To the Graduate Council:

I am submitting herewith a thesis written by Michael Spencer Palmer entitled "The Design and Implementation of a Field-Scale Monitoring System to Evaluate Spatial Variability within Production Cotton Fields." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering Technology.

John B. Wilkerson, Major Professor

We have read this thesis
and recommend its acceptance:

William C. Hart

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

THE DESIGN AND IMPLEMENTATION OF A FIELD-SCALE MONITORING SYSTEM TO EVALUATE SPATIAL VARIABILITY WITHIN PRODUCTION COTTON FIELDS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Michael Spencer Palmer

May 1997

Dedication

This thesis is dedicated to my parents

Harold and Helen Palmer

for their guidance and support.

ACKNOWLEDGMENTS

The author expresses his sincere gratitude to his major professor Dr. John B. Wilkerson, without his advise, encouragement, and friendship I could have never finished this project.

Appreciation and thanks is also extended to my graduate committee, Mr. John Bradley, Dr. Michael Buschermohle, and Dr. William Hart. Their advice and assistance were invaluable to me during my research endeavors.

Special gratitude is expressed to the entire staff of the Milan Experiment Station for their extreme patience and answers to the many questions and most importantly for their gracious hospitality during my stays in Milan. Also the help of Mr. Paul Elliott, Mr. Walker Garner, Mr. Jason Goodwin, and Mr. Craig Wagoner was not only needed but greatly appreciated.

Thanks is also extended to Dr. Don Howard, Mrs. Janet Gibson, and Dr. Don Tyler of the West Tennessee Experiment Station in Jackson for always providing information and advice whenever needed.

Thanks is expressed to fellow graduate students Page Barker, Henry Moody, and Ruixiu Sui for their assistance in the field and the lab.

The author would also like to thank Mr. Larry Click, undergraduate professor at Tennessee Technological University, for preparing me not only for graduate school but for the challenges in life.

ABSTRACT

Much interest has been focused on site-specific crop production since the introduction of grain yield monitoring systems. Considerable research has been conducted in the area of site-specific grain production. Lack of a cotton yield monitor has slowed implementation of site-specific practices in cotton production. However, due to the intense level of management commonly associated with in cotton production, it may prove to be an ideal crop for site-specific practices.

Preliminary testing was conducted in the fall of 1995 to verify that a batch weighing system used in conjunction with Global Positioning System (GPS) equipment was a satisfactory method of monitoring cotton yield variability for field-scale research. The objective of the yield monitoring system was to enable field-scale research, rather than being restricted by small plots. The weighing system was improved in 1996 by increasing the weighing capacity, ease of operation, and reduction of the basket weight to cotton capacity ratio.

In 1996 a five-acre portion of a production cotton field in Milan, Tennessee was selected to monitor spatial variation throughout the growing season. The field was divided into 182 plots. An extensive soil survey was performed on the field in the spring revealing six soil series within the test area. Soil samples were extracted and analyzed from each plot in the spring and the fall. Soil moisture was monitored throughout the growing season from 26 observation sites within the test area.

The overall objective of the research was to relate soil chemical and physical

variability within a production field to crop yield. 1996 field data was the first of collected a three-year study. Therefore, information obtained from 1996 field data collected cannot be considered conclusive without statistical replication. It should be noted that weather patterns tend to have an effect on spatial performance of crops. Although some of the variables measured during the first year had a greater affect on yields than others.

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CHAPTER 1

INTRODUCTION

Variability, as defined by Webster, is the tendency to vary from average characteristics of species (Webster, 1987). In the agricultural industry, variability can be associated with almost anything from market prices to crop yields. For centuries farmers have realized that variation exists within their fields. Before machines were used to produce crops, field sizes were small and could be managed according to individual needs. With the incorporation of large tractors, harvesters, and implements, field sizes became large, producers tended to treat fields according to average characteristics. Ignoring variability was the easiest way to manage it. Presently many producers believe that to gain maximum economic yield (MEY), inputs have to be managed more efficiently. Research is underway to develop variable application and positioning systems to allow fields to be managed as small sub-units promoting input efficiency.

Carr et al. (1991) coined the phrase "farming soils not fields". This implies that soils with differing yield potential sometimes vary within a single field, and should not be fertilized with the same rate. A similar approach is used in dairy feeding programs across the country. Higher producing cows in the herd are not fed the same ration as the lower producing cows. If the same ration was used, milk production would decrease for the higher producers, and the lower producers would remain at the same level. This is also true for production of crops. Some locations in a field may have higher yield potentials than others. Therefore it maybe more economical to fertilize them differently. This new technology in crop production has been given a multitude of names including: site-specific crop management, variable-rate technology, farming by the foot, prescription agriculture, and precision farming. Site-specific crop management (SSCM) will be used to describe this technology herein.

Research is currently being conducted in the domain of managing spatial variability within a field by universities and industries around the world. Grain yield monitors have received a substantial amount of press in the last few years, and many producers are adapting this new technology as it becomes commercially available. In conjunction with a positioning system, yield monitors allow spatially variable yield maps to be generated. Yield maps are, without challenge, an integral part of site-specific crop management, although they do not provide all of the answers. By studying a yield map a producer can determine where variability exists within a single field for a single season. However, unless a complete history of the field is known, an accurate hypothesis of why the variability exists and what to do about it cannot be made.

A Geographic Information System (GIS) is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (ESRI, 1996). In short, a GIS can be described as a database in which to store the history of a geographic location. A GIS database for crop production should include: yield, soil type, nutrient levels, soil acidity, soil organic matter content, and other forms of spatial data for a particular field. For SSCM to reach its full potential in crop production, a GIS database must be synthesized for the crop production location. Several years of data are needed to establish a GIS database that will be beneficial to a SSCM program (Kvien et al., 1995).

To date a large percentage of the research performed in SSCM has been centered around grain production. This is due in part to the commercialization of grain yield monitors that can be retro-fitted to almost any modern combine. Yield monitoring systems for cotton, potatoes, and other specialty crops are currently under development and should be commercially available in the near future.

Almost 16 million acres of cotton was harvested in the United States during the 1995 season, 660 thousand acres in Tennessee alone (USDA, 1996). There is much enthusiasm about SSCM for Tennessee cotton production. Cotton producers are anxious for the release of a commercially available cotton yield monitoring system. Although a yield monitor will aid in the implementation of SSCM, it is not necessary for farmers to benefit from this new technology. Much can be learned from an extensive soil mapping and crop scouting program. Farmers that have good databases built for their fields will be a step ahead when yield monitors are introduced commercially.

Justification for Research

While considerable research in precision farming has been reported in the literature, limited research results have been published on cotton yield variability and the factors affecting this variability. This is in part due to limitations in measurement instrumentation for documenting cotton yield variability on a field-scale basis. A cotton yield measurement system is not commercially available at the present time for either production or research needs. Therefore, it is proposed to develop an instrumented cotton yield measurement system for real-time yield determination on a commercially-available spindle cotton picker. Additional research is also merited to address the inherent spatial variability within a cotton field. This would require establishing a protocol for documenting, managing, and analyzing the variables commonly believed to affect cotton yields within a field.

Objectives

The objective of this research project was to develop a system to measure and document the spatial variations within a production cotton field. Specific objectives included:

- Design and fabricate an accurate system for mapping yield variation for field-scale research.
- On a field-scale basis, document soil chemical and physical properties and crop growth variability throughout a growing season and relate them to cotton yield, and
- Develop and manage a GIS database for managing and interpretation of site-specific data related to cotton yield.

CHAPTER 2

REVIEW OF LITERATURE

Site-Specific Crop Management

Profits are the excess in returns over expenditures. Increasing profit is the goal of every production oriented enterprise, including the agricultural industry. Producers are constantly looking for ways to increase profits. Production costs in the agricultural industry continue to rise, an increase of $91.1 million in Tennessee alone between 1988 and 1994 (TDA, 1996). To combat these trends, producers must develop new strategies that will decrease expenses per unit of production output. Methods such as no-till crop production, integrated pest management and crop rotation are practices used extensively by producers today to decrease expenses and increase profits. Another practice that is still in its infancy is the implementation of site-specific crop management.

Site-specific production involves several technologies in the specific areas of: (1) sensing, (2) location determination, (3) geographic information, (4) management, and (5) variable rate control (Schueller, 1991). A producer must develop a system that involves all, or a combination of, these technologies that will fit into their operation for a SSCM program to be effective.

Concept

Sawyer (1994) states that the concept of SSCM assumes: (1) variation exists within fields, (2) crop yield is influenced by the variation, (3) the variability can be identified, measured, and mapped, (4) models are available to predict crop response to variable-rate applications of inputs, (5) and tools are available to process spatial information and apply inputs according to specific locations within the field. Along with these stipulations, producers need to become knowledgeable of how to manage the information and how to apply that knowledge to their operation. Effective information management is the integral part of SSCM that will determine success (Smith, 1996). To obtain success, farmers will have to become better agronomists as well as technicians.

Implementation

Site-specific crop management is not the accumulation of high tech equipment. Rather, it is the acquisition and use of information obtained from site-specific practices (Vanden Heuvel, 1996). Factors involved in SSCM include documentation of yield, soil test, and soil properties with a precise description of the location within the field where the data was collected (Reetz, 1994). With this information, a strategic plan can be devised to employ the Best Management Practices (BMP) to obtain the Maximum Economic Yield (MEY) from that location within the field. SSCM provides the opportunity to reduce, but not in every instance, the applications of seed and fertilizer to soils depending on their productive nature, without reducing yields.

SSCM is practiced today by farmers that spot spray pests or adjust fertilization rates according to differing soil properties within a field (Vanden Heuvel, 1996). This is an example of site-specific operations in its simplest form. Improvement of this approach is possible due to the wide variation within fields and crops (Schueller, 1991). Hayes et al. (1994) states that yields can be maintained with reduced chemical inputs if applications are matched with specific field conditions. To determine the specific field conditions, a detailed soil sampling program must be maintained. The primary motivation behind SSCM is to improve the economic returns to the producer by managing crops on a smaller scale than the field by field basis. Until recently, implements were designed to cover the most area in the least amount of time. To achieve this, fields had to be treated as a single management unit. SSCM relies on the assumption that uniform applications of inputs do not maximize input efficiency or field profitability (Sawyer, 1994).

Improvements over conventional methods of input distribution are possible due to wide variations within fields and crops (Schueller, 1991). The basic philosophy of SSCM is that seed and fertilizer application rates should be matched to the inherent productivity of soils without reducing crop yields (Goering and Han, 1993). Along with maintaining yields, SSCM also has a secondary benefit of increasing the efficient use of inputs, thereby reducing their introduction into the environment (Schueller, 1991). Environmental concerns are predicted to be a major factor in crop production in the future.

Yield goals influence recommendation rates of crop inputs. These goals are obtained in part from past yield histories documented by yield maps. Yield goals should match soil properties within the field. In a study conducted in Illinois it was discovered that out of 75 randomly chosen producers, 57% were over applying nitrogen by an average of 0.35 pounds of N per bushel of expected yield (Reichenberger, 1992). This was attributed to incorrect estimates of yield potential. Barbosa (1996) concluded that application of nitrogen to corn based on yield potential has the capability of increasing profit potential within a field.

Yield Monitoring. Yield monitoring provides the ability to detect yield variations within a field during harvest operations. On-the-go yield monitors combined with positioning systems allow producers the ability to generate yield maps. These maps provide important information for developing strategies for SSCM (Birrell et al., 1996). Yield maps also supply an indication to farm operators that localized problems of soils, pests, or fertility levels exist, and permit producers to quantify the impact these problem areas have on profitability (Searcy et al., 1989).

Monitoring the spatial variation in yield provides a good basis for developing machine control maps for field operations such as the distribution of fertilizers (Stafford et al., 1991). Yield monitoring also provides the farmer the ability to determine if previous management decisions were profitable, such as crop variety selection or pest management programs. Auernhammer and Muhr (1991) stated that in a system of environment friendly and yield oriented fertilizing, yield mapping will become the base for all variable-rate procedures.

Field Positioning Positioning is crucial to every aspect of site-specific management of crop production (Smith, 1996). Knowledge of localized position is required to spatially reference field operations during data acquisition and variable-rate application (Goering, 1992). Without this information an accurate prescription of inputs cannot be applied, therefore nullifying the effectiveness of a SSCM program. According to Auernhammer and Muhr (1991), for agricultural production to move from uniform to space dependent applications, a simple, safe, readily available, and inexpensive position detection system for agricultural machines will have to be utilized.

Accurate positioning can be achieved by several methods such as dead reckoning, microwave radio-location, and the global positioning system (GPS) (Auernhammer and Muhr, 1991; Bae et al., 1987; Clark and McGuckin, 1996). GPS is the most commonly used system in site-specific agricultural applications. The Navstar Global Positioning System is a satellite-based radio navigation system developed and operated by the U.S. Department of Defense (Harrison et al., 1992).

GPS relies on signals from 24 satellites that are orbiting 11,000 miles above the surface of the earth in a non-geosynchronous orbit. GPS is based on satellite trilateration. This implies that GPS receivers must locate and communicate with at least three satellites to determine positions. GPS receivers collect signals transmitted from satellites. Distance from the satellite is then calculated by determining the time lag between the time the signal was sent from the satellite and captured by the receiver. By determining the distance to each satellite an accurate measurement of position can be obtained. To be able to calculate the elevation of a position a fourth satellite is required.

Communication between GPS receivers and satellites is in the form of a pseudo-random code. By using this type of communication GPS receivers can clearly recognize faint signals. Another reason for the pseudo-random code is that it allows the Department of Defense the ability to control access to the system. There are two types of this code, the C/A code and the P code. The P code can be encrypted so only the military can use the satellites and the C/A code is for civilian use. The C/A code is controlled by a method called Selective Availability (S/A). This is the process of introducing clock and satellite position errors to give a false indication of the distance to the satellite. Differential correction techniques can correct for the error introduced by S/A. This is the process of collecting data for a known geo-referenced point, calculating the error, and correcting subsequent measurements from that information (Hurn, 1989).

Differential correction requires the use of two receivers. One receiver is considered the reference or base station. It is placed on a established reference point and data is collected from the satellites to determine a position. Collected positions are then compared to the coordinates of the reference point. This allows a correction factor to be calculated and applied to roving GPS receivers that are being used at the same time in that area (Harrison et al., 1992). Positional data for site-specific applications can be either corrected by post-processing or in real-time. Post processing involves the use of computer assisted data filtering and smoothing routines to fit the correction factor calculated by the base station to the data collected by the roving units (Harrison et al., 1992). Real-time correction is accomplished by a rover unit receiving correction signals from the base station while it is collecting data from the satellites. Communication between the rover receiver and the base station are signals sent via VHF-FM radio waves (Harrison et al., 1992). All historic data collection used in SSCM can use post-processing. However, real-time correction must be used when applying materials using variable-rate technology (Auernhammer et al., 1994). Accurate positions must be instantaneously known to determine desired application rates.

Soil Sampling. According to Wollenhaupt and Wolonski (1994), grid soil sampling is the simplest way to be introduced to an SSCM program. Traditional soil sampling procedures consist of extracting several soil samples from a field and bulking them together to obtain an average analysis of the nutrient status of a field. This is an effective method of sampling if the chemical properties of the soil throughout the field are uniform. However the fact is that all soils are naturally variable. Their chemical and physical properties change horizontally across the landscape and vertically down the profile (Carter, 1993). Grid sampling allows the producer to divide a field into smaller areas to identify the variability of the soil properties and make applications of nutrients according to individual soil needs.

It is crucial for a soil testing program to identify areas of nutrient deficiency and excess (Sawyer, 1994). Wollenhaupt et al.(1994) defines the goal of soil sampling for variable-rate applications to be the ability to document the soil test variability within a field, instead of defining the median soil test value. Fixen (1994) states that grid soil sampling is the key that unlocks the hidden yield potential of a field. An extensive soil sampling program is critical when developing variable-rate application maps (Feetz, 1994). Many dealers are offering services for soil sampling on a grid basis to help producers establish a variable-rate fertilization program.

There are many differing opinions on what cell size should be used when gridding a field. Recommended cell sizes range from 0.025 - 2.5 acres (Bullock et al., 1994; Feetz, 1994; Goering and Han, 1993). Peitscher (1992) suggest that cell size not exceed 20 meters when testing for nitrate distribution. He also suggests that for all factors other than nitrate a 50-meter grid should be used. Recommendations made by Feetz (1994) propose that samples should be taken from one-acre grids unless the field has a history of high soil tests and applications of fertilizers that exceed crop removal of nutrients. If the latter is true, sampling should be done on two-acre grids (Feetz, 1994). Other research suggests that samples should be taken on a 220-foot grid unless variability is high, and then a smaller grid should be used. If variability is minimal, a larger grid may be used (Franzen and Peck, 1995). Restrictions remain in grid size selection no matter what grid is to be used. Upper bounds of cell size are agronomic, such as landscape and soil type. Lower bounds are restricted to mechanical ability and accuracy, such as harvester and applicator width and GPS resolution (Han et al., 1994; Schueller and Wang, 1994).

Along with cell size selection, there are differing opinions on which is the best method of extracting samples within the grid. The three methods that are most commonly used are grid-cell, grid-point, and feature sampling. Grid-point sampling entails compositing samples taken from a chosen area around the intersection of grid lines. For example, samples would be extracted within a twenty foot radius of the intersection of the grid lines. Grid-cell sampling involves pulling samples randomly within the cell area and combining them to obtain an average for the entire cell. Feature sampling depends on the incorporation of field information to determine where samples should be taken. With feature sampling, there is not a defined grid in which to extract from. Topography, soil type, water patterns, and prior cultural practices determine the sampling design. The benefit of feature sampling is that a more directed approach is taken, allowing fewer samples to reflect the soil characteristics more accurately (NESPAL, 1995).

Variable-rate Technology. With the results of an extensive soil sampling and yield monitoring program a variable-rate application map can be constructed. Variable-rate technology (VRT) consists of applying fertilizers and chemicals to fields based on past yields and other site-specific data to ensure that they are used as efficiently as possible, and maximum crop production efficiency is obtained (Klemme et al., 1992). It is emphasized that excess inputs should be avoided. The goal of VRT is reaching optimum yields with precision applications of inputs. If only what is needed is applied, environmental problems, decreased yields, and substandard crop quality that may be attributed to over application of inputs are minimized (Hilde, 1994; Wallace, 1994).

VRT relies on the use of controllers to vary the application rates of inputs. In a simple form the operator may act as the controller and manually adjust the rate of application during field operations. Controller accuracy is very crucial when applying inputs at varying rates. Location determination is also critical to be able to apply inputs according to crop or soil requirements. Results from a test conducted by Schueller and Wang (1994) suggest that if variable-rate field operations are not carried out with a high degree of accuracy, the placement of fertilizers and chemicals are no better than broadcast rates. Soil tests of fields may reveal many levels of variability. Controller accuracy may be limited in the ability of treating every change in a fields characteristics, therefore similar levels should be grouped together to allow the controller accuracy to be acceptable (McCauley and Whittaker, 1993).

There are two different approaches to VRT, real-time sensing and application by means of computer generated control maps. Real-time sensors include soil organic matter sensors, nitrate sensors, weed sensors, and others. Control maps are generated from field histories or from crop scouting reports. Researchers in Georgia conducted a herbicide application test using real-time sensors and computer controlled maps. Results from their tests indicated that weed control was acceptable in both situations. Reported herbicide savings for the real-time sensor and the computer controlled maps were 86 and 70 percent respectively (NESPAL, 1995). McGrath and Leedahl (1990) executed a test using a soil organic matter sensor to match the rate of application of herbicides to the soil organic matter. Results indicated excellent weed control at all test sites.

Researchers and farmers are evaluating the concept of varying fertilizer rates within fields because of concerns associated with water quality and narrow profit margins (Wollenhaupt et al., 1994). Wallace (1994) stated that being 100 percent efficient in the uptake of nitrogen by plants is necessary to avoid environmental problems. Merideth (1996) reported that the most misused agronomic input in the Mississippi Delta is nitrogen (N). Over application nitrogen is typical, and that results in excessive cotton growth and nitrate leaching into the groundwater along with other problems.

Data Analysis. Effective management of information is the key to the success of SSCM (Smith, 1996). To manage the data, a procedure has to be used that will store and organize spatial information so that it can be displayed for analysis by operators and consultants. A system of this type is called a Geographic Information System (GIS). Geographic Information Systems are computer programs that provide a means of graphically presenting, analyzing, and interpreting data, as well as linking management information and records to specific points within a field (Feetz, 1994).

Geographic Information Systems have been developed to handle applications of spatial information (Han and Goering, 1992). True GISs rely on two main factors for analyzing data, spatial operations and data linkage. Spreadsheet and statistical programs can handle simple geographic or spatial data manipulation. However, only GIS packages can perform spatial operations and data linkage. Spatial operations involve combining geographic locations with data to answer specific questions about those locations. Data linkage allows a GIS to link data according to a geographic position. Therefore many different types of data can be combined to create map layers (ESRI, 1995).

Benefits of SSCM

Precision agriculture has improved to the point to where individuals involved in the agricultural industry (growers, industry, universities, and governmental agencies) have the opportunity to help implement a more efficient system of crop production while improving environmental stewardship (Vanden Heuvel, 1996). Probably the growers are the most obvious recipients of the benefits of SSCM. The public will benefit from increased crop production efficiency, which translates into lower food and fiber prices as well as reduced environmental pressure. Production efficiency from SSCM can mean a rise in the economic return, or the reduction of environmental loading as a result of decreasing amounts of pesticides and fertilizers used in production (Vansichen and De Baerdemaeker, 1993).

Incorporation of a yield monitoring program provides the grower with a better perception of where variability lies within fields and the economic impact of the variability. Yield maps may be used both for the determination of input management programs and to evaluate results of previous management strategies (Birrell et al., 1996).

Positioning systems used in conjunction with yield monitors and soil sampling rigs allow producers the ability to obtain accurate locations of the variability within the field. With this information further investigation can be conducted to determine the cause of the variability and allow corrective procedures to be employed. Positioning systems also allow better control of application procedures such as reducing skip and overlap control during applications of inputs (Larson et al., 1991).

Incorporation of grid soil sampling into a SSCM program gives the producer a better indication of the fertility level and the extent of variation within fields (Wibawa et al., 1993). Studies reported by McGraw (1994) state that grid sampling of 50 random fields showed economic gains in 48 fields ranging from 2 to 4 dollars per acre. Net returns above soil testing and variable-rate spreading of the 48 fields averaged between 10 and 20 dollars per acre. Hilde (1994) reported that by reducing the nitrogen variability in sugar beet fields, beet quality drastically increased. These improvements were rewarded by increased beet quality payments.

Variable-rate technology presents the most benefits of a SSCM program. Advantages of VRT are both economical and environmental. When fertilizer levels are matched to crop requirements, plants are more likely to use the fertilizer during the growing season, thus reducing the chance for the fertilizers, especially nitrates, to leach into groundwater or surface water (Goering and Han, 1993).

SSCM holds the greatest potential for reducing seed and fertilizer requirements than for increasing crop yields for given amounts of seed and fertilizer (Goering and Han, 1993). Growers benefit from VRT through greater profits and improved efficiency of all inputs (Fixen, 1994). Higher yield from areas that were under fertilized and reduced inputs from the areas that were over fertilized translates into more profits for the producer (Fixen, 1994). Schueller (1992) reported increased returns ranging from 10 to 40 dollars per acre from spatially variable fertilization. Auernhammer and Muhr (1991) noted that spatially variable herbicide applications could reduce chemical costs from 60 to 70 percent. A grower in Indiana reported increases in yield due to variable-rate seeding of corn in 1994 and 1995 of 2 to 14 and 2 to 8 bushels per acre respectively (Gibbons, 1995).

SSCM has the capacity to improve input efficiency, field profitability, and environmental stewardship (Sawyer, 1994). These improvements will foster implementation of this technology. However, it must be remembered that technology will never be a substitute for sound agronomic judgement (Vanden Heuvel, 1996).

Obstacles

As with any new methodology, SSCM will not likely make the transition into traditional practices without drawbacks. Not all growers will readily accept changing production practices (Buckley et al., 1996). A marketing research firm in California conducted a study on how producers are likely to proceed into SSCM programs. Farmers were grouped into five different categories according to their willingness to accept the new technology, innovators, trend setters, trend watchers, low-risk takers, and no-risk takers. Innovators are defined as producers that are the first to experiment with new technology and move directly into the adoption stage. Trend setters are growers that are likely to be on the cutting edge of technology, although their approach is more conservative. Trend watchers are more likely to observe the experiences of the innovators and the trend setters before adopting new practices. Low-risk takers are not going to accept practices until the risk is minimal and improvements have been confirmed by others. The last group is the no-risk takers. This is the group that will never adopt new technology due to factors such as retirement or stubbornness. Innovators and no-risk takers make up 5 percent of the population each, trend setters claim 15 percent, 35 percent are the trend watcher, and the bulk, 40 percent are the low-risk takers (Buckley et al., 1996).

Increased profits are likely to be the factor that convinces producers to adopt SSCM, although profits are not increased in every case. Wibawa et al. (1993) reported that yields were increased due to varying the amounts of nutrients by soil needs, but the increased cost of grid soil sampling resulted in less net return than conventional methods of fertilization and soil sampling. Sawyer (1994) notes that if within field variation of factors that influence yield is minimal or nonexistent, the economic return to SSCM will be negative. Factors that limit the effectiveness of a SSCM program are the cost of implementation, lack of expected increase in crop yield, and the lack of input savings (Sawyer, 1994).

Another factor that may impede the introduction of site-specific operations is the fact that university research programs have shifted from production agriculture to more environmentally oriented ones (Vanden Heuvel, 1996). Also, because of the advancement in technology there is an increasing need for professional agronomists to interpret the masses of data that will be collected (Vanden Heuvel, 1996). Spatially-variable control can not be effective unless good management practices (IPM, MEY, etc.) are already in place (Schueller, 1996) and producers make the commitment to begin detailed monitoring and record keeping procedures to build a farm data base (Feetz, 1994). Although producers may be hesitant to engage in site-specific practices, the day may come when environmental restrictions require SSCM in order to comply with governmental regulations (Schueller, 1995).

Spatial Variability Within Fields

All fields are not the same. This is common knowledge among researchers and producers alike. In the past assumptions, have been made that single fields are homogeneous to simplify management decisions. With new technologies, decisions are not easier to make, just some of the guess work has been removed. If it were feasible, fields could be managed by the square inch with the new equipment available. This could possibly increase yields, although at the present time it is not necessary. In the future, as land becomes more scarce and the demand for food and fiber increases, higher levels of precision may be needed to accommodate public needs. For now, producers need to identify areas of spatial variability within their fields and make management decisions based on benefits that could be generated.

Spatial variability is present in almost every field, whether it be related to soil structure or weed infestations. It is the role of site-specific production to minimize the effects of the variation on profits generated from crop production. Chung et al. (1995) states that farming operations have a significant effect on the spatial variability of soils. Long term cropping and soil management practices tend to change the pattern and spatial structure of soil properties (Chung et al. 1995).

Yield Variability

Yield monitoring allows farmers to measure and document yield variation that exists within their fields. Yields can be affected by a number of factors including but not limited to soil compaction, weed pressures, and low fertility. Yield variability has been documented in many crops. Researchers at the National Environmentally Sound Production Agriculture Laboratory (NESPAL) in Georgia have conducted yield variability mapping on: corn, cotton, wheat, soybeans, canola, peanuts, and oats (NESPAL, 1995). Variation in yields have also been documented on sugar beets, potatoes, green beans, and other crops (Hilde, 1994; Hollist et al., 1996; ,Schneiter, 1995).

Dean Pennington, now a researcher at Mississippi's Delta Branch Experiment Station, began documenting the yield variability in alfalfa fields in Arizona in the early 1980's (Kepple, 1988). He also was a leader in determining yield variability in cotton fields. In a test conducted in 1988, Pennington reported that cotton yields varied from 900 to 1900 pounds of lint per acre within a single field with the field average being no more than half of the maximum yield. According to Pennington (1988) non-uniform soils caused this spatial yield variability. He states that yield at any location in the field is a function of the integration of the environment at that location with the genetic potential of the plant (Pennington, 1988).

Soil Variability

Uehara et al.(1984) states that it is the inability of producers to deal with the spatial variability that prevents them from accurately predicting soil performance and behavior. Soil variability within a field is considered the root of many other sources of variability and directly influences limitations of nutrient availability, water supply, and physical rooting conditions (Kvien et al., 1995). Research plots are intended to eliminate the variability, therefore allowing a good representation of how the treatment will affect the performance of the test specimen. Variability of the soil tends to increase with field size (McGraw, 1994; Schueller, 1992), therefore plot sizes are generally small. This is the justification that treatments often react much differently when they are applied to production fields. A study conducted by Kachanoski and Fairchild (1993) states that traditional plot sizes may not be as valid as once thought due to the soil variability within the plot.

The effect of soil variability is most noticeable through excesses and deficiencies of water and nutrients which affect crop yield (Pennington, 1988). Referring to research conducted by Scheitzer (1980), Carr et al. (1991) stated that differing fertility levels between soils in some fields were largely to blame for crop yield variability. Many factors of the soil structure and chemistry can cause yield variability throughout a field such as, water holding capacity and nutrient level. McGraw (1994) concluded that previous land uses, such as building sites and areas near barns, that received heavy applications of manure, generally test very high in nutrients. These areas tend to skew soil test averages for a field which result in fertilizer recommendations being lower than what is actually needed for optimum yields. Wibawa et al.(1993) summarizes the constraints of managing soil variability by understanding fertility variation within and among soil map units in a field, quantifying and estimating the productivity of soil map units, and defining practical management units in a field.

Oosterhuis et al.(1991) observed variability in the surface soils of a cotton field, but stated that the primary differences were in the subsoil. Results of their study revealed that surface soils varied in clay content 2 to 8 percent, and subsurface soils varied 1 to 65 percent clay. Oosterhuis et al.(1991) also noted that cotton growth tended to improve in areas with higher subsurface clay content. It was further noticed that these areas also had a higher soil nutrient status.

Chung et al.(1995) conducted a study on sampling strategies for determining the fertility of a soil. Variations of phosphorus (P), potassium (K), and organic matter (O.M.) were observed to be higher in the subsurface (20-40 cm) soils than in the surface (0-20 cm) soils. The reverse was evident for soil pH. Bulk density for both depths studied was consistent throughout the soil profile. Soil P was the most variable of the soil properties tested. The authors suggest that the best sampling strategy is to sample intensively in the direction perpendicular to the normal cropping direction. It is proposed that sampling in this manner gives unbiased estimates of the mean values of soil properties.

Soil type variations affect crop performance and the amount of nutrients removed from an area in the field (Bullock et al., 1994). Sawyer (1994) summarizes several studies by concluding that in some cases considerable yield diversification occurs within soil types, as much as across soil types. Colvin et al. (1991) reported that, based solely on the overlap of the one standard deviation error, it is clear that each soil type does not produce characteristic crop yields. A study conducted by McGraw (1994), surveyed 392 fields in southern Minnesota ranging in size from 35 to over 150 acres. Results indicated that larger fields, which had a diverse history of past farming practices, generally included a wider variety of soil types.

Beckett and Webster (1971) determined that the coefficient of variation of soil organic matter (SOM) tended to increase with the increased distance between samples, concluding that SOM is spatially correlated. Sudduth et al.(1991) states that SOM in the Midwestern Corn Belt can vary considerably within field soil map units, but levels do not fluctuate over small distances. Alsip and Ellingson (1991) reported a variation SOM variation from 2 to above 4.5 percent in a 20-acre Minnesota field.

Soil organic matter is directly proportional to pesticide adsorption (McGrath and Leedahl, 1990). Herbicide requirements increase with SOM (Goering, 1992), therefore given that SOM is likely to be variable within fields, determining a single herbicide rate would be difficult. Adjusting herbicide rates based on SOM can be justified by preventing over or under application causing environmental loading, poor weed control, unnecessary expense, and damage to subsequent crops (Brubaker et al., 1994).

CHAPTER 3

METHODS AND MATERIALS

Yield Measurement System

The ability to measure yield variation within the test area was an integral part of the experiment. Thus a yield monitoring system was designed and constructed to measure cotton yield variability in real-time. The yield monitoring system was installed on a Case International 2155 4-row cotton picker. In conjunction with the yield monitoring system, GPS was used to determine the location of the picker as it traveled through the field. This allowed geo-referenced positions to be matched with cotton flow rates, thus forming the data set needed to produce yield maps.

The monitoring system had to meet the following design criteria: (1) accurately measure and record yields in real-time over a finite distance (10 to 15 feet of row), (2) interface yield data collection with positioning data, (3) install inside the harvester transport basket without greatly hindering normal operation, and (4) minimize measurement errors due to field dynamics. To fulfill these criteria an instrumented weigh basket was designed to collect and weigh cotton as it accumulates in the harvester's cotton transport basket.

Design and Fabrication of Weighing Basket

Preliminary tests were conducted during the 1995 harvest season with a prototype weighing basket. Overall dimensions were 8 feet long, 8 feet wide and, 4 feet tall and with a capacity of 256 cubic feet. The unit was constructed from expanded metal, tubular steel, and sheet metal. The empty basket weighed approximately 700 pounds. The unit was suspended from four 1000 pound tension load cells, one at each corner, from two inch square tube beams running the length of the picker basket. Lateral movement of the basket was minimized by the addition of two, four bar linkage systems, that allowed free movement in the vertical plane while restricting movement in the horizontal plane. The basket unloaded using a center hinged folding floor. The floor was raised by two cables operated by a electric (12-volt DC) winch and a series of pulleys. The design was intended to allow cotton to fall out of the basket through the opening between the floor and the walls of the basket and onto the unloading conveyer chains.

Instrumentation for Yield Monitoring System

A Campbell Scientific 21X datalogger was used to record real-time signals from each of the four 1000 pound load cells. Outputs from each of the load cells were sampled every 0.1 second and integrated over one second. Per second averages from each load cell were summed to obtain a total basket weight and transmitted serially (RS-232) every second to a laptop computer (see Appendix B1 for program). A program executed by the laptop computer paired each basket weight value with the time of day. These times were recorded to enable synchronization of weight and field positions (see Appendix B2 for program).

Two survey grade GPS receivers were used to record position data for the yield monitoring system. One receiver, a Trimble 4000DL-II/IIR, was used as the rover unit on the picker. The other receiver, a Trimble 4000RL-II/IIR, collected stationary data from a known reference position and transmitted real-time correction signals to the rover unit.

Communication between the receivers was accomplished by way of two Trimble Trimtalk modems that transmitted signals via FM radio waves. This allowed real-time corrections of positions to be performed. Corrected positional data was then transmitted from the rover unit to the laptop computer through a serial link. Again, the time of day was recorded with each position value to allow data synchronization. Weight data and position data were stored in separate files on the laptop computer's hard drive in ASCII format. Figure 1 is a flow chart of the instrumentation used on the yield monitoring system.

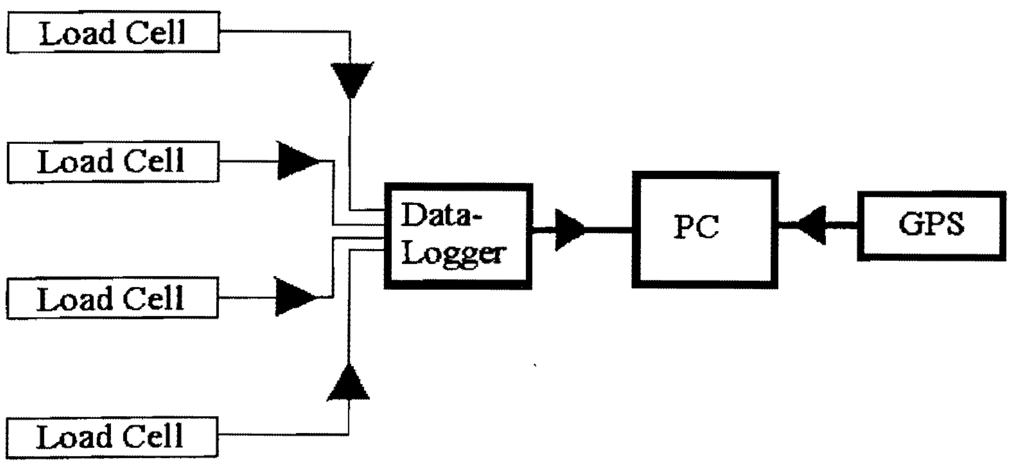


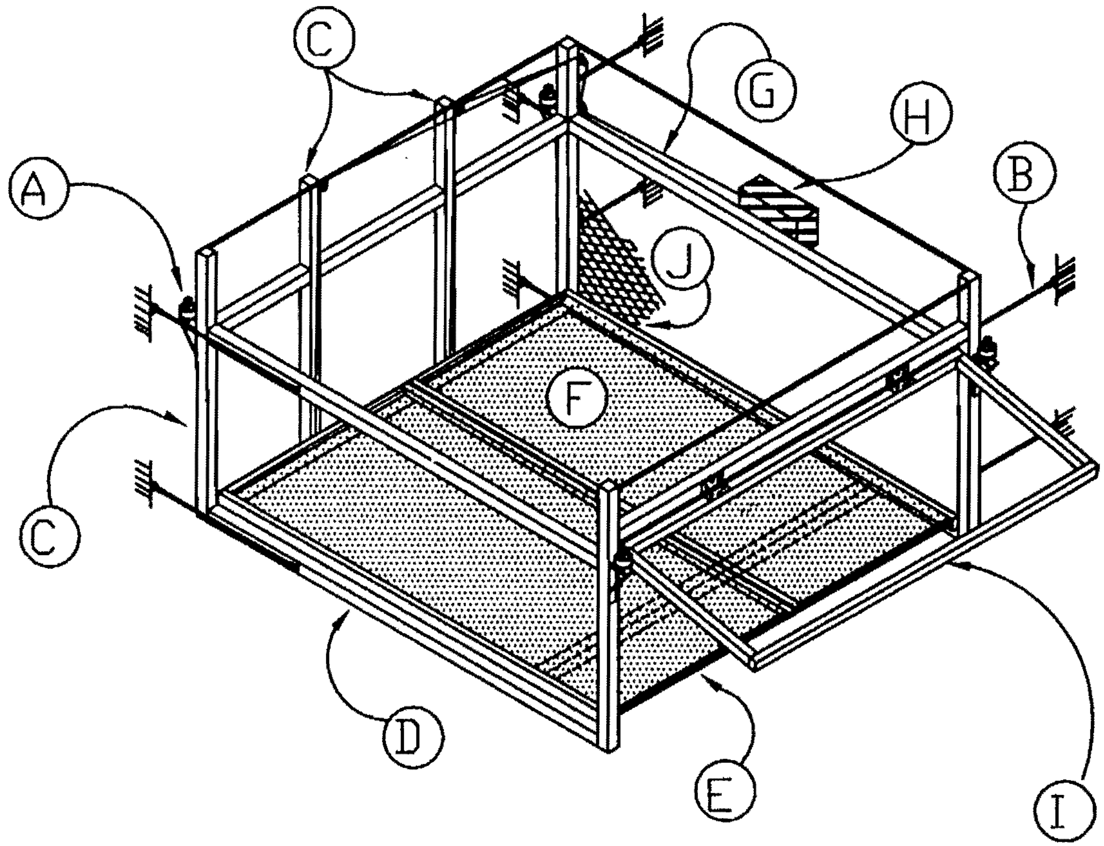
Figure 1. Flowchart illustrating the instrumentation of the yield monitoring system.

Evaluation of 1995 Design

Approximately 20 acres of cotton were yield mapped with this prototype system during the 1995 harvest season. The design proved to be effective in generating data but had several faults. One problem encountered with the prototype unit was that the harvester conveyor fans that blow cotton from the picker heads through the conveyer chutes to the transport basket produced a large volume of air. This resulted in a cyclone effect occurring inside the weighing basket and caused some cotton to be blown out of the unit. Thus, deflection shields were constructed and installed around the perimeter of the basket to control air paths and reduce the amount of cotton that escaped the basket. Another problem was that unloading the cotton from the basket was more difficult than expected. Cotton tended to clump together and bridge between the retracted floor and the basket wall inside the basket and would not fall to the unloading conveyer without manual assistance. Finally, full scale measurement resolution was reduced due to the empty basket weight being a large percentage of the total weighing system capacity.

Design Modifications to the Weighing Basket

To prepare for the 1996 harvest season, the weighing basket was redesigned with the principles of operation similar to the original prototype unit. The new basket was supported from four load cells (A in Figure 2) suspended from beams running the length of the picker, and the same four-bar linkage systems (B in Figure 2) were used to prevent movement in the horizontal plane. In order to reduce weight new construction materials were selected. These included unistrut channel for the framing and polycarbonate material



A = 1000 pound load cells

B = Four-bar linkage system

C = Structural upright

D = Structural cross member

E = Floor main frame

F = Polyethylene floor cover

G = Cables

H = 12 volt DC winch

I = Basket door

J = Expanded metal sides

Figure 1: Schematic drawing of the weighing basket used during the 1996 harvest season. (not to scale)

for the floor. Also a higher void ratio expanded metal was selected for the sides to allow air to exit the basket with less restriction.

Dimensions of the basket are 9 feet long, 10 feet wide, and 5½ feet tall. Structural frame members (C and D in Figure 2) including the cross members and the uprights of the main frame are constructed from 12 gage 1⅝-inch unistrut. Construction of the floor was in two different sections. This was to allow installing and removing the floor easier. The main frame of the floor (E in Figure 2) include two 10-foot sections of 14 gage, 2½ by 1¼-inch unistrut running the width of the basket. They were connected together on each end with a section of 14 gage, 1¼ by 1¼-inch channel. A sheet of $^{5}/_{16}$-inch twin wall polycarbonate was used to cover the floor frame (F in Figure 2). Two pieces of 1-inch square tubing were bolted to the ends of the floor panels linking them together. The entire perimeter of the basket was covered with flattened ¾-inch expanded metal (J in Figure 2). Volumetric capacity of the new basket was 495 cubic feet, 52 percent greater than the previous design. The new basket weight (700 pounds) was about the same as the old basket.

With the new design cotton was blown directly into the weighing basket (Figure 3), this eliminating the need for deflecting shields around the basket perimeter. The new basket unloaded via a tilting floor (Figure 4). Cables (G in Figure 2) driven by a winch (H in Figure 2) lifted the interior edge of the floor and the exterior corners moved in horizontal tracks. A hinged door (I in Figure 2) that lifted from the bottom and pivoted at the top was added on the unloading side of the basket. This allowed cotton to slide down the floor and out the door onto the unloading conveyers of the picker.

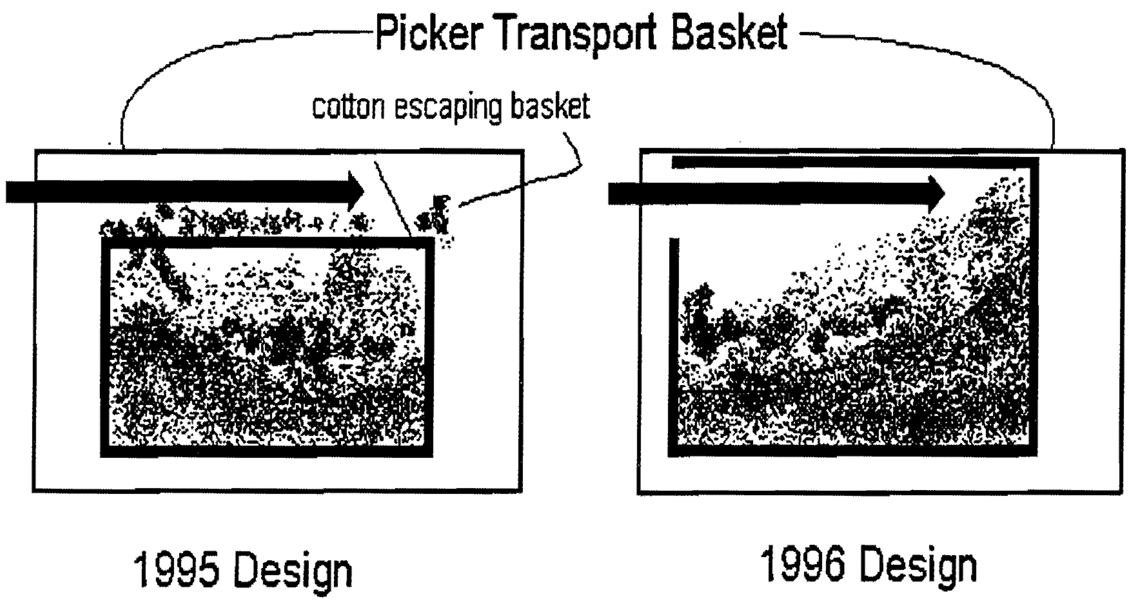


Figure 3. Illustration of different methods of cotton entering the weighing basket.

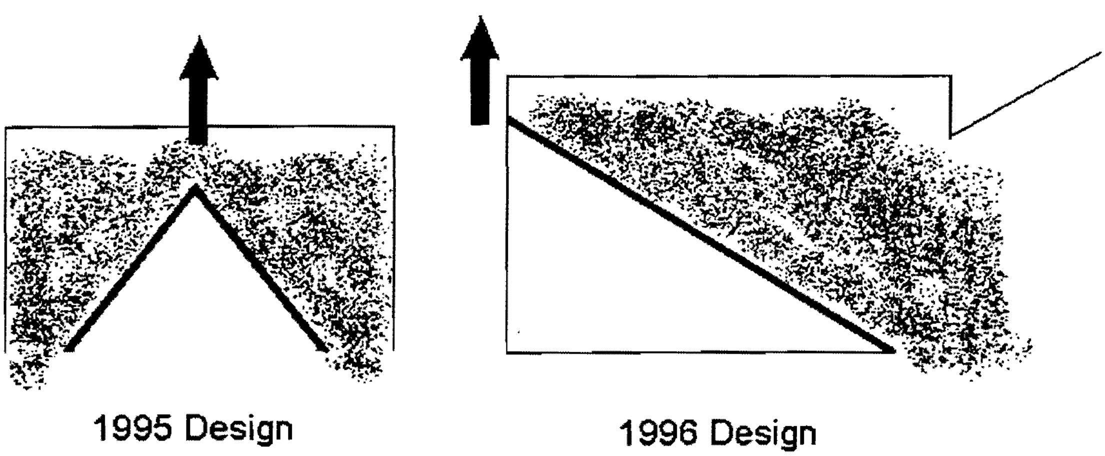


Figure 4. Sketch of basket unloading methods used for the years of 1995 and 1996.

Calibration

Preliminary testing of the basket was conducted in Knoxville before taking the unit to the field. Testing procedure consisted of placing a known weight inside the basket at different locations and comparing the given weight with the known. This test was performed to ensure that each load cell was operating properly and supporting the desired amount of the load. Periodically throughout the harvest season a similar test was performed to verify that the load cells were functioning properly.

Data Collection Protocol

Based on field experiences from the 1995 harvest season, a experimental protocal was developed. A systematic approach was used during field operation, to ensure that accurate data with,minimal errors was collected. A series of steps were followed each time the picker made a pass through the field. Protocol for test area harvesting consisted of:

- PDOP (position dilution of precision) was monitored on the GPS receiver before each pass to ensure a satisfactory satellite coverage (PDOP<4).
- GPS-weigh basket synchronization program was started on the laptop computer.
- Empty basket weight was noted.
- Picker fans were turned on and the engine was brought up to operating speed.
- Data was recorded for five seconds while the picker was stationary.
- The picker was brought to operating speed prior to entering test area.
- A constant travel speed of two miles per hour was maintained while picking.

- GPS time was recorded every time the picker crossed a mapping unit boundary.
- When the picker reached the end of the field it was stopped for five seconds with the fans on.
- Fans were turned off, allowed to stop turning, and a full basket weight was recorded.
- The data acquisition routine was stopped.
- Basket was unloaded.

Field Evaluation

Site Selection

In Tennessee cotton production is limited primarily to the western part of the state. Field research was conducted at The University of Tennessee Agricultural Experiment Station in Milan, Tennessee. This test was conducted within a small portion of a large 20 acre production field indentified as A-11.

Since 1993 this field had been in continuous no-till cotton. Fertilizer has been applied in the spring with a broadcast rate of 80-80-80 for the past two years. Lime was last applied in the spring of 1993 at a rate of 1000 pounds per acre. Cotton was no-till planted on existing rows on May 9, 1996. Row spacing was 30 inches. The Stoneville 132 variety was planted at a desired rate of 2.5 to 3 plants per foot of row.

Mapping Unit Layout

For this study a wide variation of factors that affect the yield was desired, such as varying soil types and soil fertility. A five-acre portion in the western part of A-11 on the Milan experiment station was chosen because of its varying soil types. The test area consisted of 112 rows measuring 780 feet in length. Each mapping unit constituted of an area 20 feet wide (8 rows) and 60 feet long, resulting in 182 total mapping units (see Figure 5). Centers of each mapping unit were flagged and later geo-referenced with a hand-held Trimble Pathfinder GPS receiver to be able to return to each individual mapping unit for evaluation later in the growing season. These dimensions were chosen to allow two passes through each mapping unit with a 4-row harvester allowing several yield data points within each mapping unit (one data point every second) to be obtained. This permitted a complete coverage of the field to be generated. There were no border rows

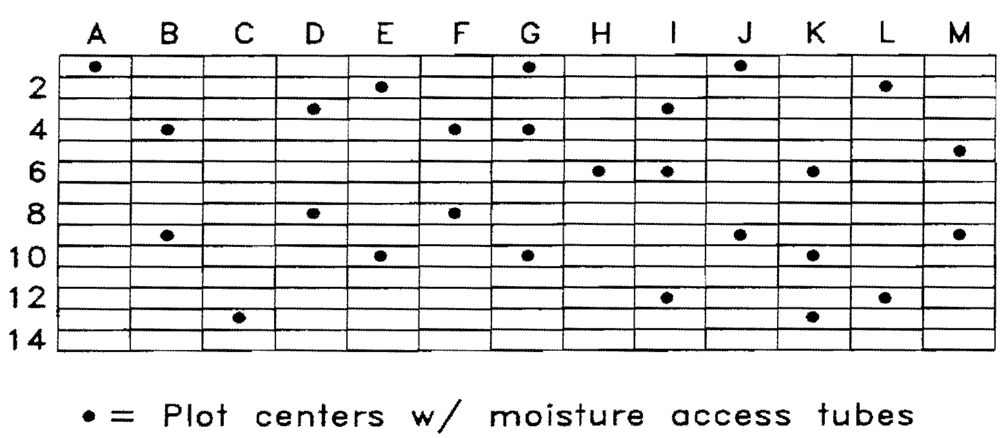


Figure 5. Schematic drawing of mapping unit layout and moisture tube locations within the test area.

between the mapping units which permitted continuous yield determination spatially within the test area.

Soil Survey and Classification

Soil types and depth to fragipan were mapped in the spring of 1996. Forty-seven soil cores were extracted within the mapping unit area and classified based on soil series and depth to fragipan. Each sampling location was geo-referenced with a hand held GPS receiver (see Figure 6).

Six different soil series were identified within the test area: Routon Silt Loam, Henry Silt Loam, Loring Silt Loam, Grenada Silt Loam, Calloway Silt Loam, and Memphis Silt Loam. A descriptive summary of each soil type identified is presented Table 1.

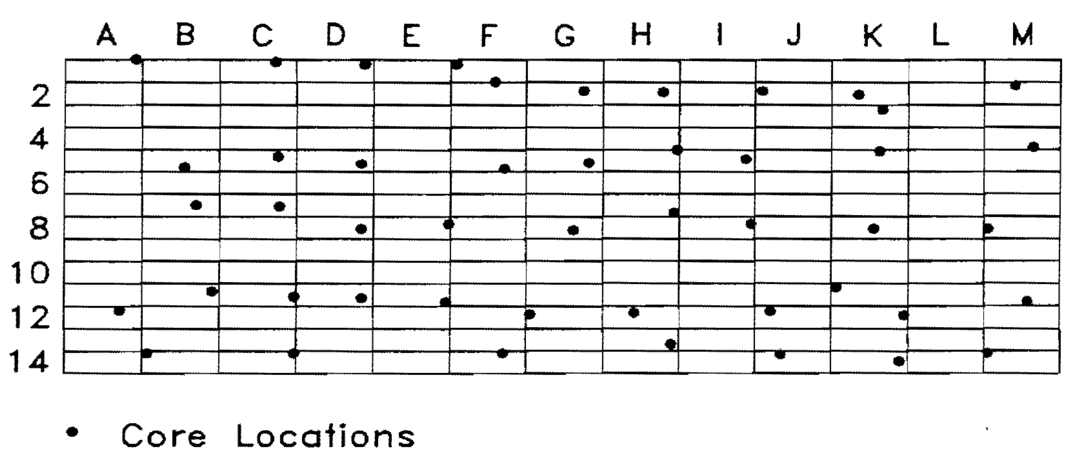


Figure 6. Locations of points in the test area where soil cores were extracted during soil classification.

Table 1. Soil types identified in the test area.

Symbol	Name	Descriptor	Taxonomic Class
CaB2	Calloway Silt Loam	1 to 3 percent slope	thermic Glossaquic Fragiudalf
GrB2	Grenada Silt Loam	2 to 5 percent slope, eroded	thermic Glossic Fragiudalf
Rt	Routon Silt Loam	0 to 3 percent slope	thermic Typic Epiaqualf
LoB2	Loring Silt Loam	2 to 5 percent slope, eroded	thermic Oxyaquic Fragiudalf
MeA	Memphis Silt Loam	0 to 2 percent slope	thermic Typic Hapludalf
HeA2	Henry Silt Loam	0 to 2 percent slope	thermic Typic Fragiaqualf

The Calloway series consists of somewhat poorly drained soils that formed in thick deposits of loess on upland and nearly level stream terraces. These soils have a fragipan and slopes in the 1 to 3 percent range. The solum of a Calloway soil is more than 60 inches thick, with fragipan depth ranging from 15 to 27 inches. In the upper part of the solum, the pH ranges from very strongly acidic to medium acidic and from strongly acidic to mildly alkaline in the lower part of the solum.

Grenada series soils are moderately well drained soils formed in deposits of loess on uplands and stream terraces. A fragipan is present in the Grenada series and slopes range from 2 to 5 percent. Grenada soil series are closely related to Loring, Calloway, and Providence soils. The solum of Grenada soil is more than 60 inches thick, depth of fragipan ranges from 17 to 35 inches. Ranges of pH throughout the soil profile are from very strongly acid to medium acid.

Loring series soils consist of moderately well drained soils that formed in deposits of loess on uplands, the slopes of these range from 2 to 20 percent with a fragipan present. Loring soils are geographically associated with Memphis, Calloway, Lexington, Grenada, and Providence soils. Thickness of the solum varies from 45 to more than 60 inches, with a depth to fragipan ranging from 14 to 30 inches. Acidity of Loring soils fluctuate from medium acid to very strongly acid throughout the soil profile.

Poorly drained soils formed from loess deposits in upland depressions and on stream terraces make up the Routon soil series. Slopes range from 0 to 3 percent. Routon soils are often associated geographically to Calloway, Center, and Grenada soils. Solum thickness extends from 45 to 60 inches. Values of acidity range from very strongly acid to slightly acid in the solum and from strongly acid to neutral in the C horizon.

Memphis soil series consist of well drained soils that formed in thick deposits of loess on uplands and terraces, with slopes varying from 0 to 8 percent. Loring, Grenada, and Lexington soil are geographically associated with the Memphis series. Solum thickness ranges from 35 to greater than 60 inches with friable properties present throughout the profile. Reaction (pH) ranges from medium acid to very strongly acid throughout the soil profile.

Henry soil series consist of deep, poorly drained soils that were formed from thick deposits of loess in depressions and nearly level areas on uplands and stream terraces. Slopes for this series range from 0 to 2 percent. Bonn, Foley, Routon, Calloway, Calhoun, and Grenada soils are associated geographically with the Henry series. Solum thickness ranges from 48 to 72 inches thick with a fragipan depth of 20 to 36 inches. Reaction throughout the upper part of the solum range from strongly acid to very strongly acid. (U.S. SCS soil survey, 1994)

Soil Nutrient Sampling

Soil samples were extracted from each mapping unit after fertilization and planting. Sampling protocol consisted of acquiring samples from the top six inches of soil within a 10-foot radius of the mapping unit center. Approximately eight samples were pulled from the existing rows and eight in the row middles and then composited to create one representative sample for each mapping unit.

Samples were analyzed at the Plant and Soil Science Soil Chemistry lab in Knoxville. Each sample was analyzed for phosphorus (P), potassium (K), magnesium (Mg), copper (Cu), zinc (Zn), water pH, and calcium chloride ($CaCl_2$) pH. All of the nutrient samples were analyzed using the Mehlichs III extraction procedure. Additional analyzation was performed by the Mehlichs I procedure for phosphorus and potassium.

Crop Scouting

During the growing season, mapping units were scouted for visual indications of nutrient deficiency or other signs of growth variability such as planter skips, insect damage, and mechanical damage from implements. Scouting consisted of physically walking through each mapping unit area and documenting any indication of growth variability. Locations of these areas were geo-referenced with a hand held GPS receiver.

Moisture Testing

Moisture measurements were taken throughout the growing season to account for the spatial and temporal variability of moisture movement in the soil. Because of time constraints, it was not feasible to obtain a moisture measurement from every mapping unit at frequent intervals, therefore 26 mapping units representing varying soil types and landscape positions were chosen to be monitored. A Troxler (Sentry 200-AP) non-contact soil moisture probe was used to perform the moisture measurements. Twenty-six polyvinyl chloride (PVC) access tubes were installed at the desired locations within the field following the procedure outlined in the Troxler manual (refer to Figure 7). Access tubes for the study were sections of 2.00 inch, schedule 40 PVC pipe cut to a length of four feet. Tubes were installed to a depth of approximately 42 inches. A PVC pipe test plug was added at the bottom of each access tube to prevent condensation and water from standing inside the tube when the water level in the soil was high.

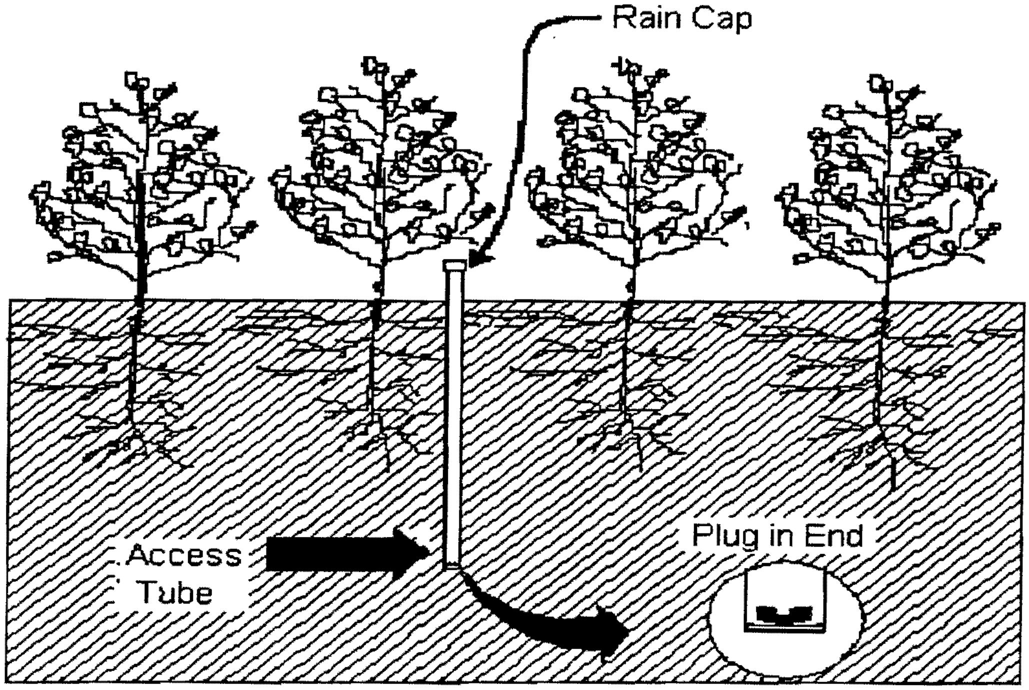


Figure 7. An illustration showing moisture access tube installation within the mapping unit area.

Moisture readings were taken on a seven-day cycle, with additional readings taken one day after rainfall events of at least one-half inch of rain. Measurements were always performed in the morning in a predetermined pattern through the field. This protocol was intended to prevent the data from being biased because of soils drying during the moisture measurement procedure (approximately 3 hours). Data were obtained at depths of 3, 9, 15, 21, 27, 33, and 39-inches. Readings were taken from these specific depths to ensure a representative sample of the moisture content of each six-inches of the soil profile.

Plant Population

Plant population counts were taken during the growing season. Stand counts were taken randomly throughout the field. Protocol for this process was to stretch a 10-foot tape along the first, third, fifth, and seventh row of each mapping unit and count the plants within the boundaries of the tape. These four counts were then averaged to obtain a mean number of plants per foot of row. Seventy of the 182 mapping units were measured.

Data Analysis

The GIS software used to manage and analyze the data collected for this project was ArcView Version 3.0 (ESRI). Kriged maps were generated using the graphical package, Surfer Version 5.01 (Golden Software, Inc.). Statistical analysis were performed using SAS for Windows Version 6.01 (SAS Institute Inc.). Additional data manipulation was performed using QuattroPro Version 6.0 (Novell, inc.), Excel Version 7.0a (Microsoft Corporation), and programs written in QBasic (Microsoft Corporation). Data obtained from the weighing basket had to go through a series of modifications before it could be used to generate accurate yield maps. One drawback of using the batch weighing method for yield mapping was that as cotton filled the basket less air could escape. Air pressure was assumed to increase linearly as the basket filled. To correct for this phenomenon, yield data files were imported into a spreadsheet and bias due to air pressure was removed. This was accomplished by calculating the general slope of the line and adjusting the data set to match the empty and full basket weights. The five second delays at the beginning and end of each pass through the field permitted this adjustment. With the errors due to air pressure removed, data was then averaged and smoothed using a five-second running average using the following equation.

$$\bar{X}_i = \sum_{n-2}^{n=2} \frac{x_i}{5}$$

This was performed by a program written in Qbasic (see Appendix B3).

Corrected yield data was then combined with GPS positional data with a separate program (see Appendix B4). The resulting data set was then combined with other spatial data including soil nutrient levels, soil type, soil pH, gin turnout, topographical, and plant population. The new data set was then imported into the GIS software package. Once in the GIS packages, the data was analyzed and maps were generated.

CHAPTER 4

RESULTS

Preliminary testing of the yield monitoring system began in 1995. Results obtained in 1995 proved that it is possible to yield map a production field in real-time using a weighing device. In 1995, a three to one yield variation existed in the same field that was mapped in 1996. Without a detailed soil nutrient and moisture testing regime, an accurate explanation of the factors that caused the variation was not possible.

Yield Monitoring System Performance

The yield monitoring system proved to be an effective method for yield mapping on a research scale basis. Eight to ten acres per day could be harvested using the monitoring system. Basket unloading problems similar to the ones encountered in 1995 still existed. Cotton tended to clump together and would not fall out of the basket as desired. Problems were overcome by an in field modification. A backstop was built to lay against the interior wall of the basket. Ropes were attached to the backstop, and were manually pulled to unload the basket. Although this procedure was more labor intensive, it proved to reduce the overall time for unloading by eliminating the need to raise the floor (i.e. slow winch drive).

Basket accuracy was measured by weighing loaded cotton trailers and comparing the recorded weights with those obtained during harvesting. Average error was 1.01

percent with a maximum error of 1.64 percent. Five trailer loads representing 55 basket loads of cotton were used in calculating the error.

Figure 8 graphically represents the output of the weigh basket during picking of one section of the test area (eight rows). Raw data (weight vs. time) collected during harvesting is represented by the upper line on the graph. Effects of air pressure on the basket can be observed by comparing the raw data with the corrected data, which is the lower line in the graph. Figure 9 illustrates changes in the mass flow rate of cotton as the picker harvested one section of the test area (eight rows). This graph displays how variable the yield was compared with the field average yield.

Yield maps were created based on output from the weighing basket combined with geo-referenced data from the GPS unit. Figure 10 shows the GPS point coverage obtained during harvest. GPS data and yield data were imported into a spreadsheet, combined, and exported into ArcView 3.0 and Surfer 5.01 to create a GIS database and surface maps of the field. Figures 11 through 13 are yield maps of first and second picking along with combined yield of the test area.

Field test results

Multiple regression analysis was run on collected data to determine the level of significance between each variable and total cotton yield. After data analysis, a great deal of variation within the field was observed, but less obvious which factors caused the variability.

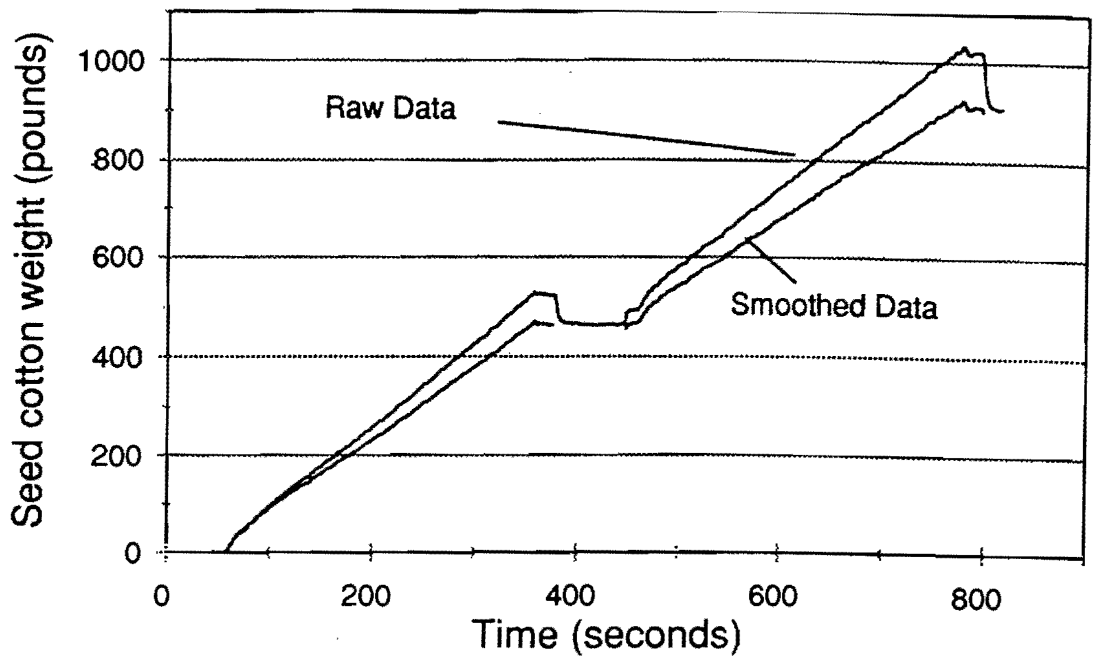


Figure 8. Graphical representation of the cumulative weight gain during harvest by the instrumented weighing basket.

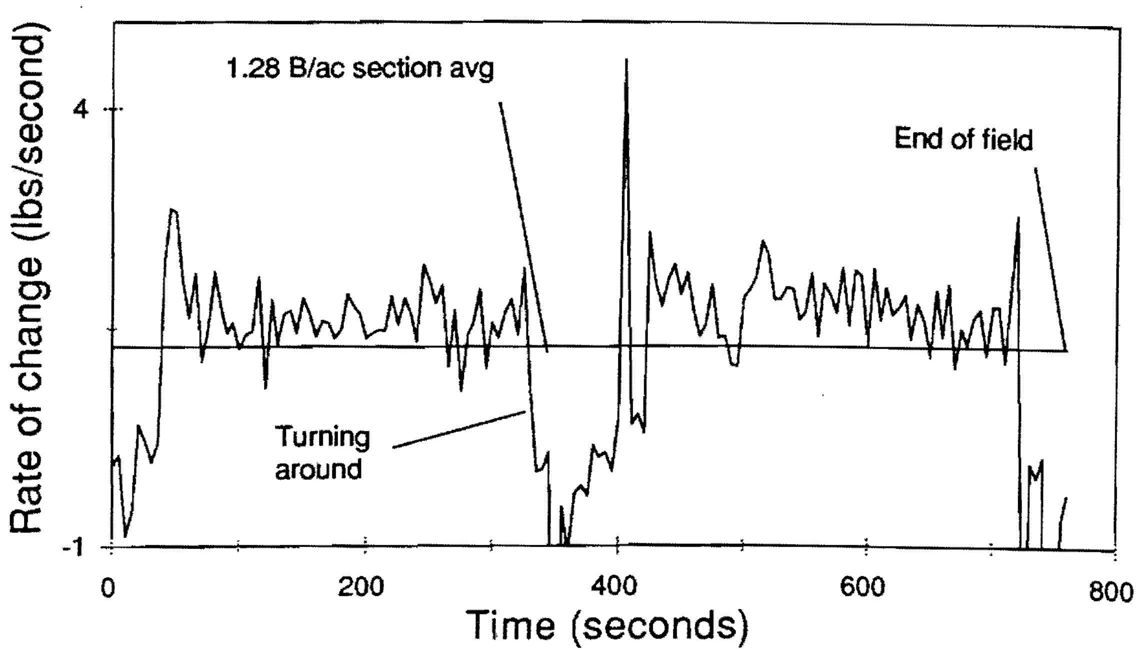


Figure 9. Mass flow rate of cotton as computed using data from weighing basket during harvest.

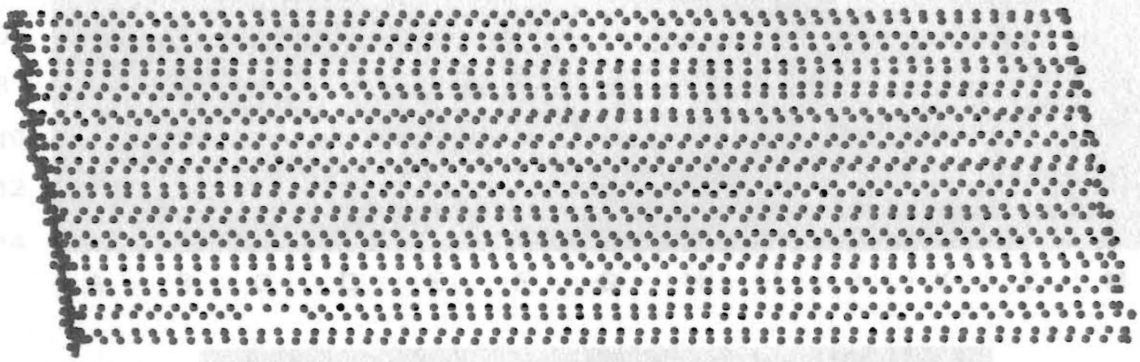


Figure 10. Point coverage of 1996 cotton yield.

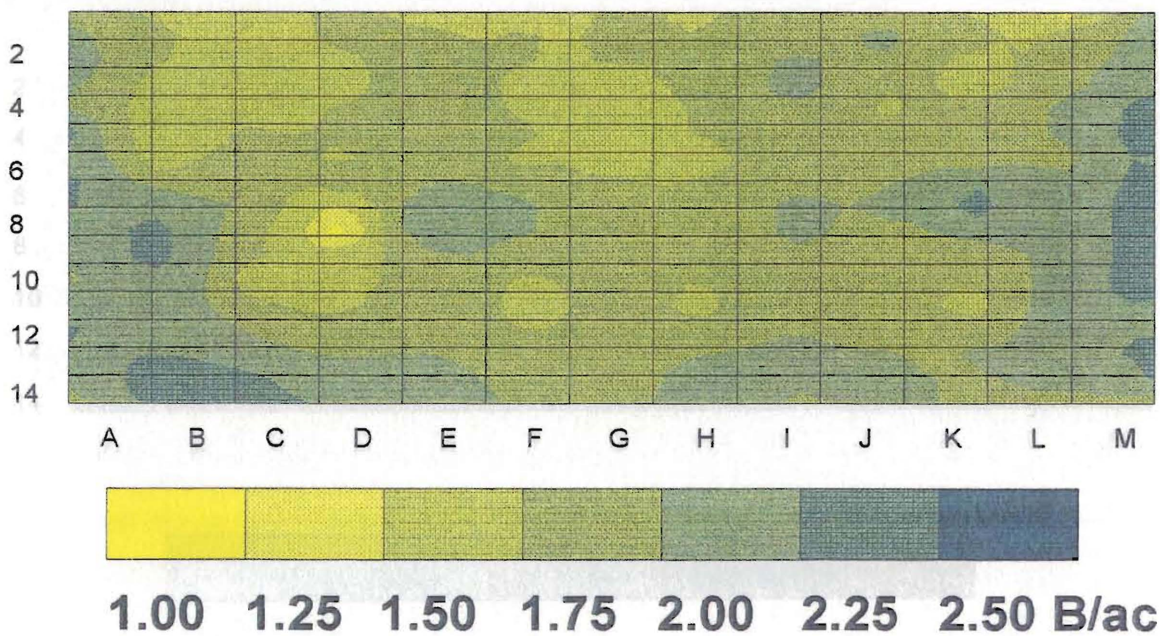


Figure 11. Yield map of the combined first and second picking yields from the test area during the 1996 harvest season.

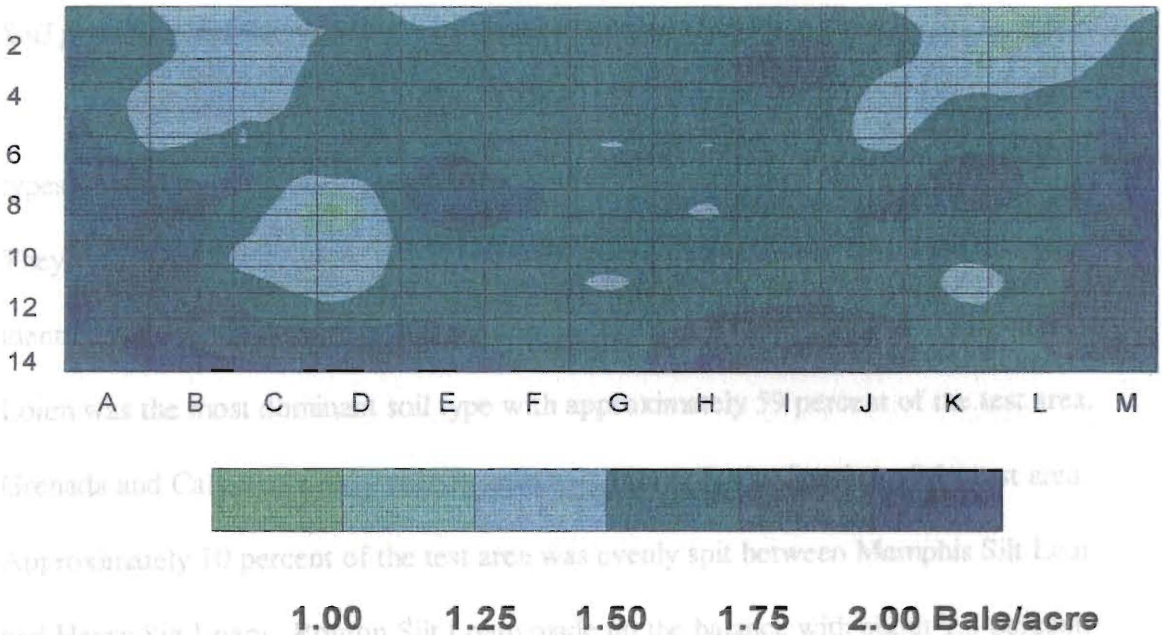


Figure 12. First picking yield map of the 1996 cotton yield in the test area.

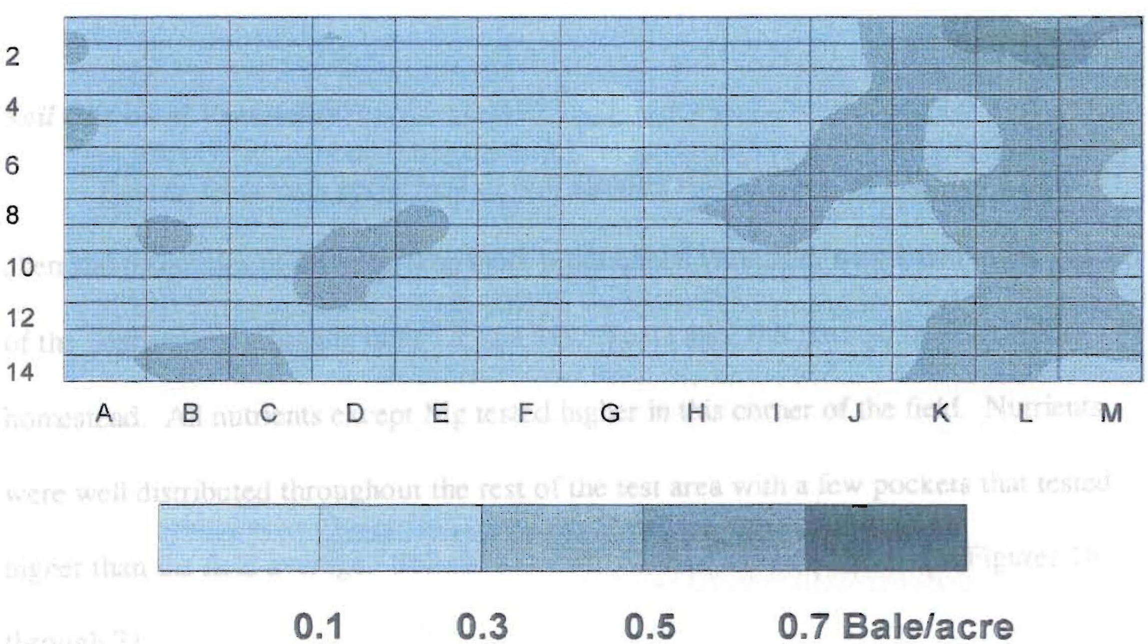


Figure 12. Second picking yield map of the 1996 cotton yield in the test area.

Soil physical variability

A wide range of soil physical variability was present within the test area. Two soil types were mapped in the test area by the U.S. SCS Soil Survey of Gibson County (1994). They were Loring Silt Loam and Routon Silt Loam. Six different soil types were identified in the five-acre field after detailed soil mapping (refer to Table 1). Loring Silt Loam was the most dominant soil type with approximately 59 percent of the test area. Grenada and Calloway Silt Loams constituted the next major fraction of the test area. Approximately 10 percent of the test area was evenly spit between Memphis Silt Loam and Henry Silt Loam. Routon Silt Loam made up the balance with about 1.5 percent. Depth to the fragipan ranged from 24 inches in the Grenada soils to 42 inches in the Loring soils. No fragipan was present in the Memphis soils. Figure 14 is a soil map of the test area along with corresponding soil types. Depth to fragipan is illustrated in Figure 15. See Appendix C for notes from soil survey.

Soil Chemical Variability

Results from tests performed on soil samples revealed a wide variation in the chemical properties of the soil. The most pronounced variability was found in the corner of the field around mapping units L1 and M1. Years ago, this part of the field was an old homestead. All nutrients except Mg tested higher in this corner of the field. Nutrients were well distributed throughout the rest of the test area with a few pockets that tested higher than the field average. Soil chemical distribution can be observed in Figures 16 through 21.

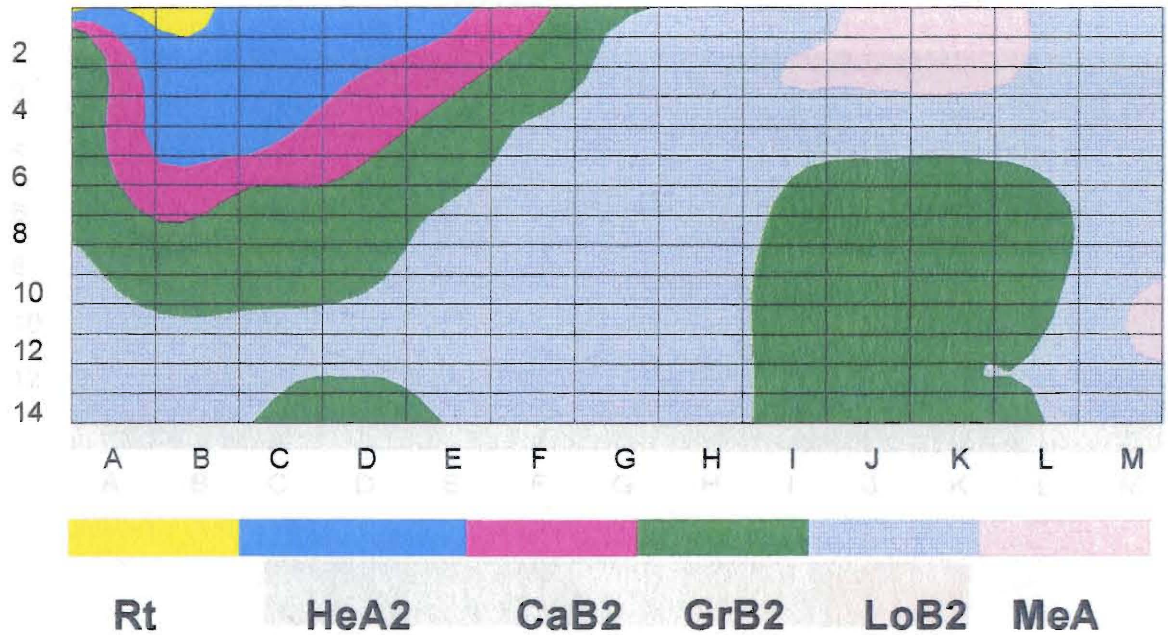


Figure 14. Soil type distribution within the test area.

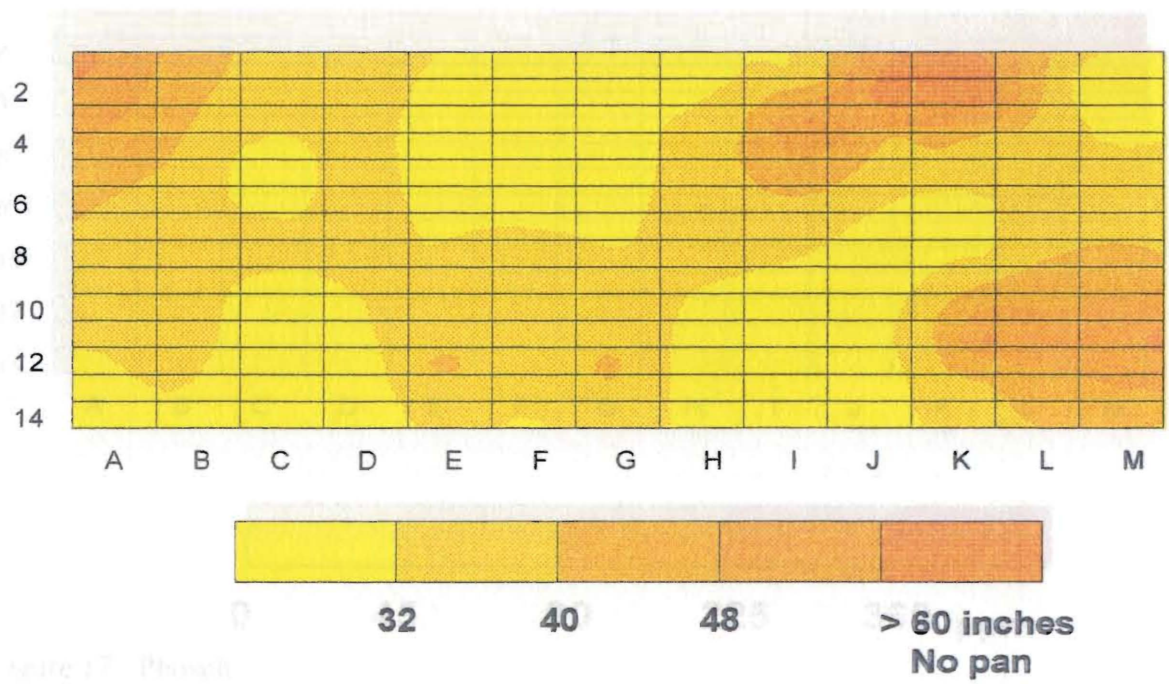


Figure 15. Depth to fragipan within the test area.

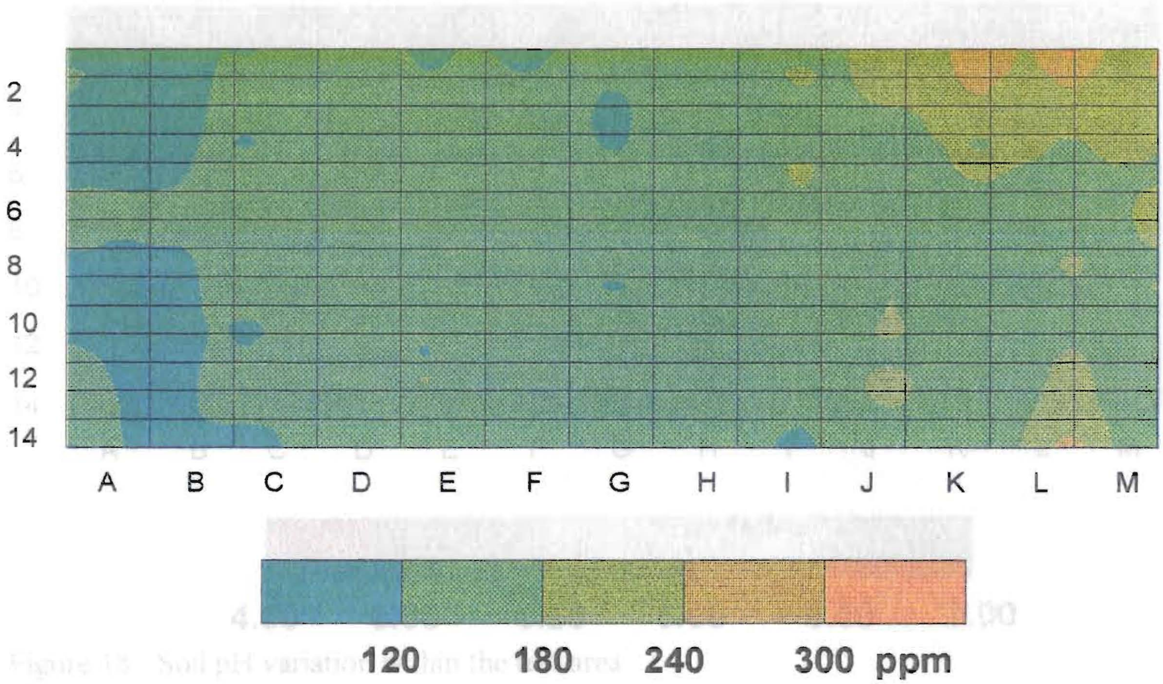


Figure 16. Potassium distribution within the test area.

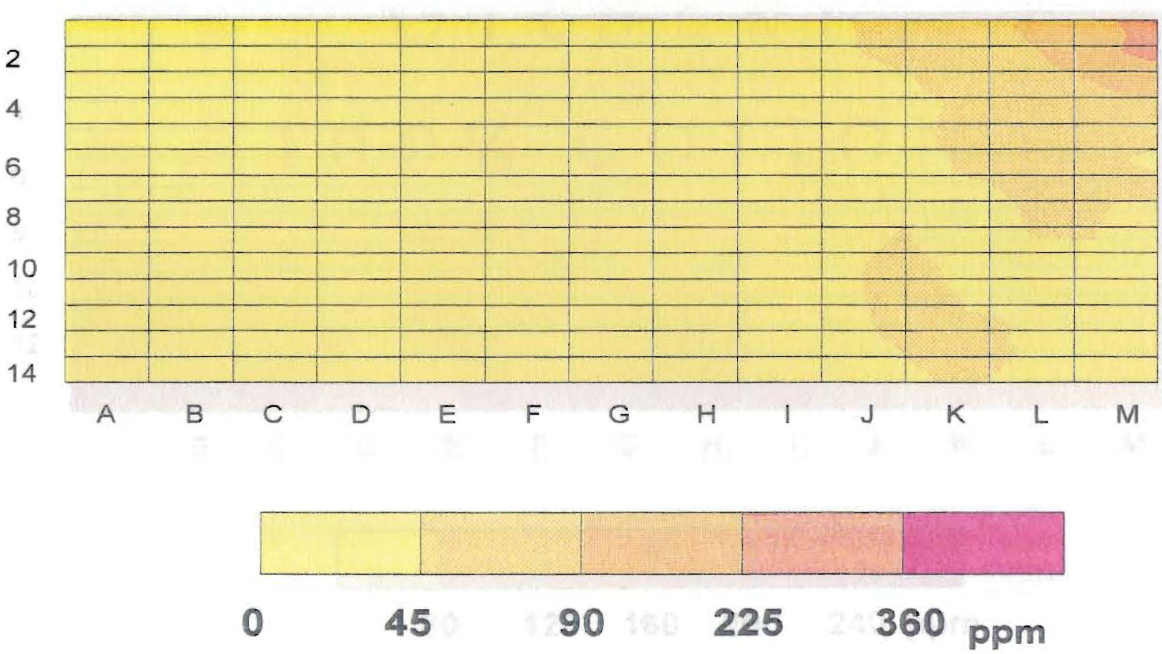


Figure 17. Phosphorus distribution within the test area.

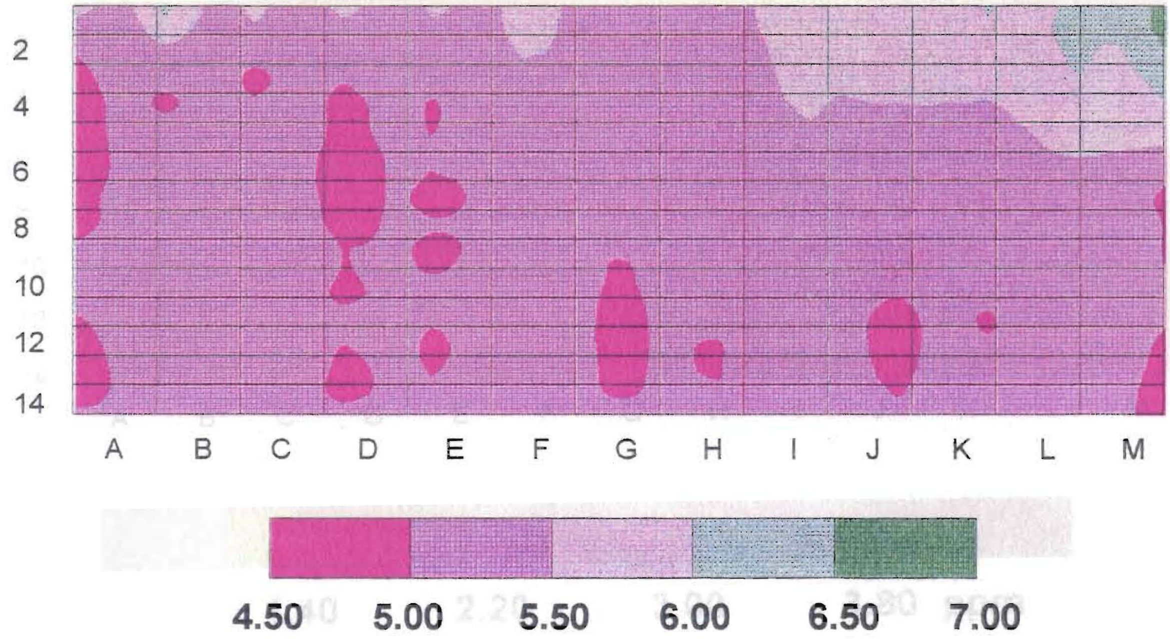


Figure 18. Soil pH variation within the test area.

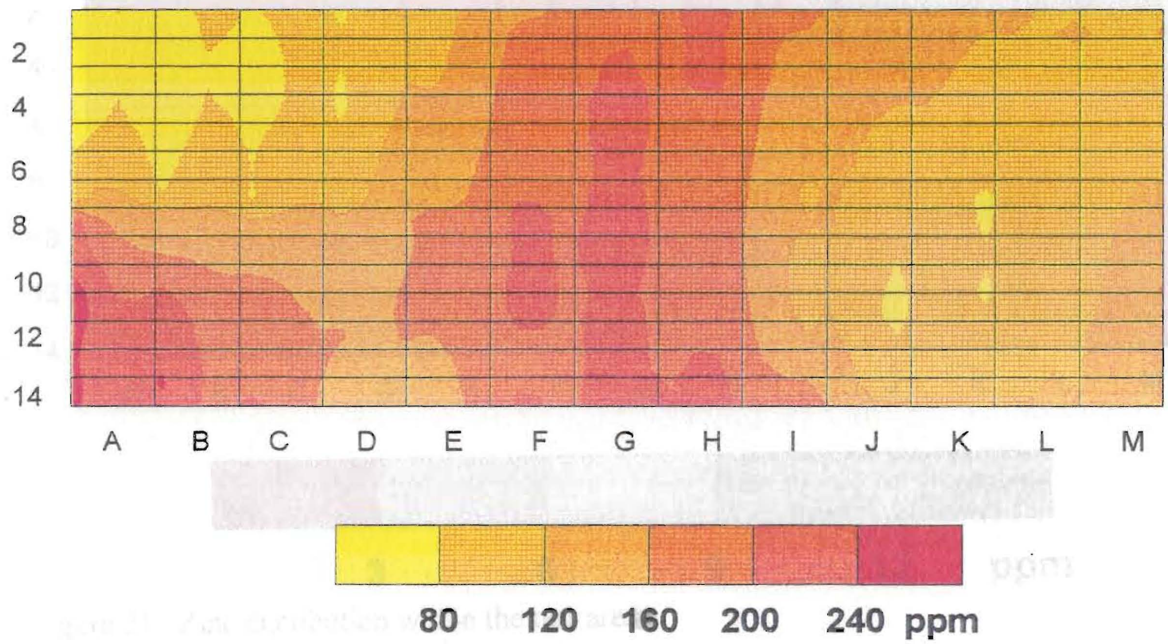


Figure 19. Magnesium distribution within the test area.

Figure 20. Copper distribution within the test area.

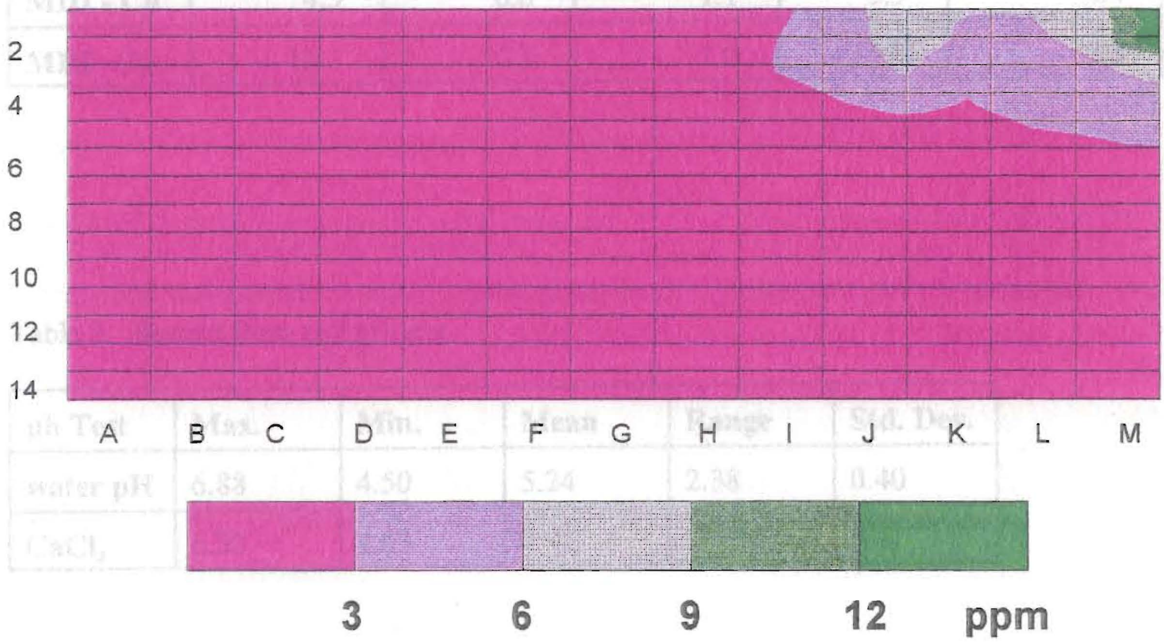


Figure 21. Zinc distribution within the test area.

Refer to Tables 2 and 3 for simple statistics describing the soil chemicals tested. Phosphorus and potassium were analyzed using the Mehlichs I (MI) and the Mehlichs III (MIII) extraction methods. Copper, magnesium, and zinc were analyzed using the Mehlichs III extraction method. pH was analyzed using both calcium chloride and H_20 methods.

Table 2. Results from soil nutrient tests.

Nutrient	**Max. ppm**	**Min. ppm**	**Mean ppm**	**Range**	**Std. Dev.**
MI - P	379.5	6.0	32.7	373.5	14.4
MIII - P	420.0	9.0	63.0	411.0	18.4
MI - K	332.5	65.0	147.7	267.5	44.6
MIII - K	534.0	102.0	226.2	432.0	72.1
MIII - Mg	274.0	38.0	143.4	236.0	61.6
MIII - Cu	4.5	0.6	1.1	3.9	0.4
MIII - Zn	16.1	0.2	1.8	15.9	2.3

Table 3. Results from soil pH test.

ph Test	**Max.**	**Min.**	**Mean**	**Range**	**Std. Dev.**
water pH	6.88	4.50	5.24	2.38	0.40
$CaCl_2$	6.50	4.03	4.91	2.47	0.41

Soil Moisture Variability

Soil moisture varied spatially within the field, but not to the extent expected. The correlation between soil type and soil moisture was found to be significant ($p<0.05$). Rank cotton growth was observed in the area of the field that had high nutrient levels and high average soil moisture for the season. This area of the field is classified as Memphis silt loam soils. Memphis soils are known to be deep, well-drained soils. Areas of the field that had the driest soils throughout the year were classified as Calloway silt loam. Calloway soils are poorly drained soils with a shallow fragipan, depths ranged from 28 to 33 inches in the test area. Figure 22 illustrates the seasonal average moisture movement patterns for selected depths.

Yield Variability

Yield values are based on the assumption that 1500 pounds of seed cotton constitute one bale of lint. During harvest, the naked eye could not detect the large measured variation in yield. First picking yields ranged from 0.53 to 2.30 bales per acre with an average yield of 1.70 bales per acre. Yields from the second picking ranged from 0.00 to 0.64 bales per acre, with an average yield of 0.25 bales per acre. Average gin turnout of the field was 39.74 percent.

Yield by soil type. Yields from each soil type can be observed in Appendix C. Results showed that the Grenada soil series had the highest yields with an overall average of 1.97

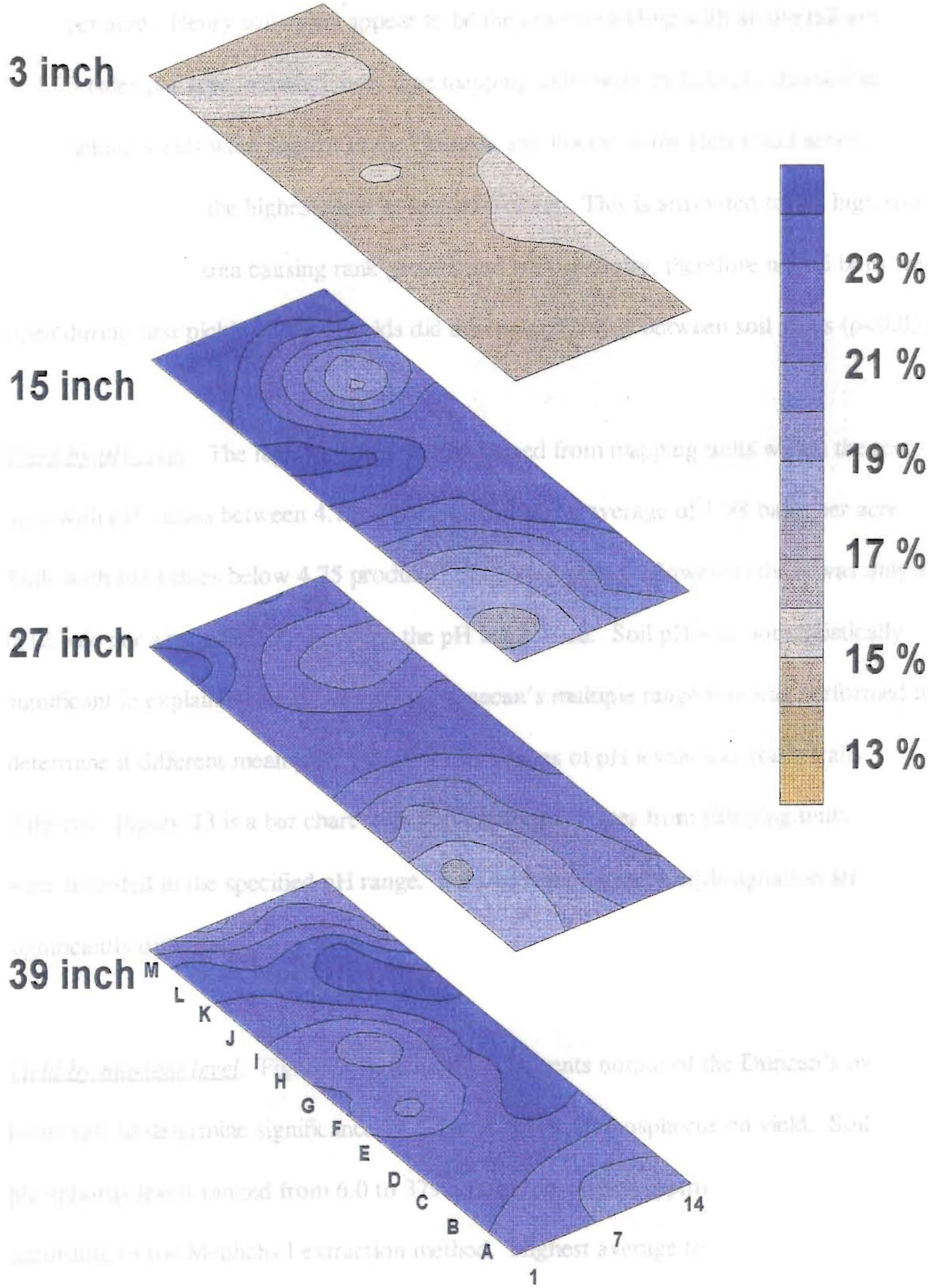


Figure 22. Average soil moisture (percent moisture by volume) for the test area at four selected depths for the entire growing season.

bales per acre. Henry soil series appear to be the lowest yielding with an overall average of 1.73 bales per acre, although only nine mapping units were included in this soil series. First picking yields were highest in the Grenada and lowest in the Henry soil series. Memphis soils had the highest yield at second picking. This is attributed to the high soil test values for the area causing rank growth and later maturity, therefore not all bolls were open during first picking. Total yields did differ significantly between soil types ($p<0.05$).

Yield by pH level. The highest yields were obtained from mapping units within the test area with pH values between 4.75 and 4.99, yielding an average of 1.98 bales per acre. Soils with pH values below 4.75 produced the lowest yields. However, there was only a 0.12 bale per acre difference between the pH levels used. Soil pH was not statistically significant in explaining yield differences. Duncan's multiple range test was performed to determine if different mean yield variations for ranges of pH levels was statistically different. Figure 23 is a bar chart depicting total yield values from mapping units that were included in the specified pH range. Bars with the same letter designation are not significantly different.

Yield by nutrient level. Figure 24 graphically represents output of the Duncan's multiple range test to determine significance of different levels of phosphorus on yield. Soil phosphorus levels ranged from 6.0 to 379.5 parts per million (ppm) within the field according to the Mehlichs I extraction method. Highest average total yields, 1.96 bales per acre, were obtained from mapping units that tested medium (9 and 15 ppm) based on

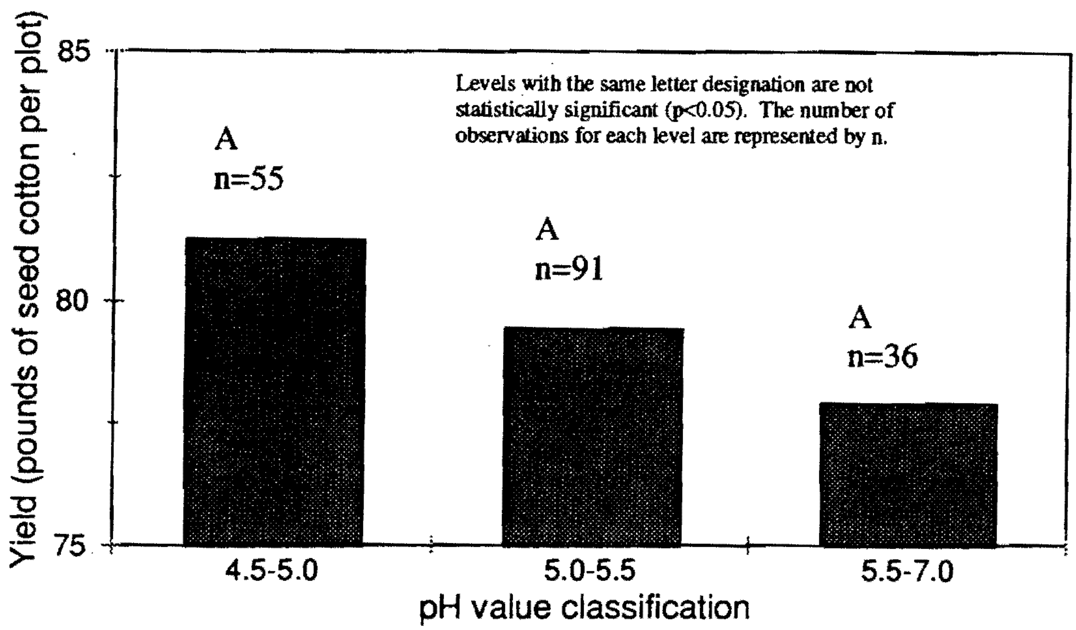


Figure 23. Mean yield results based on pH values.

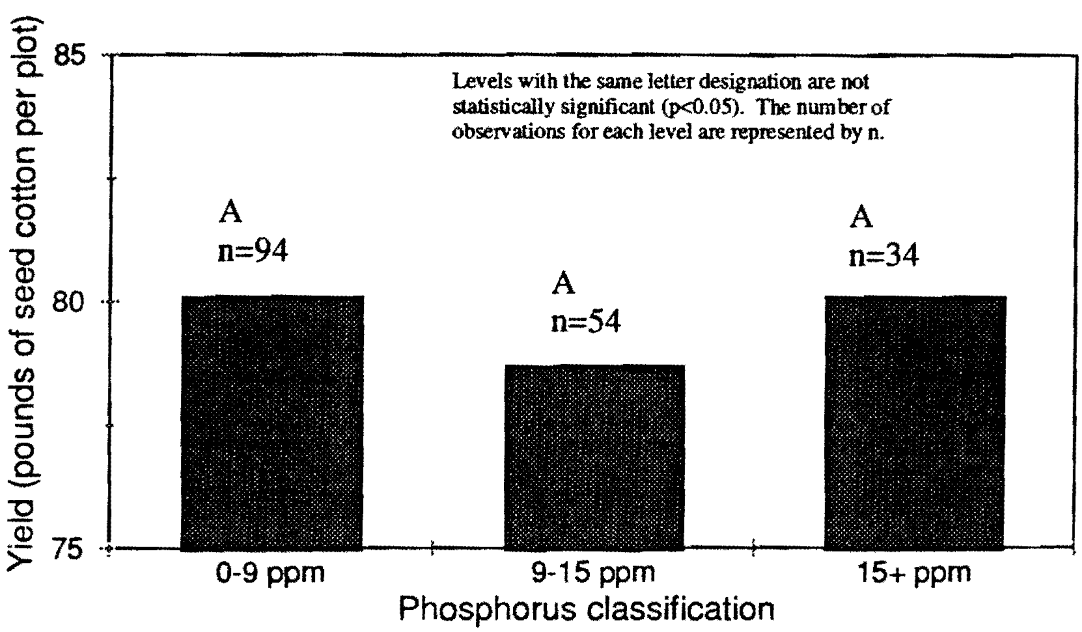


Figure 24. Mean yield results based on ranges in phosphorus levels.

The University of Tennessee soil test ratings, forty-five mapping units were included in this classification. One hundred and six mapping units in the high classification (15 to 60 ppm) had an average total yield of 1.93 bales per acre. Average total yield of the 16 mapping units that tested in the very high (60 + ppm) was 1.90 bales per acre. Lowest average total yields were from mapping units with P levels between 6 and 9 ppm (low). Total yield was 1.88 bales per acre with 15 mapping units considered.

Highest mean yields by potassium levels were in mapping units that tested very high (160+ ppm). Total yield from these 56 mapping units averaged 1.97 bales per acre. No mapping units tested in the low category (0 to 45 ppm), and 124 tested in the high level (80 to 160 ppm), with an average total yield of 1.92 bales per acre. Only two mapping units were classified in the medium category (45 to 80 ppm). Average total yield from these mapping units was 1.63 bales per acre. Figures 25 thru 28 represent the mean yield by varying levels of potassium, copper, magnesium, and zinc.

There was not a single soil nutrient that explained a significant level of the variability in total yield ($p<0.05$). However, magnesium was found to significantly affect the first picking yields ($p<0.05$). Magnesium and potassium were significant on second picking yields ($p<0.05$).

Yield by interactions between soil nutrients. Some interactions between soil chemicals were found to significantly affect yields. The interaction between phosphorus and magnesium was found to significantly affect total yields ($p<0.05$). There were no significant interactions between soil nutrients and first picking yields ($p<0.05$). Some

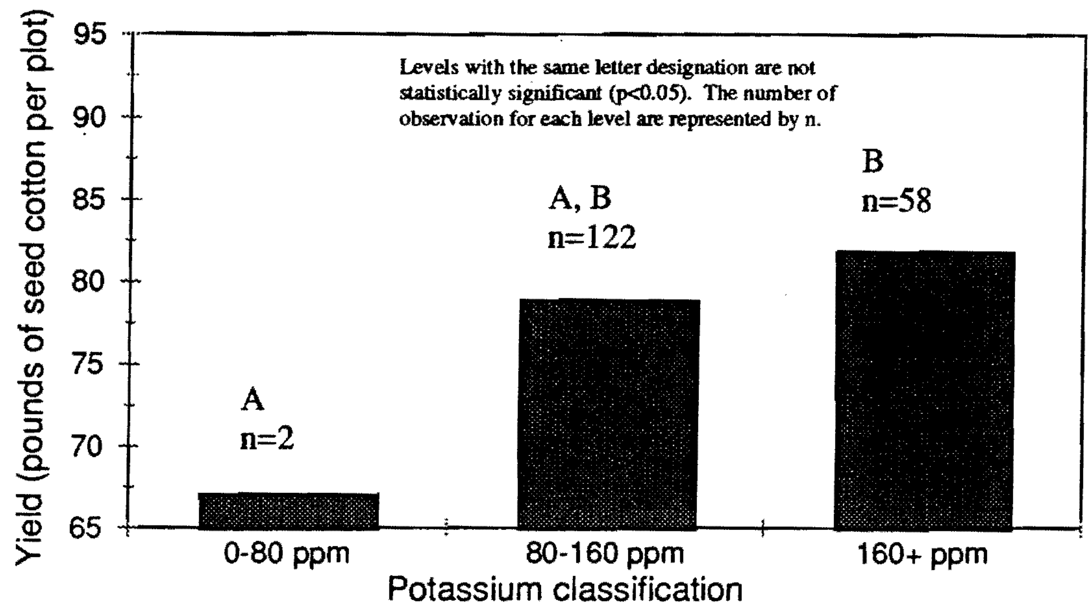


Figure 25. Mean yield results based on ranges in potassium levels.

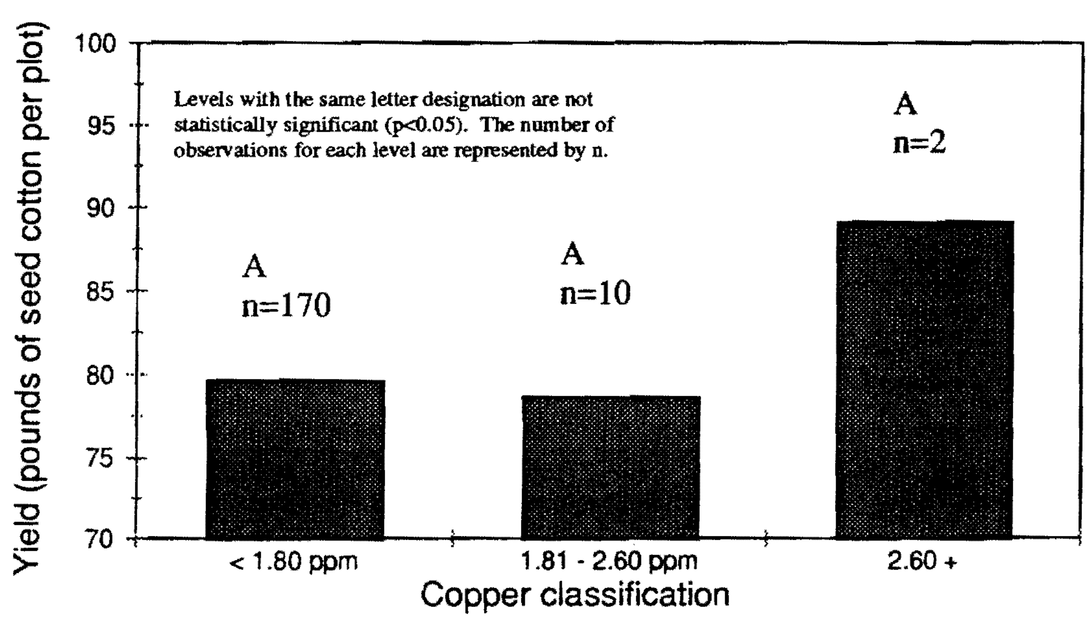


Figure 26. Mean yield results based on ranges in copper levels.

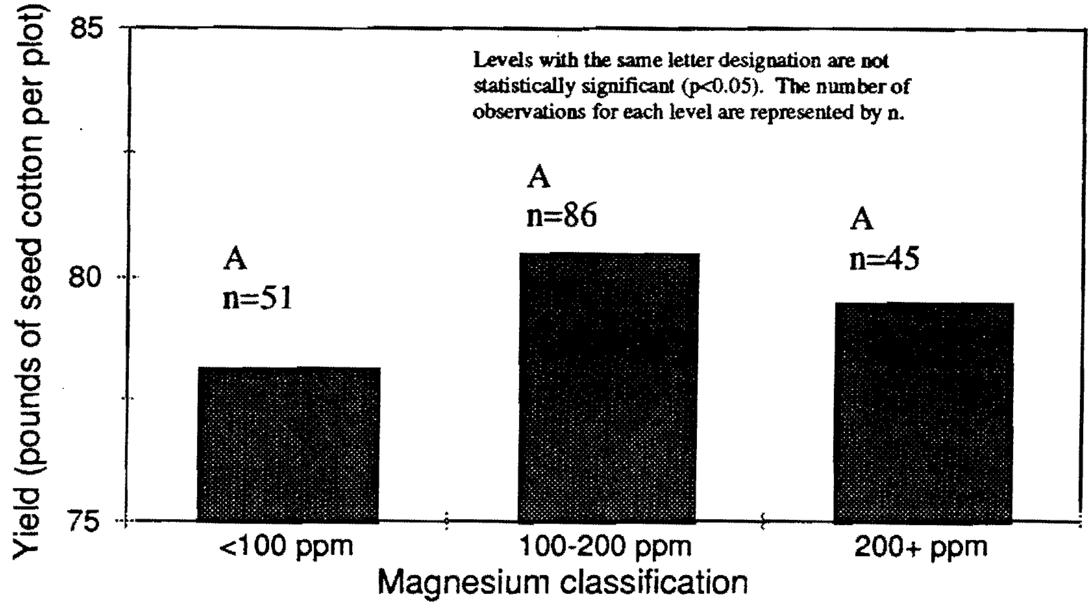


Figure 27. Mean yield results based on ranges in magnesium levels.

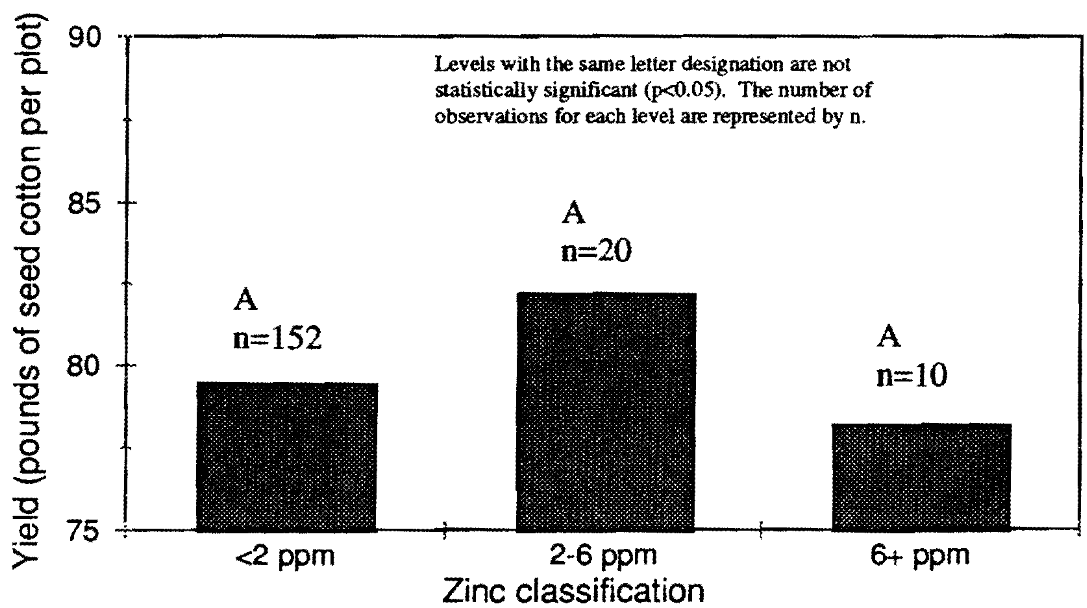


Figure 28. Mean yield results based on ranges in zinc levels.

variation in second picking yields could be explained by the interaction between magnesium and phosphorus and between magnesium and zinc ($p<0.05$).

Yield by moisture patterns. Soil moisture was not found to significantly affect yield. Although there was a trend of less significance as soil depth increased. Moisture might have a significant effect on yields if rainfall was inadequate during peak fruiting periods. During the 1996 growing season rainfall was adequate except for a 12 day period between the dates of June 26 and July 7, though this dry period did not seem to affect soil moisture. Figure 29 is a graph of the cumulative rainfall for the mapping unit area throughout the growing season. Soil moisture did show a significant difference between soil types ($p<0.05$).

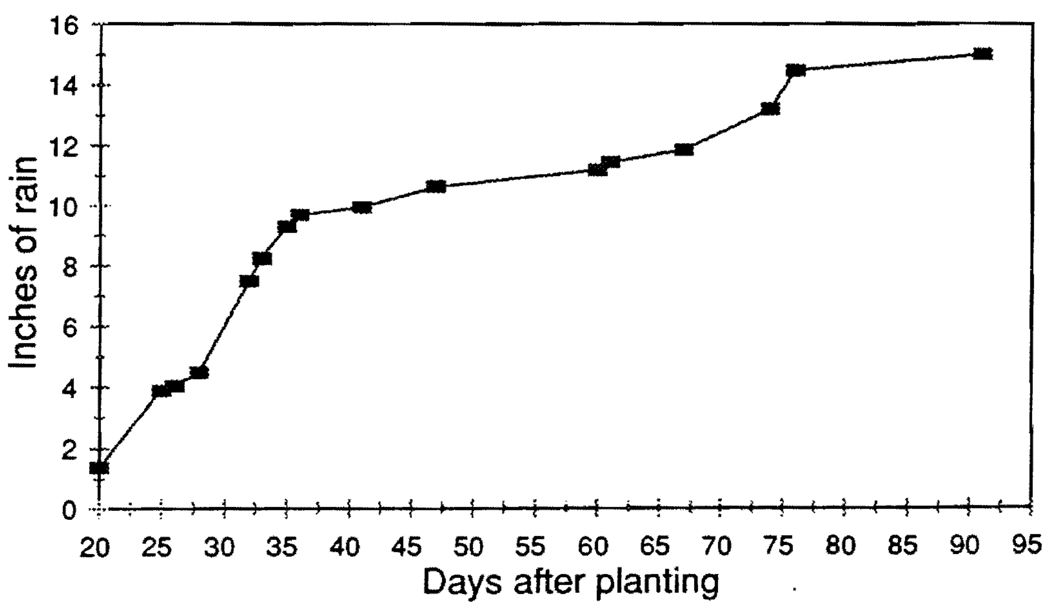


Figure 29. Cumulative rainfall on the test area throughout the growing season.

CHAPTER 5

CONCLUSIONS

There were three major objectives associated with this research project. The first was to design and fabricate an accurate system for cotton yield mapping on a production scale field. The second objective was to document the spatial variability within a field and relate the measured variability to yield. The third objective was to develop a GIS database for managing and analyzing the spatial variability within the test area. Spatial variables included in the evaluation were: soil type, soil nutrient level, soil moisture, soil pH, pest pressures, plant population, and first and second harvested yields. The following conclusions are based on the experience and results from the first year of a three year study.

- The cotton yield measurement system developed for this project proved to be an accurate and effective research tool for documenting cotton yields within a production-scale field.
- The yield monitoring system in conjunction with a DGPS unit provided to be an accurate tool for developing real-time cotton yield maps.
- Within the 5 acre test area, six soil type were identified with depth to a fragipan varying from 24 to 60+ inches. Mean yield differences between soil types varied for xx to xx bales/ acre and were found to be statistically significant ($p<0.05$)
- Variation in soil potassium and phosphorus appeared to affect yield, however these nutrients did not show statistically significance in part due to the limited number of

samples within some nutrient classes.

- Soil moisture did not prove to have a significant effect on yield, in part due to adequate rainfall through the growing season.
- ArcView (version 3.0) proved to be an effective GIS tool for storing, managing, and displaying spatial information collected within the cotton field.
- Further research is justified in the realm of employing variable-rate technology to cotton production.
- Based on the analysis of a one year study and field observations, further research is justified in the area of variable-rate control of production inputs to cotton.

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APPENDICES

APPENDIX A

Appendix A1. Local coordinates of the centers of each mapping unit.

Plot	Latitude	Longitude	Plot	Latitude	Longitude
A - 1	35°55.976542	88°42.820874	I - 3	35°55.929279	88°42.898375
B - 1	35°55.969543	88°42.829999	J - 3	35°55.923594	88°42.906498
C - 1	35°55.963213	88°42.838955	L - 3	35°55.912054	88°42.922514
D - 1	35°55.956739	88°42.847967	M - 3	35°55.906409	88°42.930486
E - 1	35°55.950427	88°42.856963	A - 4	35°55.983836	88°42.829220
F - 1	35°55.943944	88°42.866052	B - 4	35°55.977413	88°42.838168
G - 1	35°55.937420	88°42.875304	C - 4	35°55.970946	88°42.846991
H - 1	35°55.930969	88°42.884556	D - 4	35°55.964271	88°42.856117
I - 1	35°55.924352	88°42.893592	E - 4	35°55.957737	88°42.865126
J - 1	35°55.918411	88°42.901326	F - 4	35°55.951290	88°42.874262
K - 1	35°55.912725	88°42.909392	G - 4	35°55.944683	88°42.883472
L - 1	35°55.907056	88°42.917395	H - 4	35°55.938218	88°42.892157
M - 1	35°55.901260	88°42.925646	I - 4	35°55.931739	88°42.901217
A - 2	35°55.978527	88°42.823845	J - 4	35°55.926009	88°42.909287
B - 2	35°55.972055	88°42.832513	K - 4	35°55.920207	88°42.917216
C - 2	35°55.965608	88°42.841279	L - 4	35°55.914516	88°42.925168
D - 2	35°55.958947	88°42.850456	M - 4	35°55.908810	88°42.933242
E - 2	35°55.952562	88°42.859332	A - 5	35°55.986368	88°42.831608
F - 2	35°55.946104	88°42.868664	B - 5	35°55.979809	88°42.840681
G - 2	35°55.939566	88°42.877842	C - 5	35°55.973418	88°42.849587
H - 2	35°55.933061	88°42.886830	D - 5	35°55.966996	88°42.858793
I - 2	35°55.926704	88°42.895815	E - 5	35°55.960328	88°42.867778
J - 2	35°55.920903	88°42.903901	F - 5	35°55.953753	88°42.877018
K - 2	35°55.915142	88°42.911996	G - 5	35°55.947336	88°42.885651
L - 2	35°55.909398	88°42.920133	H - 5	35°55.940707	88°42.894925
M - 2	35°55.903624	88°42.928149	I - 5	35°55.934220	88°42.904173
A - 3	35°55.981003	88°42.826186	J - 5	35°55.928325	88°42.912259
B - 3	35°55.974515	88°42.835328	K - 5	35°55.922945	88°42.920117
C - 3	35°55.968081	88°42.844348	L - 5	35°55.917013	88°42.928001
D - 3	35°55.961744	88°42.853243	M - 5	35°55.911105	88°42.936084
E - 3	35°55.955331	88°42.862372	A - 6	35°55.988608	88°42.834105
F - 3	35°55.948853	88°42.871414	B - 6	35°55.982190	88°42.843027
G - 3	35°55.942335	88°42.880350	C - 6	35°55.975587	88°42.851959
H - 3	35°55.935804	88°42.889673	D - 6	35°55.969132	88°42.861030

Plot	Latitude	Longitude	Plot	Latitude	Longitude
E - 6	35°55.962703	88°42.870128	C - 9	35°55.982565	88°42.860125
F - 6	35°55.956349	88°42.879327	D - 9	35°55.976241	88°42.869173
G - 6	35°55.949634	88°42.888152	E - 9	35°55.969713	88°42.878015
H - 6	35°55.943043	88°42.897360	F - 9	35°55.963097	88°42.887073
J - 6	35°55.930777	88°42.914630	G - 9	35°55.956841	88°42.896106
K - 6	35°55.925092	88°42.922446	H - 9	35°55.950259	88°42.905357
L - 6	35°55.919215	88°42.930654	I - 9	35°55.943886	88°42.914393
M - 6	35°55.913507	88°42.938680	J - 9	35°55.938107	88°42.922415
A - 7	35°55.991012	88°42.836804	K - 9	35°55.932254	88°42.930312
B - 7	35°55.984652	88°42.845826	L - 9	35°55.926516	88°42.938384
C - 7	35°55.978141	88°42.854831	M - 9	35°55.920883	88°42.946483
D - 7	35°55.971615	88°42.863994	A - 10	35°55.998224	88°42.844512
E - 7	35°55.965244	88°42.873063	B - 10	35°55.991756	88°42.853502
F - 7	35°55.958627	88°42.882019	C - 10	35°55.985215	88°42.862935
G - 7	35°55.951990	88°42.891149	D - 10	35°55.978912	88°42.871783
H - 7	35°55.945566	88°42.900252	D - 10	35°55.972315	88°42.880947
I - 7	35°55.939239	88°42.909450	F - 10	35°55.965856	88°42.890031
J - 7	35°55.933559	88°42.917726	G - 10	35°55.959362	88°42.899129
K - 7	35°55.927859	88°42.925803	H - 10	35°55.952789	88°42.908053
L - 7	35°55.921759	88°42.933461	I - 10	35°55.946232	88°42.917297
M - 7	35°55.916094	88°42.941829	J - 10	35°55.940434	88°42.925436
A - 8	35°55.993353	88°42.839521	K - 10	35°55.934701	88°42.933080
B - 8	35°55.986955	88°42.848306	L - 10	35°55.929124	88°42.941149
C - 8	35°55.980483	88°42.857529	M - 10	35°55.923381	88°42.949246
D - 8	35°55.974089	88°42.866477	A - 11	35°56.000822	88°42.847380
E - 8	35°55.967482	88°42.875616	B - 11	35°55.994269	88°42.856308
F - 8	35°55.960974	88°42.884741	C - 11	35°55.987788	88°42.865427
G - 8	35°55.954552	88°42.893585	D - 11	35°55.981249	88°42.874306
H - 8	35°55.947962	88°42.902718	E - 11	35°55.974790	88°42.883310
I - 8	35°55.941468	88°42.911729	F - 11	35°55.968178	88°42.892316
J - 8	35°55.935705	88°42.919789	G - 11	35°55.961647	88°42.901269
K - 8	35°55.930039	88°42.927965	H - 11	35°55.955052	88°42.910378
L - 8	35°55.924259	88°42.936053	I - 11	35°55.948581	88°42.919341
M - 8	35°55.918451	88°42.944155	J - 11	35°55.942976	88°42.927361
A - 9	35°55.995723	88°42.842115	K - 11	35°55.936993	88°42.935004
B - 9	35°55.989249	88°42.851230	L - 11	35°55.931144	88°42.943057

Plot	Latitude	Longitude
M - 11	35°55.925419	88°42.950392
A - 12	35°56.003113	88°42.850000
B - 12	35°55.996656	88°42.859133
C - 12	35°55.990141	88°42.868274
D - 12	35°55.983765	88°42.877208
E - 12	35°55.977198	88°42.886324
F - 12	35°55.970729	88°42.895268
G - 12	35°55.964235	88°42.904331
H - 12	35°55.957665	88°42.913321
I - 12	35°55.951174	88°42.922577
J - 12	35°55.945482	88°42.930474
K - 12	35°55.939893	88°42.938483
L - 12	35°55.934212	88°42.946301
M - 12	35°55.928386	88°42.954434
A - 13	35°55.000000	88°42.852720
B - 13	35°55.999126	88°42.861275
C - 13	35°55.992594	88°42.870760
D - 13	35°55.986127	88°42.879712
E - 13	35°55.979692	88°42.888821
F - 13	35°55.973258	88°42.897753
G - 13	35°55.966801	88°42.906902
H - 13	35°55.960104	88°42.916038
I - 13	35°55.953626	88°42.925068
J - 13	35°55.947876	88°42.933017
K - 13	35°55.942266	88°42.941213
L - 13	35°55.936606	88°42.949427
M - 13	35°55.930995	88°42.957598
A - 14	35°56.007994	88°42.855427
B - 14	35°56.001354	88°42.864023
C - 14	35°55.995332	88°42.873694
D - 14	35°55.988669	88°42.882426
E - 14	35°55.982182	88°42.891383
F - 14	35°55.975679	88°42.900421
G - 14	35°55.969097	88°42.909404
H - 14	35°55.962692	88°42.918470
I - 14	35°55.956218	88°42.927602

Plot	Latitude	Longitude
J - 14	35°55.950278	88°42.935798
K - 14	35°55.944596	88°42.943730
L - 14	35°55.938879	88°42.951675
M - 14	35°55.933448	88°42.960288

Appendix A2. Local Coordinates of moisture access tubes.

Plot	Latitude	Longitude
A - 1	35°55.976542	88°42.821409
G - 1	35°55.937918	88°42.875091
J - 1	35°55.919600	88°42.901586
E - 2	35°55.952632	88°42.859420
L - 2	35°55.908940	88°42.920276
D - 3	35°55.960813	88°42.852716
I - 3	35°55.928673	88°42.897710
B - 4	35°55.977214	88°42.837798
F - 4	35°55.950307	88°42.874876
G - 4	35°55.944806	88°42.882743
M - 5	35°55.911117	88°42.935538
H - 6	35°55.943555	88°42.898009
I - 6	35°55.937074	88°42.906955
K - 6	35°55.925519	88°42.922863
D - 8	35°55.973237	88°42.865688
F - 8	35°55.960297	88°42.883833
B - 9	35°55.988800	88°42.851284
J - 9	35°55.938201	88°42.922594
M - 9	35°55.920780	88°42.946421
E - 10	35°55.972191	88°42.880881
G - 10	35°55.959696	88°42.899659
K - 10	35°55.934484	88°42.933207
I - 12	35°55.951066	88°42.922357
L - 12	35°55.933989	88°42.946110
C -13	35°55.991768	88°42.870003
K -13	35°55.941419	88°42.940401

Base Station Coordinates

35°56.014600   88°42.864900   Elevation = 110.000 meters

Appendix A3. Results from Soil Survey of field A-11.

Hole #	Soil Type	Depth to pan (inches)	Comments
1	Routon silt loam	*	
2	Henry silt loam	38	
3	Henry silt loam	32	
4	Calloway silt loam	28	
5	Grenada silt loam	24	wet
6	Loring silt loam	32	wet pan
7	Loring silt loam	30	
8	Memphis silt loam	*	slightly pannish at 45"
9	Loring silt loam	30	
10	Memphis silt loam	*	
11	Loring silt loam	31	
12	Loring silt loam	32	
13	Loring silt loam	34	
14	Loring silt loam	36	
15	Loring silt loam	36	
16	Loring silt loam	38	wet pan
17	Loring silt loam	30	
18	Calloway silt loam	33	
19	Henry silt loam	29	
20	Henry silt loam	40	
21	Calloway silt loam	33	
22	Grenada silt loam	33	
23	Grenada silt loam	33	
24	Loring silt loam	32	
25	Loring silt loam	32	
26	Loring silt loam	34	
27	Grenada silt loam	26	
28	Grenada silt loam	31	
29	Loring silt loam	40	weak pan
30	Memphis silt loam	*	
31	Loring silt loam	32	
32	Grenada silt loam	*	disturbed
33	Grenada silt loam	30	
34	Loring silt loam	24	
35	Loring silt loam	42	weak pan
36	Loring silt loam	42	weak pan
37	Loring silt loam	25	
38	Loring silt loam	30	
39	Loring silt loam	34	
40	Grenada silt loam	25	
41	Loring silt loam	25	
42	Grenada silt loam	24	
43	Loring silt loam	30	
44	Loring silt loam	30	
45	Grenada silt loam	30	
46	Grenada silt loam	36	
47	Loring silt loam	38	

* where no depth to pan is listed, the soil series has no fragipan

APPENDIX B

Appendix B1: Datalogger program used to convert signal from load cells to total basket weight.

```
Program:WEIGHT6
Flag Usage:
Input Channel Usage: LOAD CELL ON FIRST 6 CHANNELS
Excitation Channel Usage: 1ST 4 L.C. ON EX1, 5-6 ON EX2
Continuous Analog Output Usage:
Control Port Usage:
Pulse Input Channel Usage:
Output Array Definitions:


*    1      Table 1 Programs
 01: .1      Sec. Execution Interval

01: P96      Serial Output
 01: 12      Printer ASCII/9600 Baud

02: P18      Time
 01: 00      Option
 02: 10      Mod/by
 03: 1       Loc : time

03: P6       Full Bridge
 01: 1       Rep
 02: 12      15 mV fast Range
 03: 1       IN Chan
 04: 01      Excite all reps w/EXchan 1
 05: 5000    mV Excitation
 06: 2       Loc :
 07: 555     Mult
 08: 0.0000  Offset

04: P6       Full Bridge
 01: 1       Rep
 02: 12      15 mV fast Range
 03: 2       IN Chan
 04: 1       Excite all reps w/EXchan 1
 05: 5000    mV Excitation
 06: 5       Loc :
 07: -350    Mult
 08: 0.0000  Offset
```

```
05: P6      Full Bridge
 01: 2      Reps
 02: 12      15 mV fast Range
 03: 3      IN Chan
 04: 1      Excite all reps w/EXchan 1
 05: 5000    mV Excitation
 06: 3      Loc :
 07: 555     Mult
 08: 0.0000  Offset

06: P33      Z=X+Y
 01: 2      X Loc
 02: 3      Y Loc
 03: 9      Z Loc :
Page 2   Table 1

07: P33      Z=X+Y
 01: 4      X Loc
 02: 5      Y Loc
 03: 10      Z Loc :

08: P33      Z=X+Y
 01: 9      X Loc
 02: 10      Y Loc
 03: 6      Z Loc :

09: P89      If X<=>F
 01: 1      X Loc
 02: 1      =
 03: 1      F
 04: 10      Set high Flag 0 (output)

10: P71      Average
 01: 5      Reps
 02: 2      Loc

11: P       End Table 1
```

Appendix B2: Computer program used to read data from the GPS reciever and the weighing basket to the laptop computer.

```
100 CLS
INPUT "ENTER DATA FILE NAME"; F$
OPEN F$ + ".WT" FOR APPEND AS #4
OPEN F$ + ".GPS" FOR APPEND AS #3

1 BEEP
OPEN "com1:9600,n,8,1,cs,ds,rb4000" FOR INPUT AS #1
OPEN "COM2:9600,N,8,1,cs,ds,rb4000" FOR INPUT AS #2
10 IF LOC(1) > 40 THEN LINE INPUT #1, x$: PRINT #3, TIME$, RIGHT$(x$, 47):
      CLS : PRINT x$
IF LOC(2) > 50 THEN LINE INPUT #2, Y$: PRINT #4, TIME$; RIGHT$(Y$, 50):
      PRINT Y$

IF INKEY$ <> "" THEN CLOSE : END
GOTO 10
```

Appendix B3: Computer program used to remove initial basket weight, smooth data, and compute rate of change.

```
INPUT "enter data file name"; f$
OPEN f$ + ".wt" FOR INPUT AS #1
OPEN f$ + ".adj" FOR OUTPUT AS #2
OPEN f$ + ".smo" FOR OUTPUT AS #3
OPEN f$ + ".rat" FOR OUTPUT AS #4
DIM wt(10000)
DIM smooth(10000)
DO WHILE NOT EOF(1)
LINE INPUT #1, x$
x = x + 1
weight = VAL(RIGHT$(x$, 6))
PRINT weight
wt(x) = weight
LOOP
counter = x
 FOR i = 1 TO 5
 sum = sum + wt(i)
 NEXT i
 basewt = sum / 5
 PRINT basewt
 FOR i = 1 TO counter
    wt(i) = wt(i) - basewt
    PRINT wt(i)
    PRINT #2, USING "####.#"; wt(i)
 NEXT i
 ' smooth the data
FOR x = 3 TO counter - 2
  avg = wt(x - 2) + 2 * wt(x - 1) + 4 * wt(x) + 2 * wt(x + 1) + wt(x + 2)
  smooth(x) = avg / 10
  PRINT #3, USING "####.#"; smooth(x)
  PRINT USING "####.#"; smooth(x)
NEXT x
' compute the rate of change in lbs/sec
INPUT "enter the number of seconds for computing the slope"; t
FOR x = 2 TO counter - 1 STEP t
  diff = smooth(x + t) - smooth(x)
  WtPerSec = diff / t
  PRINT USING "##.###"; WtPerSec
  PRINT #4, USING "##.###"; WtPerSec
NEXT x
```

Appendix B4: Computer program used to link GPS files with yield files.

```
INPUT "Enter the position source file name.", file$
INPUT "Enter the weight source file name.", ffile$
INPUT "Enter the output file name.", ofile$
REM*****Count the number of lines in the source file*****
OPEN file$ FOR INPUT AS #1
OPEN ffile$ FOR INPUT AS #2
INPUT "Next GPS time", tim
DO WHILE NOT EOF(1)
LINE INPUT #1, x$
a = VAL(MID$(x$, 51, 6))
t$ = LEFT$(x$, 8)
PRINT a, t$
IF a = tim THEN
PRINT a
DO WHILE NOT EOF(2)
LINE INPUT #2, y$
tt$ = LEFT$(y$, 8)
wt$ = RIGHT$(y$, 6)
wt = VAL(LTRIM$(wt$))
IF tt$ = t$ THEN
PRINT tt$, wt$
OPEN ofile$ FOR APPEND AS #3
WRITE #3, a, t$, wt
CLOSE #3
INPUT "Next GPS time.", tim
GOTO 30
END IF
LOOP
30 END IF
LOOP
CLOSE #1
CLOSE #2
END
```

APPENDIX C

Table C1. First picking yields by soil pH levels.

pH	Max	Min	Mean	Count	Range	Std. Dev.
4.5 - 4.99	2.30 B/ac	0.53 B/ac	1.72 B/ac	55	72.86	11.75
5 - 5.49	2.25 B/ac	1.29 B/ac	1.67 B/ac	91	40.37	8.51
5.5 - 5.99	2.11 B/ac	1.05 B/ac	1.65 B/ac	26	43.46	9.24
6 - 6.49	1.83 B/ac	0.90 B/ac	1.38 B/ac	8	38.48	11.70
6.5 - 7	1.85 B/ac	1.46 B/ac	1.66 B/ac	2	16.32	11.54

Table C2. First picking yields by soil P levels using U.T. soil test ratings.

P level	Max	Min	Mean	Count	Range	Std. Dev.
Low	2.26 B/ac	1.20 B/ac	1.745B/ac	88	43.49	8.79
Medium	2.30 B/ac	0.53 B/ac	1.63 B/ac	90	72.86	10.57
High	1.85 B/ac	0.90 B/ac	1.45 B/ac	4	39.36	16.53
V. High	none	none	none	none	none	none

Table C3. First picking yields by soil K levels using U.T. soil test ratings.

K level	Max	Min	Mean	Count	Range	Std. Dev.
Low	none	none	none	none	none	none
Medium	1.49 B/ac	1.48 B/ac	1.49 B/ac	2	0.18	0.13
High	2.25 B/ac	0.53 B/ac	1.68 B/ac	124	71.17	9.93
V. High	2.29 B/ac	0.90 B/ac	1.67 B/ac	56	57.71	10.85

Table C4. First picking yields by soil types.

Soil Type	Max B/ac	Min B/ac	Mean	Count	Range	Std. Dev.
Routon	1.59	1.49	1.54	3	4.43	2.22
Henry	1.79	1.34	1.50	9	18.58	5.55
Loring	2.30	0.53	1.69	107	72.86	10.82
Grenada	2.11	1.28	1.71	44	35.04	7.61
Calloway	1.95	1.33	1.55	10	25.38	7.05
Memphis	2.01	1.05	1.61	9	49.67	16.13

Table C5. Second picking yields by pH levels.

pH	Max	Min	Mean	Count	Range	Std. Dev.
4.5 - 4.99	0.48 B/ac	0.05 B/ac	0.23 B/ac	55	17.96	3.45
5 - 5.49	0.50 B/ac	0.0 B/ac	0.25 B/ac	91	20.76	4.52
5.5 - 5.99	0.48 B/ac	0.10 B/ac	0.24 B/ac	26	15.73	4.68
6 - 6.49	0.64 B/ac	0.17 B/ac	0.44 B/ac	8	19.47	6.15
6.5 - 7	0.61 B/ac	0.39 B/ac	0.50 B/ac	2	9.24	6.53

Table C6. Second picking yields by soil P using U.T. soil test ratings.

P level	Max	Min	Mean	Count	Range	Std. Dev.
Low	0.41 B/ac	0.0 B/ac	0.21 B/ac	88	16.93	3.69
Medium	0.65 B/ac	0.05 B/ac	0.29 B/ac	90	24.61	4.83
High	0.61 B/ac	0.38 B/ac	0.47 B/ac	4	9.48	4.44
V. High	none	none	none	none	none	none

Table C7. Second picking yields by soil K using U.T. soil test ratings.

K level	Max	Min	Mean	Count	Range	Std. Dev.
Low	none	none	none	none	none	none
Medium	0.17 B/ac	0.14 B/ac	0.14 B/ac	2	3.00	2.12
High	0.50 B/ac	0.0 B/ac	0.24 B/ac	124	20.76	4.29
V. High	0.64 B/ac	0.30 B/ac	0.30 B/ac	56	23.58	5.17

Table C8. Second picking yields by soil type.

Soil Type	Max B/ac	Min B/ac	Mean B/ac	Count	Range	Std. Dev.
Routon	0.34	0.14	0.22	3	0.20	4.42
Henry	0.43	0.14	0.23	9	0.30	4.12
Loring	0.64	0.00	0.25	107	0.64	4.79
Grenada	0.50	0.10	0.26	44	0.40	4.55
Calloway	0.34	0.05	0.21	10	0.29	3.92
Memphis	0.57	0.25	0.36	9	0.32	4.75

Table C9. Yield and soil nutrient data from each mapping unit in the test area.

X	Y	One Pick	Two Pick	Total Yield	Water pH	P ppm	K ppm	Mg ppm	Cu ppm	Zn ppm	Plant Pop.
1	a	1.59	0.14	1.74	5.84	42.00	87.50	56.00	0.80	1.40	1.5
1	b	1.49	0.17	1.66	6.19	30.00	65.00	64.00	1.00	0.80	.
1	c	1.51	0.17	1.68	5.63	33.00	115.00	76.00	0.80	1.10	2.275
1	d	1.55	0.25	1.80	5.70	31.50	117.50	72.00	0.90	1.10	2.425
1	e	1.44	0.18	1.63	5.64	27.00	105.00	96.00	1.40	1.10	.
1	f	1.48	0.10	1.58	5.88	9.00	77.50	154.00	1.60	0.90	.
1	g	1.62	0.14	1.76	5.50	9.00	120.00	178.00	1.10	1.20	.
1	h	1.61	0.13	1.74	5.54	6.00	112.50	252.00	0.90	0.70	1.925
1	i	1.56	0.19	1.75	5.98	10.50	115.00	190.00	1.10	1.90	.
1	j	1.48	0.33	1.81	5.76	75.00	225.00	140.00	1.60	11.10	.
1	k	1.15	0.54	1.69	6.06	76.50	310.00	128.00	2.40	6.80	.
1	l	0.90	0.38	1.28	6.16	177.00	332.50	114.00	2.40	11.00	2.25
1	m	1.46	0.61	2.07	6.88	379.50	242.50	118.00	2.60	15.90	.
2	a	1.79	0.43	2.22	5.02	33.00	135.00	60.00	0.80	1.30	2.275
2	b	1.54	0.34	1.88	5.72	40.50	105.00	66.00	0.70	3.50	.
2	c	1.34	0.26	1.59	5.48	46.50	132.50	64.00	0.70	1.00	2.25
2	d	1.49	0.35	1.84	5.30	33.00	132.50	76.00	1.10	1.10	.
2	e	1.52	0.33	1.85	5.42	22.50	120.00	108.00	1.70	1.40	.
2	f	1.63	0.20	1.83	5.80	9.00	130.00	172.00	1.30	0.90	.
2	g	1.60	0.19	1.80	5.50	9.00	125.00	212.00	1.00	1.00	1.925
2	h	1.56	0.18	1.74	5.54	12.00	142.50	212.00	1.20	0.90	.
2	i	1.64	0.16	1.79	5.84	16.50	222.50	152.00	1.30	3.70	1.875
2	j	1.83	0.33	2.16	6.15	84.00	220.00	124.00	1.80	10.80	.
2	k	1.40	0.57	1.96	6.00	85.50	306.50	118.00	1.90	5.70	.
2	l	1.45	0.64	2.09	6.43	130.50	260.00	132.00	2.10	7.80	.
2	m	1.85	0.39	2.24	6.84	364.50	252.50	124.00	4.50	16.10	2.025
3	a	1.95	0.23	2.18	4.87	28.50	112.50	48.00	0.70	1.40	.
3	b	1.58	0.14	1.71	5.16	28.50	90.00	42.00	0.60	0.80	.
3	c	1.49	0.16	1.65	4.72	30.00	135.00	38.00	0.80	0.80	1.95
3	d	1.56	0.05	1.61	4.99	31.50	115.00	66.00	0.70	0.80	.
3	e	1.62	0.25	1.88	5.01	19.50	132.50	104.00	0.90	1.30	2.025
3	f	1.59	0.13	1.72	5.56	7.50	117.50	176.00	1.00	1.30	.
3	g	1.63	0.13	1.76	5.13	7.50	95.00	214.00	1.30	0.80	1.6
3	h	1.84	0.07	1.92	5.07	10.50	170.00	242.00	1.10	0.80	1.625
3	i	2.10	0.11	2.20	5.74	13.50	142.50	150.00	1.40	4.80	.
3	j	1.55	0.31	1.86	5.97	30.00	174.00	122.00	1.30	9.00	.
3	k	1.05	0.39	1.45	5.68	63.00	217.50	116.00	1.50	4.10	.

3	l	1.23	0.48	1.71	6.08	94.50	227.50	86.00	2.30	7.00	.
3	m	1.57	0.44	2.01	6.32	138.00	222.50	80.00	2.00	6.90	2.225
4	a	1.60	0.24	1.84	4.76	37.50	102.50	50.00	0.80	1.10	1.925
4	b	1.35	0.17	1.52	4.85	31.50	107.50	44.00	0.60	0.80	1.725
4	c	1.33	0.14	1.47	5.04	31.50	112.50	44.00	0.90	1.00	.
4	d	1.60	0.14	1.75	4.86	31.50	130.00	68.00	0.70	0.80	.
4	e	1.61	0.12	1.73	4.94	16.50	125.00	126.00	1.70	0.70	.
4	f	1.48	0.21	1.69	5.22	15.00	150.00	184.00	0.90	0.60	1.9
4	g	1.41	0.04	1.45	5.11	6.00	110.00	246.00	1.00	0.90	.
4	h	1.50	0.24	1.75	5.07	24.00	175.00	188.00	1.10	1.10	.
4	i	1.79	0.18	1.97	5.58	22.50	145.00	142.00	0.90	2.10	.
4	j	1.36	0.29	1.65	5.49	27.00	120.00	120.00	1.20	3.40	2.25
4	k	1.58	0.26	1.84	5.48	46.50	172.50	106.00	1.80	2.70	2.1
4	l	1.73	0.39	2.12	5.77	58.50	169.00	96.00	1.60	3.50	.
4	m	1.97	0.39	2.36	5.98	87.00	197.50	102.00	2.10	4.80	.
5	a	1.89	0.48	2.38	4.92	30.00	117.50	52.00	0.70	1.30	1.925
5	b	1.38	0.24	1.62	5.22	37.50	107.50	50.00	0.80	0.70	.
5	c	1.51	0.34	1.85	5.01	30.00	144.00	66.00	0.80	1.10	.
5	d	1.61	0.22	1.83	4.94	37.50	176.50	74.00	0.80	0.90	2.175
5	e	1.73	0.21	1.94	4.95	40.50	155.00	126.00	1.30	0.90	.
5	f	1.66	0.16	1.83	4.99	13.50	145.00	180.00	1.20	0.80	1.975
5	g	1.72	0.14	1.86	5.03	6.00	122.50	246.00	1.20	0.70	.
5	h	1.76	0.07	1.83	5.19	12.00	122.50	216.00	1.30	0.80	.
5	i	1.60	0.26	1.86	5.51	18.00	207.50	132.00	1.20	1.30	1.775
5	j	1.41	0.43	1.85	5.44	37.50	182.50	112.00	1.10	1.90	.
5	k	1.65	0.24	1.89	5.38	52.50	195.00	112.00	1.40	2.10	.
5	l	1.64	0.43	2.07	5.75	51.00	160.00	98.00	1.10	2.20	1.925
5	m	2.06	0.48	2.54	5.88	43.50	147.50	106.00	1.60	3.90	.
6	a	1.84	0.21	2.04	4.66	19.50	120.00	76.00	0.90	0.80	.
6	b	1.43	0.11	1.54	5.06	28.50	125.00	48.00	1.00	0.90	1.575
6	c	1.48	0.27	1.75	5.07	31.50	135.00	64.00	0.90	1.10	.
6	d	1.46	0.18	1.64	4.73	37.50	137.50	92.00	0.80	0.90	.
6	e	1.66	0.11	1.77	5.02	21.00	167.50	140.00	1.20	1.10	1.975
6	f	1.51	0.13	1.64	5.16	10.50	127.50	190.00	1.10	0.80	.
6	g	1.38	0.00	1.39	5.08	7.50	127.50	216.00	1.00	0.70	.
6	h	1.40	0.13	1.53	5.03	9.00	150.00	210.00	1.00	1.00	1.575
6	i	1.52	0.20	1.72	5.31	36.00	190.00	112.00	1.00	1.30	.
6	j	1.44	0.50	1.95	5.27	34.50	150.00	86.00	1.10	1.50	.
6	k	1.63	0.16	1.78	5.33	48.00	165.00	112.00	1.30	2.10	2.2
6	l	1.49	0.39	1.88	5.46	39.00	130.00	88.00	1.20	2.00	.

6	m	1.98	0.17	2.15	5.13	39.00	200.00	112.00	0.90	2.30	1.975
7	a	2.12	0.32	2.43	4.96	28.50	160.00	94.00	1.00	0.90	.
7	b	1.83	0.28	2.11	5.28	27.00	141.50	78.00	0.90	0.50	2.175
7	c	1.93	0.18	2.11	5.02	37.50	120.00	68.00	0.90	1.20	2.05
7	d	1.91	0.17	2.08	4.82	30.00	167.50	92.00	0.80	0.90	.
7	e	1.83	0.22	2.05	4.76	15.00	117.50	132.00	1.30	1.10	.
7	f	1.72	0.29	2.00	4.95	12.00	175.00	206.00	1.00	1.00	1.8
7	g	1.82	0.23	2.05	4.99	7.50	140.00	222.00	1.30	0.70	1.85
7	h	1.68	0.24	1.92	5.16	15.00	130.00	190.00	1.00	0.70	.
7	i	1.63	0.41	2.04	5.29	18.00	127.50	106.00	0.90	1.30	1.6
7	j	1.69	0.31	2.00	4.98	36.00	177.50	84.00	1.20	1.40	.
7	k	2.09	0.34	2.43	5.03	43.50	185.00	62.00	1.10	1.60	.
7	l	1.76	0.41	2.17	5.31	33.00	156.50	90.00	1.00	1.60	.
7	m	2.30	0.15	2.45	4.80	48.00	190.00	130.00	1.00	1.60	.
8	a	1.93	0.16	2.09	4.78	6.00	95.00	224.00	0.90	0.60	1.8
8	b	2.00	0.28	2.28	5.01	12.00	85.00	152.00	0.60	0.50	.
8	c	1.60	0.21	1.81	5.22	28.50	159.00	126.00	1.60	0.80	.
8	d	0.53	0.31	0.85	4.89	31.50	150.00	126.00	0.80	0.80	.
8	e	2.14	0.34	2.48	5.09	13.50	112.50	194.00	1.10	1.00	1.725
8	f	1.85	0.26	2.11	5.06	9.00	127.50	226.00	1.10	0.70	.
8	g	1.69	0.14	1.84	4.97	10.50	117.50	248.00	0.90	0.70	.
8	h	1.37	0.32	1.69	5.12	15.00	132.50	182.00	1.10	0.70	1.7
8	i	1.68	0.41	2.08	5.46	16.50	127.50	122.00	1.20	2.00	.
8	j	1.90	0.15	2.05	5.20	49.50	182.50	86.00	1.20	1.90	.
8	k	1.86	0.39	2.26	5.27	33.00	115.00	70.00	1.10	0.90	1.8
8	l	1.74	0.30	2.03	5.22	61.50	190.00	106.00	1.00	1.20	.
8	m	2.14	0.35	2.50	4.97	30.00	167.50	148.00	1.00	1.10	1.6
9	a	1.93	0.13	2.06	5.17	6.00	85.00	236.00	0.90	0.70	.
9	b	1.94	0.40	2.34	5.48	12.00	82.50	152.00	0.90	0.80	1.75
9	c	1.56	0.31	1.88	5.21	24.00	157.50	140.00	1.50	1.00	.
9	d	1.44	0.29	1.74	5.00	27.00	187.50	128.00	0.90	0.90	.
9	e	1.53	0.33	1.86	4.70	16.50	140.00	160.00	1.00	0.60	.
9	f	1.63	0.25	1.88	4.98	7.50	144.00	214.00	1.10	0.70	1.7
9	g	1.56	0.17	1.73	4.93	10.50	102.50	242.00	1.00	0.80	.
9	h	1.64	0.19	1.83	4.99	12.00	104.00	188.00	1.10	1.00	.
9	i	1.55	0.42	1.97	5.33	39.00	110.00	94.00	1.10	1.50	1.925
9	j	1.66	0.11	1.76	5.19	51.00	187.50	62.00	1.20	1.70	2.425
9	k	1.47	0.32	1.80	5.30	36.00	131.50	72.00	1.10	1.40	.
9	l	1.63	0.41	2.03	5.25	43.50	177.50	110.00	1.10	1.90	1.8
9	m	1.95	0.32	2.26	4.88	27.00	190.00	148.00	0.90	1.30	.

10	a	1.89	0.05	1.93	5.15	6.00	110.00	268.00	0.70	0.70	.
10	b	1.97	0.20	2.17	5.47	10.50	100.00	210.00	0.90	0.60	.
10	c	1.28	0.28	1.56	5.22	15.00	96.50	182.00	0.90	1.00	.
10	d	1.20	0.32	1.52	4.84	19.50	152.50	148.00	0.70	0.20	1.775
10	e	1.74	0.26	2.00	5.30	15.00	120.00	180.00	1.00	0.70	.
10	f	1.62	0.08	1.70	5.12	9.00	112.50	234.00	1.10	0.80	1.95
10	g	1.65	0.23	1.88	4.90	10.50	115.00	208.00	0.90	0.90	1.9
10	h	1.54	0.22	1.76	4.99	15.00	125.00	190.00	1.40	1.10	.
10	i	1.77	0.11	1.88	5.68	58.50	180.00	104.00	1.30	1.90	.
10	j	1.60	0.16	1.76	5.00	64.50	205.00	62.00	1.20	1.90	1.85
10	k	1.56	0.27	1.83	5.09	39.00	117.00	68.00	1.20	2.20	.
10	l	1.80	0.35	2.15	5.36	45.00	166.50	106.00	1.40	2.00	1.75
10	m	2.26	0.25	2.51	5.08	19.50	156.50	170.00	1.20	1.00	.
11	a	1.99	0.20	2.19	4.96	9.00	127.50	274.00	0.70	0.50	.
11	b	1.87	0.26	2.13	5.47	9.00	90.00	242.00	0.80	0.80	
11	c	1.72	0.21	1.92	5.37	13.50	127.50	200.00	0.90	0.60	1.625
11	d	1.40	0.39	1.79	5.18	22.50	152.50	160.00	0.80	0.90	.
11	e	1.64	0.20	1.84	5.00	9.00	105.00	170.00	1.10	0.90	.
11	f	1.53	0.12	1.64	5.43	9.00	132.50	218.00	1.10	0.80	2.175
11	g	1.35	0.34	1.68	4.84	10.50	131.50	228.00	1.10	1.10	.
11	h	1.59	0.07	1.66	5.09	13.50	120.00	196.00	1.20	0.30	1.725
11	i	1.58	0.20	1.78	5.32	31.50	149.00	108.00	1.20	1.40	.
11	j	1.61	0.20	1.80	4.62	61.50	136.50	58.00	1.20	1.50	.
11	k	1.27	0.28	1.55	4.91	45.00	170.00	82.00	1.20	1.50	1.7
11	l	1.75	0.41	2.16	5.25	48.00	185.00	116.00	1.50	2.10	.
11	m	1.85	0.25	2.09	5.03	21.00	185.00	152.00	1.10	1.20	1.625
12	a	2.05	0.27	2.32	4.79	13.50	127.50	256.00	0.80	0.70	.
12	b	1.86	0.17	2.03	5.26	10.50	121.50	244.00	1.00	0.90	1.7
12	c	1.74	0.27	2.01	5.24	13.50	147.50	200.00	0.70	0.80	2.025
12	d	1.61	0.20	1.81	4.94	19.50	121.50	162.00	0.90	0.80	.
12	e	1.70	0.22	1.92	4.86	22.50	235.00	154.00	1.80	1.20	.
12	f	1.49	0.34	1.83	5.32	12.00	147.50	200.00	1.10	0.90	1.8
12	g	1.78	0.19	1.97	4.80	15.00	147.50	226.00	1.00	1.20	.
12	h	1.72	0.17	1.89	4.85	16.50	155.00	210.00	1.40	1.40	.
12	i	1.87	0.24	2.11	5.15	27.00	170.00	112.00	1.30	1.20	2.2
12	j	1.75	0.20	1.95	4.74	61.50	252.50	72.00	1.30	1.20	.
12	k	1.66	0.45	2.11	5.02	48.00	145.00	78.00	1.30	1.60	.
12	l	1.79	0.36	2.15	5.37	51.00	197.50	118.00	1.20	1.60	1.825
12	m	1.93	0.37	2.30	4.88	16.50	130.00	154.00	1.00	1.00	.
13	a	1.94	0.16	2.09	4.50	9.00	157.50	254.00	0.70	0.60	1.85

13	b	2.15	0.39	2.55	4.98	12.00	97.50	256.00	0.70	0.60	.
13	c	1.89	0.38	2.27	4.92	12.00	120.00	188.00	1.00	0.70	1.475
13	d	1.98	0.23	2.21	4.75	19.50	125.00	152.00	0.90	1.00	.
13	e	1.94	0.20	2.13	4.95	16.50	124.00	146.00	0.90	1.20	1.7
13	f	1.72	0.14	1.86	5.35	9.00	125.00	202.00	1.50	1.00	1.575
13	g	1.55	0.22	1.77	4.85	12.00	161.50	216.00	0.90	1.00	.
13	h	1.98	0.17	2.15	4.93	7.50	112.50	226.00	1.40	0.80	.
13	i	1.86	0.26	2.12	5.41	13.50	115.00	166.00	1.00	1.10	.
13	j	1.96	0.17	2.13	4.94	43.50	142.50	90.00	1.20	1.00	.
13	k	1.62	0.32	1.94	4.98	55.50	165.00	90.00	1.00	1.40	1.725
13	l	1.98	0.31	2.29	4.94	40.50	185.00	112.00	0.90	1.30	.
13	m	2.03	0.35	2.38	4.84	21.00	139.00	154.00	0.80	1.00	.
14	a	1.72	0.17	1.88	5.22	7.50	111.50	250.00	0.90	0.80	1.675
14	b	1.98	0.28	2.26	5.48	7.50	117.50	224.00	0.80	0.50	
14	c	2.11	0.31	2.42	5.53	10.50	87.50	216.00	0.80	0.50	.
14	d	1.87	0.30	2.16	5.17	21.00	130.00	138.00	1.00	1.20	.
14	e	1.94	0.27	2.21	5.34	19.50	165.00	136.00	1.10	0.90	1.675
14	f	1.74	0.22	1.96	5.40	7.50	130.00	212.00	1.20	0.70	.
14	g	1.57	0.21	1.78	5.15	9.00	146.50	250.00	1.00	1.00	.
14	h	2.08	0.20	2.28	5.15	9.00	164.00	256.00	1.00	1.00	.
14	i	1.82	0.11	1.92	5.41	9.00	87.50	208.00	1.00	1.20	1.8
14	j	1.70	0.30	2.01	5.05	46.50	180.00	128.00	1.20	0.50	.
14	k	1.60	0.39	1.99	5.11	46.50	170.00	112.00	1.10	1.40	1.45
14	l	1.52	0.28	1.80	5.42	39.00	301.50	156.00	1.20	1.10	.
14	m	1.65	0.19	1.83	4.72	13.50	112.50	160.00	0.80	0.80	1.9

APPENDIX D

Appendix D. Summary of statistics.

General Linear Models Procedure

Duncan's Multiple Range Test for variable: TOTAL YIELD

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 179 MSE= 114.7265
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 5.709521

Number of Means	2	3
Critical Range	12.51	13.17

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	POTASSIUM
A	81.806	58	160 + ppm
A B	78.845	122	80-160 ppm
B	67.050	2	45-80 ppm

Alpha= 0.05 df= 178 MSE= 117.7253
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 7.137672

Number of Means	2	3	4
Critical Range	11.33	11.93	12.33

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	PHOSPHORUS
A	89.070	2	60 + ppm
A	80.075	94	0-9 ppm
A	79.520	32	15-60 pmm
A	78.668	54	9-15 ppm

Alpha= 0.05 df= 177 MSE= 117.3244
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 16.90748

Number of Means	2	3	4	5
Critical Range	7.352	7.739	7.996	8.186

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	pH
A	81.973	47	4.75-4.9
A	79.417	91	5-5.5
A	78.014	10	6-7
A	77.830	26	5.5-6
A	76.818	8	4.5-4.75

Alpha= 0.05 df= 178 MSE= 117.9146
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 1.899441

Number of Means	2	3	4
Critical Range	21.99	23.15	23.92

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	COPPER
A	92.61	1	4.2+ ppm
A	85.53	1	2.60-3.4 ppm
A	79.61	170	< 1.80 ppm
A	78.62	10	1.80-2.60 ppm

Alpha= 0.05 df= 177 MSE= 115.8827
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 33.62459

Number of Means	2	3	4	5
Critical Range	5.181	5.454	5.635	5.769

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MAGNESIUM
A	81.872	37	120-16
A	81.255	42	80-120
A	79.616	48	200+
A	77.553	21	160-20
A	76.641	34	<80

Alpha= 0.05 df= 179 MSE= 117.5821
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 19.15966

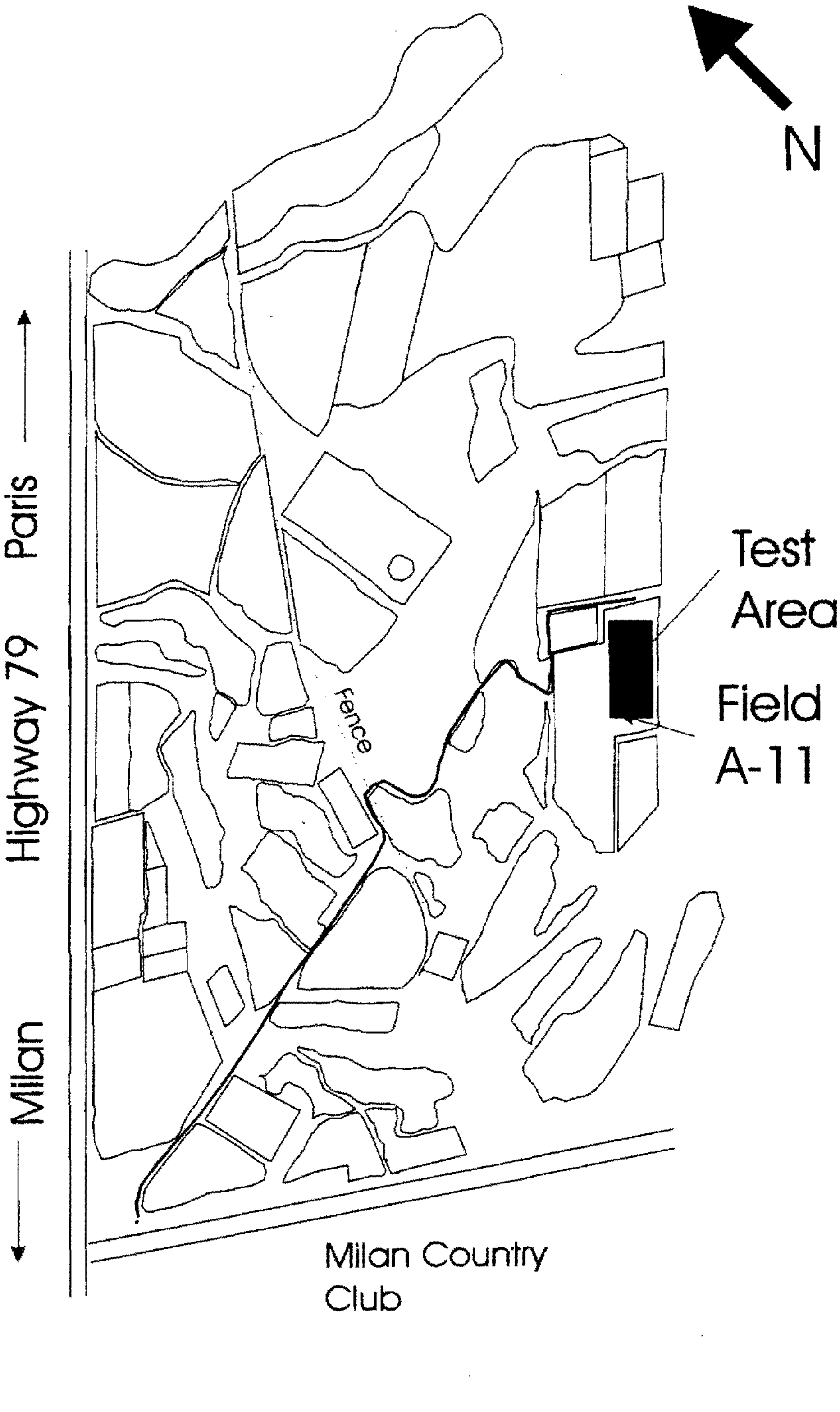
Number of Means	2	3
Critical Range	6.913	7.277

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	ZINC
A	82.162	20	2-6
A	79.426	152	<2
A	78.195	10	6+

APPENDIX E

Appendix E. Sketch of north tract portion of the Milan Experiment Station.



VITA

Michael Spencer Palmer was born on October 13, 1971 in Nashville, Tennessee. He graduated from White House High School in May of 1989. In August of 1989 he entered Tennessee Technological University and received a Bachelors of Science degree in Agricultural Engineering Technology in May of 1994. The following August he entered graduate school at The University of Tennessee with an assistantship in Agricultural Engineering Technology. In May of 1997 he completed the requirements for a Master of Science degree in Agricultural Engineering Technology.