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I am submitting herewith a thesis written by Curtis B. McDaniel entitled "Evaluation of Soybean Yield Variation for Sites in Tennessee with Landscape and Soil Classification Using GPS/GIS Technologies." I have examined the final copy of this thesis for form and content and recommend that it be accepted in a partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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Evaluation of Soybean Yield Variation for Sites in Tennessee with Landscape and Soil Classification Using GPS/GIS Technologies

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Curtis B. McDaniel

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DEDICATION

This thesis is dedicated to the memory of my grandmother, Joye Elizabeth Kempf, whose name best describes what she brought to those closest to her. I also dedicate this work to my parents, Kenneth and Debbie McDaniel, and brother, Brian McDaniel. The love, support and friendship you have provided means the world to me and inspires me to strive to do my best in life.

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ABSTRACT

Crop yields vary spatially across field landscapes. This variation in production can be quantified on a site-specific basis with current technologies like global positioning systems (GPS) and yield monitoring equipment. However, the factors affecting yield are not as easily identified due to spatial differences in topography and inherent soil properties. This research focused on identifying areas of varying production and examining topographic factors affecting yield variation. Detailed elevation data were used to distinguish the major topographic factors affecting soybean yield. Furthermore, intensive soil classification data available for each field was combined with topography information in an effort to increase explanation.

The objective of this study was to determine to what degree detailed topographical information, alone or together with intensive soil mapping data, explains yield variability on a field scale. High resolution field topography data was collected using Real-Time Kinematic Differential GPS (RTK-DGPS). Topographical variables were used to model hydrological parameters within selected fields in Tennessee. Soil classification and topographical variables were compared with soybean yield variability.

Topographical variables for each field used in this study were combined into classes based on hydrological parameters, landscape position, and percent slope. These landscape classes were compared with 1997 and 1999 soybean yields in an effort to explain yield variation. Significant explanation of yields varied from field-to-field and year-to-year. Results showed that landscape classification explained a maximum of 27.6% of yield variation for all sites and years in this study. In-field soybean yield variability for 1999 was better explained by landscape positions than in 1997. Yields in 1999 were lower than normal

due to lack of precipitation. Significant yield explanations were obtained when landscape classes identified landscape areas that were not conducive to crop production under droughty conditions, such as ridgetops and sideslopes with greater slopes. It was determined that 1997 in-field yield variability was better explained when landscape classification delineated areas of excessive water accumulation. In these areas, yields were significantly lower due to stand reduction and stunted growth caused by excessive water accumulation.

Landscape classification and soil mapping unit data increased the amount of soybean yield variation explained in this study. Models that contained both variables explained as much as 33.89% of the yield variation present in fields examined. Soil mapping units provided a majority of the yield explanation produced from models with landscape and soil variables.

Statistical analysis was conducted to determine how well landscape classes derived from topographic data described soil mapping units within each field. Results showed that significant relationships existed between the two variables, but the amount of correlation was not consistent among the fields. However, further investigation revealed that landscape classes were useful in identifying soil unit polygons. Visual interpretation of the two data layers in a GIS format offered a better understanding of the relationships between landscape position and soil units. The ability of landscape classification to aid in determining specific soil "breaks" within fields depends on the subjective and knowledgeable adjustment of data sets to fit unique field characteristics.

Soybean yields for 1997 and 1999 at the Franklin County sites were compared statistically in an effort to determine correlations between multiple year soybean yield data. Statistical analysis was conducted on normalized yield classes for all fields. Significant

relationships existed between the two years of soybean yield for each field, but the amount of relation varied from field-to-field. Results showed the areas of average yield remained constant from 1997 to 1999. However, the below average areas in 1997 were frequently part of the average yielding areas in 1999. The soybean yields for areas of excessive water accumulation were not as adversely affected in 1999 compared to 1997. When investigating multiple year yield differences, consideration must be placed on the potential yield of an area depending on the topographic location within a field and the effect of different yearly weather conditions to that specific area.

Areas of differing soybean production were identified by landscape classifications. Results from this study show that landscape classification based on topographic and hydrological features provides insight into varying yields in different fields. The amount of yield explanation depends on individual field characteristics and varies accordingly. With this in mind, further investigation may need to be focused on using multiple year data to identify, adjust and interpret classification techniques adaptive to individual field characteristics.

TABLE OF CONTENTS

CHAPTER	Page #
1. INTRODUCTION	1
Background	1
Objectives	3
2. REVIEW OF LITERATURE	5
Yield Responses According to Landscape Position	5
Soil Properties Associated with Landscape Position	7
Hydrological Aspects of Landscape Positions	9
3. MATERIALS AND METHODS	12
Site Selection and Description	12
Franklin County	12
Lake County	13
Yield Measurements	13
Soil Data	18
Elevation Data Collection	20
Landscape Classification	24
Statistical Analysis	32
Explanation of Yield Variation by Landscape Classification	33
Explanation of Soil Mapping Units by Landscape Classes	35
Multiple Year Yield Comparisons	40
4. RESULTS AND DISCUSSION	42
Soybean Yield Explanation by Landscape Classes	42
Yield Variation Between Landscape Classes	50
Franklin County - Site F1	50
Franklin County - Site F2	55
Franklin County - Site F3	60
Lake County - Site L1	60
Effect of Landscape Classes with Soil Mapping Unit on Yield Variation	67
Franklin County - Site F1	69
Franklin County - Site F2	70
Franklin County - Site F3	73
Lake County - Site L1	75
Correlation of Landscape Classes with Soil Mapping Units	76
Multiple Year Soybean Yield Data Correlation	87
Comparison of 6 and 10 Meter Grid Cell Sizes	93
5. SUMMARY AND CONCLUSIONS	96

Page #

BIBLIOGRAPHY 99

APPENDICES 103
Appendix A. Project Site Map 104
Appendix B. Soil Series Taxonomy 106
Appendix C. Yield Data Export Examples 108
Appendix D. Yield Maps 111
Appendix E. Soil Maps 119
Appendix F. RTK-GPS Data Collection 124
Appendix G. Elevation Data Accuracy 128
Appendix H. Elevation Maps 130
Appendix I. Percent Slope Maps 135
Appendix J. Drain and Ridge Location Maps 140
Appendix K. Landscape Position Maps 145
Appendix L. Landscape Classification Maps 150

VITA 159

TABLES

TABLE		Page #
1.	Landscape classes created at each site from classification methods 1 and 2.	31
2.	Nugget, sill and range values determined with semivariograms used in SAS® MIXED procedures for each field and year of soybean yield data to account for spatial relationships.	34
3.	Original and adjusted degrees of freedom for landscape classes under both classification methods for site F1 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.	36
4.	Original and adjusted degrees of freedom for landscape classes under both classification methods for site F2 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.	37
5.	Original and adjusted degrees of freedom for landscape classes under both classification methods for site F3 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.	38
6.	Original and adjusted degrees of freedom for landscape classes under both classification methods for site L1 in 1997. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.	39
7.	Summary of ANOVA results for landscape classifications versus 1997 and 1999 soybean yields for each site and each landscape classification system. Pr > F values less than 0.05 are significant. R^2 values were included only if Pr > F values were less than the 0.05 α-level.	43
8.	Number of observations or grid cells (N) for sites F1 and F2 contained by each landscape class for each classification method. Observations were the same for each year of yield data.	45

TABLE **Page #**

9. Number of observations or grid cells (N) for sites F3 and L1 contained by each landscape class for each classification method. Observations were the same for each year of yield data. 46

10. Mean soybean yields in bushels per acre (bu/ac) by each site for 1997 and 1999. 49

11. Summary of ANOVA results for models containing landscape classes and soil mapping unit data for each field and year. R^2 values are not reported where neither variable in the model was not significant at the $\alpha = 0.05$ level. 68

12. Chi-square and gamma statistic results produced for landscape class versus soil mapping unit frequency tables for each site. Chi-square probability is significant at the $\alpha = 0.001$ level. Gamma values closer to one represent stronger relationships between variables. 79

13. Site F1 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures. 80

14. Site F2 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures. 82

15. Site F3 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures. 84

16. Site L1 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures. 85

17. Chi-square and gamma statistic results for Frequency Tables produced from SAS® FREQUENCY analysis. Gamma values closer to zero indicate independence of each variable. Values closer to one represent dependence of the variables with each other. Chi-square probability is significant at the $\alpha = 0.001$ level. The variables tested in this analysis were 1997 normalized yield data versus 1997 normalized yield data. 88

18. Site F1 frequency table results from yield correlation SAS® FREQUENCY procedures. 89

19. Site F2 frequency table results from yield correlation SAS® FREQUENCY procedures. 91

TABLE **Page #**

20. Site F3 frequency table results from yield correlation SAS® FREQUENCY procedures. 92

21. Yield mean separation results for 6 meter and 10 meter grid sizes for each landscape classification method. Means with the same letter are not significantly different. 94

C.1. Example of yield export for site F1. 110

C.2. Example of yield export containing calculated yield and MPH for site F1. . . . 110

G.1. Vertical and horizontal accuracies of elevation data for each site. 129

FIGURES

FIGURE		Page #
1.	Illustration of erroneous yield data point removal due to edge effects for site F1. Illustration includes: (A) raw yield data points, (B) points within boundary used for data analysis, (C) yield data points remaining after clipping.	17
2.	Illustration of fixed radius interpolation method used for producing (A) the 1997 soybean yield map for site F1. (B) The circles represent a 10 meter radius which was used for 10 meter grid sizes. Yield points in red were used for interpolation of the yield point in the center.	19
3.	Illustration of RTK-GPS including (A) RTK initialization and (B) field mapping.	21
4.	Illustration of the potential problems with analysis of (A) preferential flow paths for site F1. (B) Grid cell numbers represents cumulative water flow into each cell. Water flow direction was modeled from low to high values.	27
5.	Illustration of landscape position classification based on the amount of rise or descent elevation.	29
6.	Process of landscape classification method 1 for site F2.	30
7.	Monthly precipitation amounts compared to the monthly precipitation averages for Franklin County sites in 1997 and 1999. Rainfall data obtained from the National Weather Service at Huntsville, Alabama (National Weather Service, 2001).	48
8.	Average yield values by landscape class (Method I) for site F1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).	51
9.	Average yield values by landscape class (Method II) for site F1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).	52
10.	Average yield values by landscape class (Method I) for site F1 in 1999.	

FIGURE **Page #**

LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 53

11. Average yield values by landscape class (Method II) for site F1 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 54

12. Average yield values by landscape class (Method I) for site F2 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 56

13. Average yield values by landscape class (Method II) for site F2 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 57

14. Average yield values by landscape class (Method I) for site F2 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 58

15. Average yield values by landscape class (Method II) for site F2 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 59

16. Average yield values by landscape class (Method I) for site F3 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 61

17. Average yield values by landscape class (Method II) for site F3 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 62

18. Average yield values by landscape class (Method I) for site F3 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 63

19. Average yield values by landscape class (Method II) for site F3 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 64

20. Average yield values by landscape class (Method I) for site L1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 65

FIGURE **Page #**

21. Average yield values by landscape class (Method II) for site L1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$). 66

22. Soybean yield (bu/ac) means for soil mapping units at site F1 in 1997 and 1999. 71

23. Soybean yield (bu/ac) means for soil mapping units at site F2 in 1997 and 1999. 72

24. Soybean yield (bu/ac) means for soil mapping units at site F3 in 1997 and 1999. 74

25. Soybean yield (bu/ac) means for soil mapping units at site L1 in 1997. 77

26. Map showing the correlation of drainage areas and the Greendale soil mapping unit at site F2. 83

A.1. Tennessee state map indicating site locations. 105

D.1. Corrected 1997 yield data positions for site F1. 112

D.2. Corrected 1999 yield data positions for site F1. 113

D.3. Corrected 1997 yield data positions for site F2. 114

D.4. Corrected 1999 yield data positions for site F2. 115

D.5. Corrected 1997 yield data positions for site F3. 116

D.6. Corrected 1999 yield data positions for site F3. 117

D.7. Corrected 1997 yield data positions for site L1. 118

E.1. Intensive soil mapping units for site F1. 120

E.2. Intensive soil mapping units for site F2. 121

E.3. Intensive soil mapping units for site F3. 122

E.4. Intensive soil mapping units for site L1. 123

F.1 Initialization of RTK-GPS. 125

FIGURE **Page #**

F.2. Initialized RTK rover unit with ATV equipped with rover GPS antenna and rover radio antenna. 126

F.3. RTK data collection with the mobile backpack rather than the ATV due to local area of water accumulation. 127

H.1 Elevation map created from detailed elevation data for site F1. 131

H.2. Elevation map created from detailed elevation data for site F2. 132

H.3. Elevation map created from detailed elevation data for site F3. 133

H.4. Elevation map created from detailed elevation data for site L1. 134

I.1. Percent slope map for site F1. 136

I.2. Percent slope map for site F2. 137

I.3. Percent slope map for site F3. 138

I.4. Percent slope map for site L1. 139

J.1. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F1. 141

J.2. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F2. 142

J.3. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F3. 143

J.4. Drainage flow patterns determined from flow accumulation in ArcView® for site L1. 144

K.1. Map illustrating ponded areas, drainage areas, ridgetop positions and sideslopes for site F1. 146

K.2. Map illustrating drainage areas, ridgetop positions and sideslopes for site F2. 147

K.3. Map illustrating drainage areas, ridgetop positions and sideslopes for site F3. 148

FIGURE **Page #**

K.4. Map illustrating ponded areas, drainage areas, ridgetop positions and sideslopes for site L1. 149

L.1. Site F1 landscape classes under classification method 1. 151

L.2. Site F1 landscape classes under classification method 2. 152

L.3. Site F2 landscape classes under classification method 1. 153

L.4. Site F2 landscape classes under classification method 2. 154

L.5. Site F3 landscape classes under classification method 1. 155

L.6. Site F3 landscape classes under classification method 2. 156

L.7. Site L1 landscape classes under classification method 1. 157

L.8. Site L1 landscape classes under classification method 2. 158

CHAPTER 1

INTRODUCTION

Background

Crop yields vary in different locations within fields. Although producers possess a general idea of the yield variation present, precise differences are usually not known. The use of global positioning systems (GPS), crop yield monitors, and geographical information systems (GIS) are allowing producers to measure and accurately pinpoint yield differences within fields (Plant et al., 2000 and Davis et al., 1998). In addition, precision technologies are supplying means to sample agronomic properties, such as soil fertility, texture and class, in an effort to understand a crop's environment and the changes of those surroundings from one part of the field to another. The ability to spatially map field properties and yields not only provides an overall perspective on yield ranges, but also gives producers an opportunity to better determine the reasons for varying yields.

Factors that influence yield encompass a range of possibilities as they relate to the soil's physical and chemical properties, both of which are required to sustain production. However, emphasis should be placed on seeking out specific variables which contribute to yield variation. The success of site-specific management using precision farming technologies depends on identifying potential factors and interactions that affect yield, understanding the causes of yield variation between areas within fields, and adjusting management accordingly. Furthermore, precision agriculture provides the opportunity to increase profitability and

reduce environmental effects of farming by comparing information gained from precision technologies with conditions present in specific parts of the field and more closely managing production strategies.

The goal of precision farming technologies is to accurately identify yield variation, potential causes for the yield differences, and aid in determining and applying economical and practical management strategies to increase production of low yielding areas and maintain high yielding areas within fields. With agriculture entering the technology age at the same time as the industry is experiencing an economic down-turn, technologies must be found that not only increase production, but are economically viable as well.

GPS technologies are currently available that aid in accurately mapping soil properties and field topography. In coordination with yield monitored data, these factors can be used to quantify the variation in production levels across fields. Prior work by Gehl (1999) showed that soil mapping units explained no more than 14% of the soybean yield variation present in Tennessee fields examined in the study. Although soil is a contributing factor to in-field yield variability, only a minor percentage of the yield variation present was accounted for by exclusively using soil mapping units. Therefore, new layers of data are needed to explain a larger portion of varying yields. As mentioned earlier, topography and landscape characteristics have an affect on yield. As a result, the ability to site-specifically quantify topographic variables may increase the capacity to accurately explain yield differences within fields.

A current technology is available for collection of detailed elevation data, by which very accurate topography maps can be derived. Real-time kinematic global positioning system

(RTK-GPS) uses GPS technology to record latitude, longitude, and elevation with centimeter-accuracy. This technology allows for quick and timely collection of survey-grade data. Also, the analysis and manipulation of this data is not as time consuming as soil property data analysis. This topographic data could prove beneficial if more explanation of yield variation can be accounted for by its use. Although soil property analysis is important to understanding soil inventory within fields, a method of determining factors affecting yield variation that is timely, economical, and provides information useful in maximizing production would be welcomed.

Topography data can be meaningful and is of interest to precision agriculture due to the relative ease of data collection and the ability to make economic improvement in crop production (Henggler et al., 1999). Yield maps together with topography maps appear to be useful in understanding yield variability within a field (Timlin et al., 1998). Spatial distribution of yields is affected by variations in topography at different scales, therefore parameters closely related to yield need to be identified. Although differences in soil properties are sometimes difficult to find in fields, differences in landscape positions are more easily recognized (Brubaker et al., 1994). If the relative value of soil properties within fields could be explained based on landscape position, it would provide agricultural producers with a useful decision aid to optimize production and enhance profitability.

Objectives

This study is a continuation of a research project that compared yields to different soil mapping units within fields to see if in-field yield variability could be explained based on soil identification and delineation. The overall objective of this research project was to determine topographic variables contributing to in-field soybean yield variability. Furthermore, the

primary purpose of the work conducted was to aid in delineating areas of varying production and identifying causes for yield differences. Specific objectives presented in this thesis are to: (i) determine possible landscape characteristics affecting yield variation through detailed topography data, (ii) determine the effectiveness of combining existing intensive soil information with additional topography data layers in explaining yield differences, and (iii) determine correlations between season-to-season yields using multiple year yield data.

CHAPTER 2

REVIEW OF LITERATURE

Topographic variation within fields is an important factor when determining the spatial and temporal differences in agricultural crops. Many soil properties that influence productivity exhibit high spatial and temporal variability (Cambardella et al., 1996). The effect of varying landscape characteristics and soil properties across landscapes on soil productivity and crop yield need to be assessed for site-specific crop management (Khakural et al., 1996). Soil physical and chemical properties, hydrology, slope, aspect, and steepness all vary with landscape position and contribute to differences in plant response (Afyuni et al., 1993). The degree to which these properties affect crop production needs further evaluation. Understanding the relationship between topography, soil characteristics, and crop production could assist in the application of site-specific management strategies. The use of precision agriculture technology increases the ability to delineate, explain, and properly treat management units in an economical and timely manner. To identify areas of different production within fields using topographical characteristics, the relationships of soil properties and landscape positions to crop production must be understood.

Yield Responses According to Landscape Position

Yields vary according to relative positions on field landscapes (Afyuni et al., 1993, Khakural et al., 1996, and Kravenchenko and Bullock, 2000). Crop yield patterns under uniform management practices often reflect the topographic conditions in which the crop is

grown. Yield on undulating land is strongly affected by landscape position and the effect varies with location due to topographic and soil variation (Afyuni et al., 1993). When precipitation is adequate and a field is well-drained, level parts often out-perform sloping areas, especially the steeper slopes present in fields. Increased crop yields have been observed on downhill, lower sloping positions, whereas, production has been found to decrease on upslope to ridgetop positions (Khakural et al., 1996, Afyuni et al., 1993, Brubaker et al., 1993, and Yang et al., 1998). Yang et al. (1998) found that higher wheat yields occurred on gentle slopes and lower yields occurred on the steepest slopes.

Yield and slope relationships have been especially noticed in dry years and appear to be related to the depth of the soil surface layer (Timlin et al., 1998). In Nebraska, Jones et al. (1989) found that corn production was generally greatest on the low-to-moderate sloping areas and least on the upper and linear slopes in studies conducted on several fields. Yield differences were attributed to deposition of soil particles, organic matter, and nutrients eroded from upslope positions and additional plant available water. This redeposition effect results in changes in the physical and chemical properties of uphill and downhill soils (Kravchenko and Bullock, 2000).

Topography-yield relationships have been studied extensively, but due to insufficient technology and resources, reported studies were conducted on a relatively small scale. Research can now be conducted on a broader scale because precision technologies can provide better efficiency and accuracy in defining agronomic properties, such as fertility, texture and other soil characteristics. Landscape position (Yang et al., 1998), slope (Changere and Lal, 1997), curvature (Timlin et al., 1998), and total surface area contributing to water inflow (Simmons et al., 1989) were considered to be the most important topographical

features affecting yields in studies utilizing topographic data on a whole-field basis.

Soil Properties Associated with Landscape Positions

Topography can affect yield by affecting soil properties. Soil properties vary across landscapes due to differences in topographic variables, parent material and soil development (Khakural et al., 1996). Soil formation is influenced by runoff, drainage and soil erosion. These processes are directly related to slope gradients, aspect, and curvature (Brubaker et al., 1994). The differences in soil formation along landscapes result in differences in soil properties, which can significantly affect crop yields. The physical location of soils on the landscape gives a background into the development of that particular soil and eventually leads to identifying key soil features that affect crop production. Topographic information provides details about geographic settings, drainage characteristics and slope ranges used in soil classification.

Slope positions have especially been useful in topography-soil property relationships. Khakural et al. (1996) observed slightly acidic surface pH levels on landscape positions with greater slope gradients. Research by Moore et al. (1993) found that slope explained at least 50% of the variability observed for several in-field variables including A horizon thickness, organic matter content, pH, and silt and sand contents. Results from other studies show that slope position significantly influences soil properties such as water-holding capacity and depth to $CaCO_3$(Timlin et al., 1998, Yang et al, 1998, Khakural et al., 1996, Sudduth et al., 1996). Positions on lower slopes have been found to have higher organic matter content, greater aggregate stability and lower clay contents than those on summit positions (Brubaker et al., 1993). Khakural et al. (1996) also found that surface organic matter content was highest on less sloping areas and lowest on eroded crests in the landscape. Increased organic matter

content and thicker A horizons both occur on less sloping positions. As a result of erosion and crop production, lower organic matter contents are found on backslope and summit positions. Slope has also been positively correlated with sand content (Khakural et al., 1996) and topsoil depth (Sudduth et al., 1996).

Soil properties such as texture, thickness of A horizon, organic matter content, soil pH, cation exchange capacity, aggregate stability, soil profile wetness and plant nutrients vary with landscape position (Afyuni et al., 1993, Brubaker et al., 1993, Khakural et al., 1996 and Moore et al., 1993). Afyuni et al. (1993) found that the thickness of the A horizon decreased with progression from the less sloping areas to the more steeply sloped areas. Research by Khakural et al. (1996) showed that the depth of A horizon varied from 15-20 cm at the eroded crest and steep-moderate slopes to as high as 75-80 cm at the less sloping positions. In a related study by Moore et al. (1993), A horizons greater than 25 cm thick were mostly confined to footslope positions where slopes were less than 2%. Since the A horizon represents the surface horizon, most activities whether mechanical or environmental have an affect on the sustainability of the surface horizon. Thicker A horizons on less sloping landscape positions have been attributed to tillage mixing of the B_t and A_p horizons, surface erosion from steeper slopes, and deposition of sediments carried by over-land flow (Moore et al. 1993). A_p horizons in lower landscapes with less clay content are thought to have better plant growth due to more plant-available water and more favorable soil physical properties than eroded landscape positions (Afyuni et al., 1993).

Less amounts of silt and clay have been found on footslope positions compared to levels observed at summit landscape positions, whereas sand content increases downslope (Brubaker et al., 1993). Soil pH and $CaCo_3$ levels generally increased downslope, with the

highest values being observed on the upper and lower linear slopes and footslopes. Increases in sand amounts downslope were contributed to soil erosion and clay eluviation. In research by Afyuni et al. (1993), footslope positions were found to have coarser soil texture. Corn yields were higher on these landscapes and positively correlated with silt content which supports higher yields as a result of better water infiltration and deeper penetration of roots.

Hydrological Aspects of Landscape Positions

Topography can also affect yield by affecting water movement through the soil profile and across the soil surface. Water availability varies with landscape position and is the most important factor controlling crop production on well-managed fields (Afyuni et al., 1993). Since soybean yield levels are primarily determined by the amount of water available to the plant throughout the growing season (Rhoton, 1990), positions in the field with the ability to hold and store water will produce better yields. Khakural et al.(1996) showed that corn and soybean yields were positively correlated with water storage in the 0-1 m profile.

Topographic attributes help explain the movement of soil water during surface runoff over the landscape (Tomer and Anderson, 1995). Topography, soil type, vegetation, and climate are key factors that control soil moisture distribution over large scales (Yeh et al., 1998). Parameters such as plant-available water, soil water potential and soil water content can be measured directly as a function of landscape position (Afyuni et al., 1993). Soils on lower landscapes have been found to contain more available water than soils on upper landscapes (Khakural et al., 1996, Jones et al., 1989). Tomer and Anderson (1995) found that surface water storage was greatest at the footslope positions of the landscape. Additional plant available water in footslope areas may be due to surface and subsurface water from higher elevations. Landscape positions that receive water from higher elevation produce the

greatest yields because a more continuous supply may be received for plant uptake (Afyuni et al., 1993).

Timlin et al. (1998) found that topography and related factors such as slope and drainage have an effect on the variation of yields, therefore, higher yields were found in the parts of the field that reflected the more uniform topography and better drainage. Yields were reported to be lowest at the summit positions in the field where soil was observed to be dense and shallow and may have restricted root development and water storage. Khakural et al. (1996) attributed low yields on summit positions to thinner A horizons, alkaline surface pH, and low surface organic matter content. In addition, decreased yields at the summit and steeper sloping areas may be due to poor soil water availability. Although the less sloped areas have thicker A horizons and considerably more organic matter, the potential for some areas to pond or have poor drainage raises concern of crop stand reduction, which inevitably leads to lower yields.

Also, the topographical characteristics on the landscapes such as slope, aspect, slope curvature and slope position have been shown to affect soil water storage (Khakural et al., 1996). Afyuni et al. (1993) found a significant correlation between the equivalent depth of soil water and clay content which suggests that soil texture has some control over the observed water content differences. The study showed that coarser textured soils at the less sloped position retained less total water than the finer textured soils found further upslope. The higher clay content in the A_p horizon of the soils found on the upslope positions in the landscape increased water holding capacity, but the additional water was not available for plant uptake. These clayey soils contained more water at -1500 kPa compared to the coarser soils found downslope. Although water holding capacity was low at the footslope, plant

available water was higher due to coarse-textured soil material.

Slope curvature can be an useful indicator of small scale variations in topography that affect crop yield and soil water content. Timlin et al. (1998) found that yields in dry years were significantly higher where curvature was concave. The yield differences were due to the type of plant-water relations and hydrologic conditions that occur when water is limiting as opposed to when there is too much water. Tomer and Anderson (1995) showed that curvature along with elevation and slope effectively explained 51-77% of the variability in profile water storage.

CHAPTER 3

MATERIALS AND METHODS

Site Selection and Description

Study sites were chosen to accommodate collection of detailed elevation data that corresponded to periods when crops were not present and weather conditions allowed coverage of each field. Sites chosen were part of a study previously reported in a M.S. thesis by Gehl (1999). Therefore, complete soil characterization data was available for each field along with an extensive spatial database. An attempt was made to include as many as possible of the available fields, but only two of the previous five sites used by Gehl (1999) were used in this study due to timing and equipment constraints. Four producer fields located on two privately-owned farms were selected as research sites. The sites were located in Tennessee counties Franklin and Lake. Appendix A contains a state map showing the geographic locations of each site in Tennessee. Sites used in this study represent various soil landscapes where soybeans are commonly grown in Tennessee. All sites chosen were in no-till soybean crop production with preference given to producers currently using yield monitors on their combines. Taxonomic classifications for the soil series referred to in this study are included in Appendix B.

Franklin County

Three fields were in Franklin county, located in lower-middle Tennessee on the Eastern Highland Rim physiographic region (Springer and Elder, 1980). The parent materials

from which the soils at this site formed were limestone bedrock and thin loess. They are identified within the Dickson-Baxter-Greendale and Bodine-Baxter-Ennis soil associations common to the site location (Soil Survey Staff, 1958). Franklin County Site 1 (F1: 35.2692^0 N, 86.2317^0 W) consisted of 22.5 acres of primarily Dickson soils on an undulating landscape. This field was cropped as full season soybeans until 1998, when corn was planted followed by soybeans in 1999. Franklin County Site 2 (F2: 35.2999^{0}N, 86.2519^0 W) included 29 acres of rolling landscape with mostly Dickson and Baxter soils. Franklin County Site 3 (F3: 35.2655^0 N, 86.2144^0 W) contained 40 acres of undulating landscape with predominantly Dickson and Mountview soil series. Site F2 and F3 were managed in a corn-soybean-wheat rotation.

Lake County

One field was used at the Lake County site. Lake County is in the northwestern corner of Tennessee, bounded on the west by the Mississippi River. The Lake County Site (L1: 36.2916^0 N, 89.5234^0 W) is 180 acres of generally level landscape on the Mississippi River alluvial flood plain. The primary soil series, Boudre and Commerce, located at this site are included in the Reelfoot-Tiptonville-Adler soil association (Soil Survey Staff, 1969). The western border of the field is bound by the Mississippi river levee and is frequently flooded. The field was managed as full-season soybeans.

Yield Measurements

Producers involved in this study had previously installed real-time yield monitors equipped with DGPS receivers for use during crop harvest. In 1997, yield monitors in the combines were calibrated on-site by project staff prior to harvest of the research fields. Each

producer was assisted during the harvest of soybeans 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. The 1999 yield data collection was not supervised by project staff.

Once the yield data was obtained from each producer, yield data was manipulated and yield maps were created for each field. Yield data were acquired from producers in an ASCII text format. Yield data files were downloaded onto personal computers from PCMCIA (Personal Computer Memory Card International Association) cards. PCMCIA cards contain yield data recorded by yield monitors on the combines during harvest. These text files included spatially oriented yield data logged every 1-2 seconds during soybean harvest. For every position, latitude, longitude, flow rate (lbs/sec) and percent moisture data were recorded. Other miscellaneous data, such as swath width, number of cycles and distance were also recorded. These data were constant throughout each yield data file.

Raw data from the yield monitors report yield as a flow rate (lbs/sec). As a result, yield in bushels per acre (bu/ac) was calculated for each data position using the following formula:

$$Y = \frac{CF(100 - MC)}{BDW}$$

where Y=yield (bu/ac)

F=grain flow rate into the combine (lbs/sec)

MC=moisture content (%)

D=distance traveled between yield data positions (in)

W=swath width being harvested by the combine (ft)

B=grain density (lbs/bu)

C=conversion constant

$5227.2\frac{inches \cdot ft^2 \cdot sec}{ft \cdot ac}$ ➪for 1 second yield data collection

$10454.4\frac{inches \cdot ft^2 \cdot sec}{ft \cdot ac}$ ➪for 2 second yield data collection

Grain flow rate (F) and moisture content (MC) were variables sensed in real time during harvest. Use of moisture content allowed estimation of dry matter content for each position. Distance (D) measures the space covered by the combine from the previous yield data position location. Swath width (W) and grain density (B) were estimated variables and held constant depending on combine header width and type of grain being harvested, respectively. Yield calculation in bushels per acre was performed using a grain density of 51.6 pounds per bushel (lbs/bu). The conversion constant converted distance (D) from inches to feet and accounted for the area coverage in acres per second (ac/sec) for each yield data position. All variables used for calculating soybean yield were contained in the yield data export files obtained from each producer with exception to grain density (B). Appendix C contains information explaining yield data export file formats and examples of yield data files used for yield calculation for this study.

Combine speed was used for filtering, therefore MPH was calculated using the formula:

$$V = DC$$

where V=velocity or speed (MPH)

D=distance traveled (in)

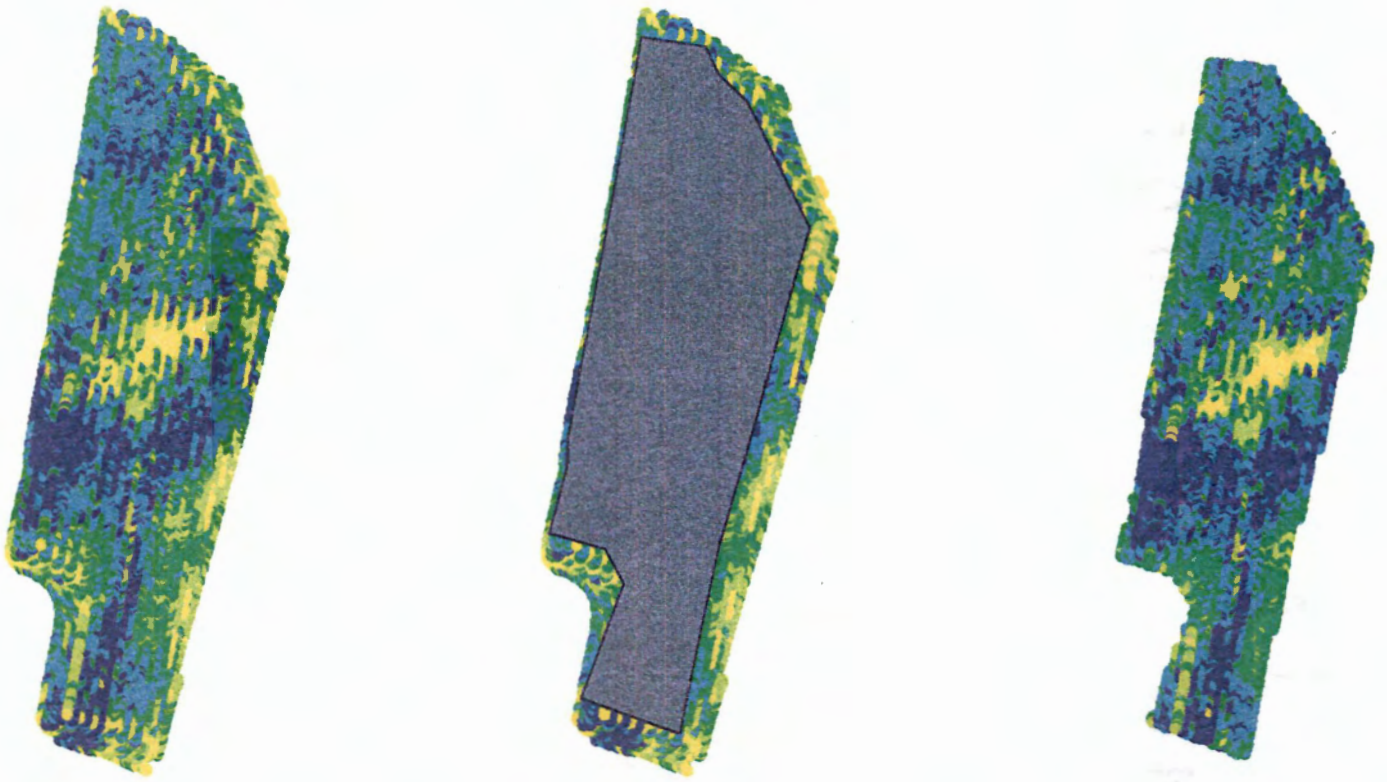
C=conversion constant

$0.056816 \frac{mi}{inches \cdot hour}$ ➪for 1 second yield data collection

$0.113633 \frac{mi}{inches \cdot hour}$ ➪for 2 second yield data collection

Distance (D) represents the distance traveled by the combine from the previous yield data position. The time between collection of data positions during harvest was constant and was typically either 1 second or 2 seconds. The conversion constant consists of factors used to convert inches to feet and feet per second (ft/sec) to miles per hour (MPH).

Complete yield data files were then imported into ArcView® 3.2 (Environmental Research Systems Institute [ESRI], Redlands, CA) where yield maps were created and filtered appropriately. Since raw yield data is often found to be highly variable and can contain misleading points, it was necessary to eliminate as many erroneous points as possible. Yield positions around the borders of each field were deleted to remove edge effects, point rows, and areas where the combine stopped or was turning. Yield measurements where the combine speed (MPH) was greater than or less than 3 standard deviations from the mean were eliminated. Yield data were shifted in time to account for the "ramping up" and "ramping down" of grain entering the combine at the beginning and end of each pass through the field. Yield data from portions of the field not eliminated by filtering were used in data analysis (Figure 1). Corrected yield maps of each field for 1997 and 1999 yield data are included in Appendix D.



(A) (B) (C)

Figure 1. Illustration of erroneous yield data point removal due to edge effects for site F1. Illustration includes: (A) raw yield data points, (B) points within boundary used for data analysis, (C) yield data points remaining after clipping.

Soybean yield point data were interpolated by Inverse Distance Weighting (IDW) with a fixed search radius to generate a grid map. IDW interpolation determines cell values using a linear weighted combination of a set of sample points (Kradilis, 2000). The weight is a function of inverse distance. In this study, the weight was set to a fixed radius dependent upon grid cell size. The length of the radius corresponded to the grid cell size used to create yield maps for each field. For this project, 6 meter and 10 meter grid cell sizes were used to produce yield maps. With 6 meter grids, a radius of 6 meters was chosen to ensure that only yield data directly in or adjacent to the combine pass of interest were used in interpolating yield grid maps (Figure 2). Likewise, a radius of 10 meters was set for the 10 meter grid cells. Six meter grid cell sizes corresponded to the approximate width of the combine header used at the Franklin county site, whereas, 10 meter grids corresponded to the approximate combine header width at the Lake county site. Further detail of grid cell size comparisons is contained in Chapter 4.

Soil Data

Intensive soil mapping was completed at each site by soil scientist from The University of Tennessee. Soils were correlated based on field observation into established series. When possible, characterization was performed in coordination with individual site landscapes and the soil series mapped in existing USDA-SCS soil surveys were used (Soil Survey Staff, 1958 and 1969). Observations of soil properties were made using a soil bucket auger. The number of observations varied at each field, but ranged from 1-2 per acre. Sampling intensity depended on the complexity of the landscape. Each sample was examined for identifiable characterizing features at different depths and assigned a slope respective to classes (0-2% A, 2-5% B, 5-12% C, 12-25% D, 25+% E). Each soil sample location was recorded using

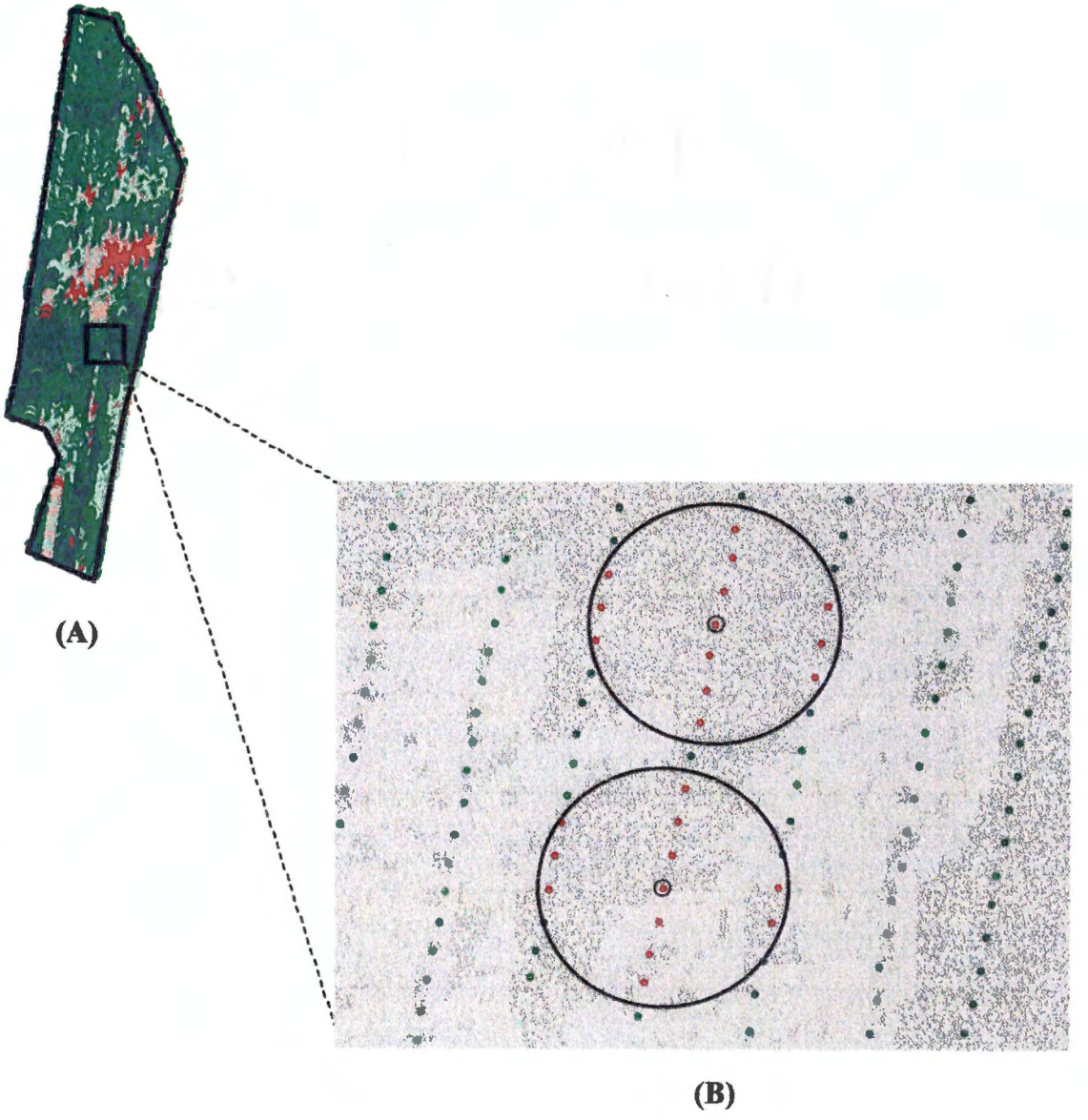


Figure 2. Illustration of fixed radius interpolation method used for producing (A) the 1997 soybean yield map for site F1. (B) The circles represent a 10-meter radius which was used for 10 meter grid sizes. Yield points in red were used for interpolation of the yield point in the center.

a Trimble AgGPS™ 132 (Trimble Navigation, Sunnyvale, CA) DGPS unit.

Following profile observations, soil mapping unit boundaries were delineated by outlining the logical soil breaks on the landscape using DGPS data collection. This was accomplished by driving a Kawasaki Mule™ (Kawasaki Motors Corp., Santa Ana, CA) all-terrain-vehicle (ATV) along the boundaries while the DGPS unit recorded the position and logged them into a palm-top computer. Boundaries were determined by visual estimation of natural slope breaks between landscape positions. This method of intensive soil characterization resulted in a more detailed estimation of the soil mapping units present in each field than could be obtained from county soil surveys. Intensive soil mapping produced soil mapping unit polygons as small as 1/5 acre, whereas published soil surveys only provide polygons on a 3-5 acre scale.

Spatial soil data was created using sampled locations and predicted soil unit boundaries in ArcView® 3.2. Following interpretation of field soil data, maps were created with all necessary corrections or changes made. Using this method, soil maps were created for the fields with boundaries georeferenced at an average error of approximately one meter. (Appendix E). Each polygon represents an individual soil mapping unit and each one was assigned a label in an attribute table in the GIS data file.

Elevation Data Collection

Survey-grade elevation data were collected for each field using a single frequency (L1) Real-Time Kinematic GPS. RTK™ (Trimble Navigation, Sunnyvale, CA) uses GPS and radio-modem technology to constantly collect centimeter accurate x, y, and z positions in real-time (Figure 3). RTK™ surveying is similar to total station surveys because both systems operate using relative measurement techniques. There is a reference and rover unit, where the

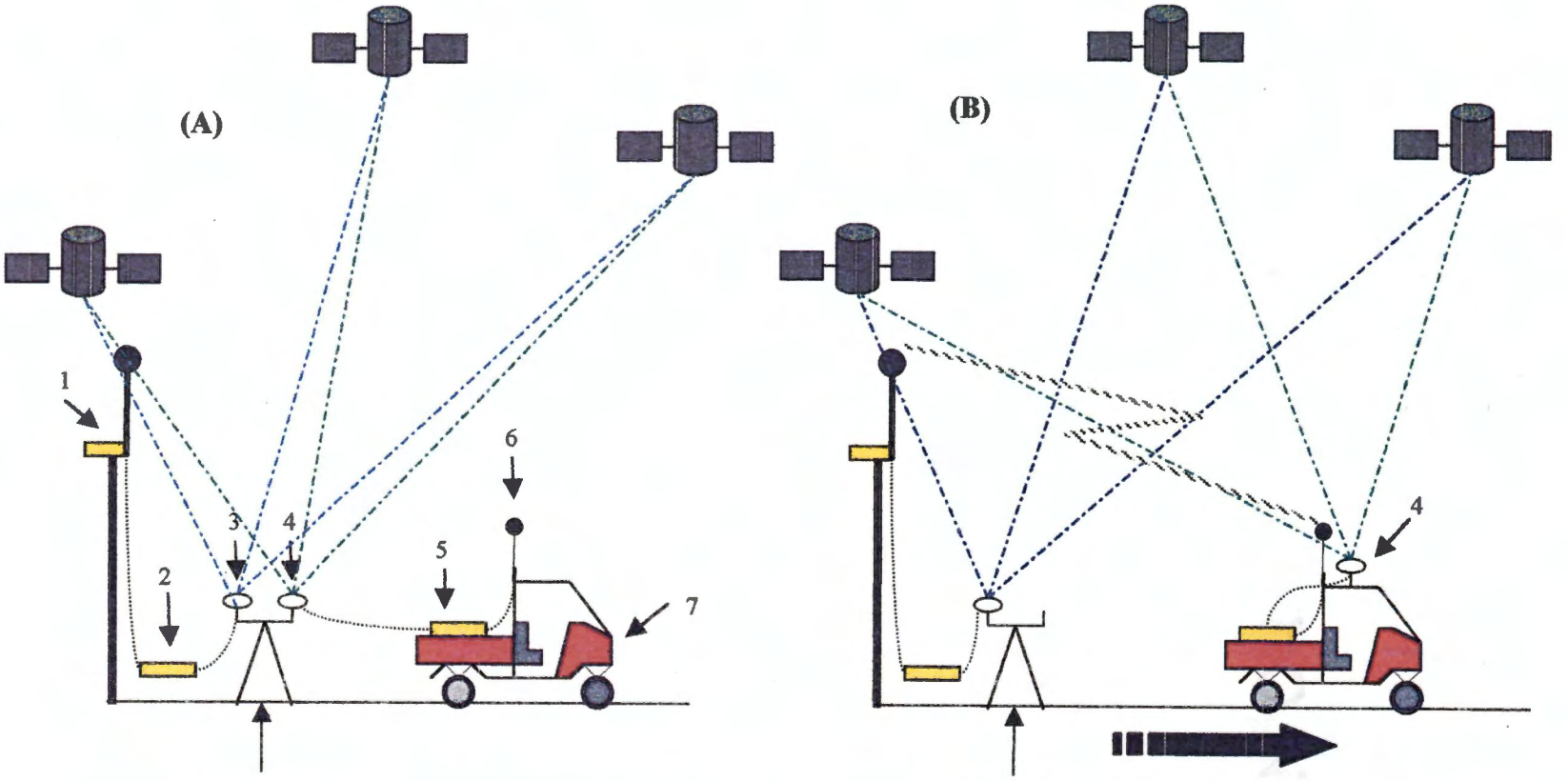


Figure 3. Illustration of RTK-GPS including: (A) RTK initialization and (B) field mapping.

position of the rover is determined relative to the reference position or base station. RTK™ differs from total station surveying because the data collection is conducted at the rover unit, meaning the reference position can be unattended. RTK™ surveying offers productive and efficient collection of very accurate elevation data.

RTK-GPS requires the use of a reference unit and a roving unit. The reference GPS unit acts as the base station at which the true location is known or assumed. Another GPS receiver acts as the roving unit that moves to unknown points. The position of the roving unit is calculated by comparing the differences in GPS signals received by the roving unit with the signals received by the base station. Since the location of the base station is known, differences in GPS signals can be corrected, thus a more accurate rover position can be determined. RTK™ obtains differential corrections using radio signals that are being transmitted between the base station and rover unit radio antennas.

Centimeter-level positioning is obtained by using differential phase processing. This process requires that the GPS receivers must resolve the change in distance between the receiver and satellite that results between the time the signal is sent and the time that is received. As a result, the roving unit must be initialized or calibrated with respect to the base station so that both receivers know the exact position on the earth's surface with respect to each other. This allows the receivers of the base station and roving unit to know the correct distance between there locations and the locations of GPS satellites being used.

RTK™ surveying was conducted at all sites (Appendix F). A reference position was set-up in each field based on the best location considering terrain and range to the rover unit. The geographic location of the base station was determined using a Trimble AgGPS™ 132 DGPS unit that collected corrected GPS positions from an Omnistar® (Fugro Companies,

Houston, TX) satellite. The world coordinates with elevation were entered into the Trimble 4000RS™(Trimble Navigation, Sunnyvale, CA) Reference Surveyor GPS receiver set up as the base station. Once the reference position was established, the rover unit was initialized and connected to the reference unit using radio data links (TrimTalk™, Trimble Navigation, Sunnyvale, CA). The roving unit consisted of a Trimble 4000DS™ (Trimble Navigation, Sunnyvale, CA) Differential Surveyor GPS unit, a radio receiver, a radio antenna and GPS antenna mounted on a Kawasaki MULE™all-terrain-vehicle (ATV). Once initialization was established, positions were collected (~ 1 Hz) as the ATV traveled through the field.

For all fields, the minimum horizontal accuracy was set at 7-8 cm; vertical accuracy was set at 4-5 cm. Elevation points were collected only if the minimum horizontal and vertical accuracies were obtained because maximum tolerances were set prior to data collection. A lower vertical accuracy compared to the horizontal accuracy setting was set to obtain more precise elevation data. Average horizontal and vertical accuracies for each field are in Appendix G. Approximately 30 foot swaths were made throughout the fields with the local minimums, maximums and intermediate areas more densely sampled to ensure accurate representation of in-field landscape characteristics. Guidance through the fields was obtained using a Trimble GeoExplorer III™ (Trimble Navigation, Sunnyvale, CA) hand-held GPS unit.

Data collected in the field were downloaded using Trimble Software Office™ (Trimble Navigation, Sunnyvale, CA). Latitude, longitude, elevation, and vertical and horizontal accuracy or uncertainty for each data position collected were exported to a common text format. The elevation text files were imported into ArcView®3.2 where elevation maps were created (Appendix H). The elevation measurements were converted into cell-based terrain maps. A spline routine with a smoothing weight of 0.1 and 12 neighboring points was

used as an interpolating method for creating elevation maps. Spline interpolation is best suited for subtle variations in data values, such as elevation, because it minimizes the total curvature of the surface (Kralidis, 2000). The number of neighboring points was selected so that the model would be sufficient for estimation at sparsely sampled level areas and at the same time would not produce over-smoothing along densely sampled slope breaks.

Landscape Classification

Detailed elevation data obtained from RTK-DGPS were used to create layers of data representing landscape characteristics and potential hydrological models including percent slope, flow accumulation and potential areas of surface water accumulation. ArcView® 3.2, along with the extensions Spatial Analyst™ (Environmental Research Systems Institute [ESRI], Redlands, CA) and Hydrological Modeling , were used to create the data layers used in this study. Maps created in ArcView® 3.2 consisted of grid cells in which each were assigned unique values related to each data layer.

Percent slope maps were created for each field (Appendix I). Slope describes the rate of elevation change and is defined as the first order derivative of the terrain. Tangent of the slope was calculated as a ratio of the difference in elevation between the centers of adjacent cells to the horizontal distance between them. The slope for each cell was obtained based on a set of 3x3 neighboring cells using the average maximum technique and was measured in percent.

Flow accumulation maps, which define the total number of cells contributing to water inflow into a given cell across fields, were determined using the Hydrologic Modeling extension in ArcView® 3.2 (Appendix J). Prior to calculating the flow accumulation, main flow directions were determined based on elevation differences. The main flow directions

corresponded to the direction of the steepest descent in elevation. Based on the flow direction map, the flow accumulation was calculated by summing all the cells that flowed into a given cell. The absolute value of the flow accumulation depended on the total number of cells in the map, hence, it was a function of both the size of the field and map resolution. As a result, flow accumulation was not applicable for comparing fields of different size. However, within a field, flow accumulation was useful in defining preferential flow paths.

An additional variable was created that reflected the areas of the fields where surface drainage would accumulate and potentially pond. The potential ponded area was created by subtracting the fill elevation from the simple terrain elevation. The fill elevation variable created with Hydrologic Modeling represents the dips or sinks in elevations where water will potentially pond. Fill elevation determines if water can flow out of each grid based on the elevation of the surrounding cells. If the model shows a depression, Spatial Analyst™ computes how much fill elevation should be added so that water will not pond. The difference between the actual elevation data layer and a layer representing elevation with all cells brought up to level with its surrounding cells is the potential area of ponding. Ponding areas were a reason for varying yields in certain fields, with the exception of F2 and F3 for which there were no areas of water accumulation.

The objective of this work was to determine if topographic variables derived from detailed elevation data could effectively explain soybean yield variation at sites located in Tennessee. Initially, work was conducted using each variable created through ArcView®3.2 procedures in statistical analysis as separate variables. However, problems existed using each variable independently, especially with flow accumulation data.

Flow accumulation depicts the drainage flow patterns that exist within fields based on

elevation differences across the landscape. These patterns model the flow of water from areas of significant water accumulation to the outlet from the field. Since flow accumulation is grid cell based, only cells in which water could directly impact or pass through were displayed. In short, only a string of several cells comprised a line representing drainage patterns (Figure 4). This presented a problem because the number of cells comprising the flow patterns were considerably lower compared to the number of cells in the entire field. As a result, significance would be easily skewed during statistical analysis due to imbalance of cells and corresponding yields.

With this in mind, efforts were made to devise a variable that represented the unique landscape characteristics encompassed in each field. Landscape classification was conducted on each field using the topographic and hydrologic variables created in ArcView® 3.2 from detailed elevation data. A procedure was developed for classifying various landscape positions based on relative elevation, percent slope, flow accumulation patterns and potential areas of water accumulation. This class variable identified areas affected by drainage flow patterns and ridgetops rather than a single string of cells.

To create landscape position classes, all data layers mentioned earlier were created for each field. Drainage flow patterns were delineated using flow accumulation models of elevation data. The flow accumulation model located flow paths within each field. Ridgetop areas were created by running Hydrologic Modeling™ on inversed elevation data. Inversed flow accumulation located the areas of maximum elevation or ridgetops within each field. Once these paths were identified, the area surrounding each line was determined as a function of elevation change and distance from the ridge or drain. An extension developed for use in ArcView® 3.2 was used to determine the area affected by each drain or ridge (Holzer, 2000).

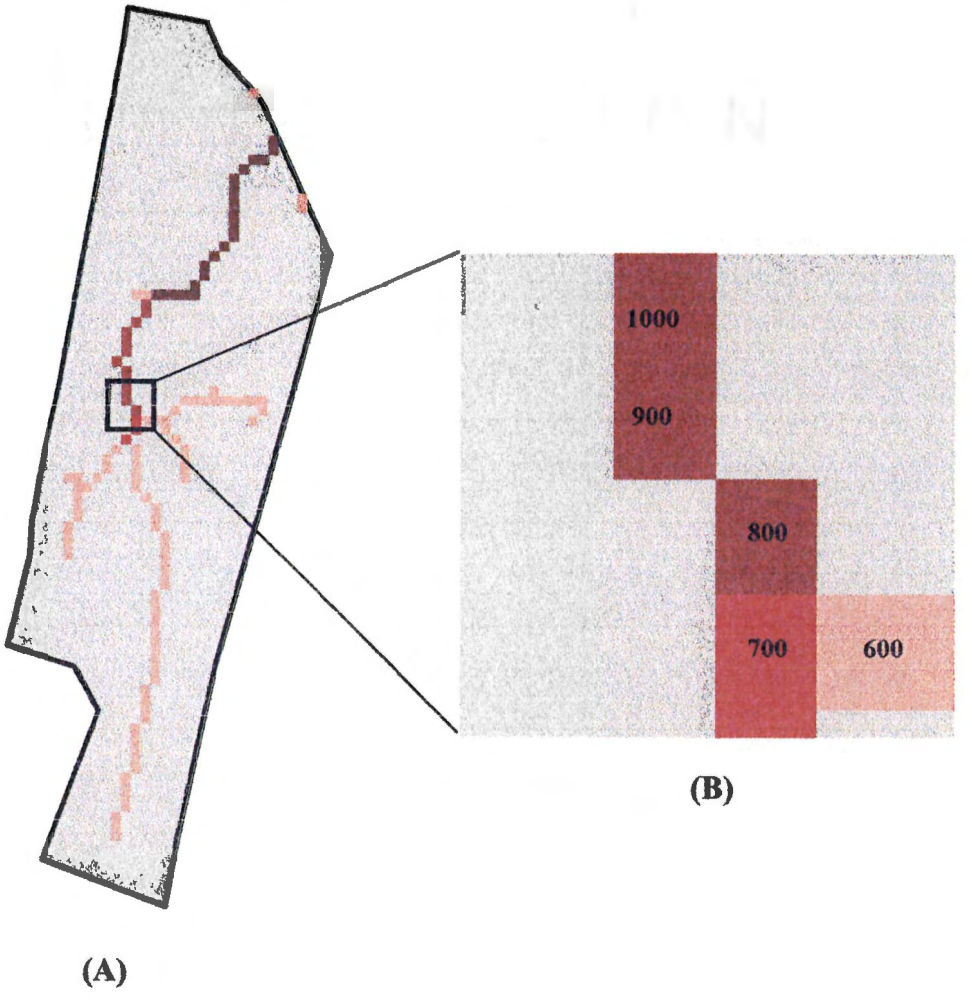


Figure 4. Illustration of the potential problems with analysis of (A) preferential flow paths for site F1. (B) Grid cell numbers represent water flow into each cell. Water flow direction was modeled from low to high values.

For each ridge or drain, 1/2 meter was the maximum change in elevation allowed either downslope from the ridges or upslope from the drains (Figure 5). Areas that buffered each drain or ridge were classified as drainage area polygons or ridgetop position polygons. Areas not identified as areas affected by either drains or ridges were classed as sideslope polygons. Further classification was conducted by determining polygons within each primary landscape position class with percent slope. The number of classes in each field were influenced by the slope ranges and position on the landscape of each landscape area polygon. Appendix K shows the landscape position polygons created for each field. When present, potential ponded area classes were also added as a landscape polygon to each classification theme.

This resulted in a landscape classification variable that included drainage areas, ridgetop areas, intermediate areas, and ponded areas. Classification was unique for each field used in this study. Two land classification variables were developed for each field using the above methodology. Classification method 1 was a more descriptive classification, whereas, classification method 2 was more arbitrary. In both cases, differences only exist between the classification based on percent slope in each landscape position area. Certain slope classes in method 1 were combined for method 2. Figure 6 illustrates landscape classification used in this study. Table 1 contains characteristics of the classes established for each field and method. Maps of landscape classes by method 1 and method 2 for each field are located in Appendix L.

Once the appropriate data layers were created for each field, they were exported to an ASCII text format and combined into a spreadsheet. SAS®(SAS Institute Inc., Cary, NC) 8.0 was used to perform statistical analysis of the data for each field. Methods described in this thesis were conducted with two grid cell size formats; 6 and 10 meter grid cell sizes.

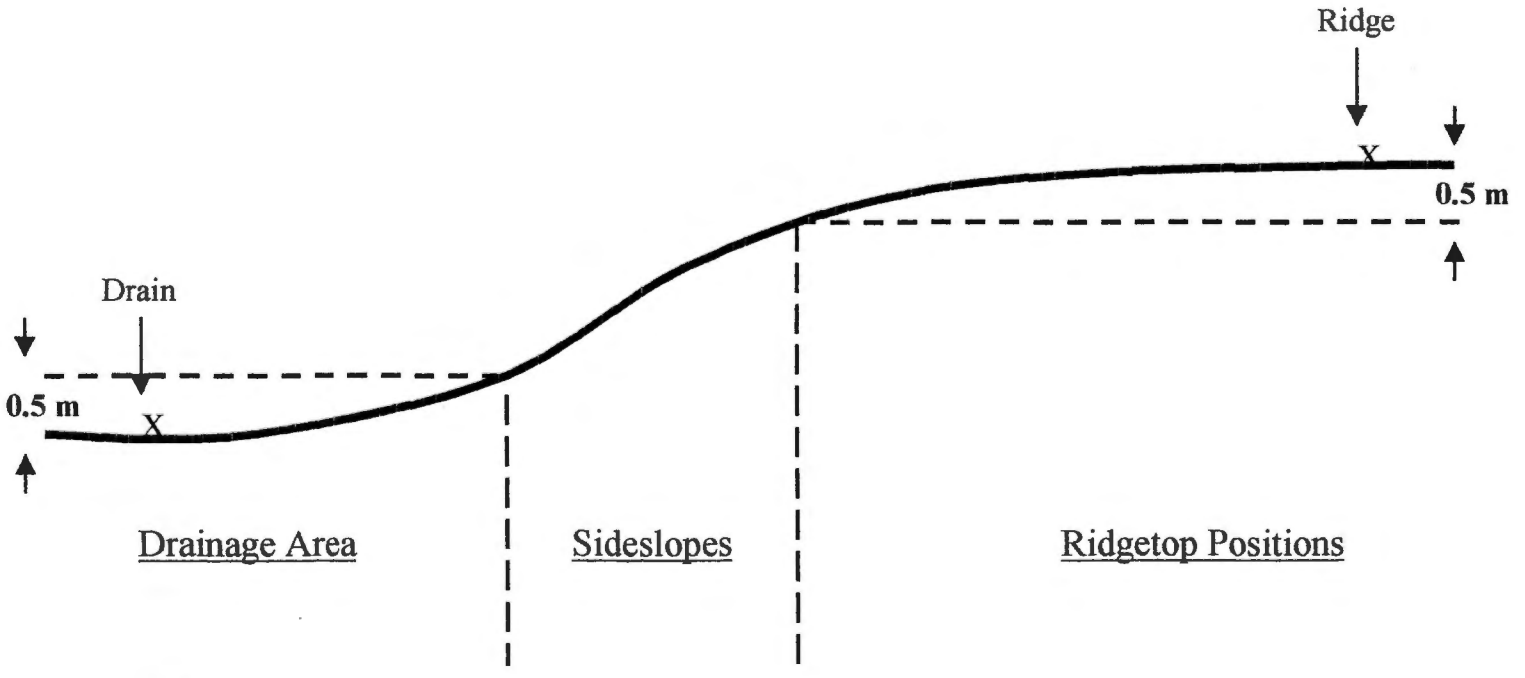


Figure 5. Illustration of landscape position classification based on the amount of rise or descent elevation.

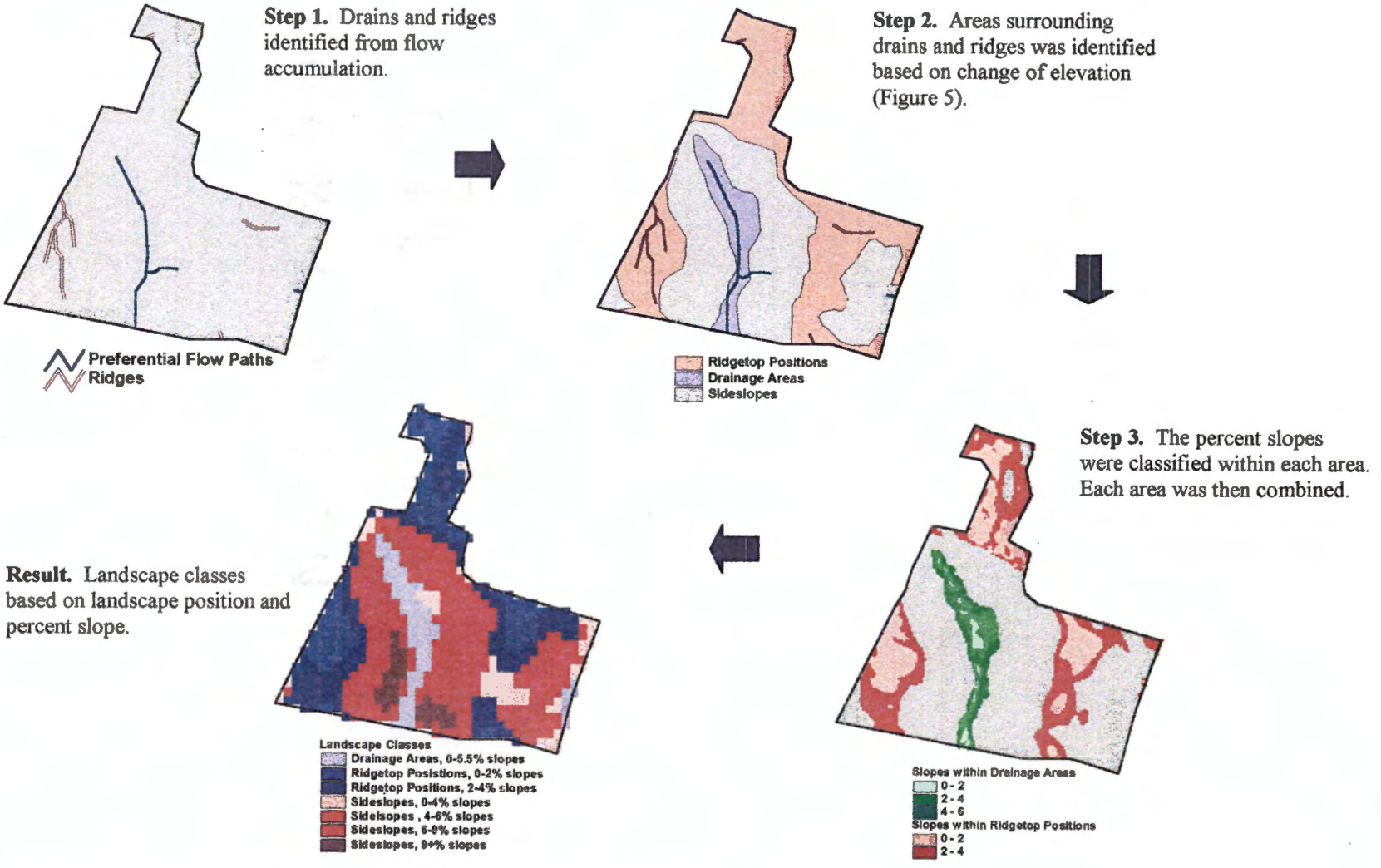


Figure 6. Process of landscape classification method 1 for site F2.

Table 1. Landscape classes created at each site from classification methods 1 and 2.

Site	Class	Method 1	Method 2
F1	1	Potential Ponded Areas	Potential Ponded Areas
	2	Drainage Areas, 0-0.75% slopes	Drainage Areas, 0-2% slopes
	3	Drainage Areas, 0.75-2% slopes	Ridgetop Positions, 0-2% slopes
	4	Ridgetop Positions, 0-2% slopes	Ridgetop Positions, 2-4% slopes
	5	Ridgetop Positions, 2-4% slopes	Sideslopes, 4+% slopes
	6	Sideslopes, 4+% slopes	-
F2	1	Drainage Areas, 0-5.5% slopes	Drainage Areas, 0-5.5% slopes
	2	Ridgetop Positions, 0-2% slopes	Ridgetop Positions, 0-4% slopes
	3	Ridgetop Positions, 2-4% slopes	Sideslopes, 4-6% slopes
	4	Sideslopes, 0-4% slopes	Sideslopes, 6-9% slopes
	5	Sideslopes, 4-6% slopes	Sideslopes, 9-13% slopes
	6	Sideslopes, 6-9% slopes	-
	7	Sideslopes, 9-13% slopes	-
F3	1	Drainage Areas, 0-1.5% slopes	Drainage Areas, 0-3% slopes
	2	Drainage Areas, 1.5-3% slopes	Ridgetop Positions, 0-2% slopes
	3	Sideslopes, 3-6% slopes	Sideslopes, 2-6% slopes
	4	Ridgetop Positions, 0-2% slopes	-
	5	Ridgetop Positions, 2-4% slopes	-
L1	1	Potential Ponded Areas	Potential Ponded Areas
	2	Drainage Areas, 0-0.58% slopes	Drainage Areas, 0-1.7% slopes
	3	Drainage Areas, 0.58-1.7% slopes	Ridgetop Positions, 0-1.5% slopes
	4	Ridgetop Positions, 0-0.5% slopes	Ridgetop Positions, 1.5+% slopes
	5	Ridgetop Positions, 0.5-1.5% slopes	-
	6	Ridgetop Positions, 1.5+% slopes	-

Analysis was performed using both grid cell sizes in an effort to determine differences associated with test using grid cell based data. Chapter 4 contains results of comparative analysis of the two grid cell sizes.

Statistical Analysis

Precision agriculture deals with data collected on a precise site-specific manner. Very often data are recorded within a few feet of each other throughout fields which results in a large quantity of data to be analyzed. Although each position at which data are collected is uniquely different, a spatial correlation is usually present. The amount of correlation and spatial variability among observations refers to variation that exists between each in space. Commonly, patterns exist in properties within fields. In order to analyze these patterns, statistics must be suited to evaluate spatial variability. Spatial statistics or geostatistics are methods of analysis that model and estimate the patterns present in spatially-oriented data, such as yield data (Ditzler, 1994).

Spatial statistics are based on the tendency of observations closer together to be more alike than observations farther apart. In agronomic perspectives, field properties measured in close proximity will usually be more alike, whereas, more distant measurements tend to be less alike. As the number of data positions increases, spatial variability also increases. Fields typically exhibit a high degree of spatial heterogeneity. Failure to use statistical methods that account for spatial dependence can result in erroneous conclusions. Significant relationships are certain to be obtained when statistical procedures are conducted with large amounts of observations, such as yield data positions. When traditional statistics are conducted with these type data sets, the power of the test is lessened to a degree that significant differences will occur when no statistical importance exists. Proper statistical

methods must be applied to obtain reliable results from spatially oriented data with a very large number of observations.

The goal of this research was to determine the relationships between certain landscape characteristics and varying levels of soybean yield. Whole fields were used in this study. Spatial statistics, in addition to conventional linear statistics, will be used to determine sets or areas of yield data points that are significantly different. The main objective of using spatial statistics is to raise the power of your test by lowering the degrees of freedom. By identifying groups of spatially-related data points that represent the same production level, the total degrees of freedom can be adjusted thus providing a stronger test for significance (Saxton, 2001). At the same time, spatial statistics allows you to obtain repeated measures on the treatments being analyzed.

Explanation of Yield Variation by Landscape Classification

Several steps had to be completed before final analysis could take place on the data sets used in this study. Compiled data sets extracted from ArcView® 3.2 were imported in SAS® 8.0. Semivariograms were first produced using the SAS® PROC VARIOGRAM procedure to determine whether exponential, gaussian, or spherical correlation models fit the yield data and to estimate the values of the nugget, sill, and range values (Ditzler, 1994). The sill, nugget, and range variables used to fit semivariograms to yield data of each field are in Table 2. Statistical analysis was conducted with 1997 and 1999 yield data, with exception to the Lake County field for which only 1997 yield data was available. Spatial spherical models were selected for all fields at the Franklin County site based on observed 1997 yield variograms. 1999 yield variograms resulted in exponential models for F1 and F2 and a spherical test for F3. The Lake County site required use of the spatial exponential model to

Table 2. Nugget, sill and range values determined with semivariograms used in SAS® MIXED procedures for each field and year of soybean yield data to account for spatial relationships.

Site	Year	Size	Nugget	Sill	Range
		(ac)	$(bu/ac)^2$	$(bu/ac)^2$	(m)
F1	97	21	12	82	80
	99		2	22	80
F2	97	28	8	17	97
	99		2	13	87
F3	97	44	10	40	77
	99		2	18	77
L1	97	195	5	55	27
	99*	-	-	-	-

*Only 1997 yield data existed for L1

fit semivariograms to 1997 yield data.

Spatial analysis relating topographic variables to yield were then performed using SAS® PROC MIXED procedures (Littell et al., 1996). The nugget, sill, and range values were added to the model for each data set prior to running the program. Spatial relationships were determined in the data based on spatial values inserted into each statistical module (Saxton, 2001). The total observed degrees of freedom (DF) for each landscape class were adjusted (Tables 3, 4, 5, & 6). As a result, spatial similarities and differences in the data associated with each class were accounted for by the spatial statistics. SAS ®PROC MIXED procedures provided results for tests of significance with corrected degrees of freedom. To determine R-square (R^2) values, SAS® PROC GLM procedures were conducted on the data sets. R-square (R^2) values are reported with test for significance provided by SAS® PROC MIXED results. Further statistical analysis included the addition of soil mapping units with landscape classes in an effort to determine how much more yield variation could be explained by adding topographic variables with existing soil inventory data. Statistical analysis using soil mapping unit and landscape classes was conducted in the same manner as landscape classes alone versus yield.

Explanation of Soil Mapping Units by Landscape Classes

Landscape classification was based on data layers interpolated from detailed elevation data. Statistical analysis was conducted to determine how well variables derived from topographic data explained existing soil mapping units within each field. SAS® PROC FREQUENCY tables were generated to determine the relationships between soil mapping units and landscape classes and SAS® CHI-SQUARE procedures were used to test for significant relationships. Basic percentages that described the matches of certain landscapes

Table 3. Original and adjusted degrees of freedom for landscape classes under both classification methods for site F1 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.

Site		Method 1			
		1997		1999	
	Class	Original DF	Adjusted DF	Original DF	Adjusted DF
F1	1	537	140	609	17.5
	2	582	78.4	611	9.35
	3	533	56.3	613	7.76
	4	534	68.2	614	8.71
	5	544	57.1	604	7.89
	6	536	76.9	607	10.4
			Method 2		
F1	1	529	136	607	16.7
	2	534	56.7	614	7.57
	3	538	69.2	615	8.54
	4	546	57.9	605	7.72
	5	532	78	611	10.2

Table 4. Original and adjusted degrees of freedom for landscape classes under both classification methods for site F2 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.

Site		Method 1			
		1997		1999	
	Class	Original DF	Adjusted DF	Original DF	Adjusted DF
F2	1	437	98.6	430	1.86
	2	359	75.7	748	1.62
	3	433	60.7	659	1.46
	4	500	90.8	599	1.63
	5	534	58.4	524	1.48
	6	620	69.8	482	1.64
	7	400	135	425	2.45
			Method 2		
F2	1	446	101	397	1.46
	2	457	52.8	595	1.11
	3	542	59.8	486	1.17
	4	626	72.1	439	1.30
	5	400	141	290	1.94

Table 5. Original and adjusted degrees of freedom for landscape classes under both classification methods for site F3 in 1997 and 1999. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.

Site		Method 1			
		1997		1999	
	Class	Original DF	Adjusted DF	Original DF	Adjusted DF
F3	1	940	164	1155	478
	2	1075	159	1159	467
	3	1159	371	1123	732
	4	1043	142	1159	436
	5	935	161	1160	474
			Method 2		
F3	1	1052	142	1161	457
	2	1059	144	1161	457
	3	1039	157	1150	482

Table 6. Original and adjusted degrees of freedom for landscape classes under both classification methods for site L1 in 1997. Adjusted degrees of freedom resulted from spatial statistics performed using SAS® MIXED procedures and represented spatial relationships that existed in the yield data.

Site		Method 1	
		1997	
	Class	Original DF	Adjusted DF
L1	1	2062	164
	2	1935	29.8
	3	2024	53.6
	4	2081	33.7
	5	2126	47.7
	6	262	1305
		Method 2	
L1	1	2069	164
	2	1953	28.3
	3	2102	30.8
	4	262	1309

classes with soil mapping unit were acquired through SAS® procedures. Dependence between the two variables was determined using gamma statistic values and average standard errors (ASE) produced by SAS® PROC FREQUENCY output tables in conjunction with SAS® MEASURES statements.

Multiple Year Yield Comparisons

Statistical analysis was performed using SAS® PROC CHI-SQUARE and PROC FREQUENCY test to determine the correlation of soybeans yields in 1997 to 1999 yields. SAS® CHI-SQUARE and MEASURES statements were included in SAS ®PROC FREQUENCY analysis. Yield data for the fields at the Franklin County site varied considerably in 1997 and 1999. As a result, yield data was normalized to allow comparison of the multiple-year soybean data based on a scale adjusted toward the yield means, rather than by actual yields observed in each year (Aspinal, 2001). Yield normalization was achieved by finding the mean yield average per year per field, dividing each grid cell yield value by the mean, and multiplying by 100. This produced values that represented the percent crop production compared to the mean soybean yield. Grid cells with values closer to 100% indicated yields resembled the overall average yield of the field. Normalized yield values greater than 100% and less than 100% represented yields that were above average and below average, respectively. With this in mind, normalized yield data were classed into average, below average and above average yield classes. Above average yield classes contained values greater than 120%. Below average yield classes consisted of grid cells with values less than 80%. Normalized yield values between 80% to 100% were classed as average yields. Yield classes bases on normalized yield values for 1997 and 1999 soybean yield data for each field were compared. Relationships between the two years of soybean yield data

were examined based on gamma statistic and ASE values produced by SAS® FREQUENCY procedures. CHI-SQUARE values were used to determine if significant relationships occurred between the two data sets.

CHAPTER 4

RESULTS AND DISCUSSION

Soybean Yield Explanation by Landscape Classes

Yield data in 1997 and 1999 were normally distributed for each field in all tests. SAS® GLM procedures indicated landscape classes, under either classification method, explained no greater than 27.6% of the soybean yield variation present at any site in 1997 or 1999. Coefficients of determination (R^2) from general linear models between yield and landscape classes ranged from 0.011 to 0.276. Analysis of variance (ANOVA) statistics from SAS® MIXED procedures showed that the majority of yield variation in both years of yield data was not significantly explained by landscape classes at the $\alpha = 0.05$ level (Table 7). Results (R^2) showed that landscape classes using classification method 1 were slightly better at explaining soybean yield differences than classification method 2 in three of the four fields, regardless of the year. The differences between method 1 and method 2 were expected due to better definition of landscape classes with method 1. However, overall explanation of yield variation by landscape classification in 1997 and 1999 soybean yield variation present for each field in this study was lower than anticipated.

The purpose of using two classification methods for determining landscape classes was to determine if substantial amounts of yield variation could be explained with less emphasis placed on slope within each landscape positional area, rather than an intense classification of the slope ranges. In effect, landscape classes with method 1 were classed

Table 7. Summary of ANOVA results for landscape classifications versus 1997 and 1999 soybean yields for each site and each landscape classification system. Pr > F values less than 0.05 are significant. R^2 values were included only if Pr > F values were less than the 0.05 α-level.

Site	Classification Method	Year	Type III F-value	Pr > F	R^2 value (%)
F1	Method 1	97	9.51	<0.0001	27.6
		99	1.91	0.0904	-
	Method 2	97	11.91	<0.0001	26.3
		99	1.50	0.1996	-
F2	Method 1	97	0.99	0.4312	-
		99	3.17	0.0045	9.0
	Method 2	97	0.21	0.9356	-
		99	4.68	0.0010	5.5
F3	Method 1	97	0.35	0.8462	-
		99	3.17	0.0132	7.3
	Method 2	97	0.60	0.5491	-
		99	0.87	0.4190	-
L1	Method 1	97	1.79	0.1122	-
		99*	-	-	-
	Method 2	97	2.90	0.0338	4.6
		99*	-	-	-

*Only 1997 yield data existed for L1.

based on more defined slope ranges, whereas, classification method 2 landscape classes dealt less with slope and were more focused on simple landscape positions. Therefore, method 1 resulted in more classes than method 2. This alone could account for the higher R^2 values observed with method 1 in this study. Detailed explanation of the classes created by each method for all fields is contained in Chapter 3 (Table 1).

It is important to note that landscape classes differed in the number of grid cells contained by each. Furthermore, the number of grids or observations in each landscape class were adjusted during spatial statistical analysis in order to account for spatial dependence of data positions (Tables 8 and 9). Several landscape classes were found to have very few observations. Statistical inferences about those classes were unreliable. Specific occurrences identified in the study are explained in each section of this chapter.

Methods 1 and 2 were statistically significant at sites F1 and F2, with 1997 and 1999 yield data, respectively. At site F3, 1999 yield data was significantly related to method 1, where no relation was observed with method 2. The opposite was observed at site L1 with 1997 soybean yields. This is attributed to the fact that the landscape classes by both classification methods for sites F1 and F2 were more similar than landscape classes for sites F3 and L1. For site F1, method 1 differed from method 2 by only one class. Drainage areas in method 1 were represented by two classes. These two classes were combined in method 2. In the case of site F2, ridgetops positions with less than 4% slope in method 2 contained areas formerly classed separately in method 1: (i) ridgetop positions, 2-4% slopes and (ii) sideslopes, 0 - 4% slopes. The classes for each method at sites F3 and L1 were not as similar. Attention must be paid to the fact that the classification methods depend on individual field characteristics. Differences in class mean yields observed from field to field and year

Table 8. Number of observations or grid cells (N) for sites F1 and F2 contained by each landscape class for each classification method.

Site		Method 1	Method 2
	Class	N	N
F1	1	20	20
	2	67	276
	3	209	89
	4	89	163
	5	163	72
	6	72	--
F2	1	69	69
	2	126	340
	3	155	212
	4	59	127
	5	212	33
	6	127	--
	7	33	--

Table 9. Number of observations or grid cells (N) for sites F3 and L1 contained by each landscape class for each classification method. Observations were the same for each year of yield data.

Site		Method 1	Method 2
	Class	N	N
F3	1	282	500
	2	218	406
	3	36	258
	4	406	-
	5	222	-
L1	1	67	67
	2	1545	1764
	3	219	1481
	4	1153	8
	5	328	-
	6	8	-

to year may only represent the inherent discrepancies in topography variations and yearly weather changes that occurred in each field.

Landscape classes also varied in explaining soybean yield variation from year-to-year. On a whole, both methods of landscape classes better explained the variation in 1999 soybean yield compared to the yields of 1997. Of the three sites with 1999 yield data available, site F1 was the only site in which 1999 yields were not statistically related to landscape classes.

Droughty conditions occurred in 1999. In contrast, greater levels of precipitation occurred in 1997. For Huntsville, Alabama, near the Franklin county sites, 1999 rainfall was approximately 11 inches below the thirty year average, while 1997 precipitation was slightly higher (Figure 7) (National Weather Service, 2001). As a result, lower yields were observed in 1999, with higher yields in 1997 (Table 10). Results demonstrate that the landscape classes did consistently better explaining yields in the dry year compared to the year where rainfall was considered slightly above average. However, 1997 yields for site F1 data had the highest amount of variation explained by landscape classes. This was due to a large area in the field that had potential for excessive water accumulation with little to no drainage which, in turn, reduced yields dramatically. Areas like this were found not to exist in sites F2 and F3. Landscape classes did not effectively explain yield variation at these sites for 1997 yield data which is a result of the lowest yielding areas of the field not being grouped into a specific landscape class, as was the case with site F1.

Yield variation was explained better in 1999 for the Franklin county sites, as a whole. Independently, a significantly greater amount of yield variation was explained at site F1 in 1997. This was attributed to plant damage by water stress in the lowest lying areas of the field. It can be concluded that landscape classes could be useful in fields when potential areas

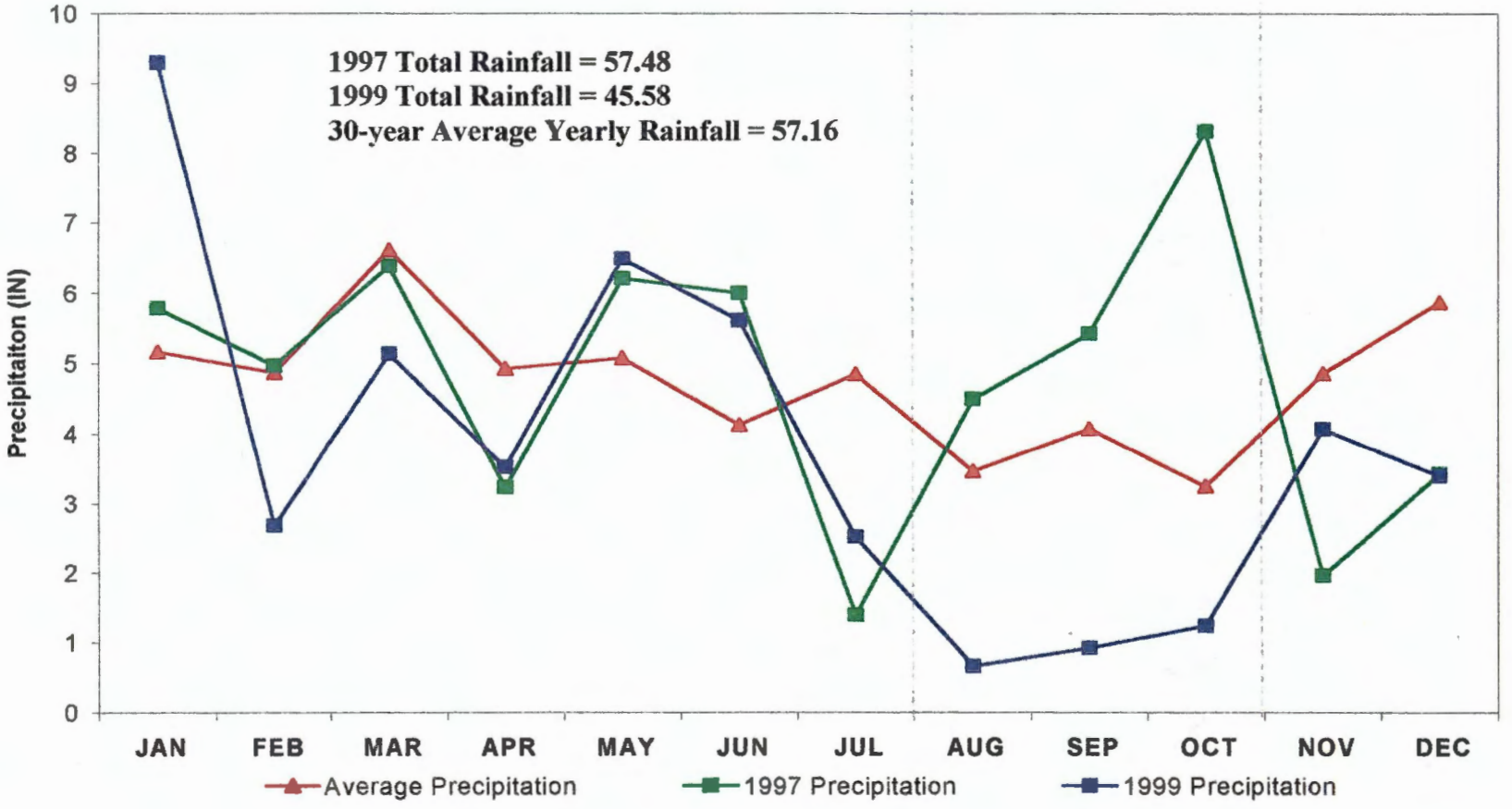


Figure 7. Monthly precipitation amounts compared to the monthly precipitation averages for the Franklin County sites in 1997 and 1999. Rainfall data obtained from the National Weather Service at Huntsville, Alabama (National Weather Service, 2001).

Table 10. Mean soybean yields in bushels per acre (bu/ac) by each site for 1997 and 1999.

Site	Year	
	1997 Yield (bu/ac)	**1999 Yield (bu/ac)**
F1	37.24	21.82
F2	43.05	18.16
F3	38.58	15.45
L1*	49.65	-

*Only 1997 soybean yield data was available for site L1.

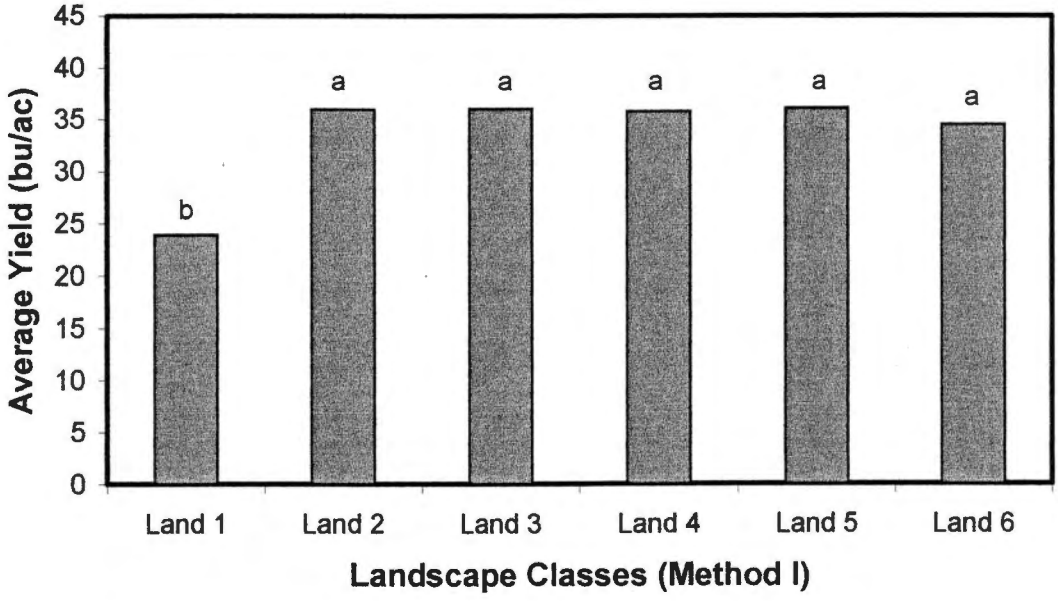
of water accumulation may exist. For sites F1 and L1, simple identification of potential ponded areas using topographical data provided just as useful information as complete landscape classification.

Yield Variation Between Landscape Classes

Franklin County - Site F1

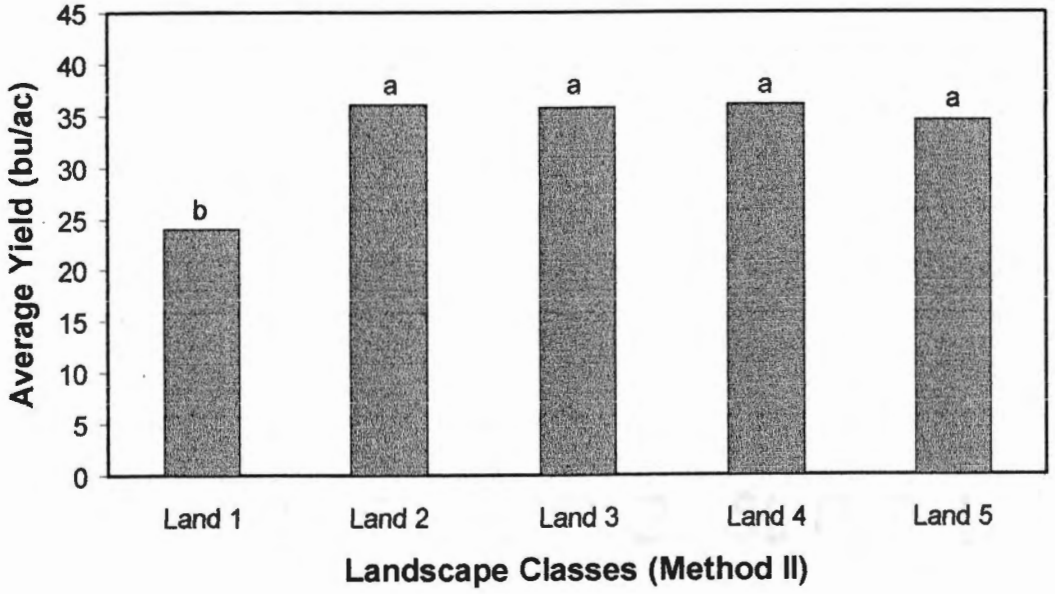
The highest amounts of yield variation for any year in this study were explained at the F1 site for 1997 soybean yield. Site F1 contained six landscape classes for method 1 and five landscape classes for method 2. The two landscape classification methods for this site differed very little and the results reflected the small differences between the two classification methods. 1997 soybean yields were significantly lower in the potential ponded areas (class 1) compared to the other classes (Figures 8 & 9). The yields were reduced in the areas of excessive water accumulation due to stand reduction and stunted growth. Meanwhile, the yields for the rest of the field were above average because of the amount of available water throughout the growing season. Landscape class mean separation results for soybean yields in 1999 were nearly opposite those of 1997.

For 1999 soybean yield data, potential ponded areas of methods 1 and 2 contained the highest average yields within the field (Figures 10 & 11). Significant yield reduction occurred on sideslope positions where slopes were greater than four percent. 1999 yield means for landscape classes better represented the differences that occurred on different landscape positions due to much less rainfall through the growing season compared to 1997. Higher yields in the lower lying areas of the field and lower yields on ridgetop and sideslope positions were observed for both landscape classification methods in 1999 yield data. This



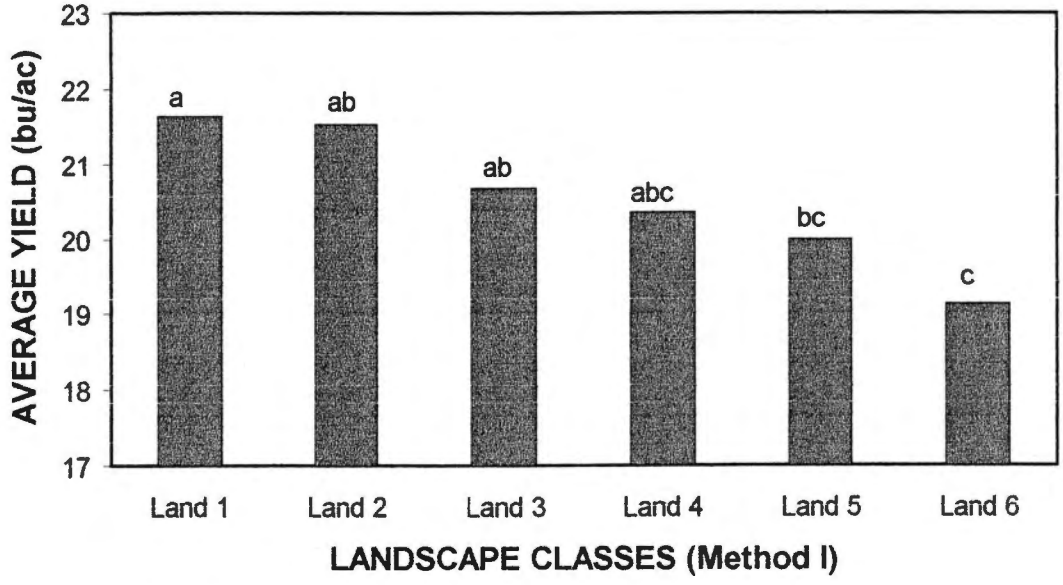
Land 1 - Potential Ponded Areas
Land 2 - Drainage Areas 0 - 0.75% slopes
Land 3 - Drainage Areas 0.75 - 2% slopes
Land 4 - Ridgetop Positions 0 - 2% slopes
Land 5 - Ridgetop Positions 2 - 4% slopes
Land 6 - Sideslopes 4+% slopes

Figure 8. Average yield values by landscape class (Method I) for site F1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



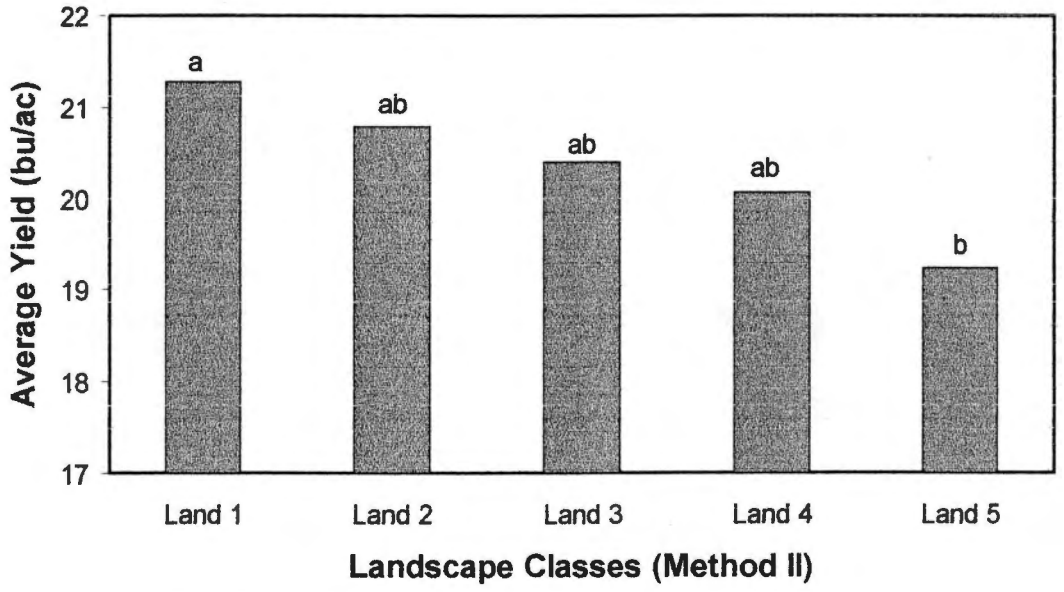
Land 1 - Potential Ponded Areas
Land 2 - Drainage Areas 0 - 2% slopes
Land 3 - Ridgetop Positions 0 - 2% slopes
Land 4 - Ridgetop Positions 2 - 4% slopes
Land 5 - Sideslopes 4+% slopes

Figure 9. Average yield values by landscape class (Method II) for site F1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Potential Ponded Areas
Land 2 - Drainage Areas 0 - 0.75% slopes
Land 3 - Drainage Areas 0.75 - 2% slopes
Land 4 - Ridgetop Positions 0 - 2% slopes
Land 5 - Ridgetop Positions 2 - 4% slopes
Land 6 - Sideslopes 4+% slopes

Figure 10. Average yield values by landscape class (Method I) for site F1 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Potential Ponded Areas
Land 2 - Drainage Areas 0 - 2% slopes
Land 3 - Ridgetop Positions 0 - 2% slopes
Land 4 - Ridgetop Positions 2 - 4% slopes
Land 5 - Sideslopes 4+% slopes

Figure 11. Average yield values by landscape class (Method II) for site F1 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).

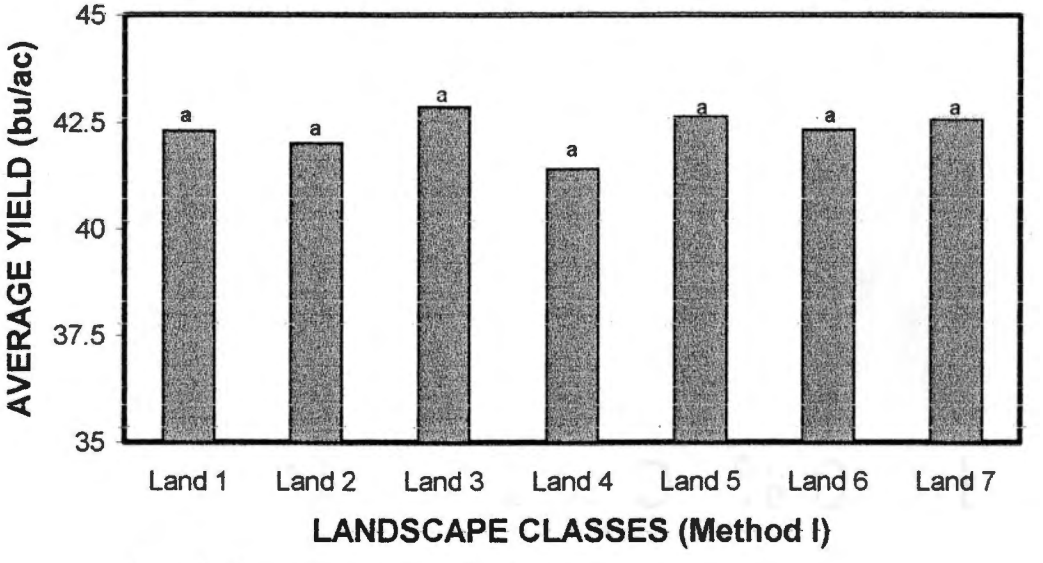
was attributed to the fact that the drought conditions in 1999 resulted in more available water for plant growth in areas that in 1997 had received too much water from upslope positions. The ridgetop and sideslope classes represented the areas most affected by the lack of water and the yields reflected that assumption.

Franklin County - Site F2

Mean values for 1997 yield data at site F2 did not show any significant differences in soybean yield between the seven landscape classes under method 1 and five landscape classes under method 2 (Figures 12 & 13). Less variation in yield existed between the landscape classes with method 2 compared to method 1, yet no significant effect on soybean yield was present for either classification method.

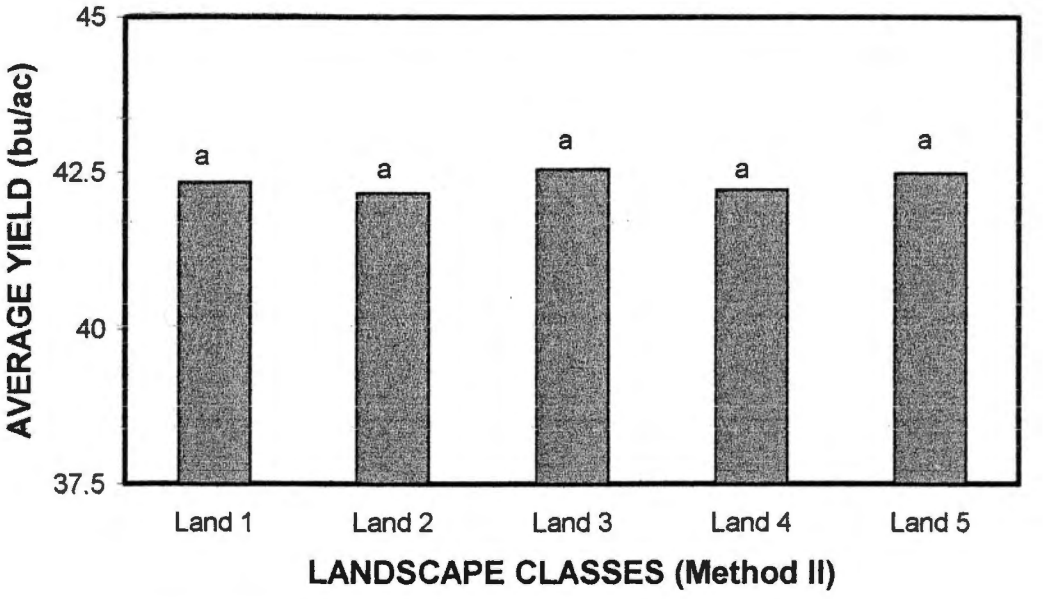
The landscape classes for 1999 showed a more variant pattern in average yields. In both methods, the significantly lower yields were found in the drainage areas with slopes ranging from 0 - 5.5% slope (Figures 14 & 15). Low yields in 1999 were surprising for the drainage areas. In that area of the field, severe erosion and water flow might have adversely affected soybean growth.

For classification method 1, the ridgetop positions had slightly better yields than the sideslope positions with exception to sideslopes with 9 - 13% slopes. Oddly, the highest yields occurred on this landscape position for both methods. Yields reflected better soil conditions, although good soils more often occur on slopes less than observed at this location. The observed soybean yields reflected a situation that supported crop growth on that region of the field which has no evident explanation.



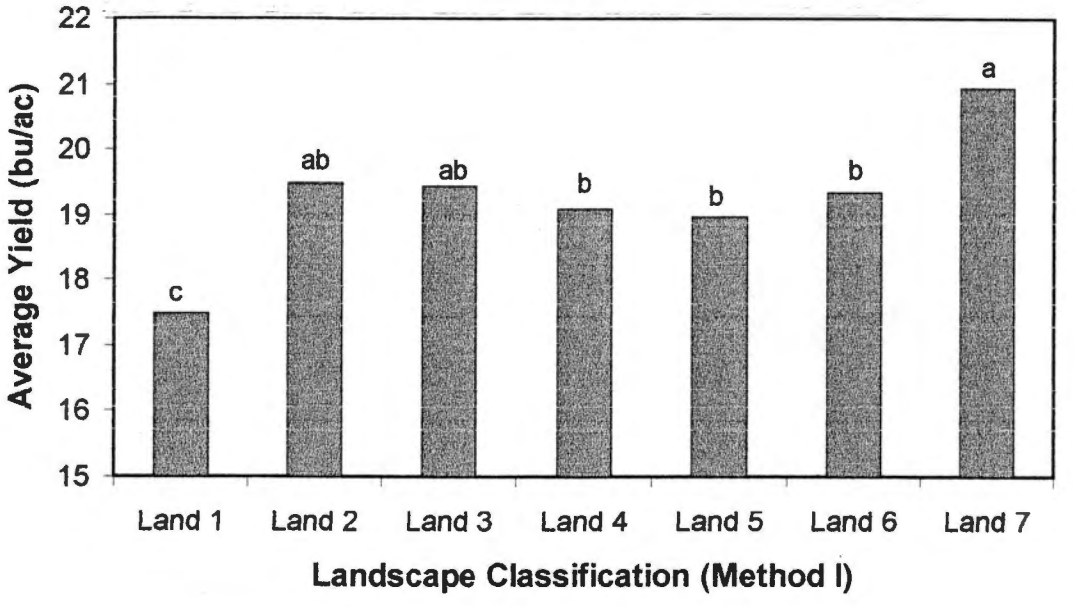
Land 1 - Drainage Areas 0 - 5.5% slopes
Land 2 - Ridgetop Positions 0 - 2% slopes
Land 3 - Ridgetop Positions 2 - 4% slopes
Land 4 - Sideslopes 0 - 4% slopes
Land 5 - Sideslopes 4 - 6% slopes
Land 6 - Sideslopes 6 - 9% slopes
Land 7 - Sideslopes 9 - 13% slopes

Figure 12. Average yield values by landscape class (Method I) for site F2 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



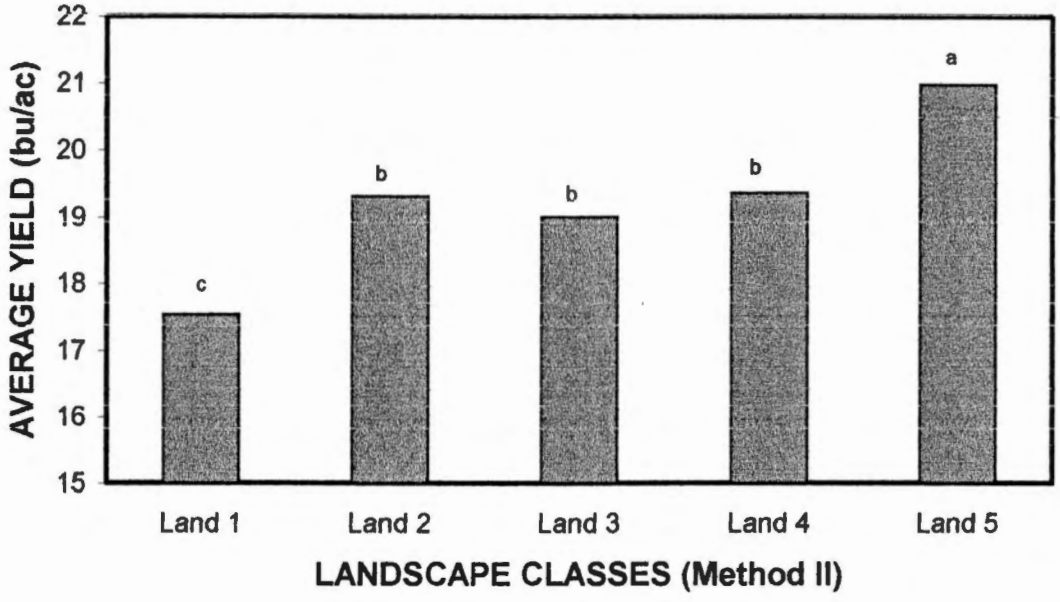
Land 1 - Drainage Areas 0 - 5.5% slopes
Land 2 - Ridgetop Positions 0 - 4% slopes
Land 3 - Sideslopes 4 - 6% slopes
Land 4 - Sideslopes 6 - 9% slopes
Land 5 - Sideslopes 9 - 13% slopes

Figure 13. Average yield values by landscape class (Method II) for site F2 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Drainage Areas 0 - 5.5% slopes
Land 2 - Ridgetop Positions 0 - 2% slopes
Land 3 - Ridgetop Positions 2 - 4% slopes
Land 4 - Sideslopes 0 - 4% slopes
Land 5 - Sideslopes 4 - 6% slopes
Land 6 - Sideslopes 6 - 9% slopes
Land 7 - Sideslopes 9 - 13% slopes

Figure 14. Average yield values by landscape class (Method I) for site F2 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Drainage Areas 0 - 5.5% slopes
Land 2 - Ridgetop Positions 0 - 4% slopes
Land 3 - Sideslopes 4 - 6% slopes
Land 4 - Sideslopes 6 - 9% slopes
Land 5 - Sideslopes 9 - 13% slopes

Figure 15. Average yield values by landscape class (Method II) for site F2 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).

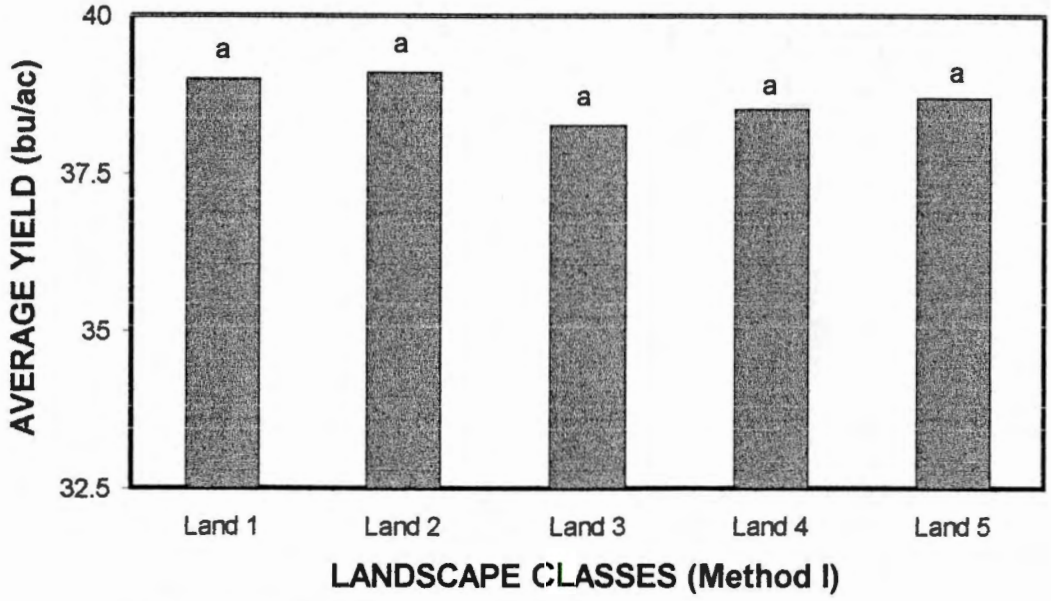
Franklin County - Site F3

Yield mean values for both landscape classification methods observed with 1997 soybean yield data were not significantly different from class to class (Figures 16 & 17). Yield means for classes in landscape method 1 were statistically different (Figure 18). No significant differences were observed between the landscape class yield means for classification method 2 (Figure 19). Classification method 2 used only the landscape position areas as classes. The combination of landscape classes in method 2 resulted in insignificant yield means between the classes. On the other hand, method 1 subdivided the landscape position classes into separate classes depending on slope.

With classification method 1, significantly higher yields were obtained in drainage areas with 0-1.5% slopes. The drainage areas and ridgetop areas with the higher slopes did not differ significantly in yield from the sideslopes. Evidently, droughty conditions lowered yields on areas with the higher slopes. Ridgetop areas with 0-2% slopes retained enough water, where runoff occurring on areas with higher slopes lessened the amount of water in the soil, available for plant growth. Drainage areas with less than 1.5% slopes collected suitable amounts of water in the dry season of 1999 from upslope positions to produce significantly higher yields.

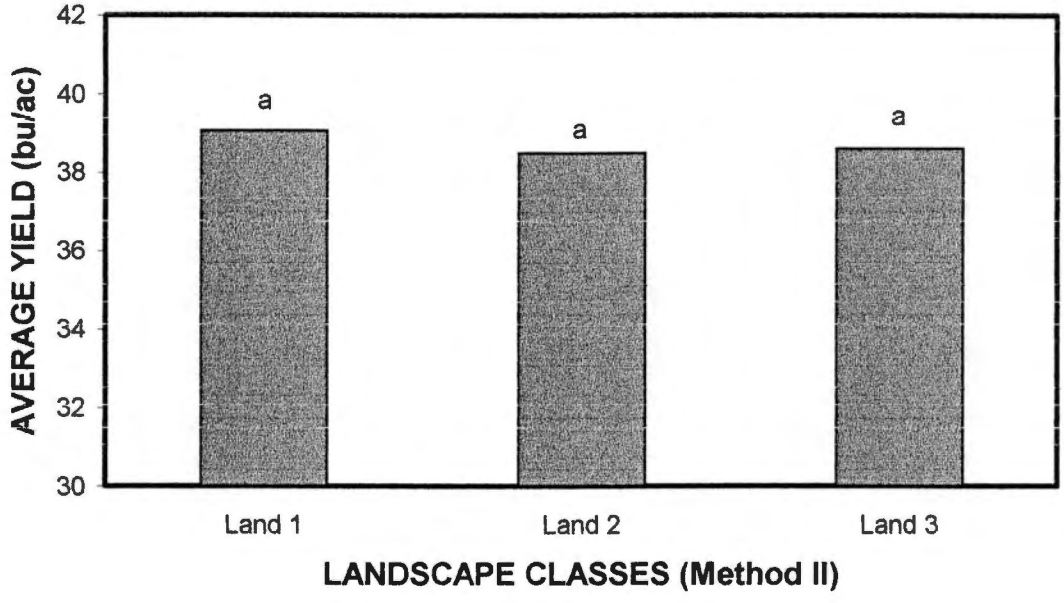
Lake County - Site L1

The only reliable year yield data for site L1 was 1997. 1997 yield means for the landscape classes under both methods showed significant differences (Figures 20 & 21). One class at this site produced unreliable data during statistical analysis. Class 6 for method 1 and class 4 for method 2 contained an extremely low number of observations. Since this was a



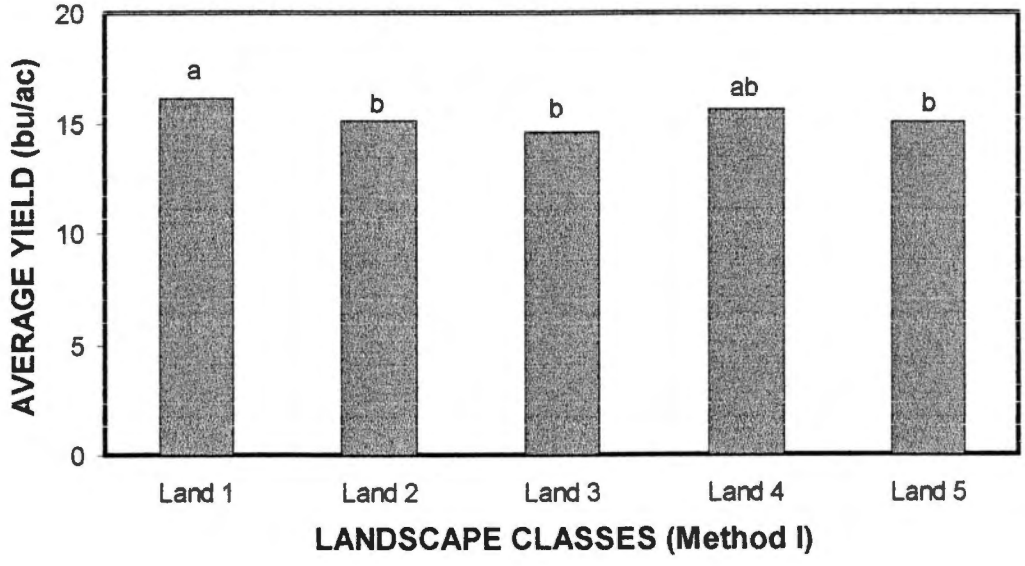
Land 1 - Drainage Areas 0 - 1.5% slopes
Land 2 - Drainage Areas 1.5 - 3% slopes
Land 3 - Sideslopes 3 - 6% slopes
Land 4 - Ridgetop Positions 0 - 2% slopes
Land 5 - Ridgetop Positions 2 - 4% slopes

Figure 16. Average yield values by landscape class (Method I) for site F3 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



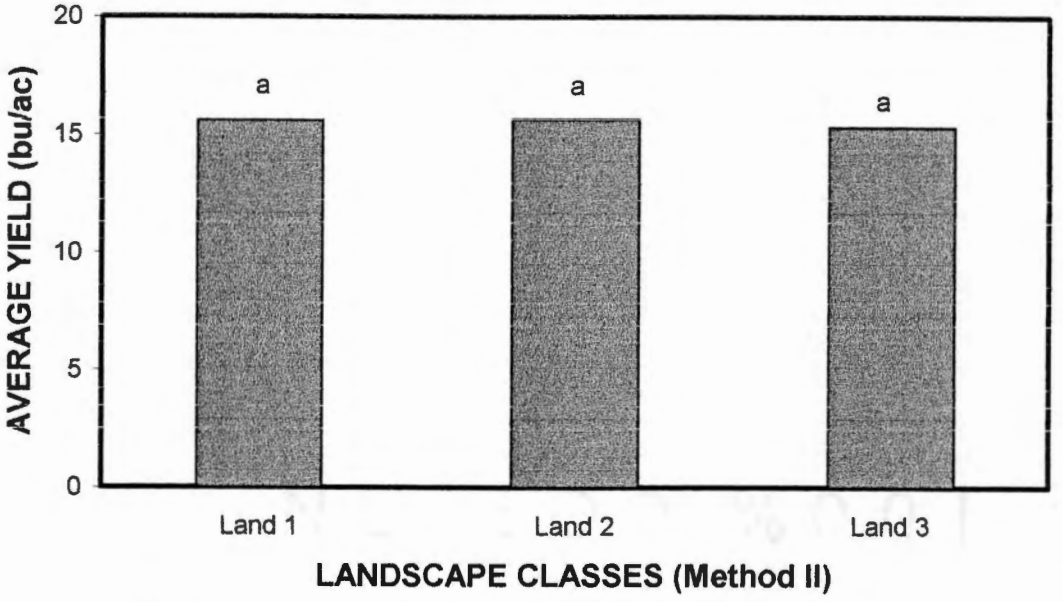
Land 1 - Drainage Areas 0 - 3% slopes
Land 2 - Ridgetop Positions 0 - 2% slopes
Land 3 - Sideslopes 2 - 6% slopes

Figure 17. Average yield values by landscape class (Method II) for site F3 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



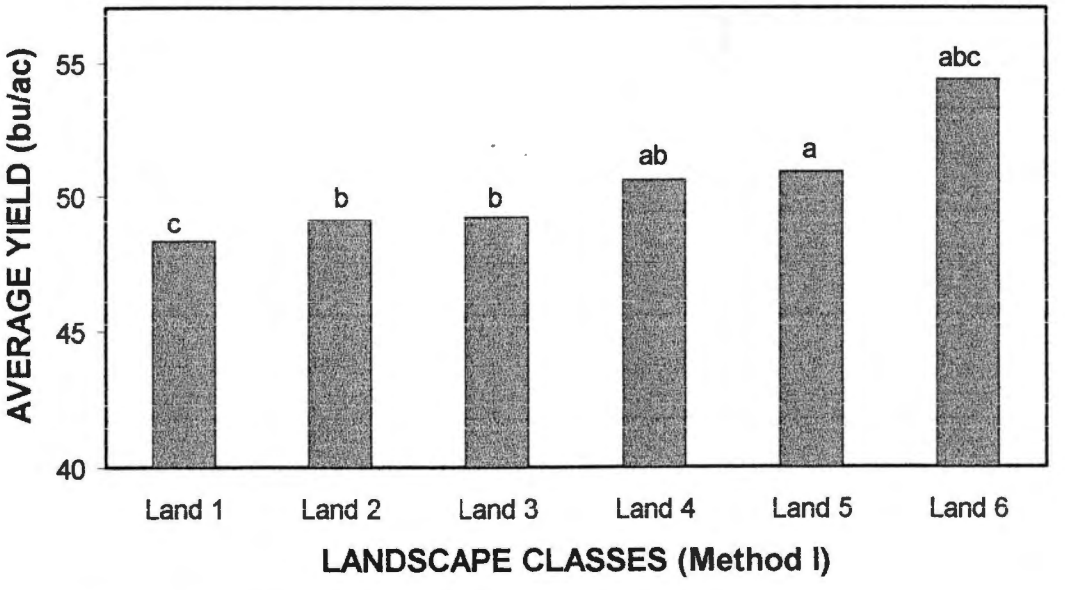
Land 1 - Drainage Areas 0 - 1.5% slopes
Land 2 - Drainage Areas 1.5 - 3% slopes
Land 3 - Sideslopes 3 - 6% slopes
Land 4 - Ridgetop Positions 0 - 2% slopes
Land 5 - Ridgetop Positions 2 - 4% slopes

Figure 18. Average yield values by landscape class (Method I) for site F3 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



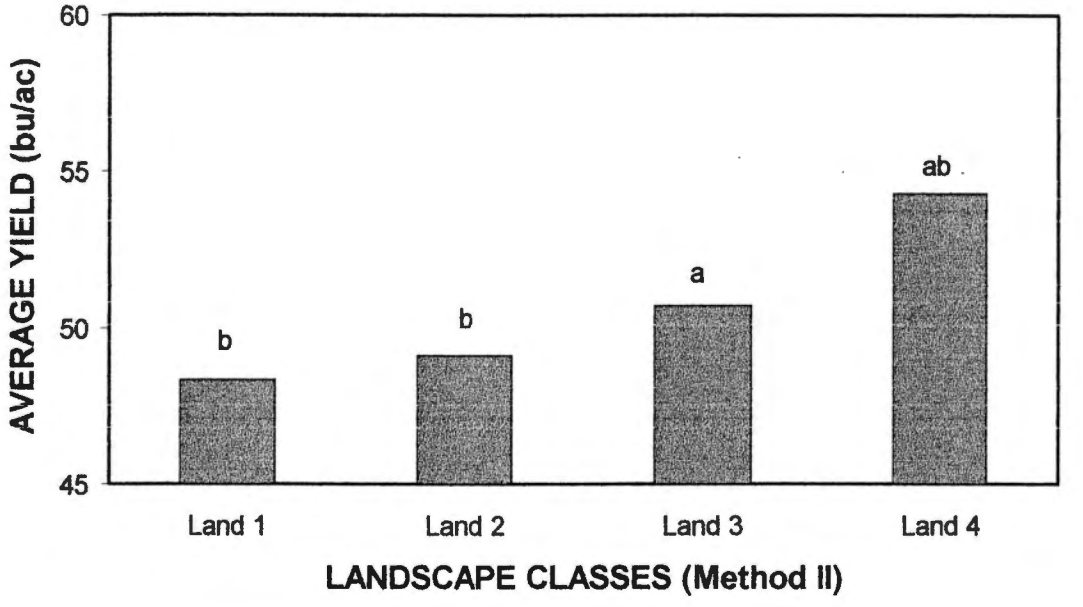
Land 1 - Drainage Areas 0 - 3% slopes
Land 2 - Ridgetop Positions 0-2% slopes
Land 3 - Sideslopes 2 - 6% slopes

Figure 19. Average yield values by landscape class (Method II) for site F3 in 1999. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Potetnial Ponded Areas
Land 2 - Drainage Areas 0 - 0.58% slopes
Land 3 - Drainage Areas 0.58 - 1.7 % slopes
Land 4 - Ridgetop Areas 0 - 0.5% slopes
Land 5 - Ridgetop Areas 0.5 - 1.5% slopes
Land 6 - Ridgetop Areas 1.5+% slopes

Figure 20. Average yield values by landscape class (Method I) for site L1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).



Land 1 - Potential Ponded Area
Land 2 - Drainage Areas 0 - 1.7% slopes
Land 3 - Ridgetop Positions 0 - 1.5 % slopes
Land 4 - Ridgetop Positions 1.5+% slopes

Figure 21. Average yield values by landscape class (Method II) for site L1 in 1997. LSD means labeled with the same letters are not significantly different ($\alpha = 0.05$).

large field, the analysis was skewed due to a larger standard error for that class. As a result, the mean yield is deceptively larger than the other classes in each method. No statistical inferences were derived from this class and it was not compared to the other classes in following conclusions for this site.

Site L1 was very level and only slight differences in elevation were present in the field. The landscape classes reflected the very subtle changes in elevation with classes divided into as small as one-half a percent of slope. Classification method 1 utilized the precise breakdown of classes, but results showed that although significant differences existed between the yield means, less emphasis should be placed on slope values. As a result, method 2 demonstrated better explanation of soybean yield and was observed in the mean values for each class.

Statistically higher yields were observed for the ridgetop positions. Both potential ponded areas and drainage areas contained yields that were not significantly different, but the yields in the potential ponded areas were slightly lower. It seems that although ponded areas and the drainage ways differ as far as water accumulation, yields were adversely affected in the subtle low-lying areas of this field.

Effect of Landscape Classes with Soil Mapping Unit on Yield Variation

SAS® GLM procedures performed using a model containing landscape class and soil mapping unit variables were statistically significant in explaining yield differences in three of the four fields for both years of soybean yield data (Table 11). Site F2 was the only field for which neither landscape classes nor soil mapping unit was effective in explaining any yield variation. In either year, the model was not statistically significant in explaining yield

Table 11. Summary of ANOVA results for models containing landscape classes and soil mapping unit data for each field and year. R^2 values are not reported where neither variable in the model was not significant at the $\alpha = 0.05$ level.

Site	Year	Model	Type III F-vale	Pr > F	Model R^2 (%)
F1	97	Method 1	9.33	<0.0001	33.89
		Soil	1.46	0.1910	
		Method 2	11.68	<0.0001	33.66
		Soil	1.46	0.1905	
	99	Method 1	1.38	0.2283	13.34
		Soil	2.31	0.0323	
		Method 2	1.02	0.3958	13.30
		Soil	2.43	0.0250	
F2	97	Method 1	0.86	0.5240	--
		Soil	0.38	0.9456	
		Method 2	0.17	0.9530	--
		Soil	0.44	0.9109	
	99	Method 1	1.59	0.1486	--
		Soil	1.07	0.3815	
		Method 2	2.17	0.0716	--
		Soil	1.02	0.4248	
F3	97	Method 1	1.72	0.1271	20.37
		Soil	8.51	<0.0001	
		Method 2	2.30	0.1006	20.06
		Soil	8.78	<0.0001	
	99	Method 1	0.53	0.7148	19.10
		Soil	9.92	<0.0001	
		Method 2	0.79	0.4527	18.80
		Soil	9.87	<0.0001	
L1	97	Method 1	1.70	0.1329	18.90
		Soil	8.57	0.0004	
		Method 2	2.70	0.0464	18.70
		Soil	8.49	0.0004	

differences.

At site F1, differences in 1997 yield were best explained by landscape classification. Although soil mapping unit was not significant, the model containing both variables for site F1 in 1997 explained the greatest amount of yield variability in this study. This was the only case in which only the landscape classification variables in the models explained a significant amount ($\alpha = 0.05$) of the yield variation present in the fields when soil mapping units were included in the model. Soil mapping unit was the most important variable in the model for sites F1 and F3 in 1999 and sites F3 and L1 in 1997. The only field in which both landscape classification and soil mapping unit variables were significant was site L1. Landscape classification method 2 and soil mapping units were significant components of the model at that site.

Franklin County - Site F1

Models containing both classification methods with soil mapping units for site F1 showed essentially identical results for 1997 yield. This was based on the fact that the classification methods used for landscape classes were very similar. The key component of both classification methods was a class representing the potential ponded areas or areas of poor drainage. Mean separation for both landscape class variables showed that class 1 contained significantly lower yields. With the addition of soil mapping units, greater explanation of yield variation was obtained. In 1999, mean separation techniques resulted in significantly different yields between landscape classes due to lack of precipitation. Landscape classifications produced significant differences in yield between classes, but neither classification method was significant in explaining yield differences when combined

in the model with soil mapping units.

Soil mapping units explained the most significant amount of yield variation in 1999 for site F1. The Taft soil unit yielded the highest in 1999 even though two years previously it had yielded the lowest (Figure 22). The same was also evident with the Guthrie soil unit for which 1999 yields were higher than had been in 1997 when compared to the other soil units. Yields were higher due to the presence of water throughout the growing season. This was the lowest-lying area of the field. In 1999, water was limiting, thus any collection of water was beneficial. In contrast, 1997 weather patterns presented too much water to that specific area and adversely affected soybean growth and production. The same applies to the Taft soil unit. This pattern can be better observed through the landscape class average yields for 1997 and 1999. In 1997, class 1, which further delineates production units in the Guthrie soil, shows the lowest yields of the field. On the other hand, 1999 average yields for the landscape classes show that class 1 produced the highest yields in the field (Figures 10 & 11).

Franklin County - Site F2

Site F2 did not show any significant explanation of soybean yield variation for either model either year (Table 11). Results from the SAS® MIXED procedures showed that neither landscape classes nor soil mapping units explained a significant amount of the yield differences present in site F2. For 1997 yield data, mean separation techniques revealed that there were no significant differences between classes in either landscape classification method (Figure 12 & 13). Furthermore, there were no differences between the means of each soil mapping unit (Figure 23).

1999 soybean yield differences were also poorly explained by the landscape class and soil mapping unit models (Table 11). Differences between yield means within landscape

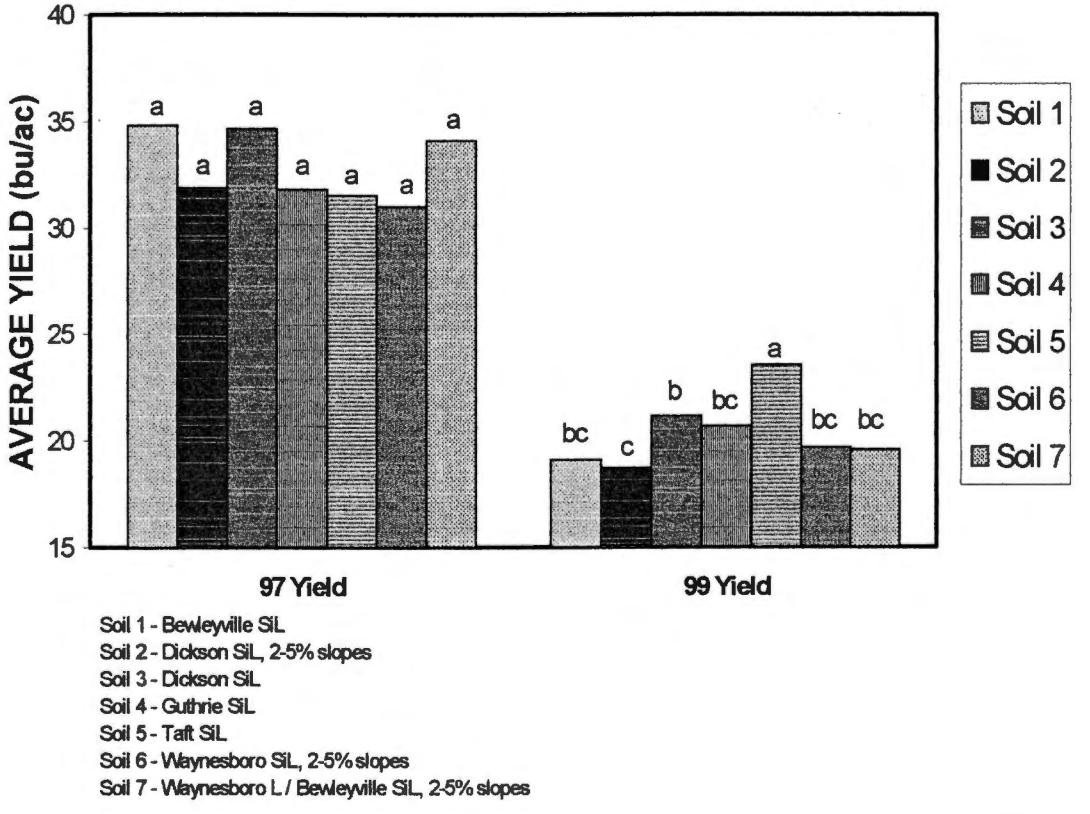


Figure 22. Soybean yield (bu/ac) means for soil mapping units at site F1 in 1997 and 1999.

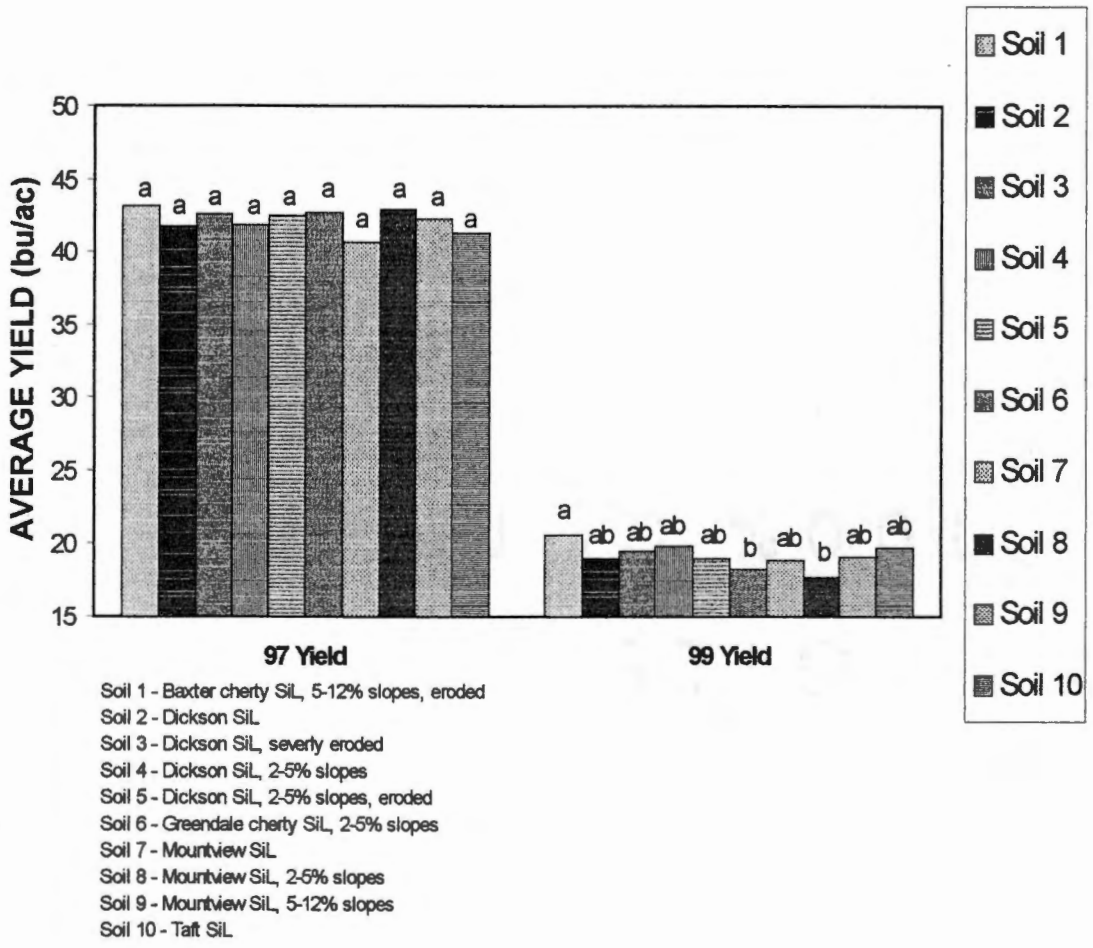


Figure 23. Soybean yield (bu/ac) means for soil mapping units at site F2 in 1997 and 1999

classes and soil mapping units were reported by mean separation techniques, but the variation was not large enough to explain a significant amount of the changes in soybean yield. Significantly lower yields occurred on Mountview and Greendale mapping units with 2-5% slopes (Figure 23). These soils are deep and well-drained and more-overly affected by lack of precipitation, thus resulting in lower yields. This was completely opposite in 1997, where those two units yielded above average. The differences in yield response for these particular soil mapping units was related to the availability of water. On the other hand, consistently higher yields were observed in both years on the Baxter cherty SiL mapping unit with 5-12% slopes. In addition, the landscape class with the highest slope range yielded significantly higher in 1999 compared to the other classes (Figures 14 & 15). This landscape class corresponded with the Baxter mapping unit. Results for yields that occurred on this particular landscape position were surprisingly high. The Baxter series mapping unit is a relatively good soil with respect to crop production. In this field, the better soil occurs on the area with the highest slopes. As a result, the higher yields in the field were found at that particular location in the field with the greater percent slopes. Seasonal growing conditions matched with some unique characteristic allowed for better crop production each year for this area.

Franklin County - Site F3

Models for site F3 explained nearly 20% of the variation in yield for 1997 and 1999 data with soil mapping units providing the most significant amount of explanation (Figure 24). Landscape classes provides were responsible for a small amount of the yield variations explained by the models for F3. 1997 average soybean yields for soil mapping units showed significantly lower yields on the Taft mapping unit. This soil unit is somewhat poorly drained and contains a fragipan. As a result, the excessive amount of precipitation adversely affected

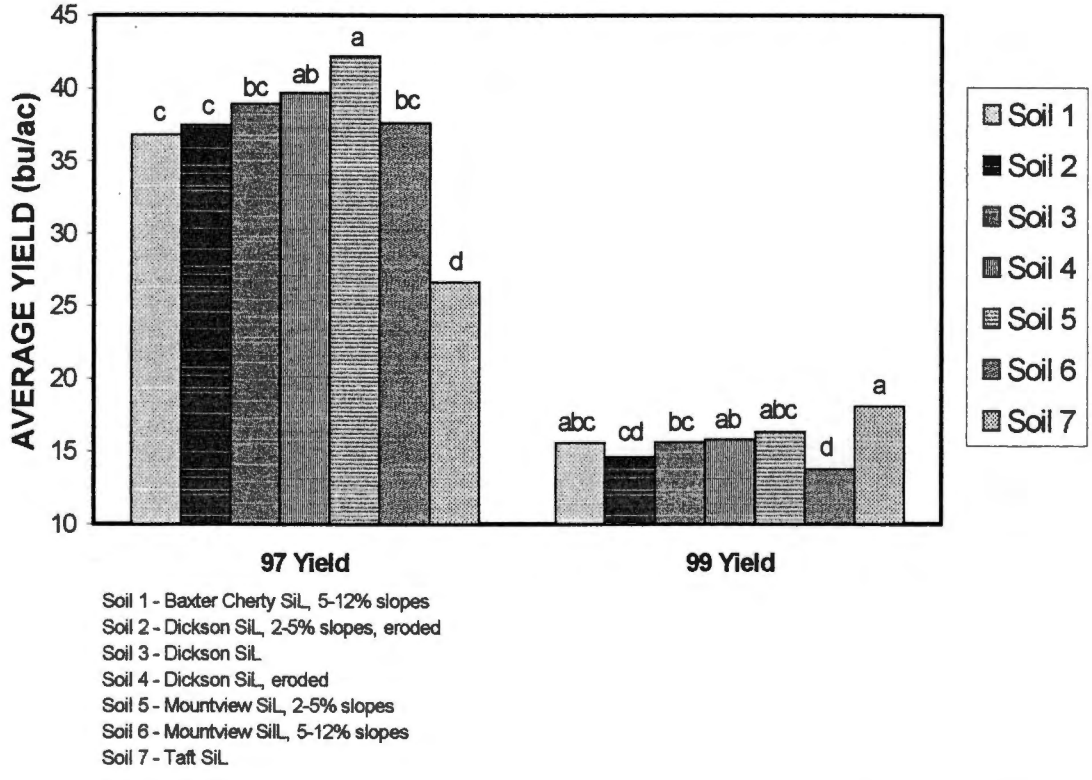


Figure 24. Soybean yield (bu/ac) means for soil mapping units at site F3 in 1997 and 1999.

crop growth in the area of the field containing this soil unit. Significantly lower yields were also found on the mapping units Baxter with 5-12% slopes and Dickson 2-5% slopes. The highest yields in the field were included in the Mountview SiL with slopes ranging from 2-5%.

Mean separation techniques for soil mapping units based on 1999 yield data also revealed a significant amount of the variation in soybean yields for site F3. Statistically lower yields were found on the Mountview mapping units with 5-12% slopes. The highest yields were obtained on the Taft SiL soils. The landscape on which this soil exists is subject to significant water flow from uphill and upslope positions. The contrasts of yields that occurred on that soil in 1997 and 1999 are due mainly to the seasonal weather conditions that occurred in each year. In 1997, soybean growth on the somewhat poorly drained Taft mapping unit was reduced greatly because the amount of water inflow was greater than what the physical properties of the soil could handle for proper growth. Although poorly drained, the 1999 yields on the Taft mapping unit were higher than the average because adequate moisture was enough to encourage growth where other positions in the field lacked sufficient water supply for production. Unfortunately, landscape classes under either method were unable to delineate these areas as was accomplished at site F1 (Figures 18 & 19).

Lake County - Site L1

Both models were significant in explaining 1997 yields for site L1 (Table 11). Classification method 2 and soil mapping units both provided significant amounts of yield explanation at the $\alpha = 0.05$ level. Landscape classification yield means showed that significantly lower yields occurred on the areas of potential ponding and lower-lying areas with slopes less than 1.7% (Figures 20 & 21). Higher yields were identified on the local

highs or slightly raised positions on the landscape. This pattern was true for both landscape classification methods. Three soil mapping units were present at the L1 site. The mean yields for the three were significantly different one from the other (Figure 25). Commerce SiL contained the highest yields while the Iberia mapping unit contained the lowest yields.

The use of detailed elevation maps allowed relation of soil mapping units to relative landscape positions in the field. Upon review of the data, the Commerce mapping unit was found to exist on slightly elevated surfaces in the field. In contrast, Bowdre and Iberia soils were found on the lower-lying areas of the field. Again, the fact that 1997 was an unseasonably wet year helped explain yield differences. All the soils in this field are classified as somewhat poorly drained, but the Bowdre mapping unit has a fluctuating water table. This soil also corresponds with the areas of the field that were classed as potential ponded areas. The higher yields on Commerce soils represented the ability of the surface landscape and soil to drain, whereas the Bowdre exists on landscapes that collect runoff from upslope positions and drainage of this water is slow, thus resulting in reduced yields.

Correlation of Landscape Classes with Soil Mapping Unit

Frequency tables of landscape classes by soil mapping unit were created by SAS® FREQUENCY procedures for each field in this study. Landscape classes derived from classification method 2 were used in this analysis. Method 2 created landscape position polygons that more closely resembled polygons created from in-field soil characterization than method 1. SAS® CHI-SQUARE analysis was conducted to determine if relationships existed between landscape classes and soil mapping unit. Results were significant at the $\alpha = 0.001$ level. Gamma values produced from frequency table statistics were used to determine either the relative amount of correlation or independence of the variables being compared. Values

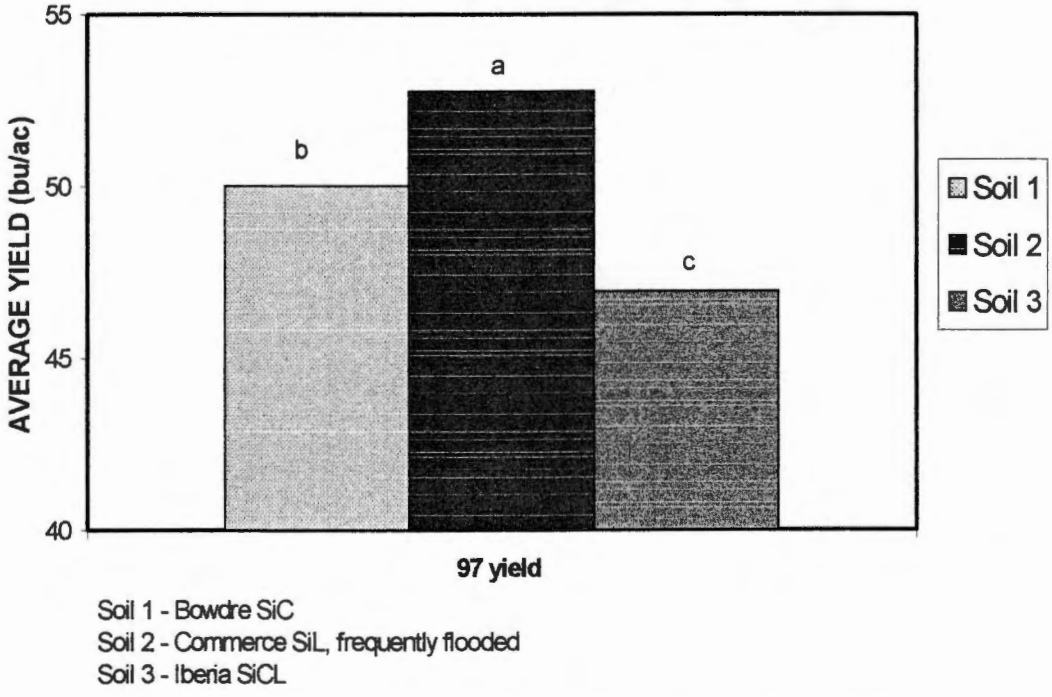


Figure 25. Soybean yield (bu/ac) means for soil mapping units at site L1 in 1997.

closer to zero indicated that landscape classes were independent of soil mapping unit, values further from zero denoted dependence of one variable on the other.

The objective of this analysis was to determine how well landscape position classification corresponded with soil mapping unit data. Since intensive soil mapping is time consuming and expensive, classification and delineation processes that implement less laborsome and intrusive methods are needed. Ideally, strong correlations between landscape classes derived from detailed elevation data and soil mapping units would enable quicker soil characterization.

Chi-square and gamma values associated with each frequency table for every site indicated that correlations of landscape classes with soil mapping units were not strong, but that relationships did exist (Table 12). Landscape classes and soil mapping units showed the most dependency at site L1. Landscape classes at sites F1 and F2 were mostly independent of soil mapping unit. At site F3, a relationship between soil mapping units and landscape classes existed; but the level of dependency was extremely lower than the values observed for the other sites. However, the results from the other fields offered insight into the classification of soil mapping unit data. Strong observational relations between the two variables can be found when the data is in a table or visually inspected in a GIS format.

At site F1, frequency tables showed that sideslopes with greater than 4% slopes corresponded well with more sloping soil mapping units regardless of soil name (Table 13). The Guthrie soil unit was found to contain 89% of the ponded area present in the field, but was mostly made up of drainage areas with 0-2% slopes. These areas also corresponded well with the Dickson and Taft mapping units.

The site F2 frequency table produced results similar to site F1, due mainly to the fact

Table 12. Chi-square and gamma statistic results produced for landscape class versus soil mapping unit frequency tables for each site. Chi-square probability is significant at the $\alpha = 0.001$ level. Gamma values closer to one represent stronger relationships between variables.

Site	Gamma value	Adjusted Standard Error (ASE)	Chi-Square value	Pr > F
F1	0.1874	0.0375	1350.20	<0.0001
F2	0.2263	0.0268	2852.76	<0.0001
F3	0.0042	0.0253	1409.51	<0.0001
L1	0.5873	0.0210	501.33	<0.0001

Table 13. Site F1 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures.

	Bewelyville Sil	Dickson SiL, 2-5% slopes	Dickson SiL	Guthrie SiL	Taft Sil	Waynesboro SiL, 2-5% slopes	Waynesboro L / Bewelyville SiL, 2-5% slopes	Totals
Potetnial Ponded Areas	* 0 ** 0.00 *** 0.00 **** 0.00	0 0.00 0.00 0.00	3 0.17 3.53 0.28	76 4.42 89.41 24.20	6 0.35 7.06 24.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	85 4.94
Drainage Areas, 0-2% slopes	0 0.00 0.00 0.00	6 0.35 0.94 6.12	393 22.85 61.50 36.76	222 12.91 34.74 70.70	18 1.05 2.82 72.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	639 37.15
Ridgetop Positions, 0-2% slopes	0 0.00 0.00 0.00	3 0.17 1.27 3.06	227 13.20 95.78 21.23	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	7 0.41 2.95 5.11	237 13.78
Ridgetop positions, 2-4% slopes	1 0.06 0.21 8.33	30 1.74 6.19 30.61	371 31.57 76.49 34.71	16 0.93 3.30 5.10	1 0.06 0.21 4.00	10 0.58 2.06 15.38	56 3.26 11.55 40.88	485 28.20
Sidelsopes, 4+ % slopes	11 0.64 4.01 91.67	59 3.44 21.5 60.20	75 4.36 27.3 7.01	0 0.00 0.00 0.00	0 0.00 0.00 0.00	55 3.19 20.1 84.15	74 4.30 27.00 54.01	274 15.93
Totals	12 0.70	98 5.70	1069 62.15	314 18.26	25 1.45	65 1.45	137 7.97	1720 100.00

* Frequency
** Percent
*** Row Percent
**** Col Percent

that the fields are on similar landscapes in close proximity with consistent soil mapping units (Table 14). Again, the sideslope areas with the higher slopes corresponded with the soils mapped with increased slopes. The Greendale soil was contained almost entirely by the drainage area landscape class. The boundary of this area nearly mirrors the boundary assigned the Greendale soil during in-field soil mapping unit classification (Figure 26). The ridgetop areas with less than 4% slope correlated well with the soils found on those particular areas in this geographic region; Dickson eroded phase soils with less than 5% slopes and Mountview soils with less than 5% slopes.

Results for site F3 showed that the landscape classes were more evenly spread over the soil mapping units (Table 15). As a result, the gamma value was lowered considerably. Even though no statistical value was identified between these two variables, the frequency table shows some of the same trends observed at sites F1 and F2. Sideslope areas with 2-6% slopes contained mostly Baxter, Dickson, and Mountview soils mapped with greater than 2% slopes. Drainage areas with 0-3% slopes corresponded well with the Dickson and Taft mapping units which occurred on level to sloping uplands. A majority of the Dickson eroded phase was found on the ridgetop positions with less than 2% slope.

The highest relationship between landscape classes and soil mapping units occurred at site L1 (Table 16). This site had only three soil mapping units. It is conceivable that less variation occurred in matching landscape classes with soil mapping units, thus increasing the gamma value for this field. On the other hand, a nearly level landscape allowed subtle changes in elevation to be accounted for with the detailed elevation data. The elevation "breaks" determined by landscape classification pointed out naturally occurring divisions in soil units that were described by in-field soil characterization. The landscape classes also

Table 14. Site F2 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures.

	Baxter cherty SiL, 5-12% slopes, eroded	Dickson SiL	Dickson SiL, severly eroded	Dickson SiL, 2-5% slopes	Dickson SiL, 2-5% slopes, eroded	Greendale cherty SiL, 2-5% slopes	Mountview SiL	Mountview SiL, 2-5% slopes	Mountview SiL, 5-12% slopes	Taft SiL	Totals
Drainage Areas, 0-5.5% slopes	* 0 ** 0.00 *** 0.00 **** 0.00	20 0.92 13.07 37.04	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	77 3.55 50.33 77.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	56 2.58 36.60 6.14	0 0.00 0.00 0.00	153 7.05
Ridgetop Positions, 0-4% slopes	0 0.00 0.00 0.00	7 0.32 0.88 12.96	175 8.06 22.10 42.89	21 0.97 2.65 95.45	75 3.45 9.47 94.94	0 0.00 0.00 0.00	212 9.77 26.77 94.64	208 9.58 26.26 82.54	88 4.05 11.11 9.65	6 0.28 0.76 100.0	792 36.48
Sidelsopes, 4-6 % slopes	8 0.37 1.14 7.02	27 1.24 3.84 50.00	195 8.98 27.70 47.79	1 0.05 0.14 4.55	4 0.18 0.57 5.06	17 0.78 2.41 17.00	12 0.55 1.70 5.36	41 1.89 5.82 16.27	399 18.38 56.68 43.75	0 0.00 0.00 0.00	704 32.43
Sidelsopes, 6-9 % slopes	16 0.74 4.53 14.04	0 0.00 0.00 0.00	38 1.75 10.76 9.31	0 0.00 0.00 0.00	0 0.00 0.00 0.00	4 0.18 1.13 4.00	0 0.00 0.00 0.00	3 0.14 0.85 1.19	292 13.45 82.72 32.02	0 0.00 0.00 0.00	353 16.26
Sidelsopes, 9-13 % slopes	90 4.15 53.25 78.95	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 0.09 1.18 2.00	0 0.00 0.00 0.00	0 0.00 0.00 0.00	77 3.55 45.56 8.44	0 0.00 0.00 0.00	169 7.78
Totals	114 5.25	54 2.49	408 18.79	22 1.01	79 3.64	100 4.61	224 10.32	252 11.61	912 42.01	6 0.28	2171 100.00

*** Frequency**
**** Percent**
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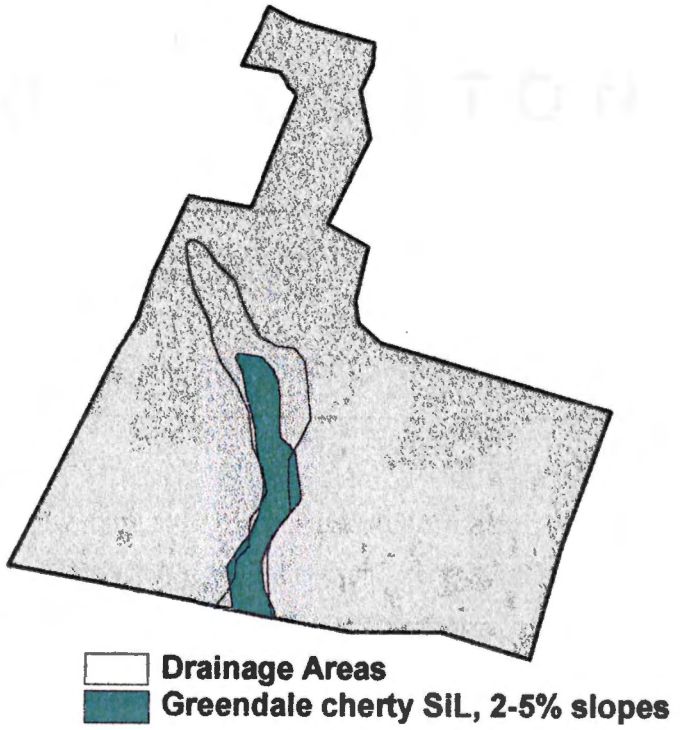


Figure 26. Map showing the correlation of drainage areas and the Greendale soil mapping unit at site F2.

Table 15. Site F3 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures.

	Baxter cherty SiL, 5-12% slopes	Dickson SiL, 2-5% slopes, eroded	Dickson SiL	Dickson SiL, eroded	Mountview SiL, 2-5% slopes	Mountview SiL, 5-12% slopes	Taft SiL	Totals
Drainage Areas, 0-3% slopes	* 12 ** 0.37 *** 0.90 **** 5.85	337 10.40 25.24 43.60	270 8.34 20.22 91.53	565 17.44 42.32 39.05	49 1.51 3.67 21.40	49 1.51 3.67 20.68	53 1.64 3.97 100.00	1335 41.22
Ridgetop Positions, 0-2% slopes	13 0.40 1.19 6.34	204 6.30 18.73 26.39	17 0.52 1.56 5.76	730 22.54 67.03 50.45	110 3.40 10.10 48.03	15 0.46 1.38 6.33	0 0.00 0.00 0.00	1089 33.62
Sidelsopes, 2-6 % slopes	180 5.56 22.09 87.80	232 7.16 28.47 30.01	8 0.25 0.98 2.71	152 4.69 18.65 10.50	70 2.16 8.59 30.57	173 5.34 21.23 73.00	0 0.00 0.00 0.00	815 25.16
Totals	205 6.33	773 23.87	295 9.11	1447 44.67	229 7.07	237 7.32	53 1.64	3239 100.00

* Frequency
** Percent
*** Row Percent
**** Col Percent

Table 16. Site L1 frequency table results from landscape class by soil mapping unit SAS® FREQUENCY procedures.

	Bowdre SiC	Commerce SiL, frequently flooded	Iberia SiCL	Totals
Potential Ponded Areas	* 69 ** 1.35 *** 76.67 **** 1.72	21 0.41 23.33 2.16	0 0.00 0.00 0.00	90 1.76
Drainage Areas, 0-1.7% slopes	2495 48.83 89.36 62.20	272 5.32 9.74 27.93	25 0.49 0.90 20.00	2792 54.64
Ridgetop Positions, 0-1.5% slopes	1441 28.20 64.97 35.93	681 13.33 30.70 69.92	96 1.88 4.33 76.80	2218 43.41
Ridgetop Positions, >1.5% slopes	6 0.12 60.00 0.15	0 0.00 0.00 0.00	4 0.08 40.00 3.20	10 0.20
Totals	4011 78.49	974 19.06	125 2.45	5110 100.00

*** Frequency**
**** Percent**
***** Row Percent**
****** Col Percent**

reinforced the physical description and location of each soil unit.

Bowdre made up nearly 80% of the soils mapped at site L1. The Commerce mapping unit was present in the other parts of the field with a small percent mapped as Iberia. A majority of the Bowdre mapping unit was found on lower lying areas in the field with less than 1.7% slope. This area on the landscape floods frequently in the spring and water predominantly stands on these locations in the field. These areas connect to pour points from the field and collect water from the higher elevated landscape positions. The upslope positions or "local highs" in the field described as ridgetop positions with slopes less than 1.5% were found to contain mostly Commerce soil units. Approximately three quarters of the potential ponded area occurred on the Bowdre soil unit. This met expectations because the areas of water accumulation obviously occurred on the lower lying areas with exception to one depressional area located on the Commerce soil unit.

Overall the relationship between soil mapping units and landscape classes depends greatly on the method of interpolation of both data sets. Although strong correlations were not pointed out in the SAS® PROC FREQUENCY analysis, the potential of landscape classification becomes of interest when identifying alternative means to intensive soil characterization. A greater emphasis should be placed on the adjustment of landscape classes as well as soil classes based on individual field characteristics. Landscape classification based on detailed elevation data using a GIS offers the ability to decipher and manipulate soil data according to visual observations from the topographical data available for a particular field.

Multiple Year Soybean Yield Data Correlation

Additional analysis was conducted to determine the spatial and temporal differences of yield for the sites in Franklin county (F1, F2, and F3) based on 1997 and 1999 soybean yield data. As mentioned earlier, the two years of yield data studied in this work varied considerably due to very different weather conditions that occurred for each year. Mean yields ranged from as low as 15.45 bu/ac to as high as 49.65 bu/ac between the two years (Table 5). SAS® FREQUENCY procedures were conducted using 1997 and 1999 normalized yield data. Gamma value statistics associated with frequency tables provided a quantified amount of relation that occurred between the two variables. SAS® CHI-SQUARE procedures were performed to determine if relationships existed between the multiple-year yield data. Both years of soybean yield data were grouped into below average, average, and above average yield classes. Yield normalization allowed for a consistent comparison of yield differences from year-to-year, regardless of the difference in yield levels.

SAS® CHI-SQUARE procedures showed that relationships existed between 1997 and 1999 normalized yield data (Table 17). Although correlations at each site were significant, the gamma values showed that the amount of dependence varied from field-to-field. Frequency tables were used to interpret and explain the reasons for the dependence of 1999 and 1997 yield data sets, one to other.

Site F1 produced the greatest amount of relation between 1999 and 1997 soybean yield data (Table 18). Results showed that 80% of the average producing areas in 1997 matched with the areas of average yield in 1999. In addition, below average classes for either year were confined to the below average and average classes of the contrasting year greater than

Table 17. Chi-square and gamma statistic results for Frequency Tables produced from SAS® FREQUENCY analysis. Gamma values closer to zero indicate independence of each variable. Values closer to one represent dependence of the variables with each other. Chi-square probability is significant at the $\alpha = 0.001$ level. The variables tested in this analysis were 1997 normalized yield data versus 1997 normalized yield data.

Site	Gamma value	Adjusted Standard Error (ASE)	Chi-Square value	Pr > F
F1	0.7073	0.0284	470.08	<0.0001
F2	0.4468	0.0834	136.67	<0.0001
F3	0.1821	0.0344	139.96	<0.0001

Table 18. Site F1 frequency table results from yield correlation SAS® FREQUENCY procedures.

99 Yield Class / 97 Yield Class	Below average yield class	Average yield class	Above average yield class	Totals
Below average yield class	* 92 ** 5.35 *** 38.82 **** 35.11	140 8.14 59.07 12.47	5 0.29 2.11 1.49	237 13.78
Average yield class	154 8.95 12.75 58.78	892 51.86 73.84 79.43	162 9.42 13.41 48.36	1208 70.23
Above average yield class	16 0.93 5.82 6.11	91 5.29 33.09 8.10	168 9.77 61.09 50.15	275 15.99
Totals	262 15.23	1123 65.29	335 19.48	1720 100.00

*** Frequency**
**** Percent**
***** Row Percent**
****** Col Percent**

90% of the time. The same applied for the above average yield classes. Very few areas were classed below average one year and above average the next.

Results for F2 also showed significant amounts of dependence for year-to-year yield data sets (Table 19). Again, the average yield class for 1997 most often corresponded to the 1999 average yielding class. However, correlations between the classes with average yields were not as good as were evident at site F1. The 1999 yield classes as a whole generally fell into the 1997 average class. This indicates that for this field lower and higher producing areas in a wet year may tend to produce average yields in dry years. The standard deviation for soybean yields was much lower in 1999 compared to 1997. Less variation from the mean accounted for lowered amounts of above or below average yield classes in the 1999 yield data.

Results from frequency tables for site F3 followed the patterns observed for sites F1 and F2 (Table 20). The major percent of matches between the two yield data sets occurred in the average yield class. The gamma value for this data was considerably lower than for the first two sites and was expected due to the lack of correlation of the 1997 and 1999 above and below average yielding areas. These areas were mostly paired with the average yield classes for this field.

Overall, correlation between 1997 and 1999 soybean yield data for these fields supported the hypothesis that areas within fields continually produce the relatively same amount compared to the field average. In this study, the below yielding areas in 1997 were most often part of the average yielding areas in 1999. When comparing multiple year yield data, consideration must be placed on the area under question within a field, the associated landscape and agronomic-related properties and weather conditions from year-to-year.

Table 19. Site F2 frequency table results from yield coorelation SAS® FREQ procedures

99 Yield / 97 yield	Below average yield class	Average yield class	Above average yield class	Totals
Below average yield class	* 44 ** 2.03 *** 17.46 **** 47.31	197 9.07 78.17 9.69	11 0.51 4.37 23.91	252 11.61
Average yield class	44 2.03 2.63 47.31	1606 73.98 95.88 79.04	25 1.15 1.49 54.35	1675 77.15
Above average yield class	5 0.23 2.05 5.38	229 10.55 93.85 11.27	10 0.46 4.10 21.74	244 11.24
Totals	93 4.28	2032 93.60	46 2.12	2171 100.00

*** Frequency**
**** Percent**
***** Row Percent**
****** Col Percent**

Table 20. Site F3 frequency table results from yield correlation SAS® FREQUENCY procedures.

99 Yield / 97 yield	Below average yield class	Average yield class	Above average yield class	Totals
Below average yield class	* 5 4 ** 1.67 *** 7.41 **** 15.08	666 20.56 91.36 25.64	9 0.28 1.23 3.18	729 22.51
Average yield class	215 6.64 12.37	1381 42.64 79.46 53.16	142 4.38 8.17 50.18	1738 53.66
Above average yield class	89 2.75 11.53 24.86	551 17.01 71.37 21.21	132 4.08 17.10 46.64	772 23.83
Totals	358 11.05	2598 80.21	283 8.74	3239 100.00

*** Frequency**
**** Percent**
***** Row Percent**
****** Col Percent**

Comparison of 6 and 10 Meter Grid Cell Sizes

Methodologies for delineating landscape classes reported in this thesis were accomplished through use of raster-based data in ArcView®. Point, line, and polygon themes representing the soil data, elevation data and yield data for each field were converted to cell-based data layers for use in statistical analysis. Throughout the development of the database for this work, the size of the cells for data layers was set at 6 meters and 10 meters. Statistical analysis for this study was performed on data obtained from both a 10 meter grid cell size and a 6 meter grid cell size. Results discussed in prior sections of this thesis were obtained from 10 meter grid cell data.

The purpose of conducting statistical analysis on both grid cell sizes was to compare the means produced by one cell size to the other. A randomized block design (RBD) was used on landscape class yield means determined from SAS® MIXED procedures. For this test, it was assumed that the differences in grid cell size was relative over all results from statistical analysis. As a result, mean separation was performed with only 1997 yield means determined for landscape classes. Means for both method 1 and 2 were used in statistical analysis. Yield means for each landscape class were the dependent variables. Blocking occurred on the landscape class with two treatments; 6 meter and 10 meter grid cell sizes. Mean separation techniques showed that no significant differences in yield means for each landscape class existed between the two cell sizes.

Yield maps interpolated based on either 6 meter or 10 meter grid cell size showed no differences in the estimation of yield for any site in this study (Table 21). The standard deviation, however, was lower with 10 meter yield and higher with 6 meter yield. This suggested the variation was reduced from the yields and supported expectations that 10 meter

Table 21. Yield mean separation results for 6 meter and 10 meter grid sizes for each landscape classification method. Means with the same letter are not significantly different.

Site	Classification Method	Grid Cell Size (m)	Yield means (bu/ac)	Letter Differences
F1	Method 1	6	35.97	a
		10	33.70	a
	Method 2	6	36.21	a
		10	33.27	a
F2	Method 1	6	42.08	a
		10	42.31	a
	Method 2	6	42.21	a
		10	42.35	a
F3	Method 1	6	38.76	a
		10	38.71	a
	Method 2	6	38.52	a
		10	38.72	a

grid cells would produce an "over-smoothing" effect for yield data since a larger grid size enveloped more yield data points. In general, a smaller grid size offers greater detail for observational inspection of yield data displayed on a computer monitor. From a statistical standpoint, 6 meter grid sizes offer the best description of yields. However, results provided from this study show 10 meter grid size yield maps are as efficient as the smaller grid size in representing yield data. Though no significant differences existed statistically, size of data files and computer restraints become important considerations for choice of cell size. Six meter grids result in larger data files which would become quite enormous on bigger fields. In many cases, the amount of computer space used during analysis would lessen by using a larger grid cell size.

CHAPTER 5

SUMMARY AND CONCLUSIONS

This study was designed to determine topographic variables contributing to in-field soybean yield variability, delineate areas of varying crop production, and identify causes for yield differences based on variables derived from detailed elevation data. Landscape positional areas were created using percent slope values and hydrological modeling techniques in ArcView® 3.2, a GIS-based program. Soybean yields for the landscape classes in each field were compared statistically using SAS® procedures and results were used to determine the capability of these landscape positional areas to explain soybean yield variation. Also, intensive soil characterization data was added to the statistical models to test the effectiveness of combining existing soil information with topography data to further explain yield variation. Analysis was conducted with 1997 and 1999 soybean yield data in an effort to study correlations between yields from one year to another. Yield data, soil data and landscape classification data were derived using GPS and GIS techniques.

Overall, results showed that landscape classes were not statistically effective in explaining soybean yields for either 1997 or 1999 soybean yield. Landscape classes were not consistent in identifying areas of varying crop production. However, in some fields and some years, statistical significance occurred between landscape classes and soybean yields. In these cases, a topographic variable most often responsible for identifying significant yield differences was the areas of potential ponding. Ponded areas were pinpointed by the landscape classification methods. Only two of the four fields contained the "potential ponded"

landscape class. For both of those fields, 1997 yields were significantly explained by landscape classification methods.

Explanation of soybean yield differences for both years was increased with the addition of soil mapping unit data to landscape classes. The use of both data layers was beneficial in determining areas of yield differences. Only one field did not show significance using models containing both soil and landscape data. The potential of landscape classification to become a useful tool for identifying areas of yield variation depends on the correlation with soil mapping units contained in each field. In addition, adjustment of soil mapping unit descriptions based on relative productivity may enhance this relationship and provide better yield explanation.

Statistical results from this study showed that certain landscape classes were effective in delineating individual soil units. These occurrences were not consistent among the data, but visual interpretation of the landscape classification and soil mapping unit data layers in a GIS format provided a better understanding of the relationship between landscape position and soil units.

Correlations were present between 1997 and 1999 soybean yields. Overall, relationships between 1997 and 1999 soybean yield data for these fields supported the hypothesis that areas within fields continually produce relatively the same yield compared to the field average. Consideration, though, must be placed on the area under question within a field and the effect that seasonal changes will have on the associated hydrological and agronomic properties.

In conclusion, the research methods presented here have the potential to become beneficial components in precision agriculture management decisions. Greater investigation

into the relations of landscape positions and the associated soil units is necessary to further utilize this data for site-specific management. A knowledgeable and continuing combination of landscape, soil, and yield classification will supply better means of identifying areas of varying production and provide insight for managing those areas.

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APPENDICES

Appendix A. Project Site Map

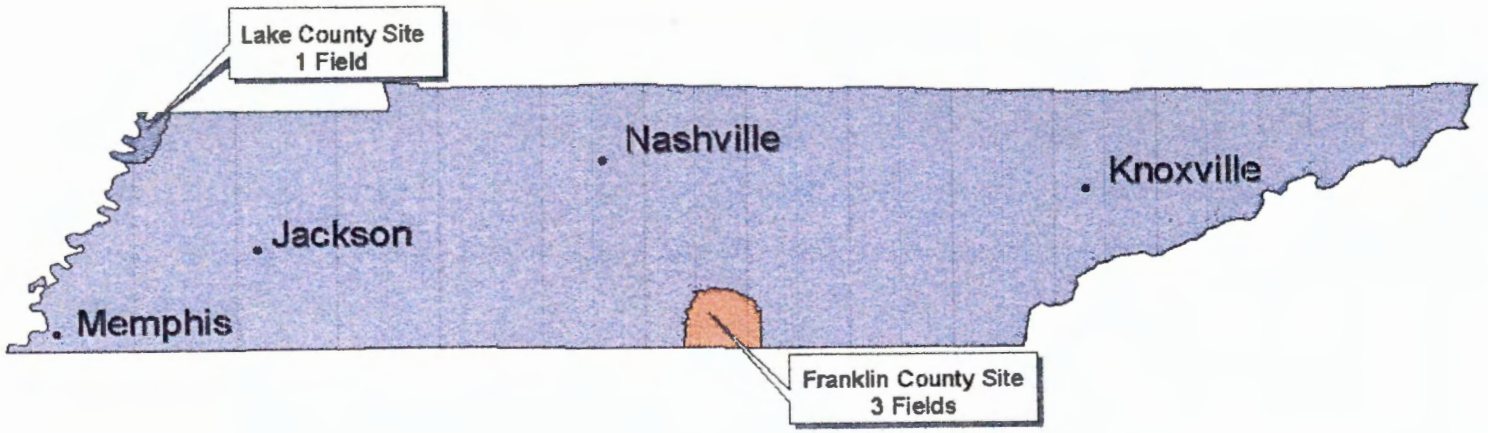


Figure A.1. Tennessee state map indicating site locations.

Appendix B. Soil Series Taxonomy

Soil Series	Classification
Adler	*coarse-silty, mixed, active, nonacid, thermic Aquic Udifluvents*
Baxter	*fine-clayey, mixed, superactive, mesic Typic Paleudalfs*
Bewleyville	*fine-silty, siliceous, semiactive, thermic Typic Paleudalfs*
Bodine	*loamy-skeletal, siliceous, semiactive, thermic Typic Paleudults*
Bowdre	*clayey over loamy, smectite, thermic Aquic Fluvaquentic Hapludolls*
Commerce	*fine-silty, mixed, nonacid, thermic Aeric Fluventic Haplaquepts*
Dickson	*fine-silty, siliceous, thermic Glossic Fragiudults*
Ennis	*fine-loamy, siliceous, thermic Fluventic Dystrochrepts*
Greendale	*fine-loamy, siliceous, semiactive, mesic Fluventic Dystrudepts*
Guthrie	*fine-silty, siliceous, thermic Typic Fragiaquults*
Iberia	*fine, smectite, thermic Vertic Haplaquolls*
Lawrence	*fine-silty, mixed, semiactive, mesic Aquic Fragiudalfs*
Mountview	*fine-silty, siliceous, semiactive, thermic Typic Paleudults*
Reelfoot	*fine-silty, mixed, thermic Aquic Argiudolls*
Taft	*fine-silty, siliceous, thermic Glossaquic Fragiudults*
Tiptonville	*fine-silty, mixed, thermic Oxyaquic Argiudolls*
Waynesboro	*fine, kaolinitic, thermic Typic Paleudults*

Appendix C. Yield Data Export Examples

Ag Leader Technology's
Advanced File Format
for Yield Data

Longitude	###.######	
Latitude	##.######	
Flow (Lbs/Sec)	##.##	
Time (GPS Time, Secs)	#########	
Cycles	#	(Seconds covered by this data)
Distance (Inches)	###	(Travel covered by this distance)
Swath (Inches)	###	
Moisture	##.#	
Status	##	(Bit 0 - 1 = Header Down)
		(Bits 1 thru 4 mask as SPOT Data)
		(Bit 5 - 1 = Automatic Moisture)
Pass	#####	Pass number within this export
Serial Number	######	Yield Monitor serial number
Field ID	F##: XXXXXXXX	
Load ID	F##: XXXXXXXX	
Grain	XXXXXXXXXXX	
GPS Status	###	
Altitude (Feet)	####	

Table C.1. Example of yield export for Site F1.

LONG	LAT	F	TIME	C	DIS	SW	MOIS	STAT	PASS	S#	F	L	GR	GPS	PDOP	ALT(ft)
-86.232064	35.271692	3.83	876247820	1	56	210	19.5	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1058.8
-86.232067	35.271679	4.08	876247821	1	56	210	19.5	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1055.5
-86.232069	35.271667	4.60	876247822	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.2
-86.232071	35.271652	4.27	876247823	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.5
-86.232074	35.271641	3.98	876247824	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.5

Table C.2. Example of yield export containing calculated yield and MPH for Site F1.

LONG	LAT	F	TIME	C	DIS	SW	MOIS	STAT	PASS	S#	F	L	GR	GPS	PDOP	ALT(ft)	Covered Ac	Yield (Bu/ac)	MPH
-86.232064	35.271692	3.83	876247820	1	56	210	19.5	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1058.8	0.0019	31.64	3.18
-86.232067	35.271679	4.08	876247821	1	56	210	19.5	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1055.5	0.0019	33.71	3.18
-86.232069	35.271667	4.60	876247822	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.2	0.0019	38.00	3.18
-86.232071	35.271652	4.27	876247823	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.5	0.0019	35.28	3.18
-86.232074	35.271641	3.98	876247824	1	56	210	19.3	33	1	962220	F17: CALDWE25	L1:	Soybeans	7	0	1056.5	0.0019	32.88	3.18

Column Abbreviations

Long=Longitude
Lat=Latitude
F=Flow Rate(lbs/sec)
C=Cycles (sec)
DIS=Distance (in)
SW=Swath Width (in)
MOIS=% Moisture
STAT=Header Status
S#=Serial Number
F=Field ID
L=Load ID
GR=Grain
GPS=GPS Status
PDOP=GPS Precision
ALT=Altitude (ft)
Covered Ac=Area Covered by Each Position (ac)
Yield=Yield for Each Position (bu/ac)
MPH=Velocity in Miles Per Hour (MPH)

Appendix D. Yield Maps

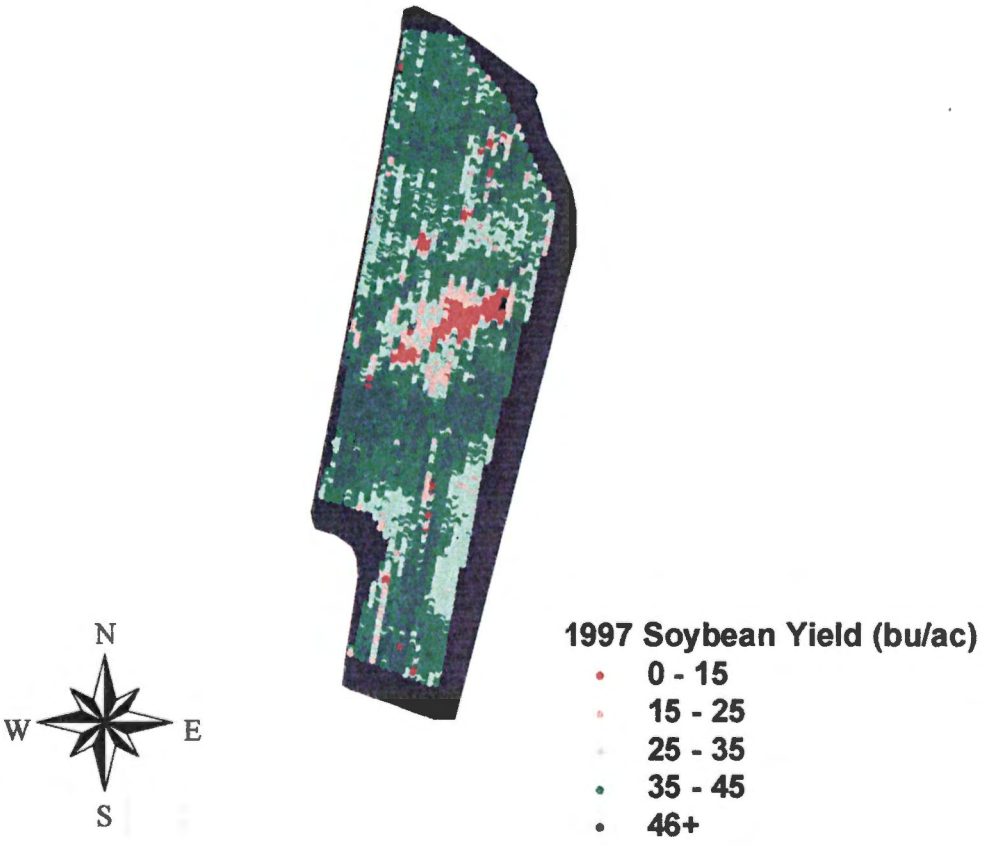


Figure D.1. Corrected 1997 yield data positions for site F1.



Figure D.2. Corrected 1999 yield data positions for site F1.

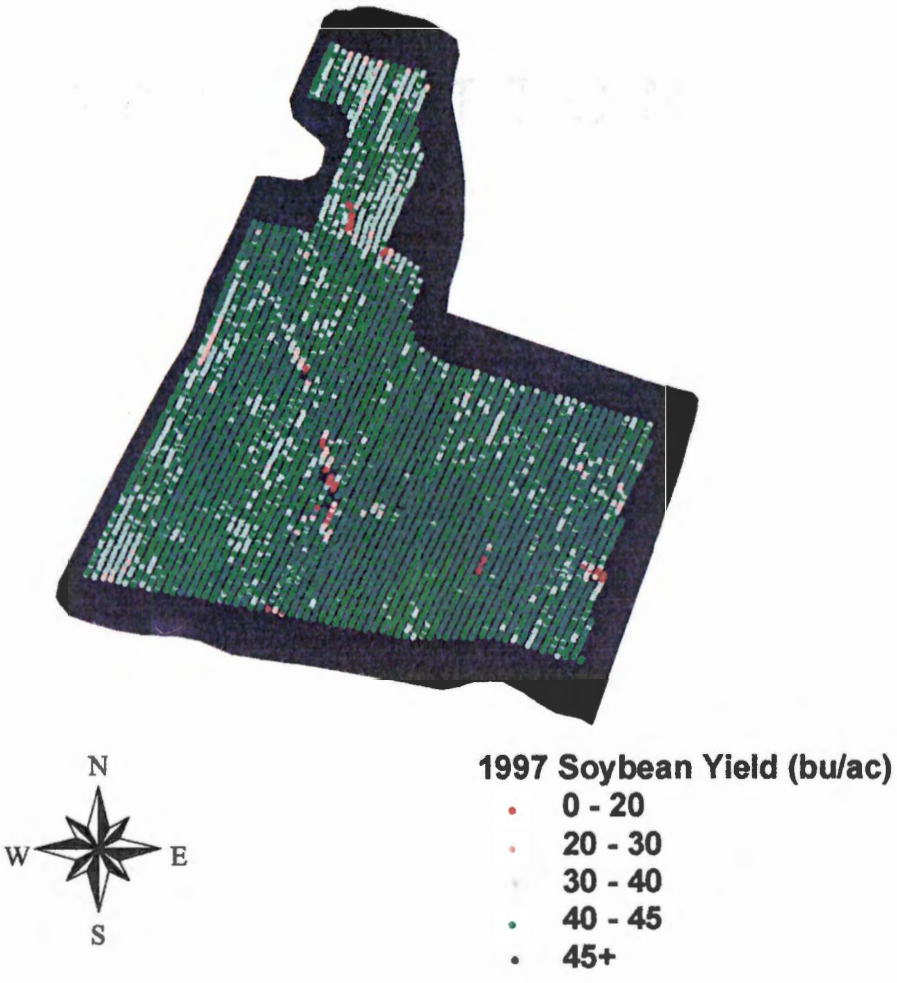


Figure D.3. Corrected 1997 yield data positions for site F2.

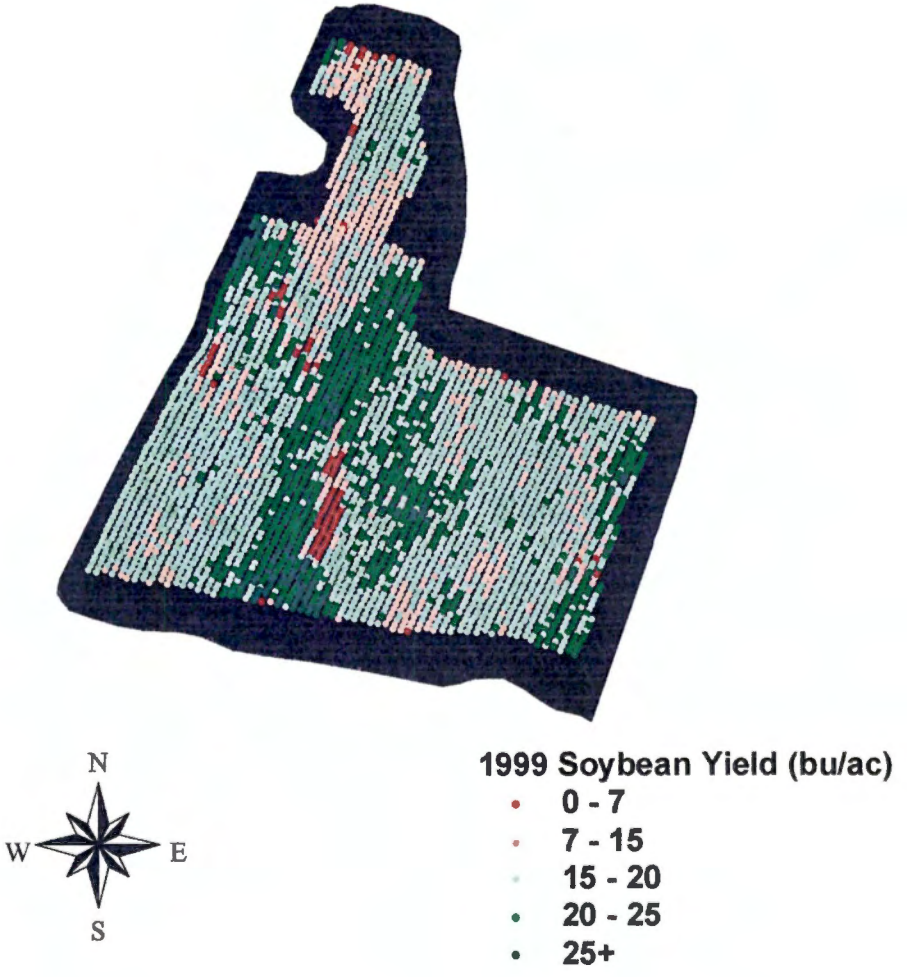


Figure D.4. Corrected 1999 yield data positions for site F2.

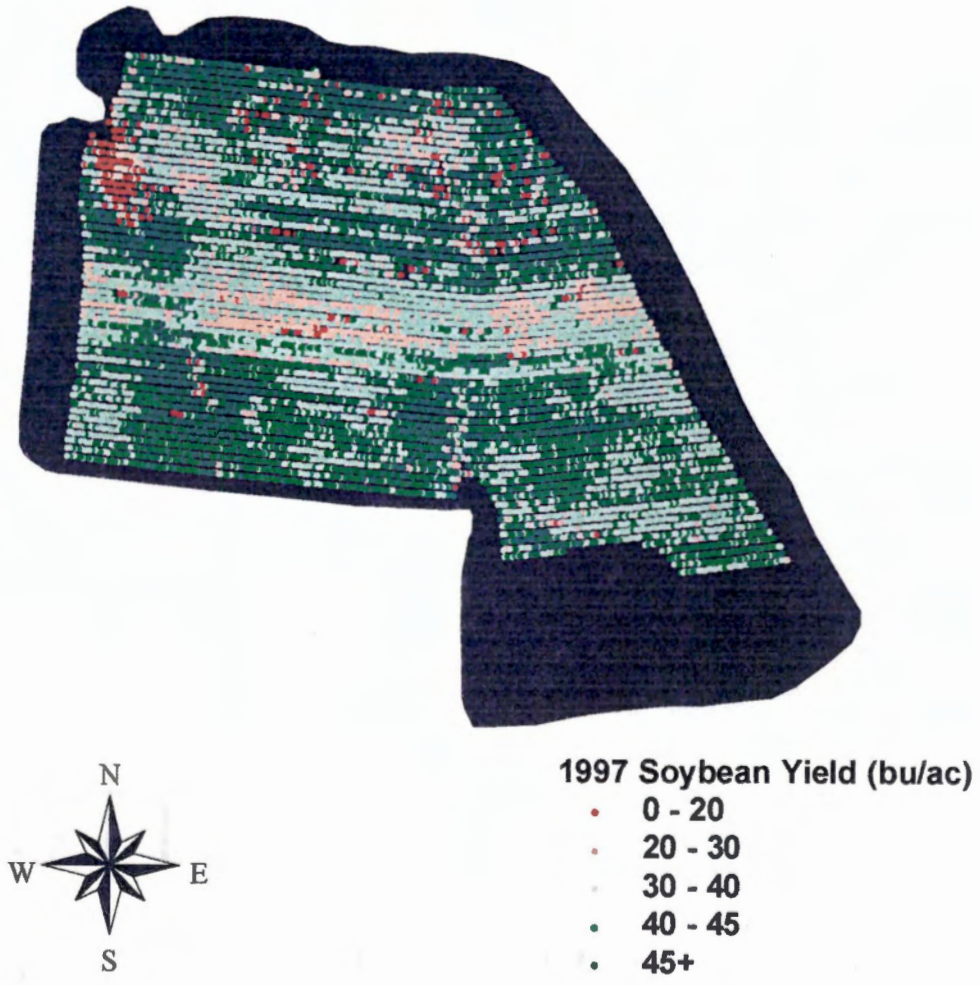


Figure D.5. Corrected 1997 yield data positions for site F3.

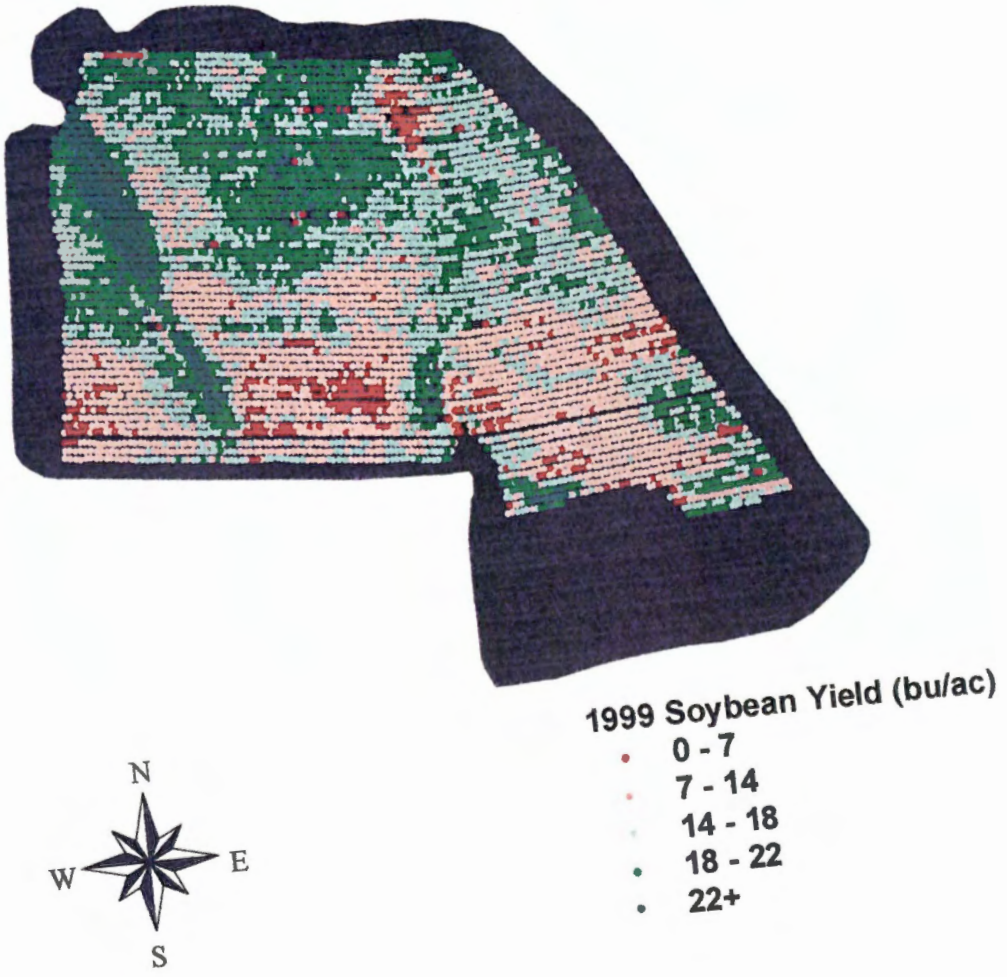


Figure D.6. Corrected 1999 yield data positions for site F3.

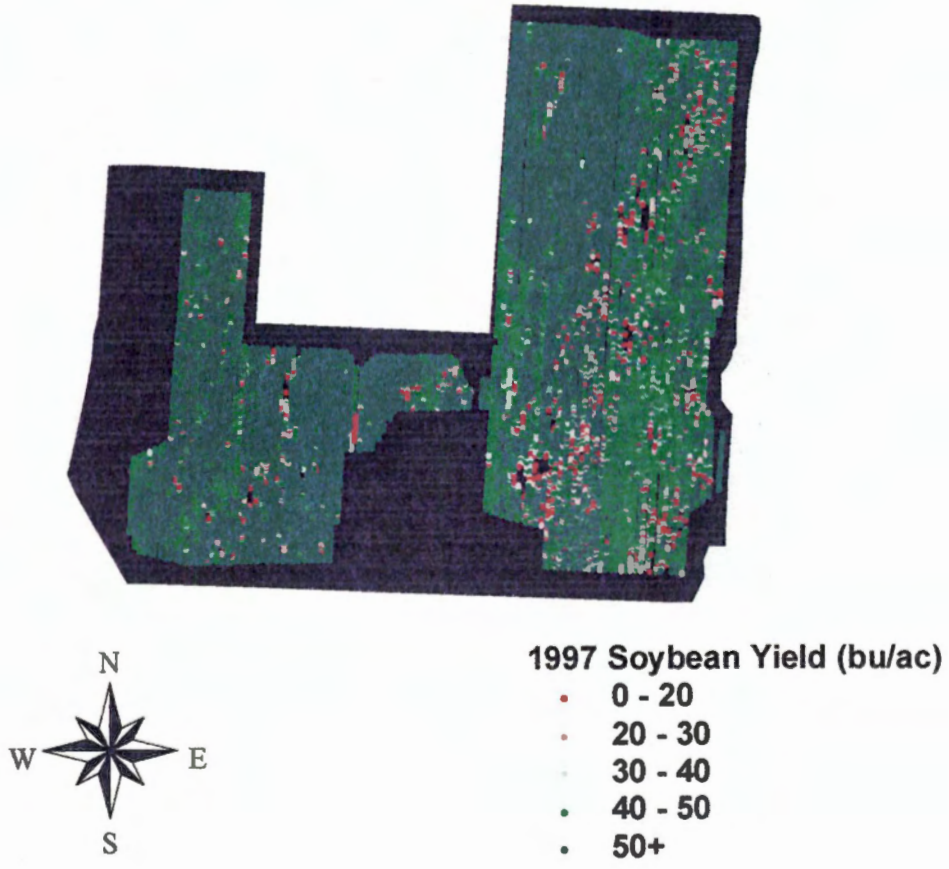


Figure D.7. Corrected 1997 yield data positions for site L1.

Appendix E. Soil Maps

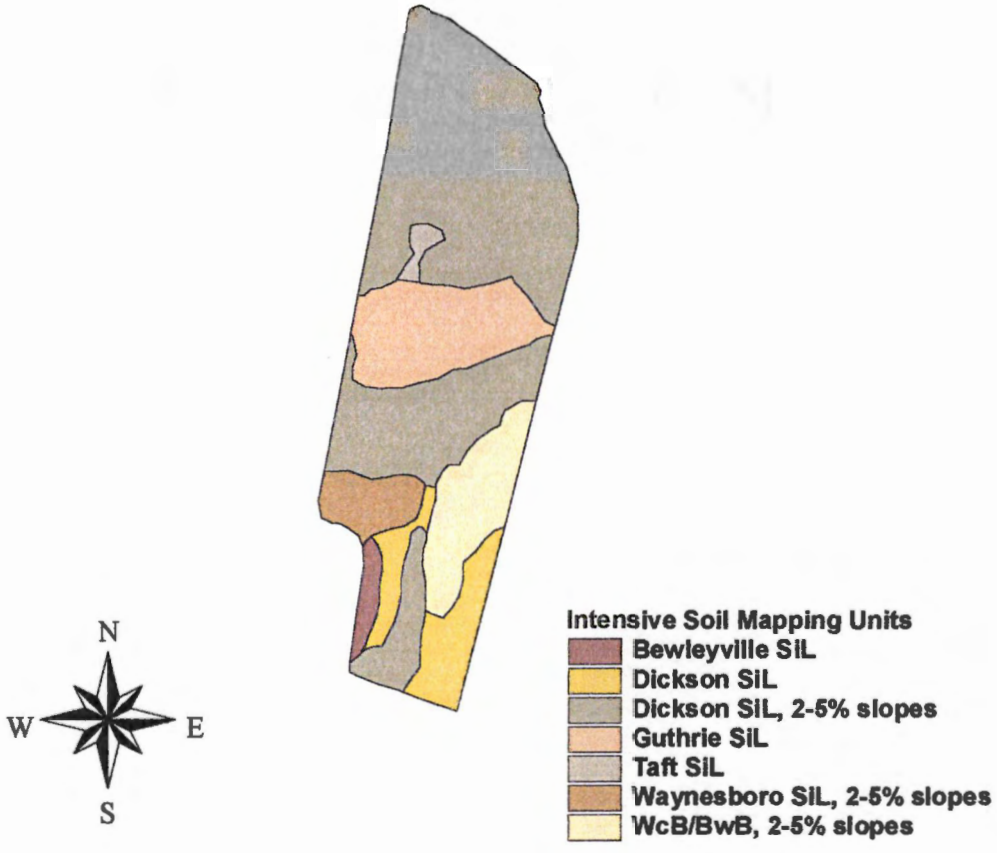


Figure E.1. Intensive soil mapping units for site F1.

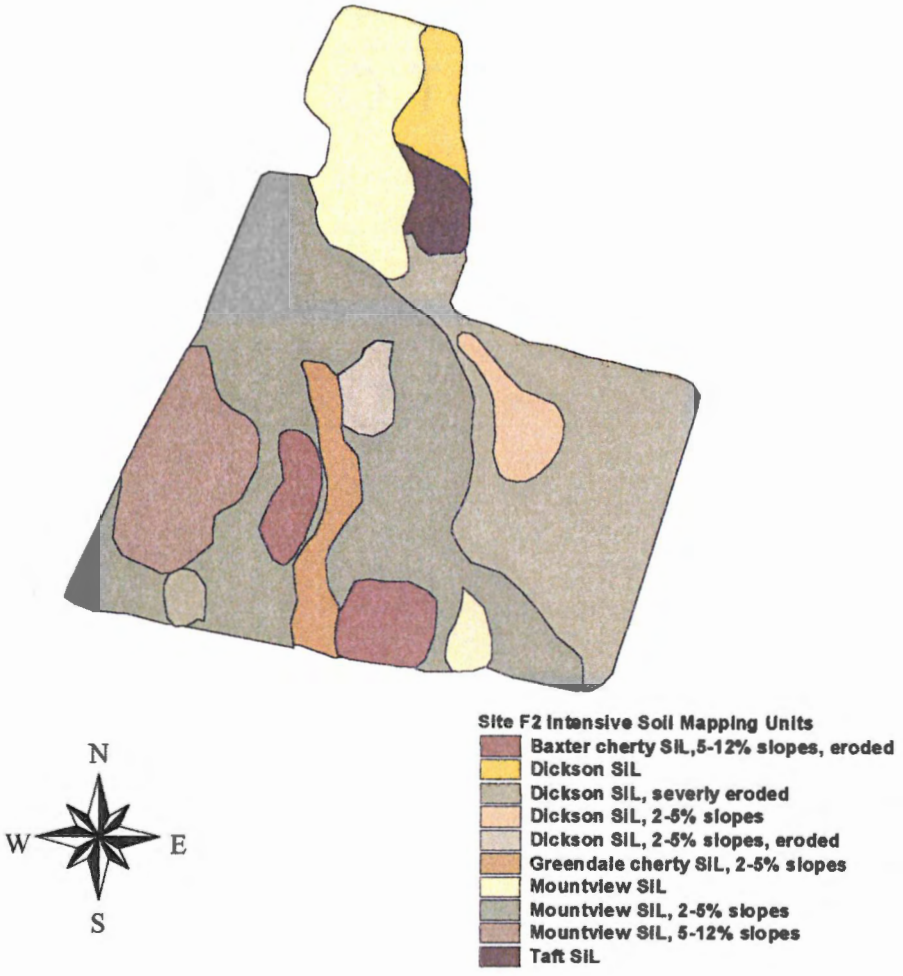


Figure E.2. Intensive soil mapping units for site F2.

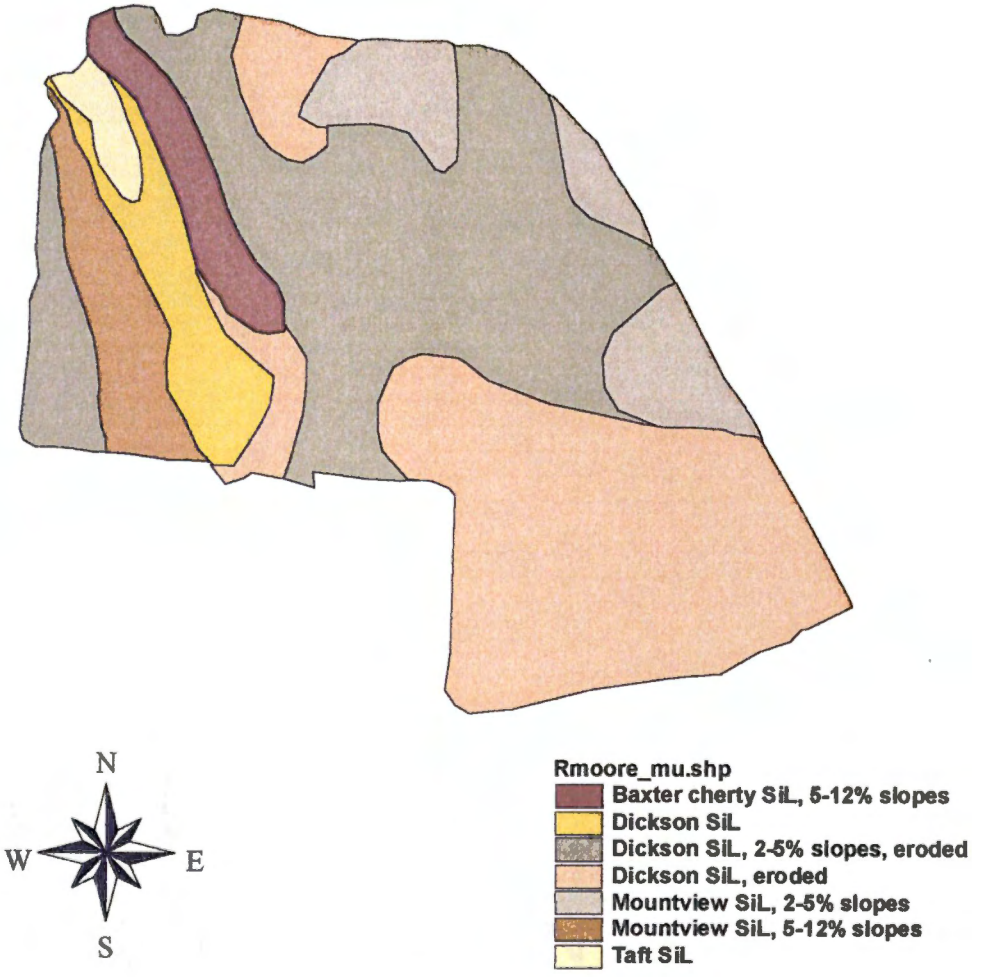


Figure E.3. Intensive soil mapping units for site F3.

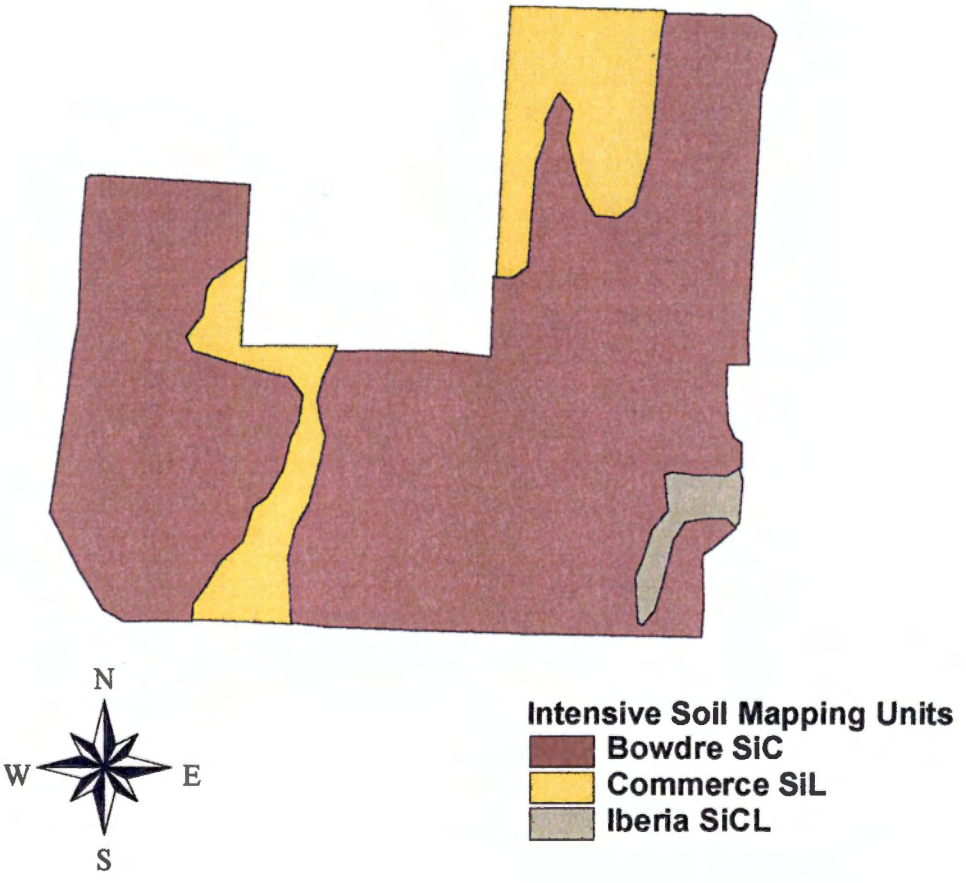


Figure E.4. Intensive soil mapping units for site L1.

Appendix F. RTK-GPS Data Collection

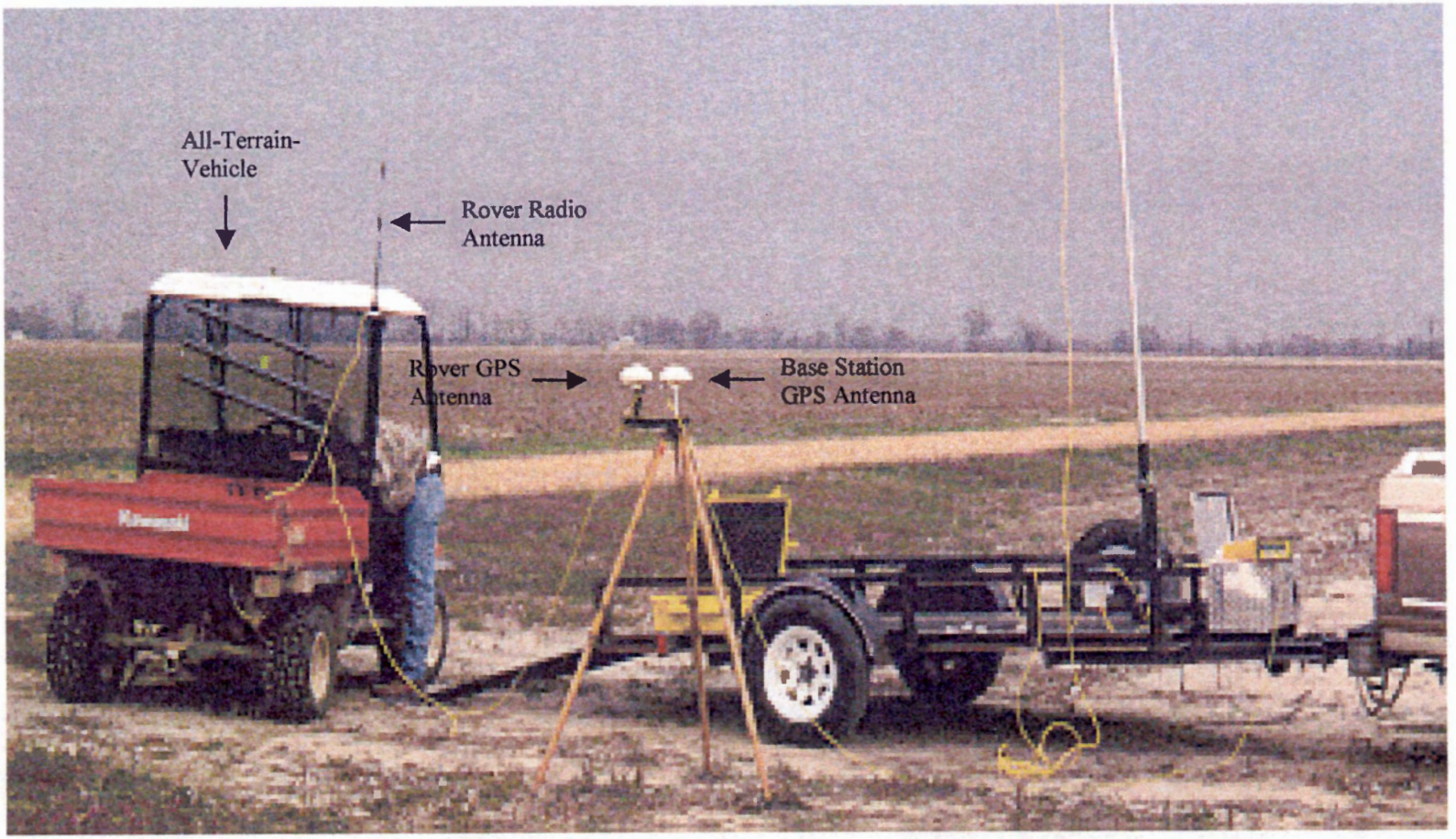


Figure F.1. Initialization of RTK-GPS.



Figure F.2. Initialized RTK rover unit with ATV equipped with rover GPS antenna and rover radio antenna.

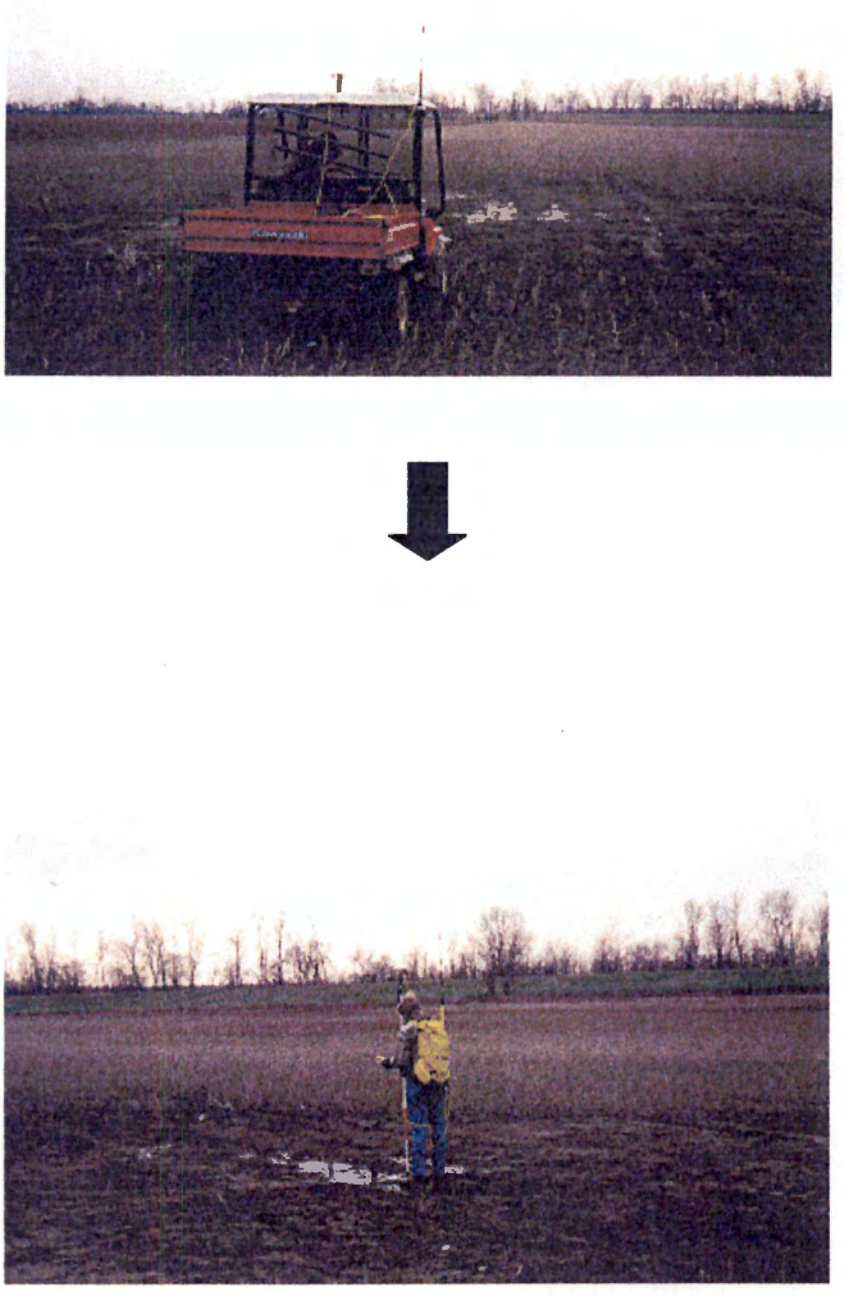


Figure F.3. RTK data collection with the mobile backpack rather than the ATV due to local area of water accumulation.

Appendix G. Elevation Data Accuracy

Table G.1. Average horizontal and vertical accuracies for elevation data collected by RTK-DGPS.

Site	Horizontal error (m)	Vertical error (m)	Observations
F1	0.016	0.023	1392
F2	0.015	0.029	1072
F3	0.013	0.024	872
L1	0.016	0.028	2449

Appendix H. Elevation Maps

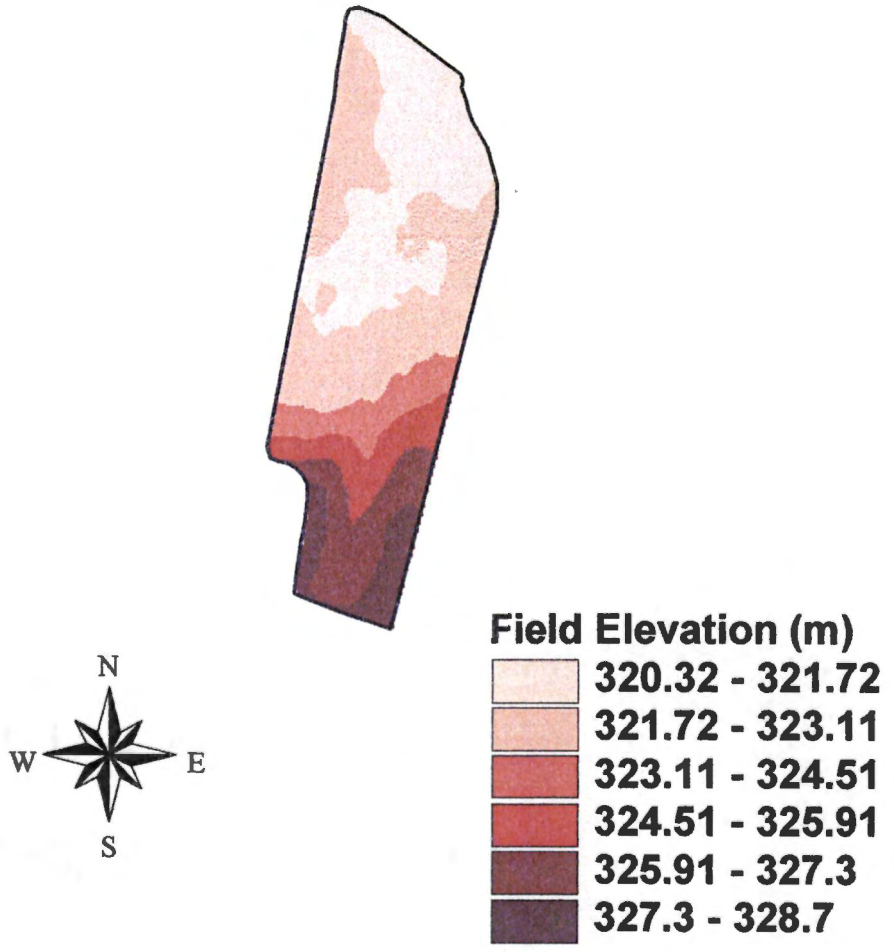


Figure H.1. Elevation map created form detailed elevation data for site F1.

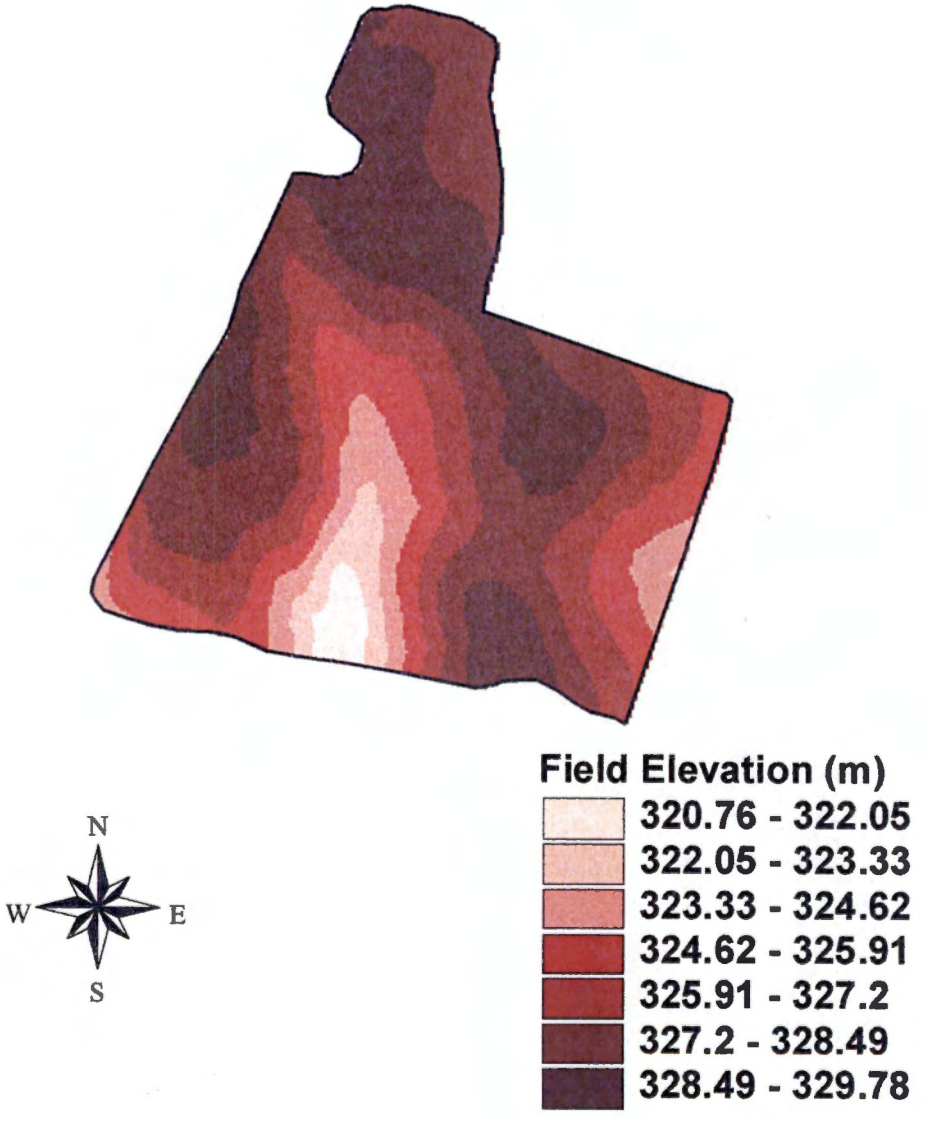


Figure H.2. Elevation map created form detailed elevation data for site F2.

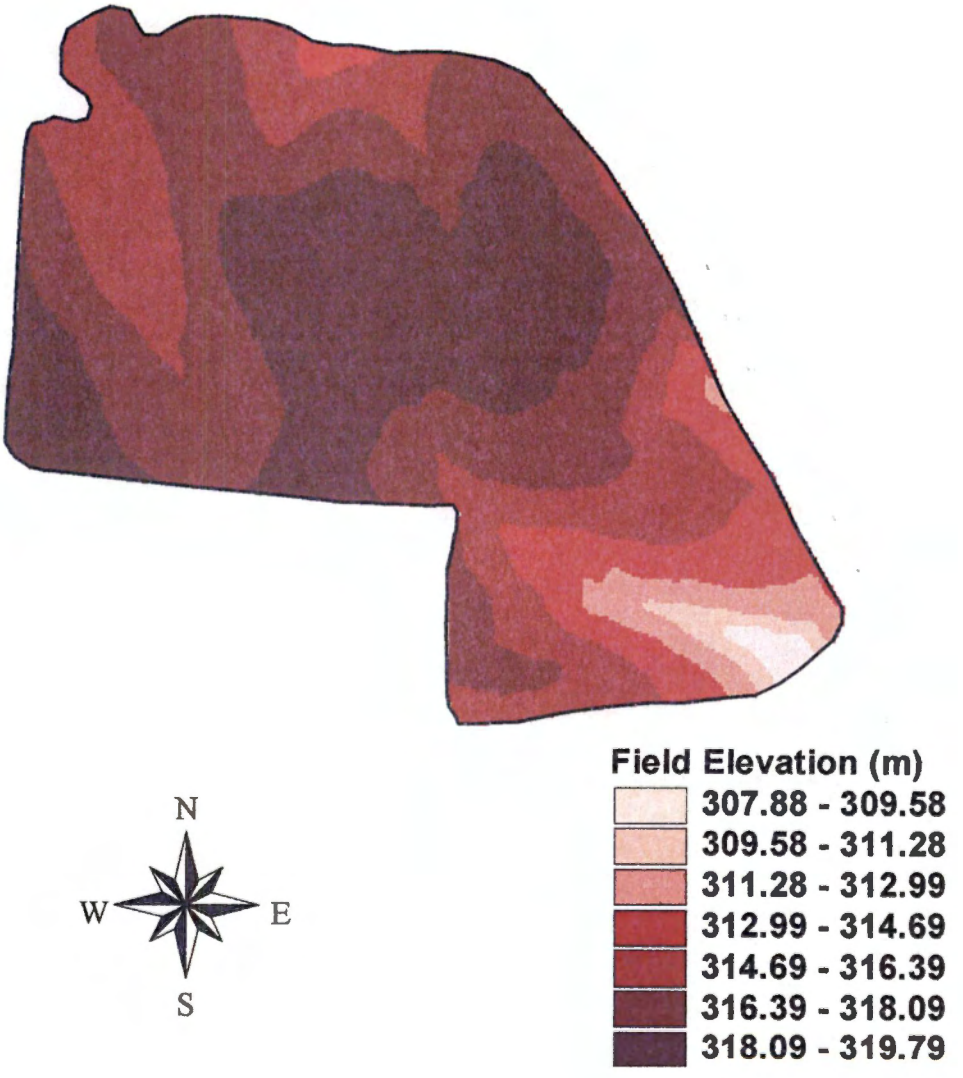


Figure H.3. Elevation maps created form detailed elevation data for site F3.

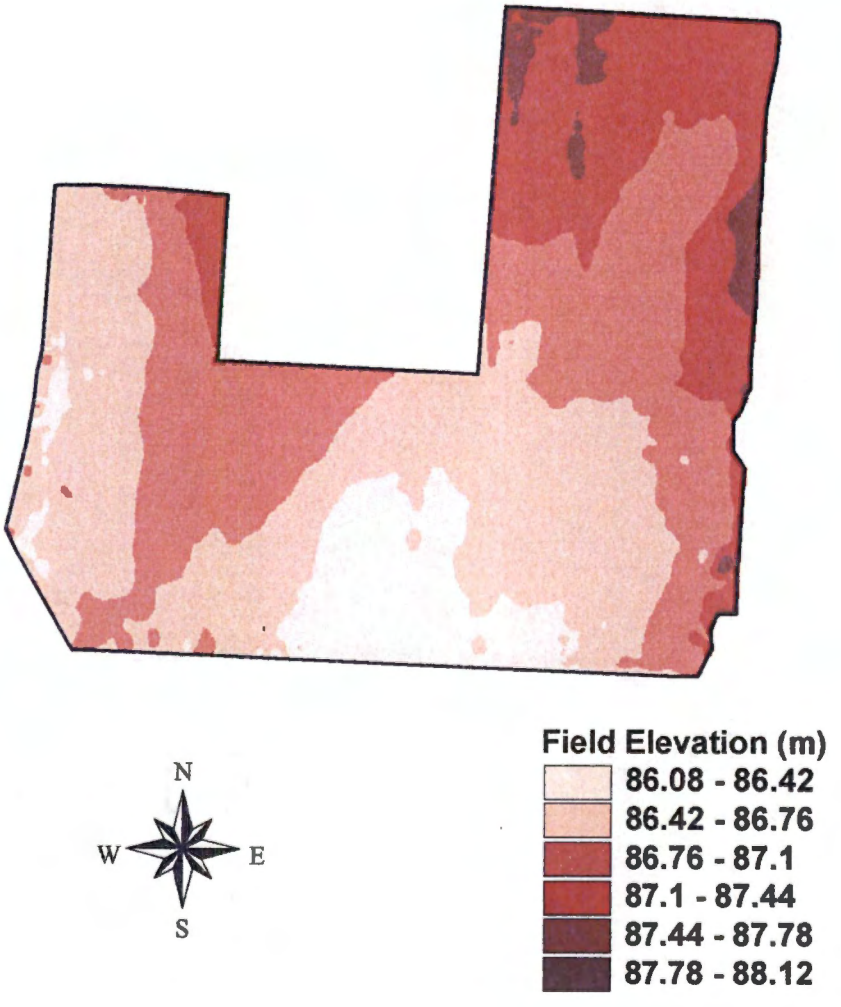


Figure H.4. Elevation maps created form detailed elevation data for site L1.

Appendix I. Percent Slope Maps

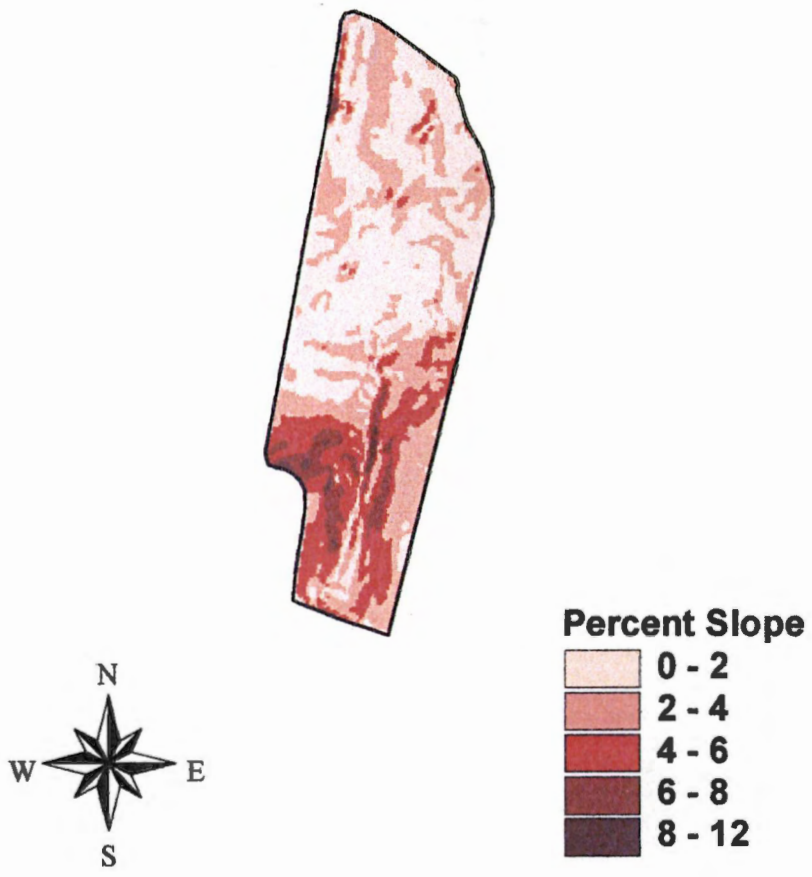


Figure I.1. Percent slope map for site F1.

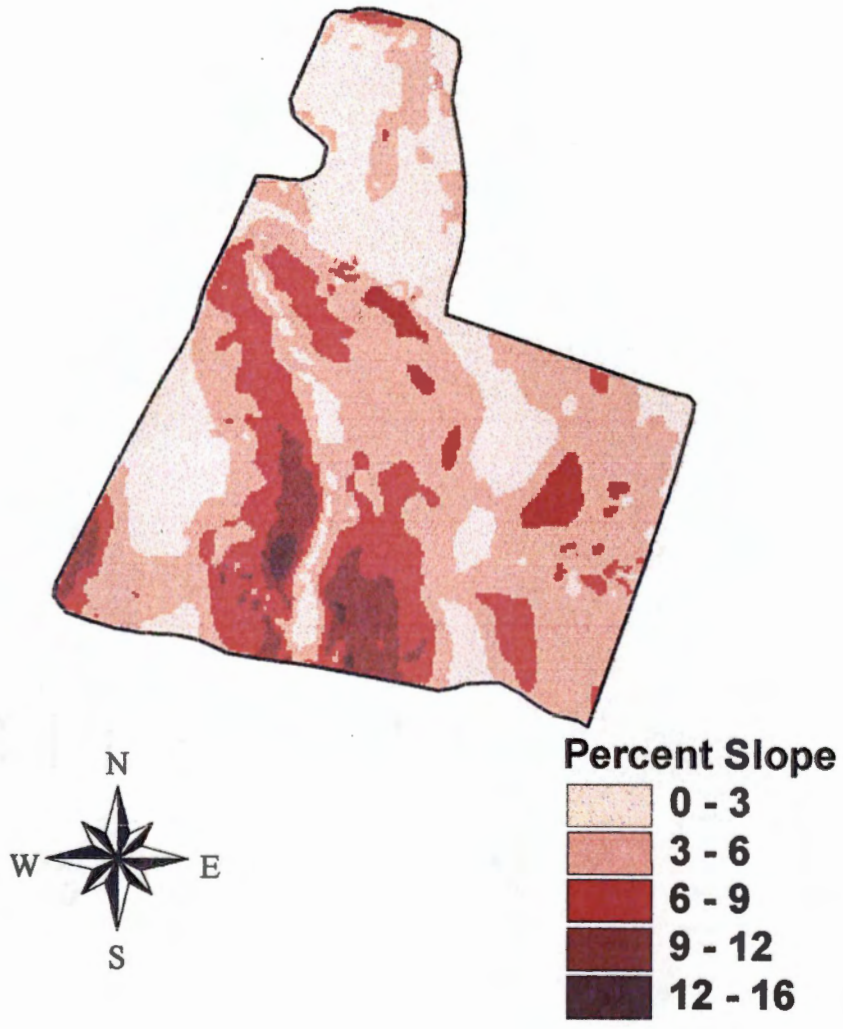


Figure I.2. Percent slope map for site F2.

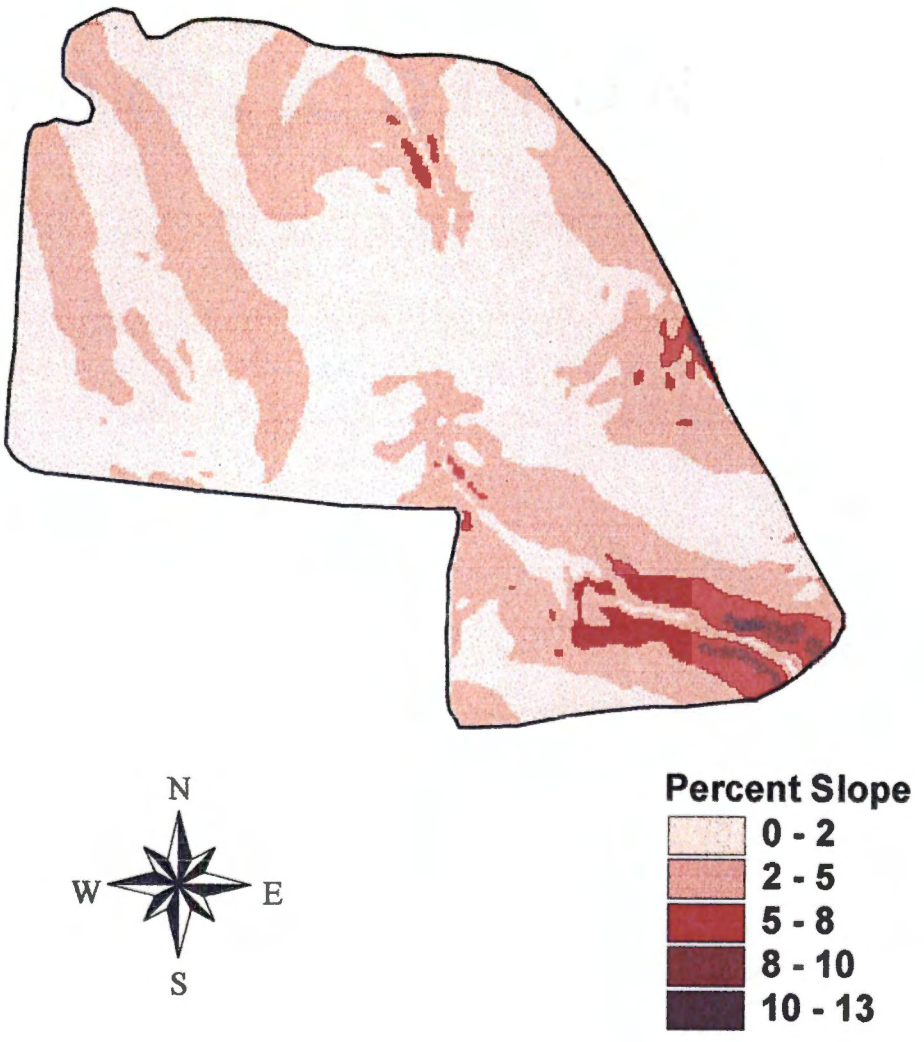


Figure I.3. Percent slope map for site F3.

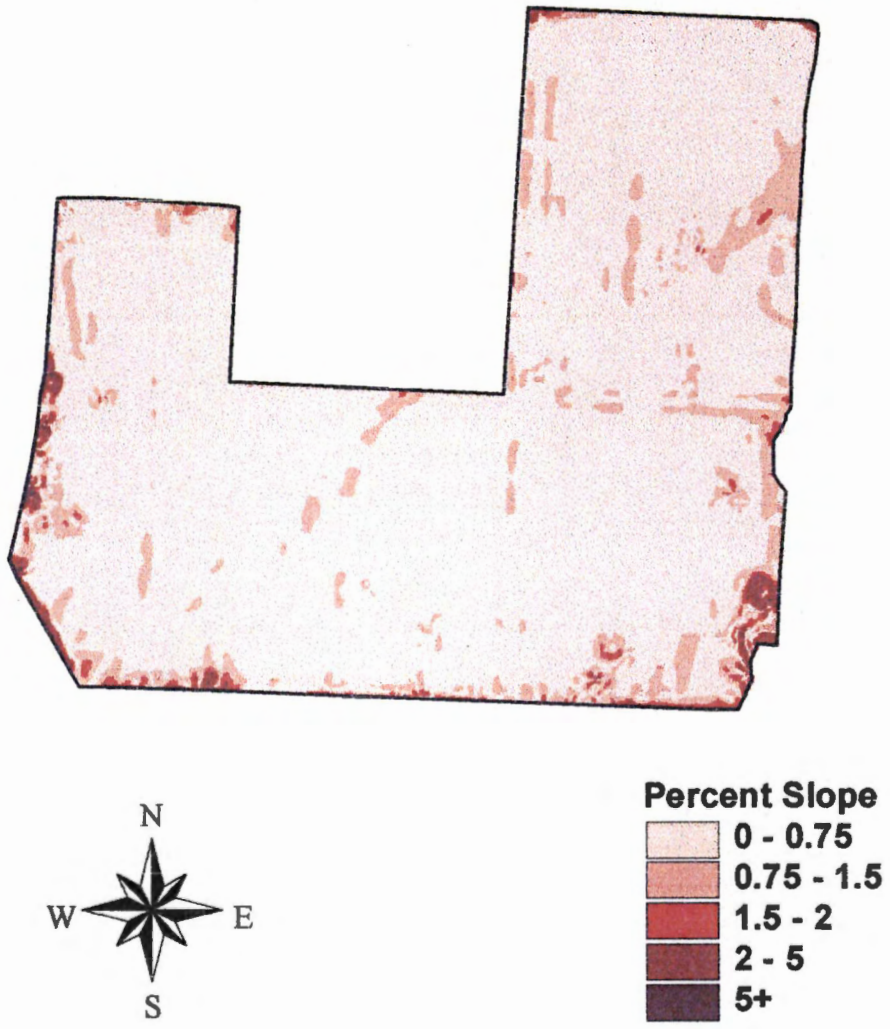


Figure I.4. Percent slope map for site L1.

Appendix J. Drain and Ridge Location Maps

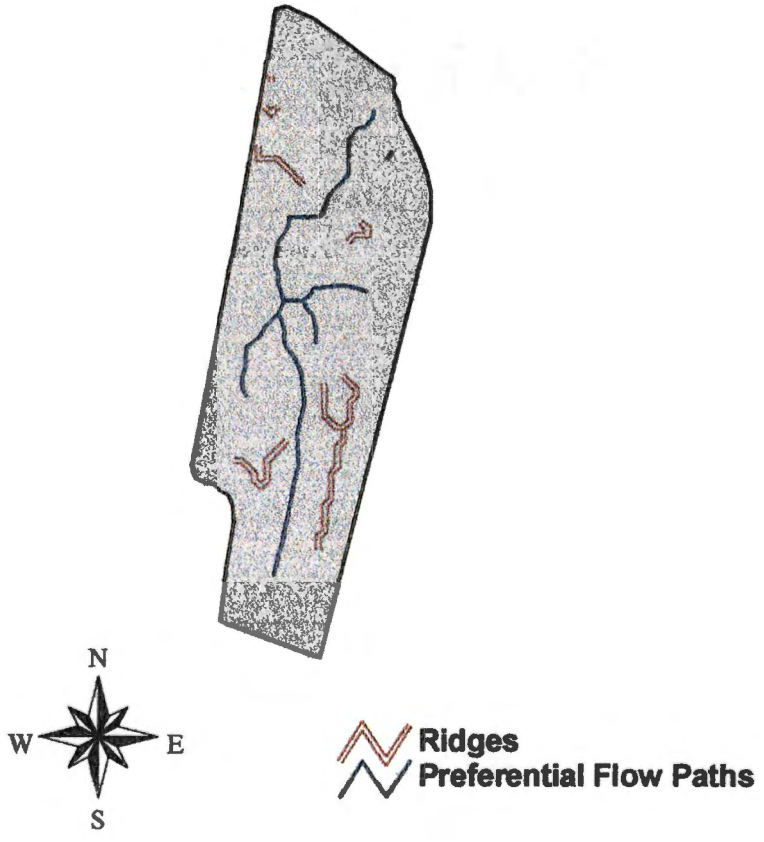


Figure J.1. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F1.

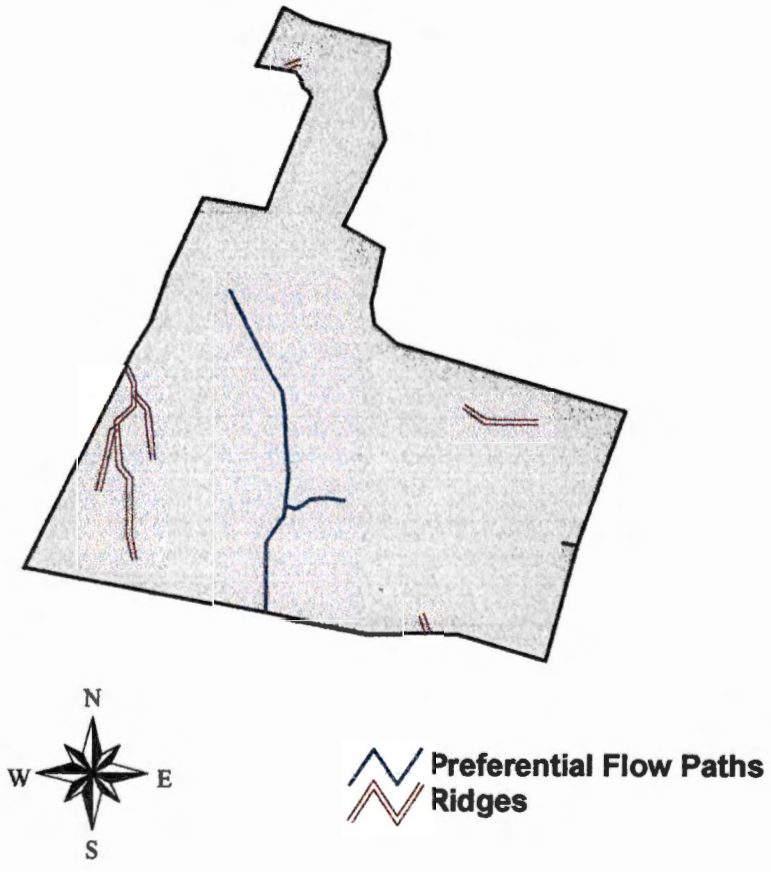


Figure J.2. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F2.

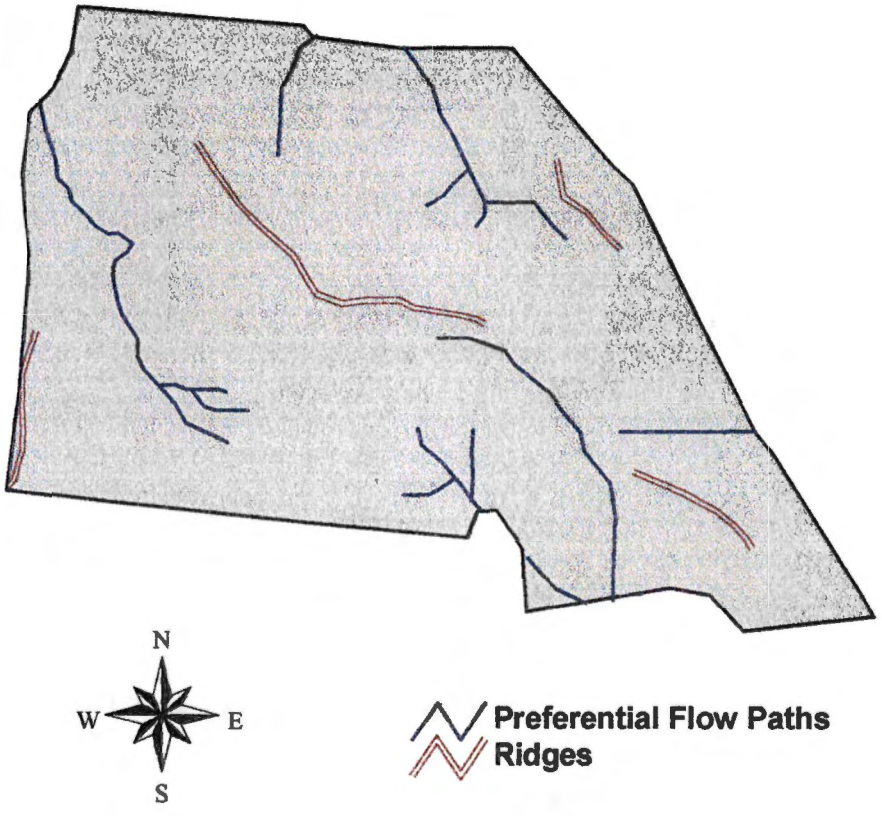


Figure J.3. Drainage flow patterns and ridges determined from flow accumulation in ArcView® for site F3.

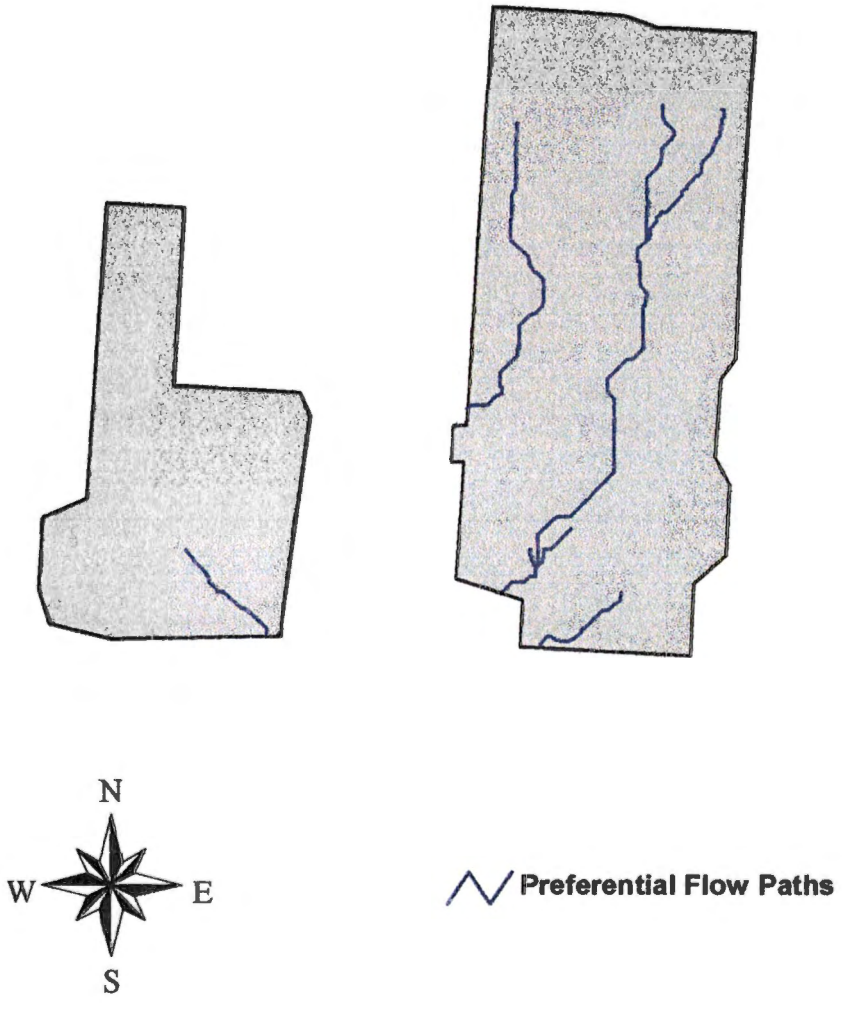


Figure J.4. Drainage flow patterns determined from flow accumulation in ArcView® for site L1.

Appendix K. Landscape Position Maps

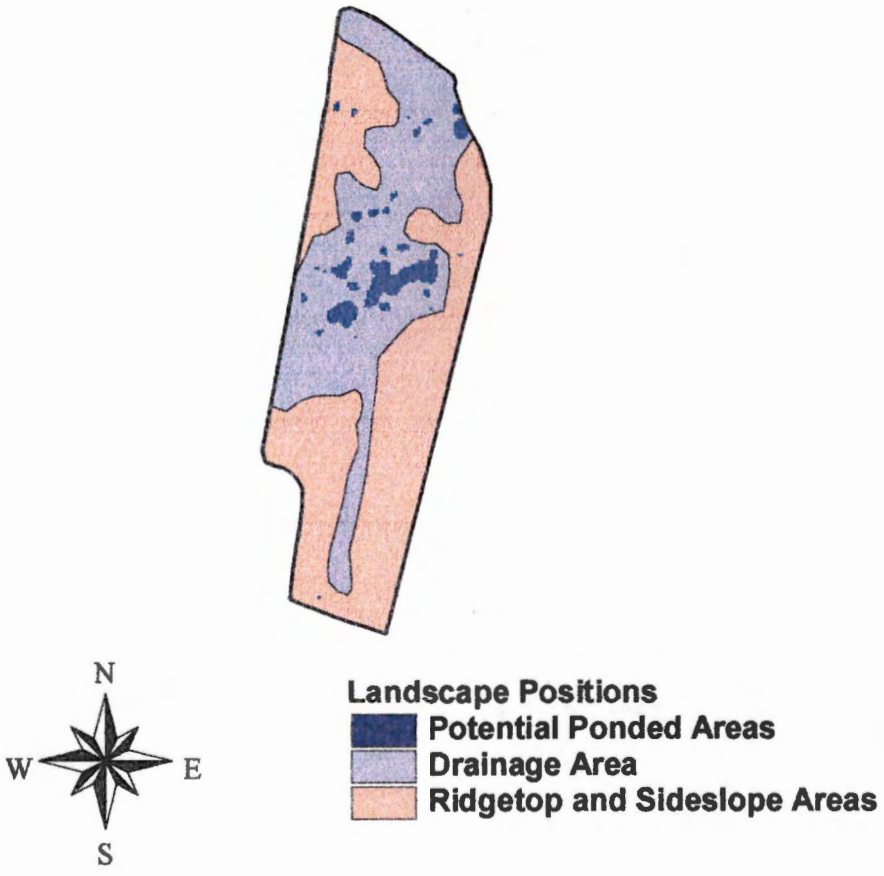


Figure K.1. Map illustrating ponded areas, drainage areas, ridgetop positions and sideslopes for site F1.

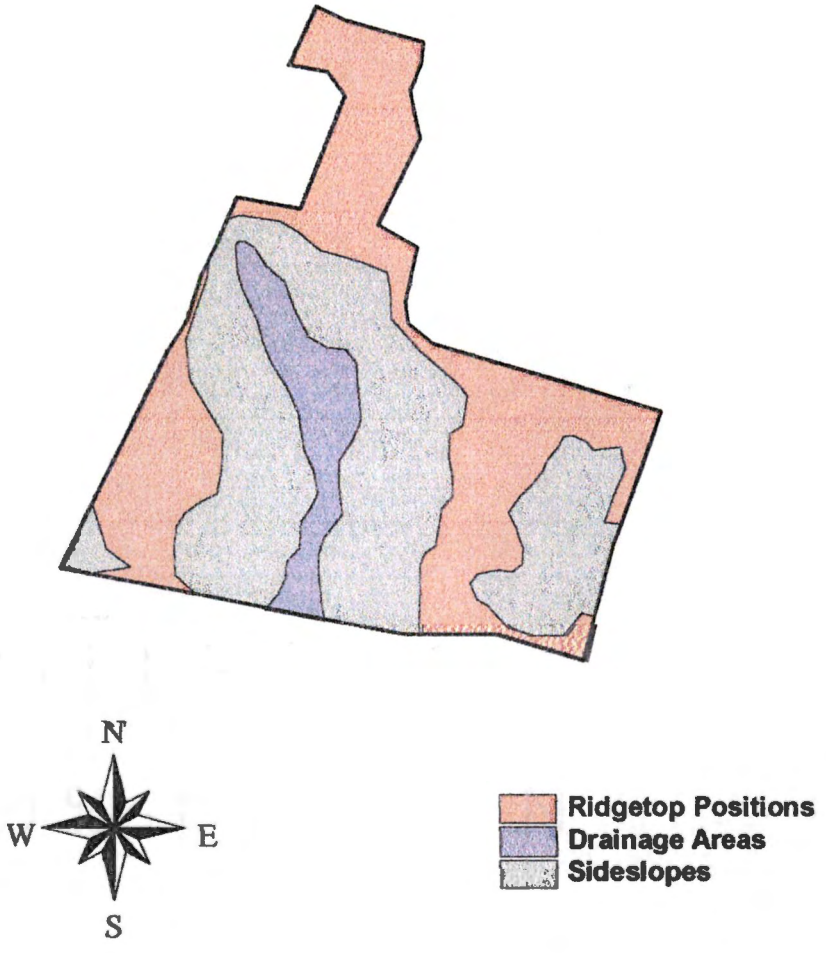


Figure K.2. Map illustrating drainage areas, ridgetop positions and sideslopes for site F2.

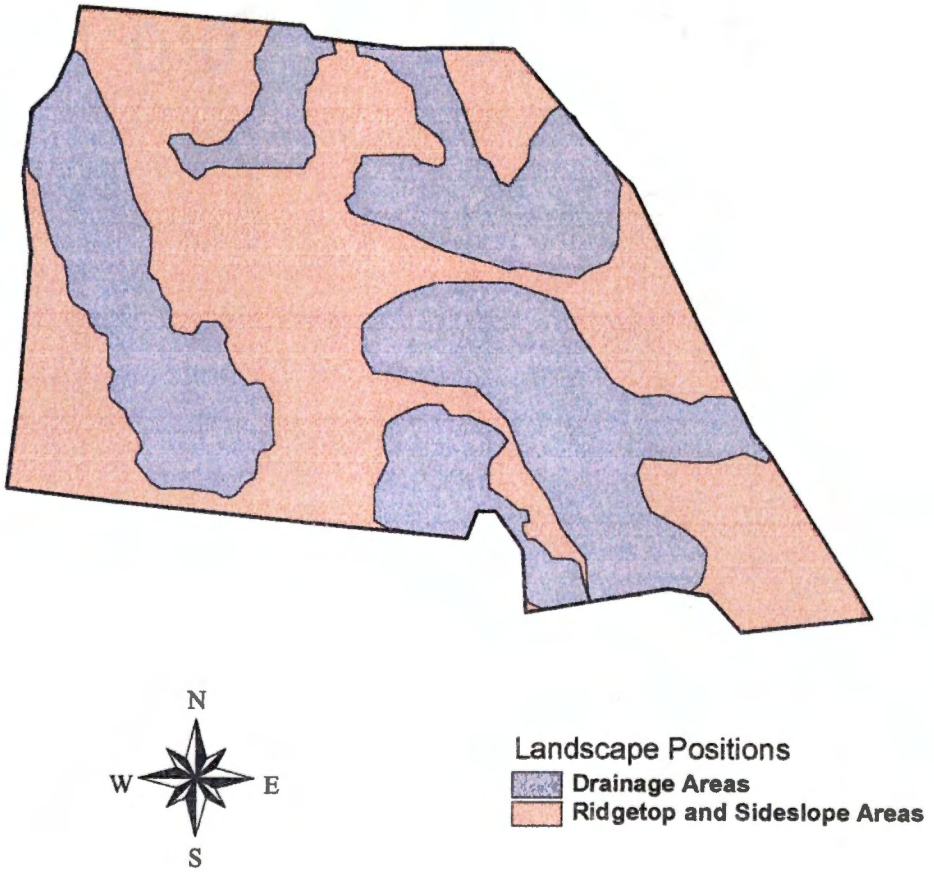


Figure K.3. Map illustrating drainage areas, ridgetop positions and sideslopes for site F3.

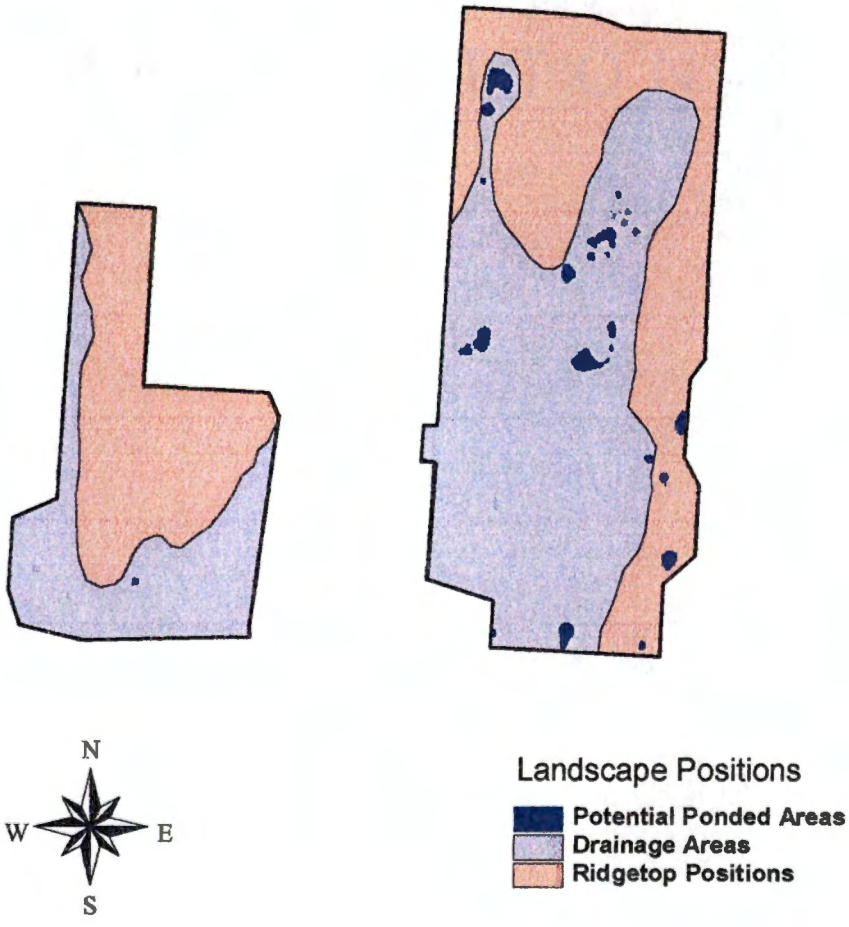


Figure K.4. Map illustrating ponded areas, drainage areas, ridgetop positions and sideslopes for site L1.

Appendix L. Landscape Classification Maps

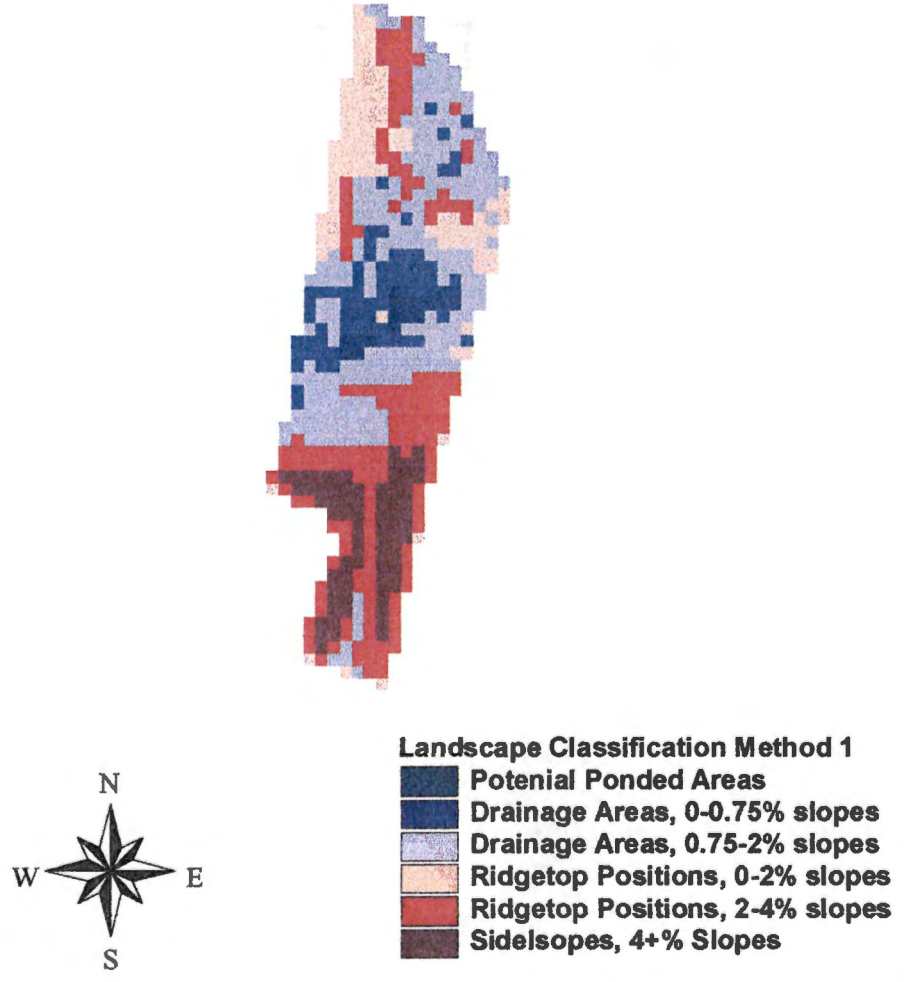


Figure L.1. Site F1 landscape classes under classification method 1.

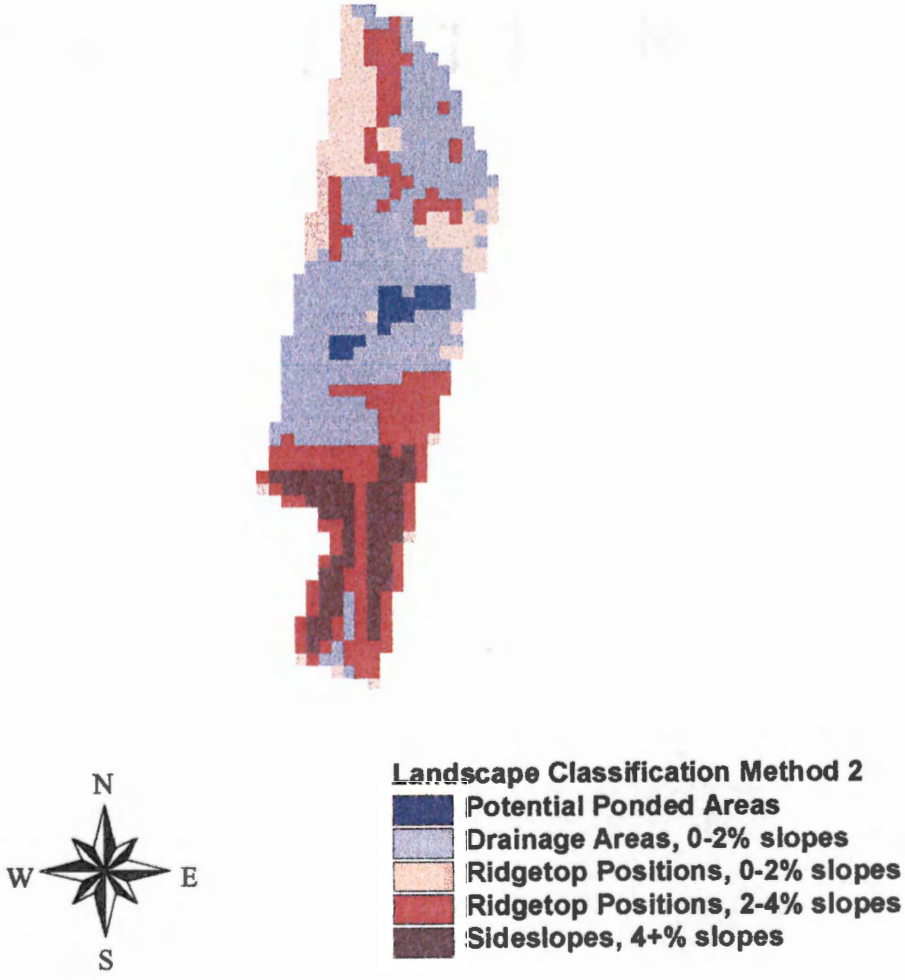


Figure L.2. Site F1 landscape classes under classification method 2.

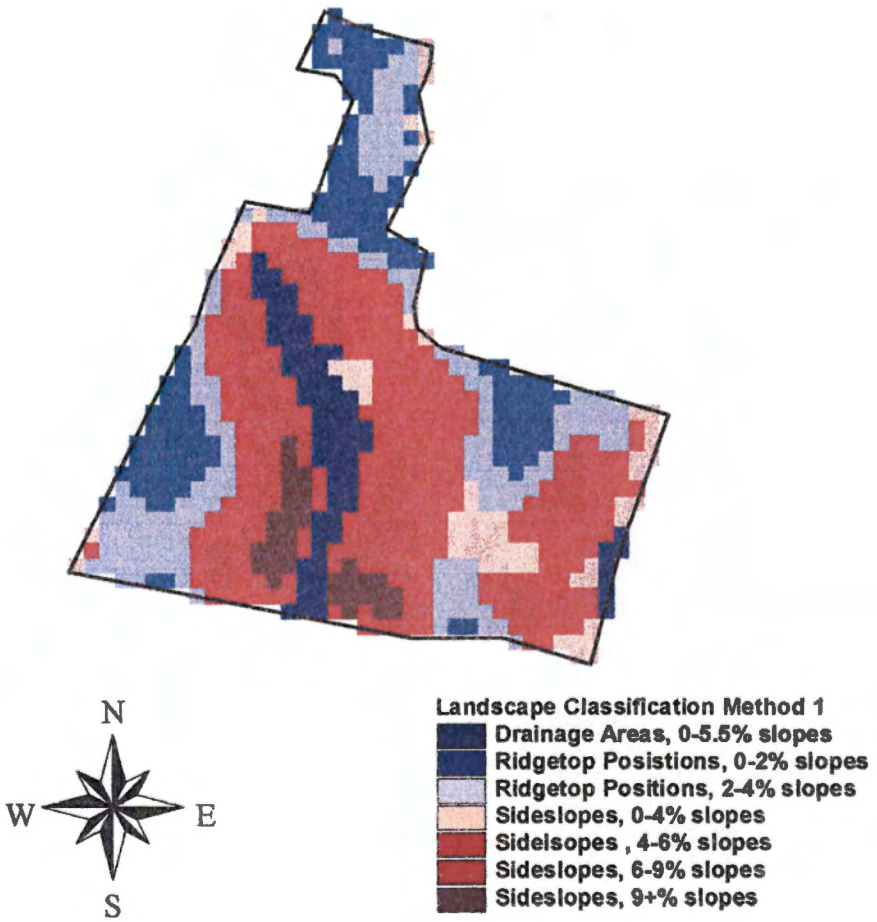


Figure L.3. Site F2 landscape classes under classification method 1.

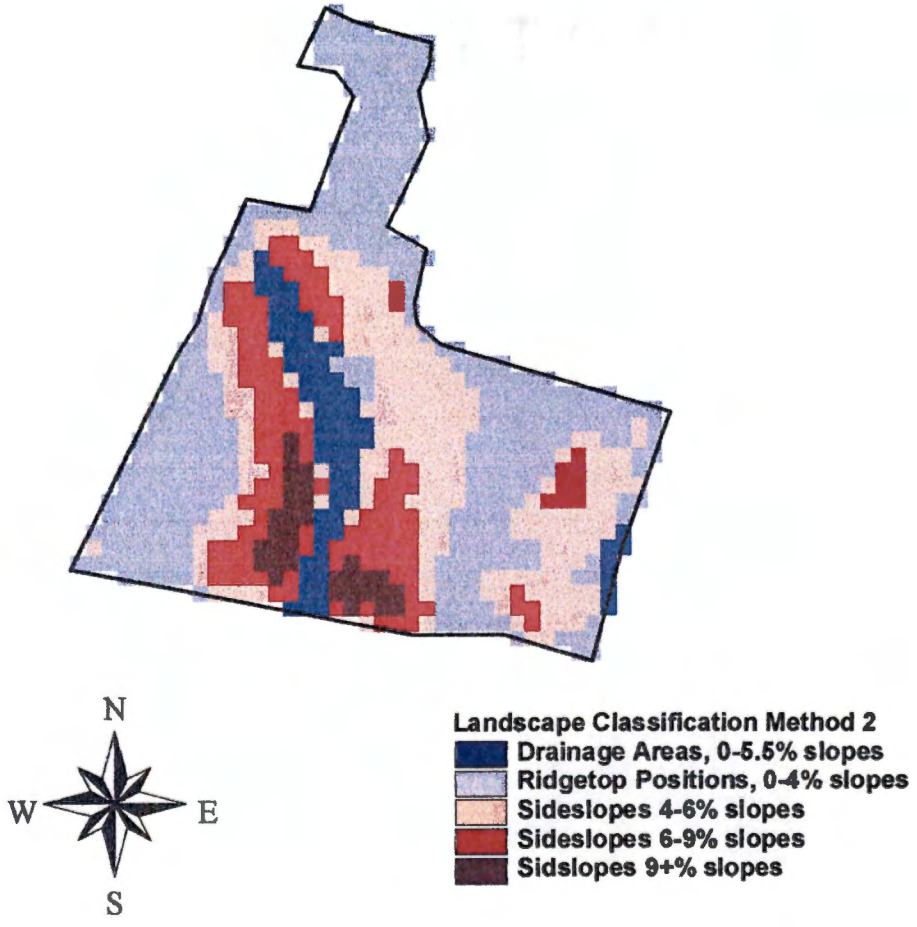


Figure L.4. Site F2 landscape classes under classification method 2.

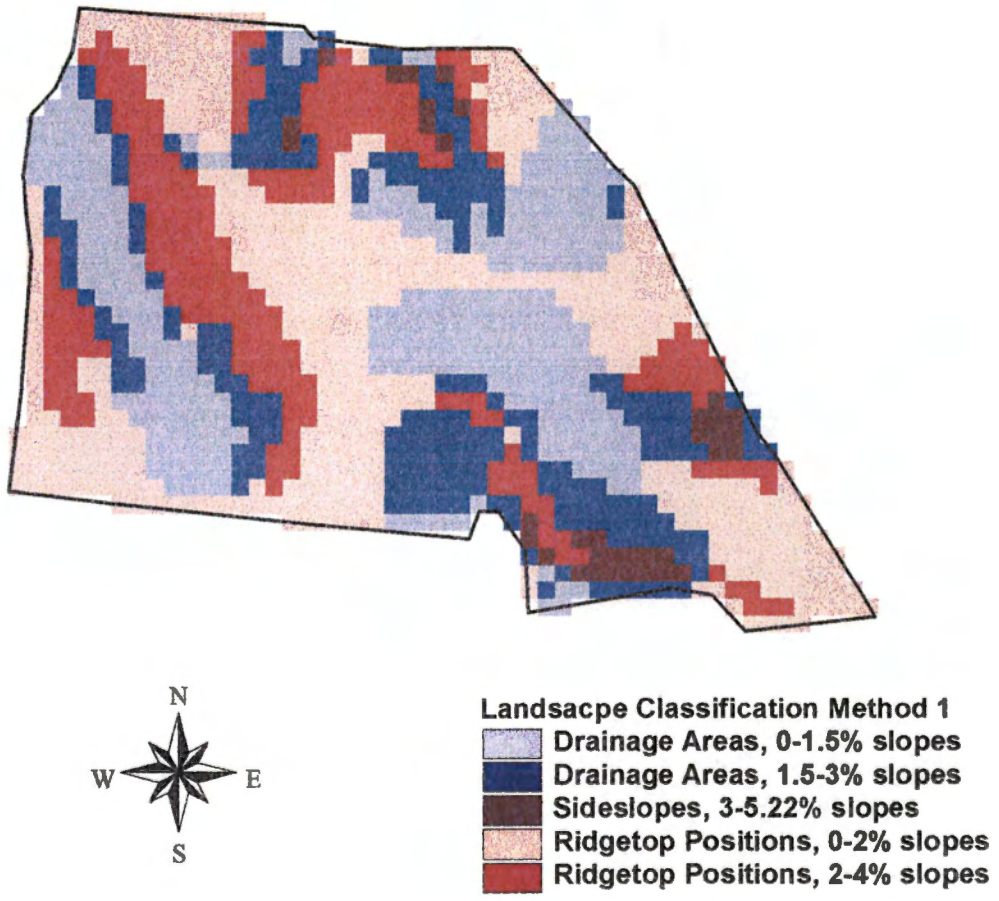


Figure L.5. Site F3 landscape classes under classification method 1.

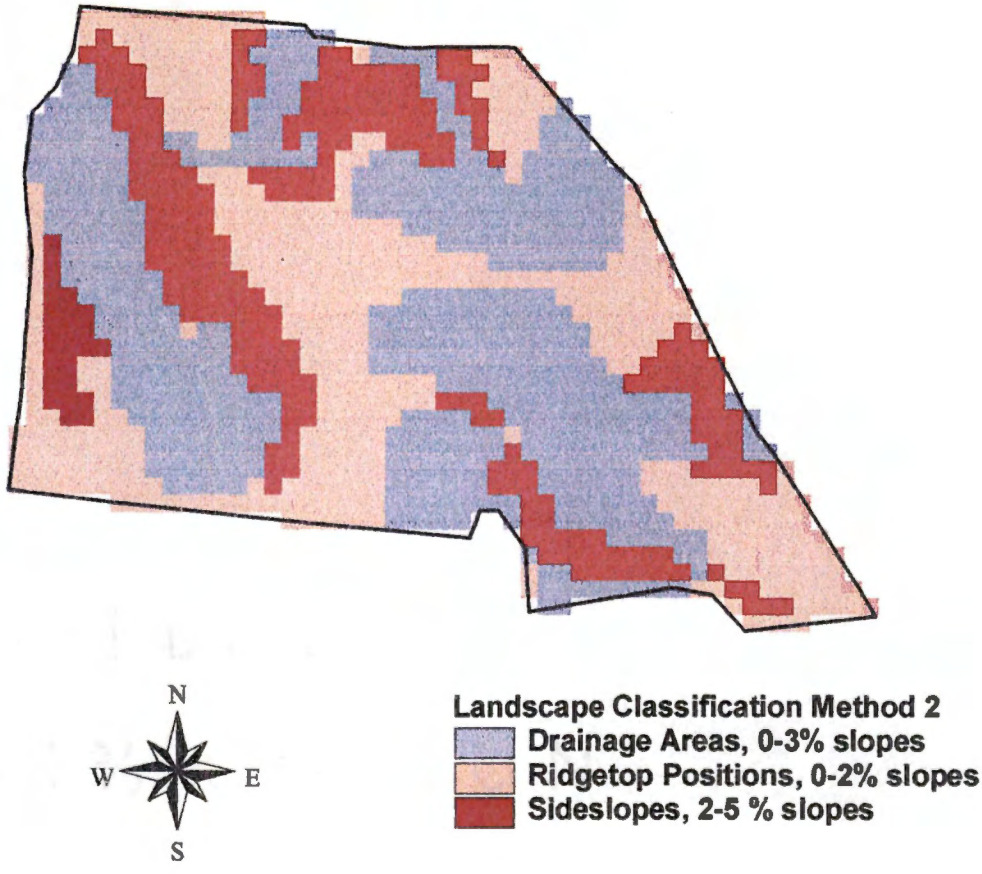


Figure L.6. Site F3 landscape classes under classification method 2.

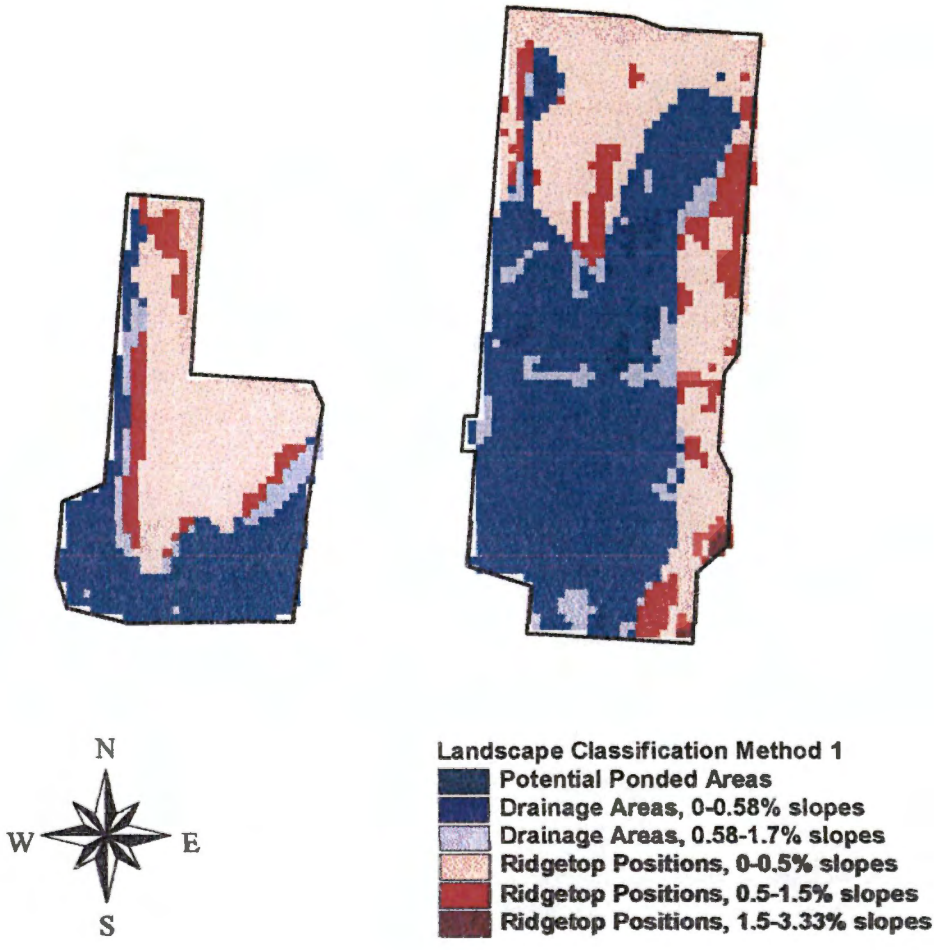


Figure L.7. Site L1 landscape classes under classification method 1.

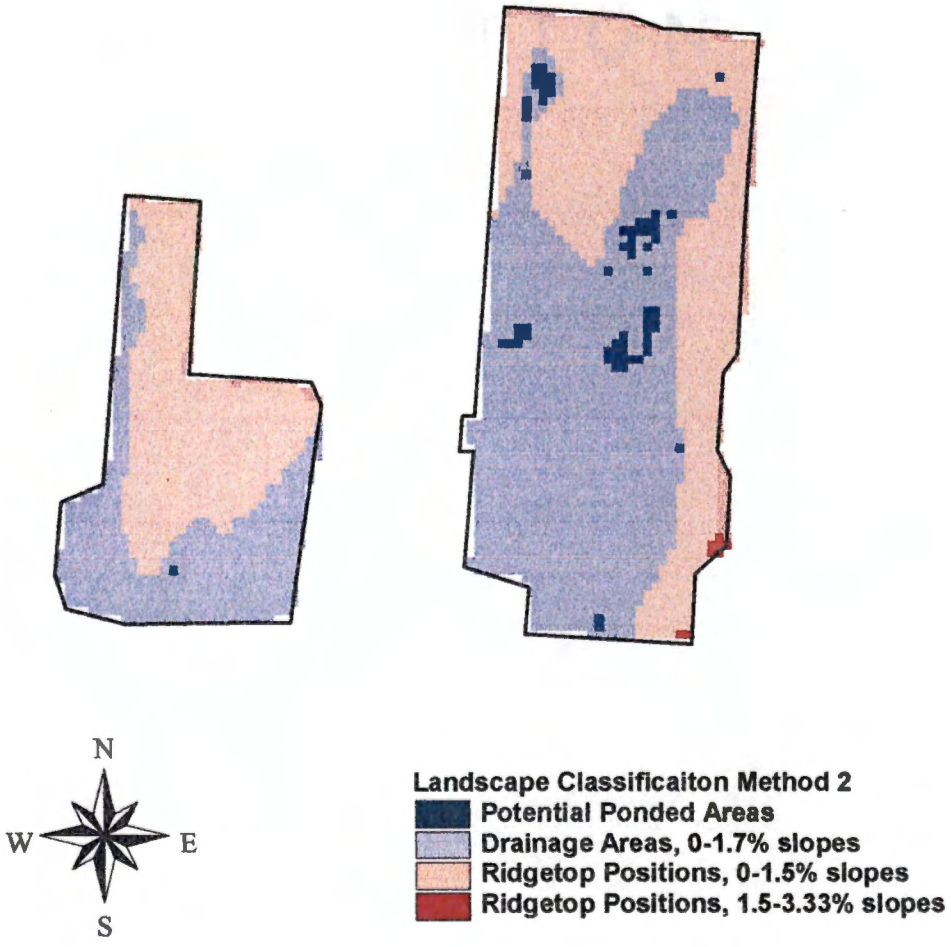


Figure L.8. Site L1 landscape classes under classification method 2.

VITA

Curtis Brandon McDaniel was born in Gibson County, Tennessee on March 25, 1977. He was raised on a family farm in Rutherford, Tennessee. He graduated Gibson County High School in May, 1995. He then enrolled at the University of Tennessee, Martin where he received his Bachelor's Degree in Agricultural Science in May, 1999. While at UTM, Curt was an active student in agriculture and member of the agricultural fraternity, Alpha Gamma Rho. During his tenure at Martin, he was recognized as the 1999 UTM Outstanding Senior in Agriculture, 1999 UTM Outstanding Agronomy Student, 1999 Alpha Gamma Rho Outstanding Senior and the 1997 Agriculture Science Student of the Year. Without delay, Curt enrolled in the Plant and Soil Science graduate program at the University of Tennessee, Knoxville as a Graduate Research Assistant. While pursuing his Master's, Curt held teaching and research responsibilities related to GPS, GIS, and precision agriculture technologies. He was also initiated into the esteemed Phi Kappa Phi Academic Honor Society and the Gamma Sigma Delta Academic Agricultural Fraternity. Curt has presented his thesis work for local and national audiences. He won first place for his work in the graduate student poster contest at the SAAS meetings in Fort Worth, Texas in January of 2001. Curt completed his M.S. degree in December of 2001 at UTK and began a career in agriculture in West Tennessee.

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