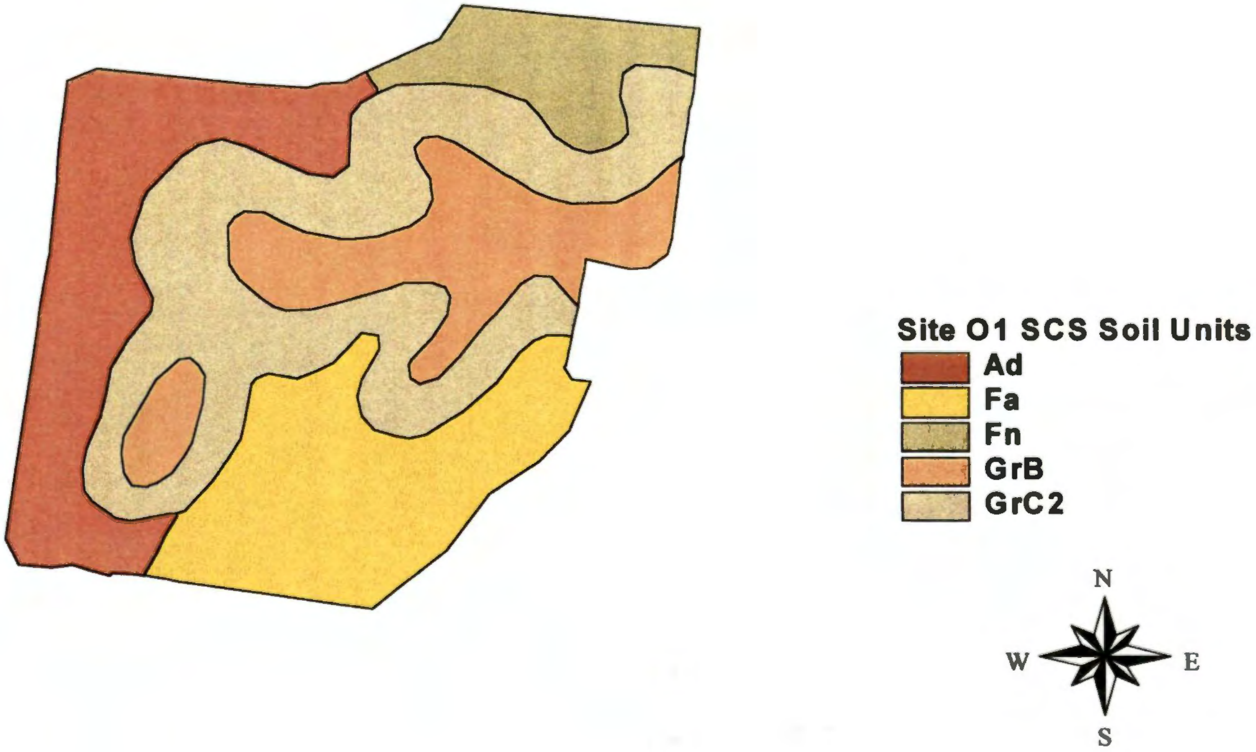

Figure E.6. Soil map reproduced from USDA-SCS county soil survey for site O1.

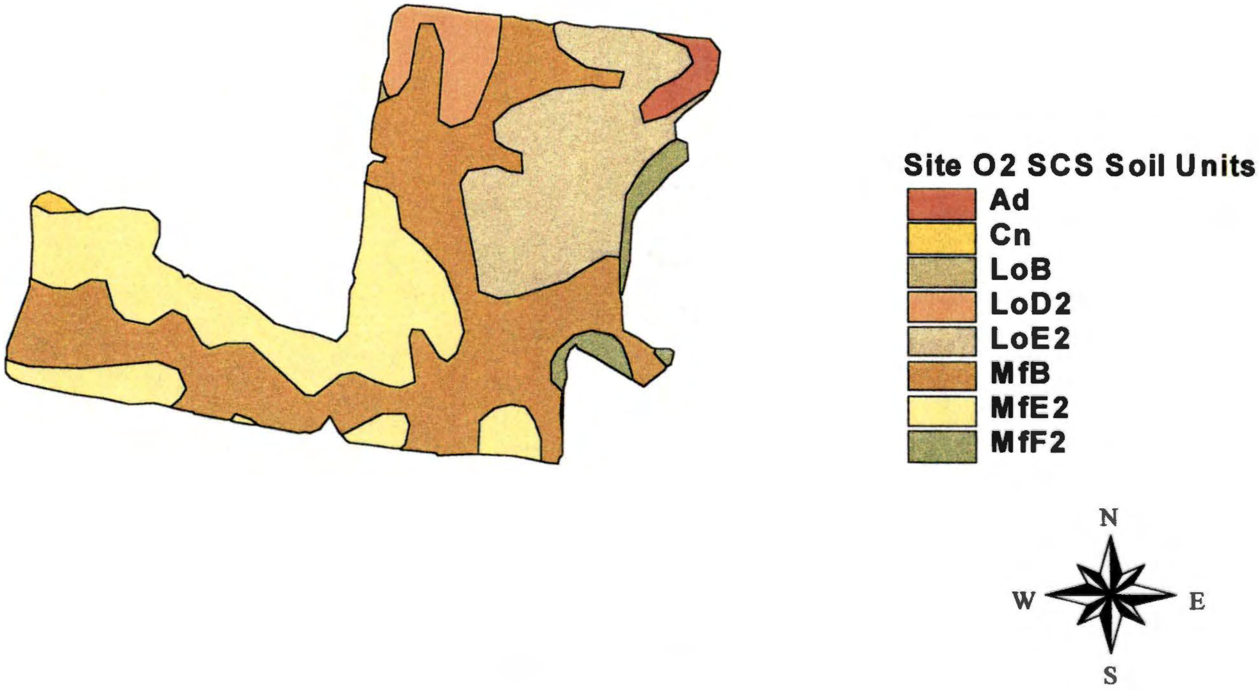

Figure E.7. Soil map reproduced from USDA-SCS county soil survey for site O2.

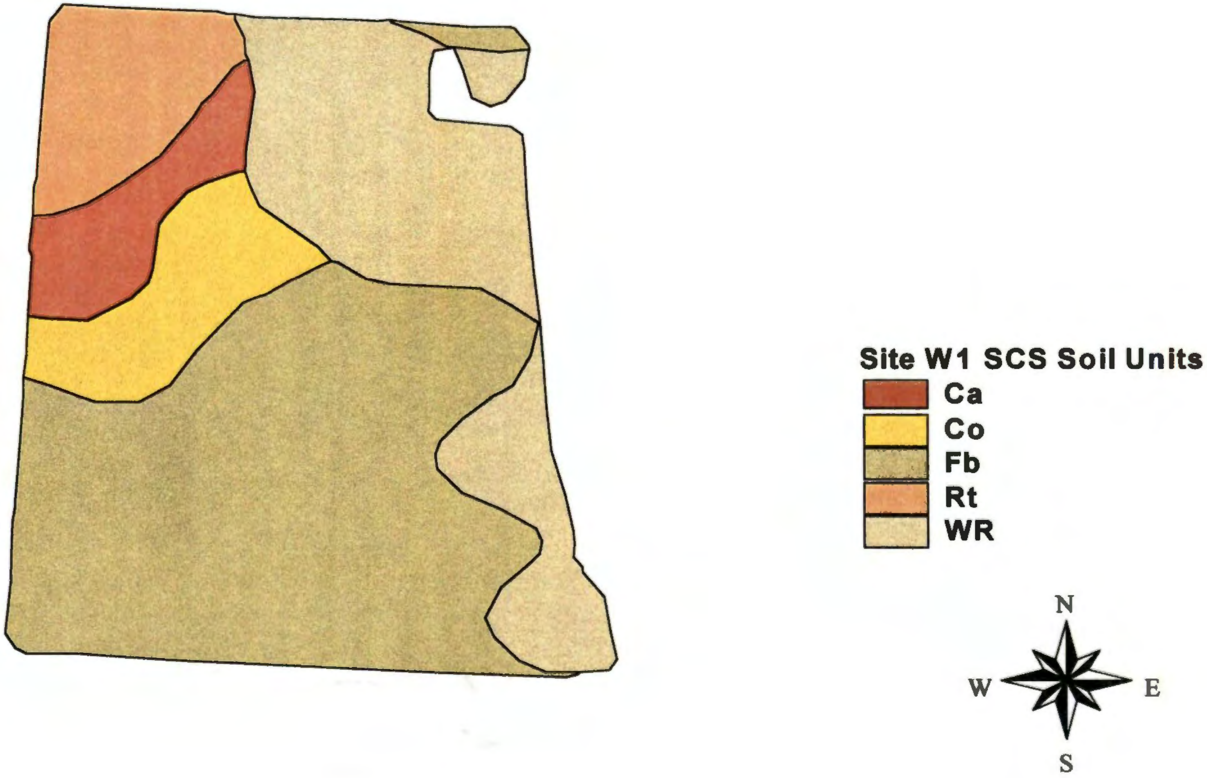

Figure E.8. Soil map reproduced from USDA-SCS county soil survey for site W1.

Figure E.9. Soil map reproduced from USDA-SCS county soil survey for site W2.

APPENDIX F. NUTRIENT DATA

Table F.1. Site F1 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
F1	Bw	242.00	46.71	6.57
	Ds	216.71	45.81	6.54
	DsB	254.60	63.71	6.68
	Gu	207.98	44.06	6.57
	Ta	201.55	43.86	6.52
	WcB	315.11	52.25	6.82
	WcB/BwB	268.50	56.14	6.61

Table F.2. Site F2 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
F2	BdC2	213.42	99.60	6.56
	Ds	252.44	75.88	6.17
	Ds3	173.25	111.89	6.40
	DsB	240.10	108.59	6.52
	DsB2	180.07	101.65	6.46
	GaB	244.24	95.82	6.46
	Mo	247.67	95.25	6.22
	MoB	225.65	95.93	6.52
	MoC	221.63	99.48	6.48
	Ta	230.16	89.79	6.15

Table F.3. Site F3 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
F3	BdC	233.18	119.83	6.82
	Ds	226.63	115.14	6.70
	Ds2	237.59	119.72	6.70
	DsB2	228.78	114.34	6.38
	MoB	213.78	117.80	6.63
	MoC2	234.97	118.51	6.62
	Ta	219.52	120.00	6.94

Table F.4. Site L1 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
L1	Bo	217.76	83.81	6.55
	Cm	198.20	93.79	6.62
	Ie	175.87	87.27	6.63

Table F.5. Site M1 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
M1	Cr	238.81	106.99	7.08
	CrB	189.30	96.28	6.92
	Ds	188.01	102.66	7.07
	DsB	197.40	93.82	6.91
	DsB2	172.82	90.10	7.04
	Gu	228.89	116.83	6.98
	PeC2	220.85	82.47	7.16
	Ta	206.71	117.83	7.12

Table F.6. Site O1 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
O1	Ad	234.73	65.55	6.31
	CaB2	171.28	39.47	6.31
	Ce	178.31	34.88	6.25
	CeB2	176.06	38.03	6.20
	Dk	207.03	70.58	6.18
	Fa	202.57	61.41	6.33
	Fn	154.04	42.78	6.46
	Rt	179.75	34.53	6.05
	RtB	179.23	40.64	6.39

Table F.7. Site O2 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
O2	CeB	184.00	34.30	6.11
	MfB	194.45	37.23	6.27
	MfC	227.15	31.60	6.07
	MfD/E	184.32	36.90	6.17
	MfE	202.91	40.02	5.76

Table F.8. Site W1 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
W1	Ca3	79.34	24.58	5.93
	Ce	78.33	21.23	6.15
	Co	87.65	27.59	6.60
	Fa	77.62	29.39	6.45
	Rt	79.28	19.05	5.92
	Wa	84.54	34.59	6.48

Table F.9. Site W2 summarized nutrient data by intensive soil mapping unit using the combined 2.5 acre and 0.277 acre grid cell sampling results and inverse distance weighted spatial analysis.

Site	Soil Unit	K (lbs/ac)	P (lbs/ac)	pH
W2	Ca	186.51	15.64	6.49
	Ca2	188.37	27.40	6.18
	CaB	186.46	34.24	6.18
	Co	216.56	39.19	6.26
	GrB2	223.56	37.11	6.40
	He	191.08	62.28	6.20
	He2	247.06	33.38	6.63
	Lo	210.20	29.27	6.38
	Lo2	248.32	34.59	6.67
	LoB	211.23	23.45	6.62
	LoB2	219.61	40.56	6.58
	LoC3	206.09	27.11	6.44
	Me	200.48	25.61	6.48
	Rt	237.63	52.38	6.46
	Vk	190.42	26.45	6.18

VITA

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