To the Graduate Council:

I am submitting herewith a thesis written by Stephen Addison Schneiter entitled "Spatial Variation in Selected Vegetable Crops in Tennessee." 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:

Accepted for the Council:

Associate Vice Chancellor
and Dean of the Graduate School

Spatial Variation in Selected Vegetable Crops in Tennessee

A Thesis

Presented for the

Master of Science

Degree

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Stephen Addison Schneiter

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In memory of
my Grandfather

Walter S. Schneiter

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ABSTRACT

Modern technology, environmental concerns, and economics are a few of the reasons that today's producers are forced to develop better ways to produce crops than in previous years. The technologies and practices of site-specific farming or prescription farming is rapidly spreading across the farming industry. The ability to spatially control the application rates within a field is revolutionizing the modern farm.

To evaluate the feasibility of this new technology, the degree of spatial variation present in the field should be known. The history of the field and the crops must be documented as well as the requirements for the crop to be grown. In recent years there has been considerable research in the area of site-specific farming relating to grain and cereal crops. However, there has been little research, on site-specific farming in vegetable production.

During the 1993 growing season The University of Tennessee Departments of Agricultural Engineering, Plant and Soil Science conducted an experiment in conjunction with PictSweet Inc., a commercial vegetable producer, to document the magnitude of spatial variation and the effect of the variation on yield of two vegetable crops. Two fields in West Tennessee that were in production by the producer were selected. The first field was in vegetable production for the first time by the producer and the crop grown was Italian green beans. The second field had been in vegetable production for several years. The crop under investigation in this field was butter beans. Plots were established in both fields which measured ten feet in length along a single bed Each field was monitored for

plant response, soil moisture, and soil fertility.

Soil fertility variables considered from each plot include aluminum, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorous, zinc, and pH. Measurements of these soil variables were collected twice during the growing season of the crop and at two depths, 6-12 inches. Soil moisture samples were taken several times during the growing season using a neutron probe. These variables were then analyzed graphically and statistically to study the variation of each across the fields and to determine their effects on the crops.

Spatial variation existed across both fields not only in yields but also in the other variables measured and collected. Results suggested that there was not any single limiting variable in the study. However, it was apparent that there were interactions between variables that had an effect on yield. It was also noted that interactions not measured in this study played a role in spatial variation in the crops. Many of these variables were management controlled.

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CHAPTER 1

INTRODUCTION

Modern farm management is recognized today as a complex process. Examples of those complexities are concerns about the environment, the increased cost of agricultural inputs, and the ever-growing demand for higher yields. These concerns have resulted in the need for better management practices. Current management techniques involve, among other things, farming fields uniformly, when in fact fields are not uniform in every aspect. Uniform treatment of fields creates areas that are over- or under-fertilized, and thus not used efficiently. This study investigates and documents the necessity for area-precise management practices, or prescription farming, in Tennessee.

Prescription farming is also referred to as variable rate technology, site-specific farming, farming by the foot, and a host of other names. These terms refer to the manipulation of agricultural inputs based on the specific needs of the soil rather than treating the entire field as one soil unit. If the characteristics of a field are known in detail, and these characteristics can be related to geographical locations, the farmer can focus on areas that need attention and treat them according to yield potential (Chen, 1994). The field can then be divided into individual areas small enough to be considered uniform and treated accordingly.

Prescription farming depends highly on two technologies to function properly: a Geographic Information System (GIS) and a Global Positioning System (GPS). New advances in technology have led to the implementation of 24 GPS satellites orbiting the earth which transmit position information continuously while orbiting the earth. These advances in navigation make it possible for farmers to find their position anywhere in a field. GIS is a computer software package which, when combined with GPS, allows spatial and attribute data to be stored, manipulated, analyzed, and displayed.

The primary question that must be asked in any investigation of the need for prescription farming is whether significant variability actually occurs in the crop under question. The intent of this study was to test the variability in selected vegetable crops produced in Tennessee. This study attempted to discover the sources of variation and to learn whether the variation has a significant impact on yield.

Numerous studies currently implement various types of prescription farming techniques in an effort to affect the variability in yield. An extensive bibliography of current research being conducted in prescription farming and spatial variability is included with this work. Much of the variability research has been conducted in grain crops, and while interest continues to grow in this field, little work has been done to implement prescription farming in vegetable production.

The growing season for most vegetable crops is considerably shorter than the growing season for most grain crops. Therefore, more vegetable crop rotations occur per year. In these cases, crops are planted promptly, generally within a couple of days after harvesting the previous crop. This procedure strives for high output by maximizing the number of annual crops from a single field. Each crop may be fertilized at planting for its specific needs. In this type of operation, multiple factors can affect crop yield such as soil type, pH, moisture, slope, management, and residual effects from fertilizers and pesticides.

This study, while taking into consideration existing practices in prescription farming, focussed on observation and documentation of current farming practices and sources of variation in vegetable production by a major producer in West Tennessee.

Prescription farming has the potential to produce higher economic returns for the farmer as well as lower the potential for environmental pollution. A study documenting such variability is valuable to prescription farming research in the area of vegetable production. By investigating the sources that lead to variation, technologies such as GPS and GIS mentioned earlier can be used to manage the inherent variability within vegetable production fields.

Objectives

The objectives of this research project were (1) to measure the spatial variability in selected fields operated by a commercial vegetable farming operation, and (2) to determine the effect of this variability on yield.

CHAPTER 2

REVIEW OF LITERATURE

Spatial Variability

Research has shown in recent years that all fields are not the same. Fields consist of different soil types containing different nutrient levels for crop production. Maximum yield depends on manipulation of inputs to fully use the individual soil type's yield potential. Also, in addition to soil type, research has shown that other soil characteristics also affect yield variations across a field. Some of these characteristics include slope, soil moisture, weeds, wild-life, and shape of the field. Spatial variability refers to these different characteristics linked to a geographical point in the field.

Soil Properties. Beckett and Webster (1971) conducted research to evaluate all previous research in soil variability. Their review documented the variation in soil properties and determined the scope of available information on in-field variation. Their review focused specifically on

1) how the magnitude of variability increases with size of the area,

2) the variability of soil properties within profile classes at differing profile elevations, and

3) the variability of soil properties within soil mapping units.

The authors acknowledge through their research that soil properties vary with depth, that nutrient and water uptake are not the same at every depth, and that nutrient and water uptake vary by soil. Differences in soil sampling occur through errors in sampling, through use of different sampling techniques and handling procedures, and through variation in location of sampling depths. Beckett and Webster surmised that variation in soil properties from point to point are derived from

- parent material,
- climate,
- topography,
- physical and chemical processes, and
- biological activities.

Overall variability of soil will depend largely on the environment but will likely increase as the study area gets larger. Other areas that introduce variations in texture and moisture regime consist of plowing; sub-soiling, ridge or furrow; and drainage placement. The review showed that in most instances variations exist in topsoil rather than in the subsoil.

Renie and Clayton (1959) conducted a study on soil type and the variable effects soil type has on fertility. The study looked at different soil types in Canada and the variability in grain yield associated with the varying soil types. The study was conducted with small randomized blocks and included three fertilizer treatments and a control. The areas in the soil units selected for this study were chosen from the fields comprised of a single soil member derived from a common parent material. These areas had been determined to have developed as a result of variation in slope, aspect, drainage, and vegetation. Renie and Clayton found that the data illustrated variability in grain yield and response to fertilizer application within relatively short distances in any field where various soil patterns existed. Furthermore, he concluded that productivity data taken from any one small experimental plot cannot be representative of the whole field.

Carr et al. (1991), proposed that most fields are made of two or more soil types which contain different crop yield potentials. Their study tried to measure crop yield difference in contrasting soils in fields managed uniformly. The research was located on four selected fields in Montana consisting of two or more distinct soil types. Soil boundaries were determined by soil survey maps and aerial photography. Grain samples were collected at harvest using a research combine. The data was subjected to one-way analysis of variance with the soil map unit as the independent variable. Carr et al found a two to one variation in yield return for barley based on soil types.

Soil Fertility Variability. Research conducted by Carr et al. (1991) looked at the fertility make-up of fields that contained at least two different soil types. Twenty soil samples were collected and mixed from each plot. The samples were taken from 0-6, 6-12, 12-24, and 24-48 in. depths. Soil test results indicated variations among soil plots in each field for N, P, and K. Fertilizer recommendations were made for each soil type based on soil test, yield goals, and Montana State University fertilizer guidelines. Fertilizers were applied in randomized block design. Treatments were applied to 40 ft. by 5000 ft. strips where the treatments crossed soil boundaries. At harvest, test weight and yield were collected for each sample. This data was studied by analysis of variance using soil units and fertilizer treatments as independent variables. In addition, each soil map unit was evaluated as a location with fertilizer treatment as the independent variable. The study concluded that yields were similar for small grains when recommended fertilizer treatments were applied as soil unit treatments as opposed to whole field treatments.

Variable fertilizer rates and yield goals was also studied by Wibawa et al. (1993). The authors stated the importance of fully understanding the soil fertility variation across fields and that the practice of varying fertilizer rates shows promise for the future. The goal of their paper was to determine whether variable rate fertilizer practice based on a combination of soil fertility information, yield goals, and soil map units would improve crop yields and net returns.

The first step in the study was to map in detail the sixty acres in North Dakota where the test would be run. Soil samples were taken from every 50 feet across the test area and were measured at 0-6, 6-12, 12-24, 24-36, and 36-48 in. depths. The soil samples were then analyzed for nitrogen, phosphorous, potassium, pH, zinc, iron, manganese, copper, and organic matter. The test were run from 1989 to 1991 growing wheat and barley in fields of varying plot size and mapping units.

Wibawa et al. found that by using a 50-foot grid in the sampling procedures apposed to 250-foot sampling grid returned higher yields. This led to their conclusion that one can accurately evaluate fertility variability in any one field by using the 50-foot sampling grid.

Polito and Voss (1991) showed in their research that increased nitrogen fertilization above recommended levels did not increase yield and could potentially increase environmental contamination.

Ndiaye and Yost (1989) found that the cabbage yield was greatly dependant on the level of potassium in the field. Their results showed that an average test level for potassium from a field may be misleading if spatial variations were not considered. The results showed that higher yields were harvested in areas of the field that had higher levels of potassium. Areas of the field that had lower concentration produced higher yields when additional potassium was added.

Similar findings were noted by Holmes (1993) in his study of soil properties for his variable rate technology project in Missouri. His findings showed that phosphorous values ranged between 9 to 90 kg. (20 to 200 lbs). and potassium ranged from less than 45 to 181 kg. (100 to 400 lbs.) in the same field. Holmes also commented that information collected for variable rate fertilizer application can also be used for variable rate pesticide application.

Roder et al. (1989) studied the effect of crop rotation on soil fertility variation. He concluded that with crop rotations between the sorghum and soybean crops, less nitrogen fertilizer would be required along with holding increased available soil moisture to obtain increased yields. Roder found that in continuous cropping systems increased fertilizer applications were necessary.

A study conducted by Oberle and Keeney (1990) examined precipitation and nitrogen levels that affected yield in Wisconsin. Their research specifically looked at the causes of nitrogen leaching into the soil with respect to the uptake by the plant and the amount of residual fertilizer in the soil. The amount of soil moisture was measured and precipitation data was collected during months before planting the corn. The rainfall data was studied for pre- and early- season effects of moisture on yield. Soil profile, the amount of residual NO_3, and precipitation data were compared to grain yield. Regression models were assembled using the collected data, and analyses were made for the variations affecting yield. Oberle and Keeney concluded that site-specific data were needed for accurate nitrogen usage in fertilization recommendations. Information on study of pre- and early- season precipitation is also useful in determining crop yield potentials and fertilizer recommendations. Other factors determined to be important for site-specific recommendations include soil organic matter contents, rooting depths, drainage, and current crop and fertilizer prices.

Soil Moisture. Polito and Voss (1991) determined the combination of producer-controlled variables that would give maximum yields under prevailing climatic conditions. The intent of their research was to determine which inputs generate a yield equal to that of the predicted value (490 bushels per acre) instead of the actual yield of 110 bushels per acre. Some of the controllable factors observed in this study were plant density, row spacing, nitrogen, phosphorous, potassium, and time of fertilization. The resulting harvesting from the experiment varied from 40 to 234 bushels per acre. The study concluded that unless the climate could be controlled, the risk for lower yields became greater. One suggested possible source of water input control was irrigation.

Research in 1989 conducted by Roder et al. looked at the relationship between soil moisture and sorghum and soybean yields, particularly the amount of water available to the plant in continuous soybean, continuous sorghum, and sorghum-soybean rotation. The study occurred over a six-year period, with precipitation and soil moisture data being collected for the research period. Soil moisture was measured using a neutron probe (Campbell Pacific 503 DR, Campbell Pacific, Pacheco, CA.), measuring in 30 cm (11.8 in.) increments to a depth of 120 cm (47.2 in.). The conclusion was that continuous cropping lowered the amount of moisture penetration into the soil, yielding a lower moisture reading, especially soybean crops.

Or and Hanks (1992) researched the effect that spatial variability induced by nonuniform water application has on soil water and crop yield. The authors pointed out that crop yield can be affected by irrigation management practices, especially under- or over-irrigation. Spatial variabilities of soil properties also affect the amount of water stored and moisture availability to plants. It is essential to consider spatial variability when determining the amount of water used to irrigate, since irrigation affects crop yield. Soil water availability is dependant on the variability of soil particles and on uniform irrigation practices. Or and Hank's objective was to find a method for investigating the effects of water deficiency and soil variability on crop yield.

An irrigation system was designed that distributed varying amounts of water by using drippers with different flow rates. The flow rates used in the study consisted of 0, 2.7, 5.3, 8.0 10.7, 13.3, and 16.0 mm/h respectively. The drippers were spaced at 1 meter intervals and were controlled by commercial pressure regulators. Soil moisture measurements were taken using a neutron probe (Campbell Pacific Nuclear). Access tubes were installed in each plot, one for every dripper. Measurements were made at only one depth, 0.3 m., and thirty random measurements were made outside the test area to document the spatial distribution in the rest of the field. Crop response measured in the corn crop consisted of plant density and plant height at various times during the growing season and also in yield for each 1 meter section of plot.

Results from the study suggest that plant height was affected by the variation in applied water. There tended to be more variation throughout the growing season in the plots that were set up for a predetermined calendar irrigation schedule than in plots that were scheduled for nonuniform irrigation.

Further studies in this area showed that yields are affected by variation in moisture retentive soils and that increased cultivation practices affected the moisture availability to a crop (Beckett and Webster, 1971; Evans and Catt, 1987).

Yield. Costigan and McBurney (1983) looked at the variation in vegetable yields in two different fields classified as the same soil series. Both fields incorporated the high use of fertilization before seeding. The study concluded that yields for cabbage and lettuce were identical when the experiment was conducted in a greenhouse where all factors were controlled. Yields varied by as much as 32 percent when grown in the field test.

Ndiaye and Yost did similar research in 1989 looking at variable yields in cabbage with respect to varying levels of fertilizer. They found that yields in one field ranging from 25 tons per hectare to 39 tons per hectare.

The causes of crop yield variations were investigated in 1987 by Evans and Catt. The research was conducted on cereal grains at four sites in eastern England, where crops were planted along transits at each site. Plots were taken from 0.5m sections of each transect. Soil samples were analyzed, and soil moisture and pH were estimated from augured cores taken from similar soils. Plant growth was measured by counting plant stands and measuring plant heights. Aerial photographs were taken for each site at numerous times during the growing season. At harvest, yields were measured by weighing grain combined from each plot.

The researchers concluded that causes of visual variations could be related to various geological and archaeological features. Some of these features included pits, post-holes, ditches, in-field river channels, and periglacial soil patterns. Aerial photographs revealed most of these features at the four sites. Photographs also pointed to differing germination and growth rates appearing as darker areas on the fields. The different rates led to varying crop densities. Increased fertilizer rates over portions of the fields produced higher yields in those areas. The researchers summarized that crop patterns arise as a result of many contributing factors and that further research would be required to point out the most important factors and determine whether these factors continually affect yield for a given site.

Karlen et al. (1990) showed corn yields to vary from 0.1Mg per ha to 2.8 Mg per ha in 1986 and 1.1 to 5.0 Mg per ha in 1987, from a four year study in South Carolina. They found wheat yields to vary 3.5 to 62 Mg per ha in 1987.

Colvin et al. (1991) showed that corn yields from the highest yielding areas of a field in Iowa in 1989 were among the lowest yields from the same area in 1990. Based on comparison of yields from 12.2 meter plots there were some plots across the field with a reported two to one yield ratio.

Pringle et al. (1993) research yield variations in corn and wheat using a yield flow sensor attached to a Case-IH combine. Two GPS units were set up in the field for position location. Yield maps were then created using data from the yield sensor and the position data. Both crops were grown on separate fields in Iowa. The corn crop was mapped from a 4.48 hectare field and ranged in yield from 3.80 tons/hectare to 16.90 tons/hectare. The wheat crop was mapped from a 17.82 hectare field. Yields for this field ranged from 0.59 tons/hectare to 4.02 tons/hectare.

Management Practices

Beckett and Webster (1971) pointed out in their research that human management also plays a large role in variability. Sources that cause variability include

- intense grazing, which increases areas of P and K,
- misplacement of fertilizers, by over-spraying or under-spraying, and
- clogged nozzles.

The authors pointed out that management requirements would increase substantially if the areas were broken down into any smaller parcels, thereby outweighing any advantages to the smaller division of variation.

Karlen (1990) documented yield variation tendencies in corn crops and defined the sources of these variations, with a four-year study in coastal plains soils. Such sources were thought to include areas that are prone to leaching and run-off and areas that are over fertilized. It was Karlen's hypothesis that without such documentation, better utilization of fertilizers and water cannot be achieved. The study was an observation of current farming trends and farm management practices by the producer. Soil maps from the local soil conservation service were used to identify soil mapping units in the test fields. Relationships between practices and yield variations were found to be both positive and negative. The final conclusions were that (1) more development was needed for a specific management practice, and that (2) while observing current practices, and comparing yield variations to map units, the only changes that could be derived were minor. These changes did not lead to the large changes in economical practices or relief in environmental concerns originally hypothesized by the researchers.

Colvin et al. (1991) pointed out that for the best yields year to year will depend heavily on management practices. Maps of the field as well as field history are important aspects of management according to Colvin, however the management plan should also consider some sort of risk assessment for each crop.

Proper collection of history for crop production has been documented in research conducted by Schueller, 1988; Macy, 1991; Han, 1992; and Chen, 1994. Macy reports the step by step procedure for documenting spatial variability on a farm as well as obtaining the data needed for accurate databases. Macy's work in Indiana mirrors work done by Holmes (1989) in Missouri. The 133 acre Macy Farm was mapped and broken up into sub-fields. Macy then explains how he used this information along with yield goals to develop a philosophies for meeting the set goals. These philosophies included establishing the proper chemical application rates, seeding rates, and application procedures. Macy concluded that each cropping season data added a new layer of information to the producer's database and more precise goals can be set and implemented.

Analysis of Spatial Variability

Spatial variability analysis of soil properties and crop yields has been addressed in research by Burgess and Webster, 1980: Gaultney et al., 1988: Ndiaye and Yost, 1989: Colvin et al., 1991: and Pringle et al., 1993. One of the more popular techniques makes use of Kriging techniques and semi-variances. Burgess and Webster define Kriging as a method of predicting values, in the form of weighted averaging, without bias and with minimum variation. Kriging can accurately be used as a means of spatial prediction. Burgess reported that the first step in Kriging is the determination of data variation. To do this data must be submitted to a semi-variogram. A variogram is, on average, half of the average squared difference between points of a given distance.

The semi-variogram has two important features: (1) it reveals the nature of the geographic variation in the property of interest, and (2) it is required to provide kriged estimates at previously unrecorded points.

Scharf and Alley (1993) and Bhatti et al. (1991) addressed the issue of statistical handling of data. They stated that accepted methods of laying out research trials cannot accurately account for spatial variation in the field. Many tests have been run examining agricultural practices such as tillage, varieties, fertilizer rates, growth regulators, row spacing, and others. While these practices have been shown to increase yields in tests, spatial variability can actually mask the effect of the practice. Scharf and Alley examine a statistical procedure that had previously been developed called the *nearest neighbor analysis* (NNA).

The principle of the nearest neighbor analysis is to use yield residuals from neighboring plots as covariates in the analysis of treatment effect on yield. The result is the assumption that high-yielding plots indicates a region of relatively favorable soil properties, while low yielding plots indicate a region of poor soil properties.

Scharf and Alley conducted yield trials by growing winter wheat in the coastal plain of Virginia. Plots were 5.5 meters wide by 5 meters long and were spaced in eight rows with five plots in each row. Each row was separated from other rows by a 2-meter alley, with two rows consisting of ten plots making up one block. Each plot in the block was applied a separate N fertilizer treatment.

Scharf and Alley concluded that position had a considerable effect on yield at all four locations and that nearest neighbor analysis was a superior blocking technique for accounting for the observed position effects. No significant treatments were detected using the traditional ANOVA procedures. Using the nearest neighbor analysis unmasked significant effects at two of the four locations. The conclusions using the nearest neighbor analysis match the conclusion from individual analysis from the two sites. The authors concluded that the nearest neighbor analysis adds to statistical power when analyzing spatial variability in fields and is a more accurate method of study than traditional methods.

Economics

Carr et al. (1991) also looked at the economic effect of fertilizing by soil type as opposed to fields. He proposed that for the highest economical yield, varying rates of fertilizer would be applied to the field types. He did find that yields were greater in fields where varying fertilizer rates were used on contrasting soils. The returns over variable costs were calculated by subtracting actual production cost in each field, based on farm records. Carr et al. concluded the importance of yield goals, accurate soil tests, and reliable fertilizer recommendations when developing a strategy for generating higher returns by farming soils and not fields.

Wibawa et al. (1993) found that treating fields on the 50-foot grid tended to increase crop yields compared to the fields on larger grids; however, it also tended to lower net returns to the farmer as the 50-foot grid resulted in increased cost for soil sampling, testing, and fertilizing. Another point presented was that the present system, utilizing a composite soil sampling system for fertilization combined with a yield goal for the field was the most profitable practice. The author mentioned that this might be the best practice for farmers that have fields with large differences between soil map units, because this is where the cost for sampling and testing greatly increased.

Holmes (1993) discussed the importance of variable rate fertilizer technology for offsetting the cost of grid soil sampling and analysis. Variable rate fertilizer led to higher yields in previously low yielding areas of the field in the Missouri study. He points out that variable rate technology is not the only process to consider when looking at the cost of producing crops. Other factors to be considered include chemical cost and cost of sampling and analyzing of the soil variables as well as the amount of sampling which will need to be done.

Another aspect of variation was discussed in an article by Dorr and Pannell (1992) in their research of the economics of improved spatially distributed herbicides. The article points out that using a boom-spray to apply herbicides can introduce several sources of spatial variation. Among these are

1) overlap of the spray boom resulting in double doses of the chemical,

2) under-lap of the spray boom so that the chemical is not even applied to some weeds,

3) variation in herbicide dosage along the boom due to nozzle design wind, boom height etc., and

4) variation in ground speed across the widths of the boom at corners.

The significance of the spatial variation is that the dosage reduces the average effectiveness of the herbicide within the field as a whole. This costs the farmer either through higher weed concentration, lower yield, or higher doses being required to achieve the same weed control.

The authors used an experiment in the control of annual rye grass in wheat to determine how spatial variations affect a herbicide strategy that is economically optimal. They also estimated the increase in profits that would result by reducing this variability. The authors used a model that predicted crop yield response to weed removal by herbicide application. Crop yield (Y) is represented using the following general form:

$$Y=Y_O[1-D(W)]$$

where Y_o is yield with no weeds present and D is the damage function representing the proportion of yield lost at weed density W. This model was then implemented by a computer spreadsheet program. Variability was entered into the spreadsheet by entering discrete probability distributions for each uncertain variable. The exact formula was determined by entering varying amounts of herbicide into the equation in varying increments. The study showed that the optimal dosage was affected little by spatial variation. The effects on profits, however, were more pronounced. Basically, as yield increases so, too, does the cost of allowing more weeds to survive as a result of variable herbicide dose.

Another reason for greater cost of variation of higher weed densities is phytoxic damage to the crop. Specifically, the higher the weed density, the higher the recommended dosage of herbicide. A double dose of this herbicide caused by overlap of the spray boom can result in phytoxicity. This depends on the crop tolerances, type of herbicide, and application conditions.

Through improved technology and greater care of application and handling by the farmer, partial reduction of variation can be achieved. By cutting cost for the producer, these improvements could lead to a savings of thousands of dollars.

CHAPTER 3

METHODS AND PROCEDURES

Two vegetable production fields were selected from a commercial operator in West Tennessee. The fields were selected because of a perceived uniform soil make-up. Each field was expected to produce three crops during the growing season; and, prior to the study, each field had produced greens for the spring growing season. The second crop in each field was investigated in this research project.

Field Identification

The first field, classified as Morgan soil, was labeled the Morgan field for this study. This field had previously been managed using a corn and wheat rotation for another farmer. Background information on the field was limited to that period since the harvest of the greens. The Morgan field was in its first year of production for the commercial producer and was planted in Italian green beans.

The second field, referred to as E-field in this investigation, has been in vegetable production for several years. This field is actually a 68.8 ha (170-acre) field of Luvual soil that had been irrigated and had been leveled to minimize slope. Plots were laid out so that the entire plot area was covered by a center-pivot irrigation system. The field had been treated with fertility amendments prior to the planting of each crop based on documented recommendations for maximum yield results of the crop. Butter beans were grown in the E-field for this study.

Plot Layout

In both fields, crops were planted in raised beds that measured 101 cm (40 inches) on center. Two rows were planted along the top of each bed. The initial step in the study was to lay out plots in both fields, which was done at germination so that plants could be readily identified in the bed and possible sites for variation might be observed.

An area of 2.31 ha (5.7 acres) in each field was marked off for use in the study. A reference point was staked and labeled for use in re-establishing a benchmark. After the benchmark was established, a transit was used to establish a baseline down the side of the field parallel to the rows. Perpendicular to this baseline, transits were laid out along which plots would be established. Distances were measured and recorded between each transect and from the transits back to the benchmark. The position for each transect along the baseline was visually located to adequately cover the visual spatial variation within the field. Once each plot was located, a flag was inserted at its center for later reference.

To minimize variation in the study from the six row planting equipment, the plots were selected from beds covered by a single planter box, the second box from the left hand side of the planter unit. Consideration was given as to which point the planter entered the field and the route the planter traveled through the field to be able to identify the beds that plots could be located in. The selected planter box path resulted in some plots being three beds apart while others were nine beds apart.

Transits crossing the baseline were labeled A through I. Each bed containing plots was assigned a number 1 through 14, with 1 being closest to the baseline. A total of 94 plots were laid out in the Morgan field and 96 plots in the E-field. The layout of plots and elevation for the Morgan field are shown in Figure 1 while the plots and elevation for the E-field are shown in Figure 2.

Plot Setup

Flags marking the center of each plot also marked the location for a moisture access tube. Fifteen centimeters (6 in.) was marked on each side with a flag allocating room for the neutron probe to be placed over the access tube. From the new flags, 1.5 m (5 ft) was measured and flagged on each side of the tube location. The total test section for each plot was about 3.1 m (10 ft), 1.5 m (5 ft) on each side of the moisture access tube. Figure 3 shows a plot layout with a neutron probe access tube installed. For each plot the same procedure was followed. Soil samples were taken, the Neutron Probe access tubes were installed, and gravimetric moisture samples were taken.

Fertility Test

Soil samples were taken from 0-15.2 cm (0-6 in.) and 15.2-30.5 cm (6- 12 in.) of soil depth. Four samples were collected from each five-foot section of every plot using a hand soil probe. Soil samples were prepared for analysis at the West Tennessee Experiment Station using the Mehlichs I Extraction Process (Klute, 1988). Soil pH readings were also measured on each sample at that time. After the pre-treatment process, the samples were sent to the University of Tennessee Plant Soil Science Department in

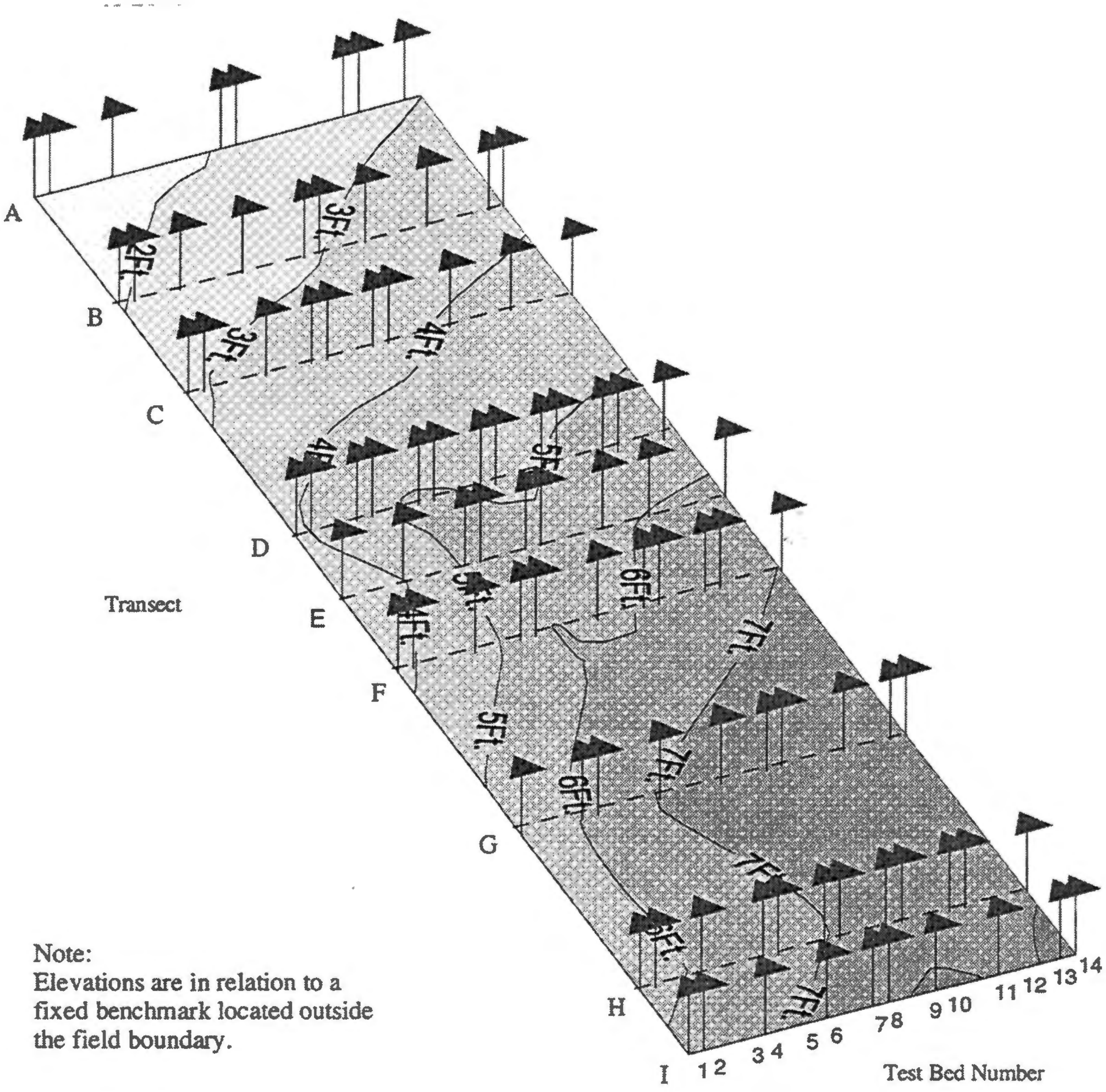

Figure 1:Elevation and plot location across the Morgan field

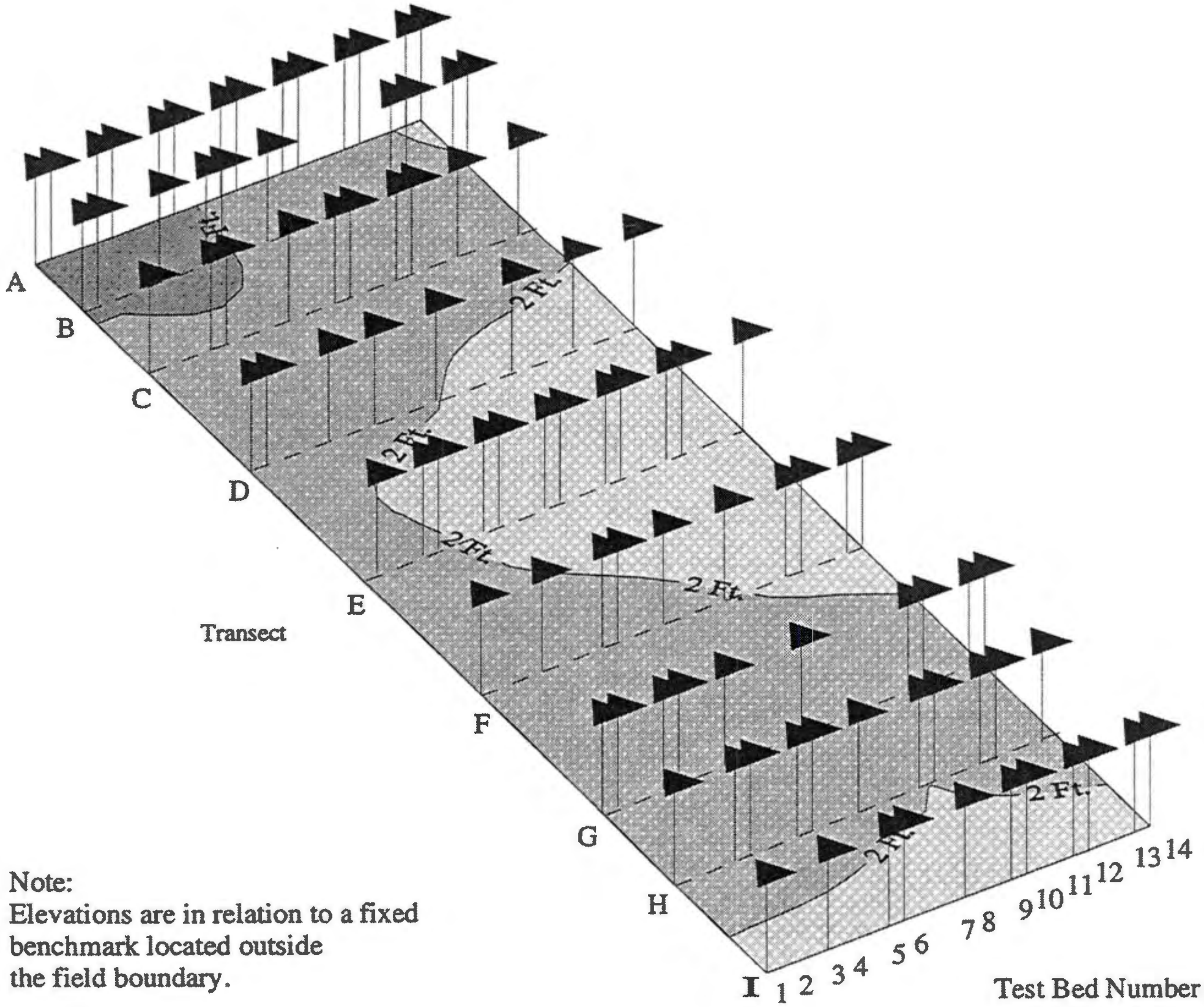

Figure 2: Elevation and plot location across the E-field.

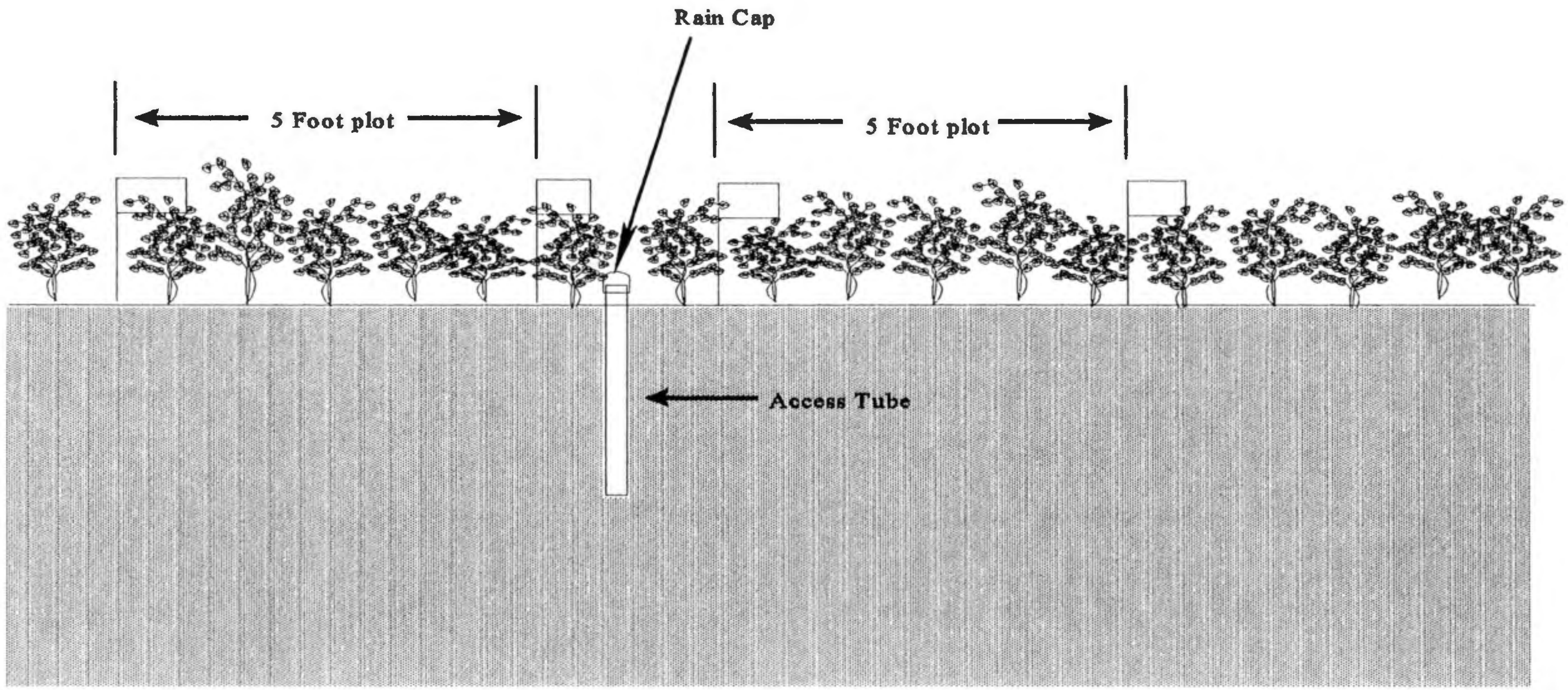

Figure 3: Illustration of a field plot showing an installed neutron probe access tube.

Knoxville for soil analysis. The samples were analyzed for Al, Ca, Cu, Fe, K, Mg, Mn, Na, P, Zn, pH.

Establishing Test Plot Coordinates

After the plots were identified, the coordinates for each plot were established with respect to an established reference point (benchmark). A total-station surveying instrument was used to measure the elevation and coordinates for each plot with respect to the benchmark. With this information, the plots in the field were accurately located at any time in the future as long as the reference point could be re-established. This will enable future researchers to precisely reproduce the plot layout in this study. Tables A1 and A2 in Appendix A list the coordinates for each plot in both the Morgan and the E-fields.

Moisture Sensing

Neutron Probe Theory. Moisture measurements for this study required frequent collection of data from the test plots. The means for collection of the data had to meet the following criteria:

- must be easy to use,
- must not interfere with management practices such as cultivation, and
- must not require taking soil samples from the plots with each sampling.

For these reasons, it was decided that the means of moisture sampling would be by neutron probe.

comparing the nuclear count ratios with gravimetric readings.

The calibration technique used for this study was done in a laboratory as opposed to field calibration. A soil column was constructed using 38.1 cm (15 in.) nominal diameter Poly Vinyl Chloride (PVC) sewer pipe. The column was 76.2 cm (30 in.) tall, which allowed enough room for the soil to be packed and for the probe to sit on top. The column was sealed at one end with a flat 1.27 cm (0.5 in.) piece of PVC to ensure a sealed environment and water retention. The column contained soil from the Morgan field that had been dried, sifted, and packed into the column to the bulk density of 1.42 g/cm^3 88.6 lbs/ft^3. The soil was packed in the column at 7.6 cm (3 in.) increments.

Accurately packing the soil in the column required calculations consisting of the diameter of the pipe and the bulk density of the soil to determine the precise amount of soil required for each 7.6 cm (3 in.) increment. The area of the pipe was multiplied by three inches to determine the volume in each 7.6 cm (3 in.) increment. The volume multiplied by the bulk density produced the amount of soil required for each 7.6 cm (3 in.) increment. The soil was packed around an aluminum access tube that had been placed in the center of the column. This soil column set-up, illustrated in Figure 4, simulates an access tube in soil conditions, that resembled those in the field.

The ideal test conditions for calibration involved obtaining readings ranging from purely dry soil up to a particular desired moisture content. Each time a reading was made with the probe, a gravimetric sample was taken, weighed, dried, and re-weighed again. Enough water was added to increase the moisture content in the soil by ten percent.

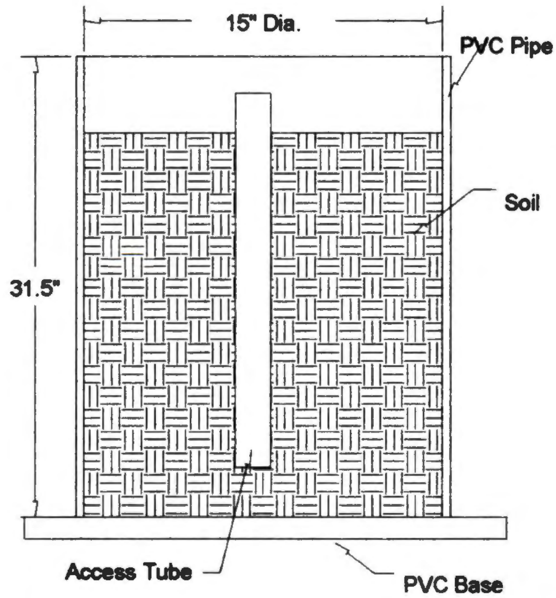

Figure 4: Cut-away view of neutron probe calibration set-up

Moisture content was determined on a dry basis using the formula:

$$\theta_{DB} = \frac{WT.\ of\ WATER}{DRY\ WT.\ of\ SOIL} * 100$$

To increase moisture ten percent, 9.10 kg (20.06 lbs) of water was added each time. Once added, the column was left to sit so the water could equilibrate in the column before a moisture reading was taken. Probe readings were taken along with collecting gravimetric samples. Water was added and the column left to equilibrate for twenty four hours. This procedure was repeated four times. Probe readings were taken at 15.2 and 30.5 cm (6 and 12 in.) depths as was done in the field. Soil samples were taken from the column at 15.2 and 30.5 cm (6 and 12 in.) depths using a soil probe. After gravimetric measurements were computed, soil was placed back in the holes to re-establish the desired compaction as best as possible.

Once the data had been collected, probe data were compared to the gravimetric data. It became apparent that since the measurements were taken at close distances, 15.2 and 30.5 cm (6-12 in.), there was some overlap in the area of neutron flow. This overlap was attributed to the radius of flow of the neutrons due to low moisture content. The calibration procedure thus caused false responses for the twelve-inch reading. For this reason the calibration computation was performed using only the readings from the first six inches. The data were analyzed using a least squares regression technique. The best fit model for the calibration of the Morgan soil was:

$$Y\ (\%DM) = 0.0105 + CountRatio * 0.0170$$

The calibration plot shown in Figure 5 produced an R^2 of 0.93. This regression line was then used to process the moisture data collected from the field to calculate the moisture content of the soil.

Access Tube Installation. In the field of green beans, seamless aluminum tubes 5.1 cm (2 in.) in diameter were used, while PVC tubes 5.1 cm (2 in.) in diameter were used in the butter bean field. Each access tube was 61cm (2 ft) in length. Access tubes were installed in holes dug in the soil profile with a hand augur. As the holes were dug, the first 5.1 cm (2 in.) of surface soil was discarded. The next 15.2 cm (6 in.) from the auger was

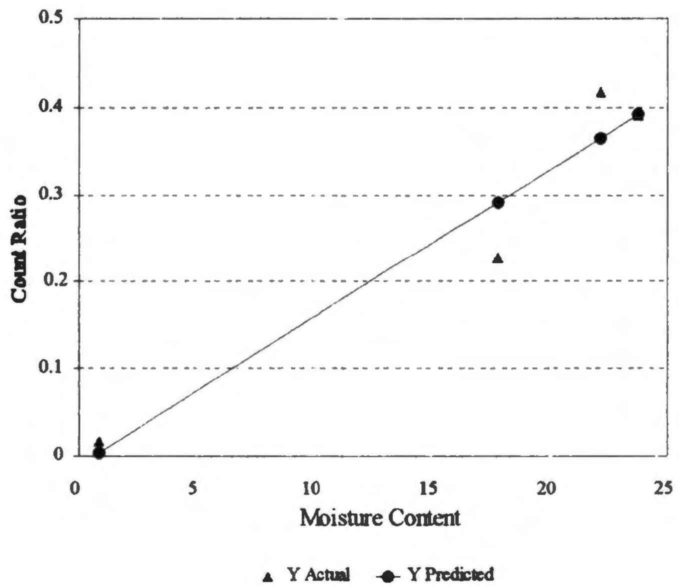

Figure 5: Neutron Probe Calibration Curve

collected and placed into a soil can and labeled (plot location and depth) for soil fertility analysis. The next 15.24 cm (6 in.) was collected and stored in the same manner. The remainder of soil was removed from the hole and set aside. Once the hole was augured, the tube was placed in the hole and inserted until the top 5.1 cm (2 in.) remained above the surface. The soil around the hole was then packed tight against the side of the tube to ensure no gaping holes existed that would allow water to run down the side of the tube. The tube was covered with a PVC end-cap to prevent water from entering the tube. The cap was painted bright orange to ease tube location in plant foliage.

Once all tubes were in place, the soil cans were collected and weighed. They were then dried, and gravimetric moisture measurements were taken. After each tube was in place, moisture measurements were taken with the neutron probe.

Access Tube Removal. After all plots had been harvested, the flags were removed from the plots. Neutron-probe access tubes were also removed using a tube puller. This puller, as illustrated in figure 6, was constructed of 1.3 cm (0.5 in.) all-thread rod shaft that had a 1.3 cm (0.5 in.) rod handle welded on to one end. Six rubber stoppers (size 9) were installed on the other end secured by a washer and lock nut. The sides of the rubber stoppers were shaved so that they were all cylindrical in shape. A flat piece of 30.5 cm (12 in.) x 5.1 cm (2 in.) x 0.3 cm (0.125 in) metal welded to a 1.3 cm (0.5 in.) nut tightened the stoppers forcing them against the sides of the tube allowing them to be removed. The field was left completely empty, with the removal of all markers and plot material, so that the producer could run harvest equipment in the field.

Producers Field Management

Morgan Farm. The producer used a pre-determined standard practice for field preparation to establish the Morgan field. The field was first cultivated to break up the top soil, turned under using a moldboard plow, disked to break the large clumps, and smoothed using a field cultivator. Treflan™ herbicide was applied during the cultivation phase of preparation. Beds were created using a bedding tillivator and then planted, two rows per bed, with Roma II Italian green beans (lot number TG2569). The seeding rate for this field was 100.1-112.1 kg/ha (90-100lbs/ac). The planter was set for 13-20 seeds per meter (4-6 seeds per foot). The Roma II seeds were pre-treated with Captan™, Thiram™, Lorsban™, Apron™, and Streptomycin™.

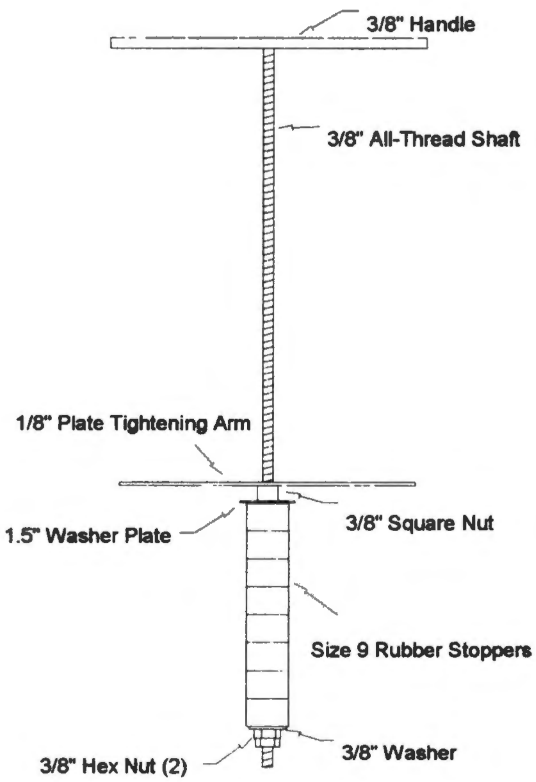

Figure 6: Neutron probe access tube puller.

The field was fertilized prior to planting with a mixture of 50-30-120 using a broadcast application. The Producer applied 431.6kg of this total blend of fertilizer per ha (385 lbs/ac), as well as zinc at 3.4 kg/ha (3 lbs/ac) and sulphur at 11.2 kg/ha (10 lbs/ac). After the field had been planted, it was side-dressed with ammonia nitrate at 112.1 kg/ha (100 lbs/ac). During cultivation of the field after germination, the field was treated with a combination of Treflan™ at 1.1 L/ha (1 pt/ac) and Dual™ at 840.6 g/ha (12 oz/ac) per ha. The field was also treated at several times during the growing season with insecticides. The first two treatments were with Sevin XLR™, with the application rates of 2.3 L/ha (1 qts/ac) and 2.9 L/ha (1.25 qts/ac). The next two applications were with Asana™, which was applied at 672.5 g/ha (9.6 oz). All insecticides were applied aerially.

E-field. Again the producer prepared this field using a pre-determined planting practice. The field was first cultivated to break up the top soil, turned under using a moldboard plow, disked to break the large clumps, and smoothed using a field cultivator. Treflan herbicide was applied during the cultivation phase of preparation. Beds were created using a bedding tillivator and then planted with Jackson Wonder lima beans (lot number 681). The seeding rate for this field was 89.7-95.3 kg/ha (80-85 lbs/ac). The planter was set for 9.75-16.25 seeds per meter (3-5 seeds per foot). The Jackson Wonder seeds were pre-treated with Thicam™.

The field was fertilized prior to planting with a mixture of 10-10-31 using a broadcast application. The producer applied 319.5 kg of fertilizer per ha (285 lbs/ac), as well as sulphur at 11.2 kg/ha (10 lbs/ac). After the field had been planted, it was side-dressed with ammonium nitrate at 168.2 kg/ha (150 lbs/ac). During cultivation of the field after germination, the field was treated with Treflan™ at 1.2 L/ha (1 pt/ac). The field was also treated on 6-18-93 with the herbicide Basagram™ using broadcast application at 1,401 g/ha (20 oz/ac). The field was treated once during the season with the postemergence herbicide Poast™ using broadcast application at 1.7 L/ha (1.5 pt/ac).

Production Harvest. The producer harvested the green beans from the Morgan field between June 19 and the 21. The field was harvested using Byron harvesters for the green beans. The total yield reported by the producer for the field was 125,403 kg (276,514 lbs) or 7,046 kg/ha (6,285 lbs/ac). The E-field was harvested on August 19 through the 21. The lima-beans were harvested using Hammachecks harvesters and modified Byron pickers using a 1978 International Harvester combine. The total reported harvest for this field was 53,108 kg (116,980 lbs), or 1,681 kg/ha (1,500 lbs/ac).

Plant Response

Fourteen days after germination plant height and population count were measured. Average plant height was measured by selecting three plants in each five foot plot section and measuring length from the ground up to the uppermost top leaf, then averaging these 3 measurements. Plant population was determined by manually counting the number of plants in each 1.5 m (5 ft) section. Measurements of plant height and population were made at this time and again at bloom. These measurements suggested that most plant growth occurred from germination to bloom, whereas, the growth from bloom to harvest was primarily in the development of the bean pod itself.

Yield response was measured by hand harvesting all of the row within each plot and observing the harvesting operation of the producer. Hand harvesting plots, resulted in an assumed harvesting efficiency of 100 percent. The yield data was used in the study to observe the variations within fields. Plastic bags were used to hold the beans when harvested, with one bag being used for each 1.5m (5 ft) section of plot. When harvesting the plots the entire plant was removed from the plot. Each bag was labeled to show plot location and the 1.5m (5 ft) section of the plot the samples had been taken. The bags were then removed from the field and weighed. They were then placed in a shady spot with the tops open to prevent the plants from heating and spoiling the beans. Once enough plots were harvested to fill a pick-up truck, the bags were sealed and trucked to the Jackson

Experiment Station, where they were placed in a cooler for further processing.

After cooling each bag was emptied, the plants were counted, and all beans, as visually identified, were manually removed from the plant. The beans were then weighed minus the plant, and all material was noted.

Statistical Analysis

The data from both fields were analyzed using statistical procedures modeled for a 95% confidence level using the SAS® software statistical package. Graphs of the data were produced using QPro® and Surfer® for Windows. A data set for each variable was created and then imported into SAS®, where each data set could be manipulated using the necessary data sets and discarding others. Appendix B contains tables of the statistical results and the probability for each variable for all models used. Appendix C contains the SAS® programs used in this study. Basic procedures to determine the average, ranges, minimum and maximum values, and the quartiles were run on the data. Regressions were run on the data sets.

CHAPTER 4

RESULTS

The main objectives of this study were to document the spatial variation in any one field and to determine whether the variation had a specific effect on yield. The study addressed many variables including soil moisture, soil pH, plant population, plant height, yield per plot, and yield per plant. Nutrient data obtained included levels of Al, Ca, Fe, Cu, Mn, Mg, P, K, Na, and Zn.

High levels of calcium carbonate in the E-field led to extraction errors beyond our control that caused unpredictable results. Therefore, soil fertility results are only reported for the Morgan field. The soil chemical analysis did not effect the pH measurements or moisture measurements in the E-field; therefore, these results are reported.

Background Observations

Visual comparison of the two fields showed the Morgan field to be a copious looking field, appearing to be high in organic matter content. The soil also had considerable structure. Figure 7 illustrates the visual uniformity in plant growth and topography of the Morgan Field. Soil bulk density for this field was measured at 1.42 g/cm^3 (88.64 lb/ft^3). The beds for this field maintained good structure throughout the growing season. The E-field, on the other hand, lacked a well-defined soil structure. The structure was so weak the beds could not hold together, and after a period of two to three weeks all signs of plant beds in this field had disappeared. Soil bulk density for this field

Figure 7: Photograph of Italian green beans (Morgan field) illustrating the visual uniformity within the field at harvest.

measured 1.39 g/cm^3 (86.8 lb/ft^3). The field was established in an area that was originally occupied by a stream that had been routed around the field to accommodate large-scale agricultural practices. It became apparent during this study that the stream was trying to re-establish itself in the field. During the course of the study several sink holes appeared in the field. Some of these holes were as much as three feet deep.

Yield Variation

There are both differences and similarities in the yield variability in each field. The Morgan field was a more productive field than the E-field as documented by the producer. Yields for the Morgan field were above average for this growing season while yields in the E-field were below normal. Figure 8 illustrates the sporadic variations in yield (from hand harvest) across the Morgan field. Variation was noted from this study in the yield harvest information from the Morgan field. As mentioned earlier, plots were hand harvested for 100% efficiency. The average harvest reported by the producer was 6,292 kg/ha (5,600 lb/ac) which was considerably lower than the hand harvest reported in this study, 11,558 kg/ha (10,310 lb/ac). This difference is illustrated in Figure 9 which shows the yield information from both this study and the average yield reported by the producer as plotted against plant population. There was a difference of 5,280 kg/ha (4,710 lb/ac) between the two sets of information. One possible explanation for the vast difference is the harvest efficiency of the mechanical harvesting unit. It was visually noted that, after the producer harvested the field, many plants with beans still remained . It was then deduced that the smaller plants were not picked up by the harvester. This led to lower net yields for the

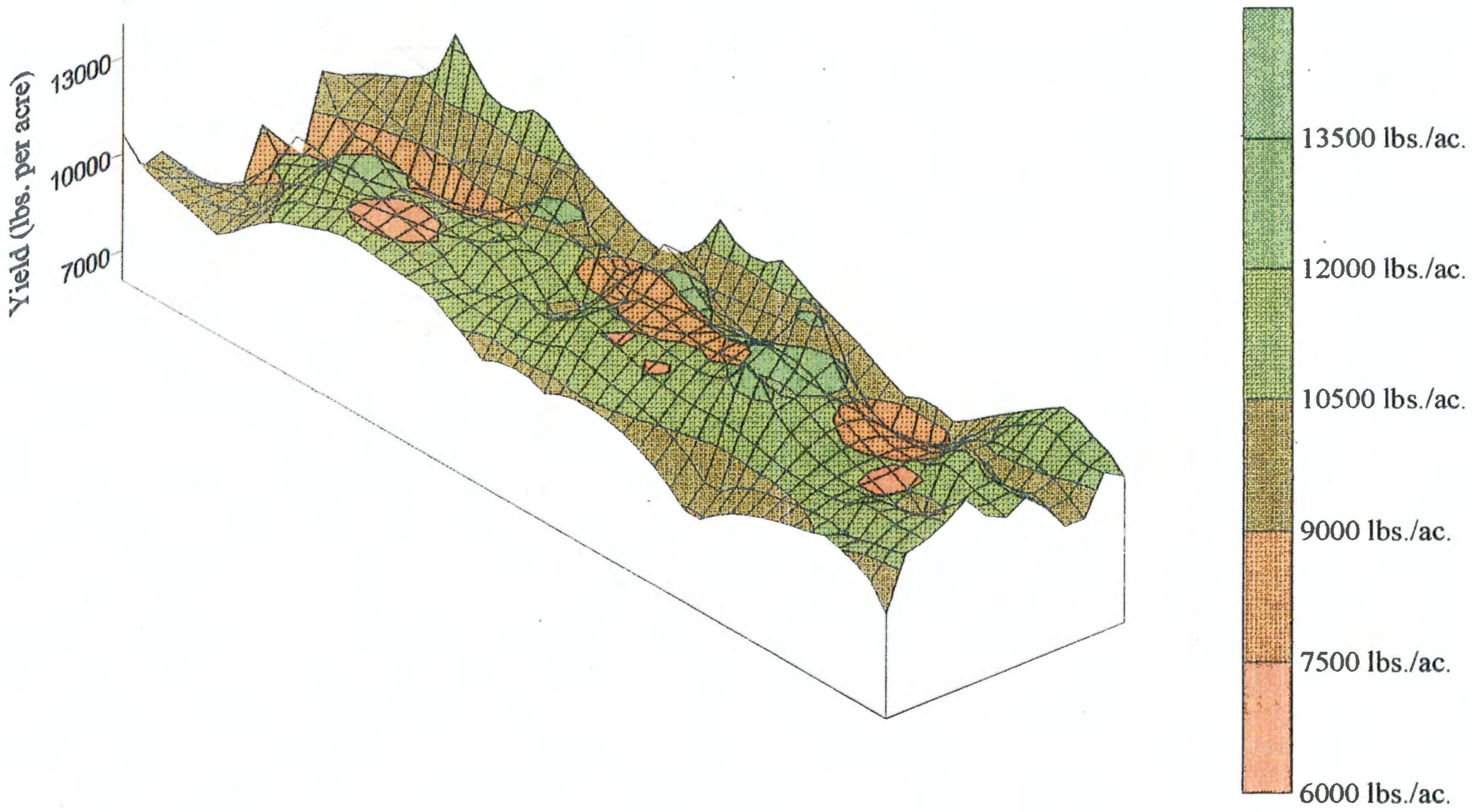

Figure 8: Hand harvested yield from the Morgan field.

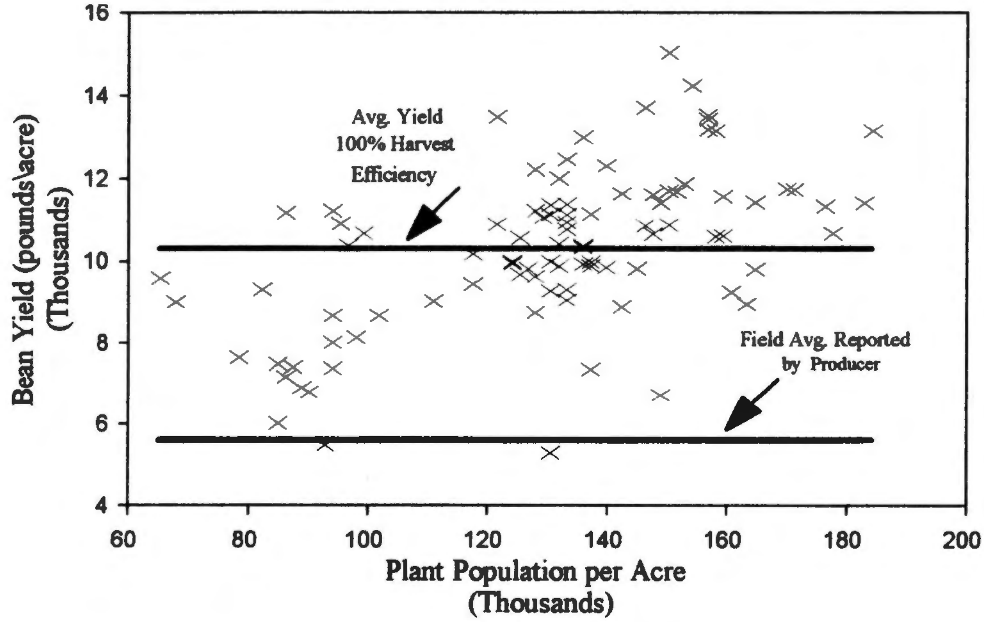

Figure 9: Yield variability in Italian green beans in the Morgan field.

producer and emphasizes the importance of plant height since only the taller plants were harvested. Step-wise-backwards-elimination statistical procedure was run using all soil nutrients, moisture data, and plant population as the independent variable and yield as the dependant variable. From this procedure Ca, Fe, K, Mg, Mn, and soil pH, soil moisture June 8 and 11, and plant population were statistically significant (α= .05) in explaining 68 percent of the yield variability. However, these variables were not significant when analyzed independently. Table 1 shows the statistical significance for each variable from the stepwise regression.

Certain areas in both fields produced higher levels of yield, while other areas produced less. The reason for this variation in each field appears to be different. Yields from the green beans ranged from 5,947 to 16,847 kg/ha (5,305 to 15,028 lb/ac), with an

Table 1: Summary of Variables found to be statistically significant in explaining the yield variability for Italian green beans in the Morgan field.

Variable	Prob>F	Average	Std. Dev
Soil Nutrients (ppm)			
Ca (0-6")	0.0185	1575	424.10
Fe (0-6")	0.0155	21.50	9.15
K (0-6")	0.0227	81.87	25.56
Mg (0-6")	0.00096	172.70	67.27
Mn (0-6")	0.0007	29.69	11.05
Ca (6-12")	0.0014	1726	442.70
Mg (6-12")	0.0084	199.50	93.39
Soil Moisture (lbs./cuft)			
June 8th (0-6")	0.051	20.16	3.72
June 11th (0-6")	0.0084	18.78	3.51
Plant Population	0.001	130,340	20.65
Soil pH (6-12")	0.051	6.668	0.334

average of 1,156 kg/ha (1,031 lbs/ac). Yields for the butter beans varied from 146 to 3,047 kg/ac (130 to 2,718 lb/ac), with an average of 1,206 kg/ha (1,076 lb/ac). Figure 10 shows the yield variation across the E-field. It was noted by the producer that the growing season was not a typical growing season for the crop in the E-field. The producer claimed that low rainfall, weed, and insect problems lowered the yield for this crop. An average yield for Butter Beans on this field would have been 2,802 kg/ha (2,500 lb/ac). Figure 11 illustrates the yield information from this study and the average yield reported by the producer plotted against population.

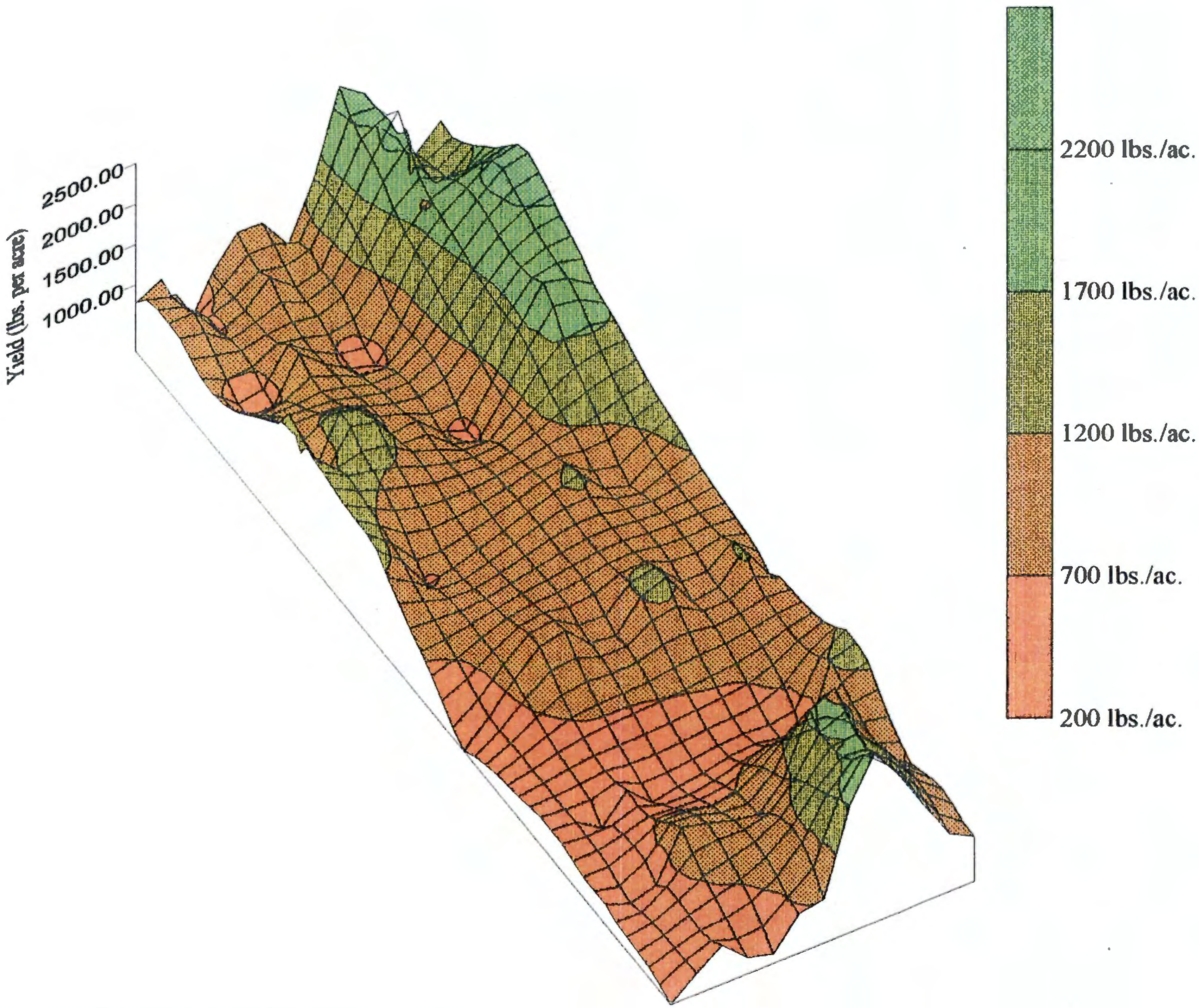

Figure 10: Hand harvested yield from the E-field.

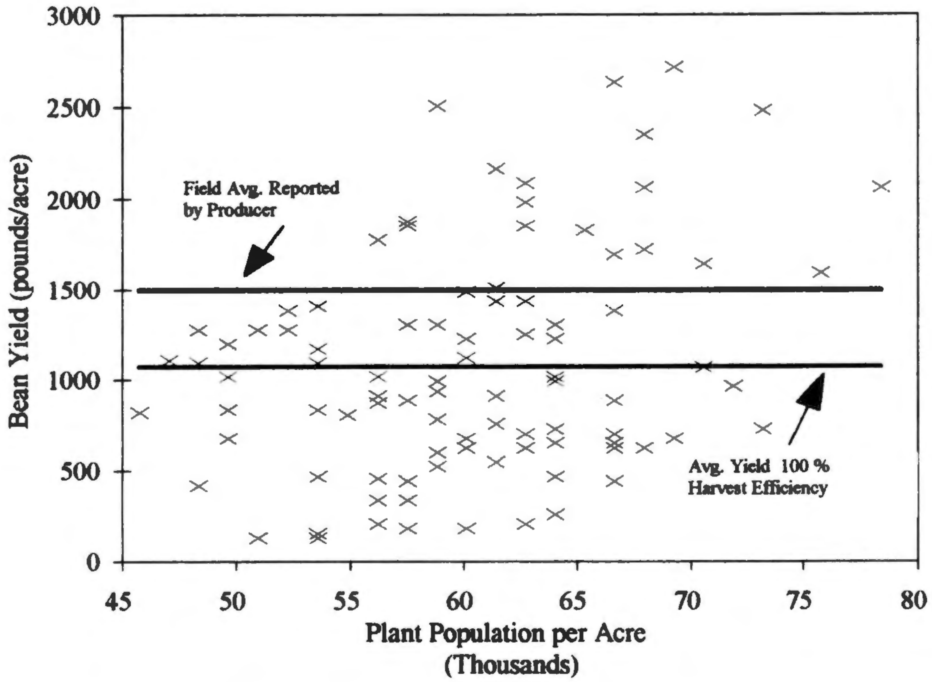

Figure 11: Yield variability in Butter Beans in the E-field.

Plant Population

Plant population showed a direct effect on the yield from both fields. As the number of plants increased per plot, the yield per plot also increased. When comparing the yield per plant, however, the relationship decreased. Figure 12 shows how an increase in plant population per plot led to a decrease in average yield per plant. Plant population varied from 73,251 to 206,568 plants/ha (65,340 to 184,259 plants/ac) with the average population being 146,121 plants/ha (130,340 plants/ac) in the green beans. Plant population varied from 51,275 to 87,901 plants/ha(45,738 to 78,408 plants/ac) in the butter beans with the average population being 67,497 plants/ha (60,208 plants/ac).

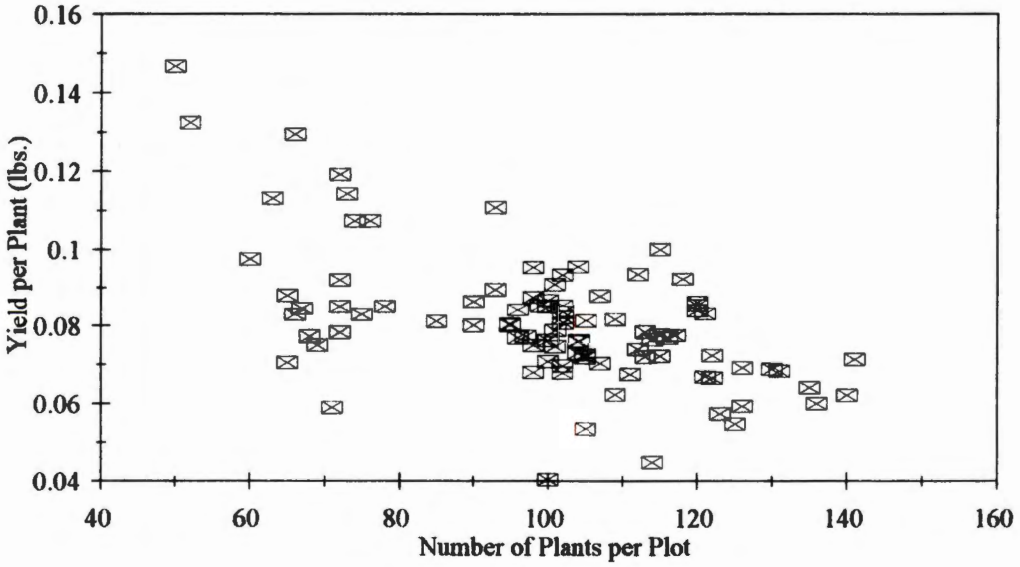

Figure 12: Graph showing relationship between population and yield per plant.

Plant population was significant (α= 0.05) in explaining yields from the backwards stepwise regression procedure (Table 1). Figure 13 illustrates the relationship between plant population and yield for the Morgan field, and Figure 14 for the E-field. These graphs also indicate there is almost a two to one variation in plant population between beds. This variability existed even though all of the beds were planted with the same planting unit.

Moisture

Even though the test area in the field were relatively uniform in topography a wide range in soil moisture was observed through the growing season. Moisture variation is

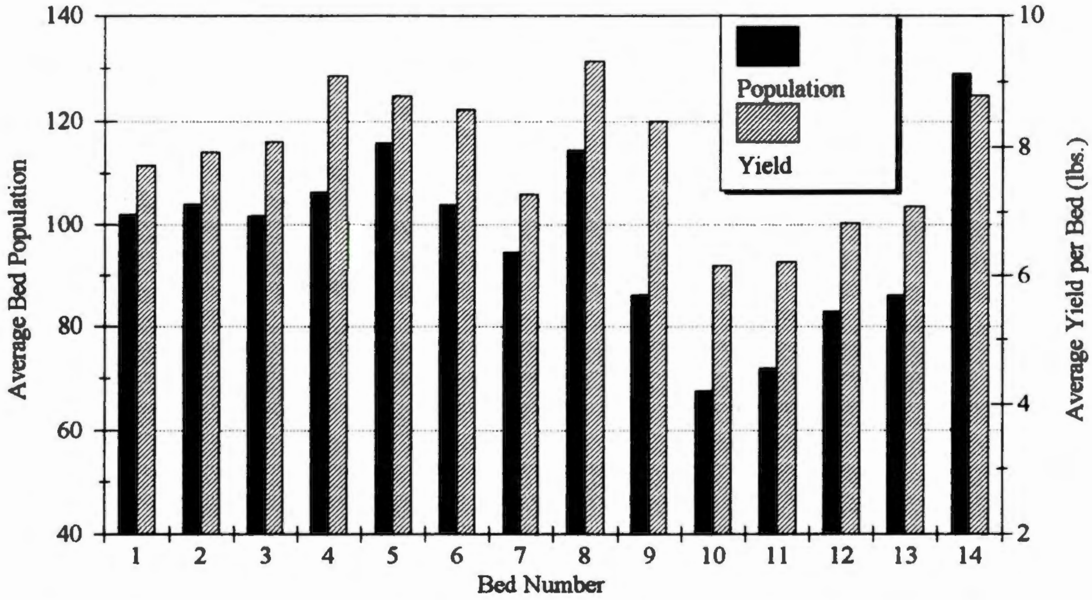

Figure 13: Yield across the Morgan field with average plant population.

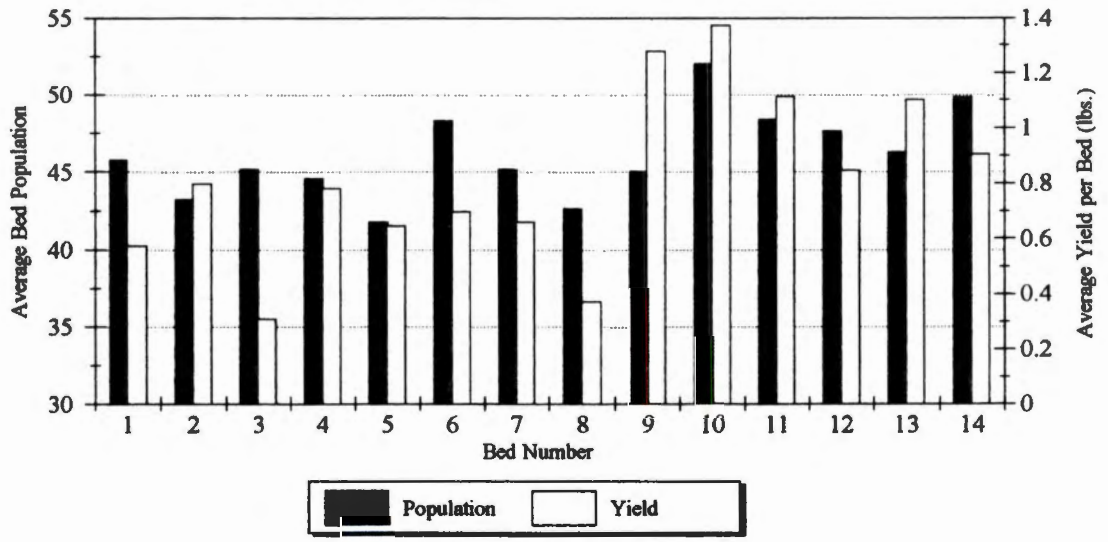

Figure 14: Yield across the E-field with average plant population.

illustrated in the surface graph, Figure 15, showing soil moisture content on four consecutive dates in order from the bottom to the top, for the Morgan field. Figure 16 shows the moisture variation for the E-field. These surfaces show how the moisture concentration varies spatially across the field and how the moisture levels changed over a period of time. Statistical analysis performed on the moisture data showed no correlation with yield which indicated moisture shortage to the plants was not a limiting factor. However when dates in the Morgan field are combined with other nutrient data moisture did become significant in explaining some of the yield variation in the Morgan field. The dates that appeared significant were for June 8th and June 11th. (Table 1). These dates were also occurred during the time of fruiting on the plants.

The irrigation unit covering the E-field had not been calibrated or maintained. The unit was experiencing leaks located close to the well head. Along the length of the boom, nozzles were clogged, had the wrong type of nozzle tip, or had no nozzle tip at all. Irrigation problems resulted in uneven moisture distribution across the study area.

Figure 17 shows soil moisture measurements from one of the producer's irrigation units. The graph illustrates the amount of soil moisture per section of the center pivot irrigation unit and the amount of water actually applied by each section. The graph emphasizes the importance of irrigation calibration, as each section of this unit applied varying amounts of water and thus varied the soil moisture content.

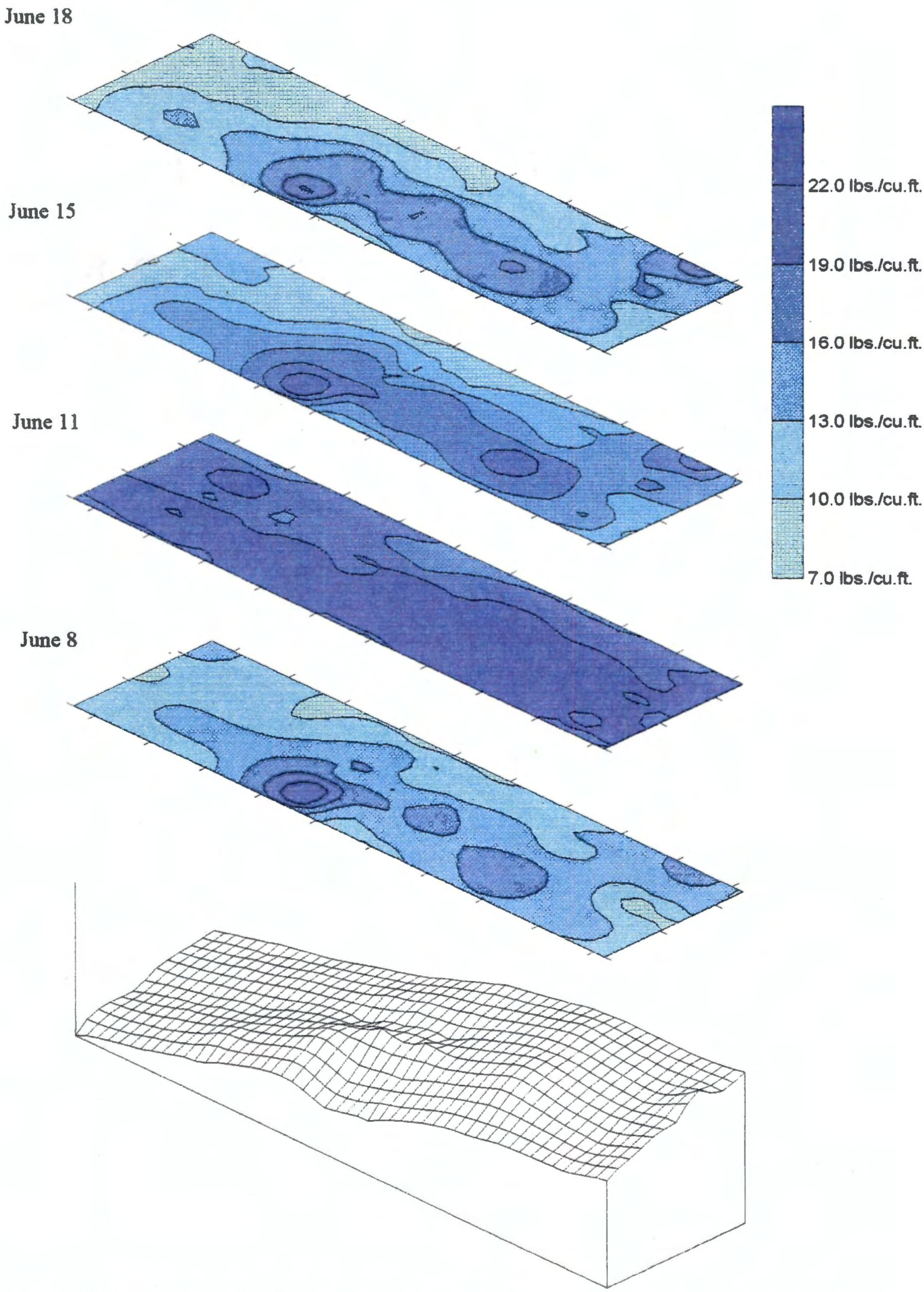

Figure 15: Moisture variability and movement on four consecutive dates in the Morgan field.

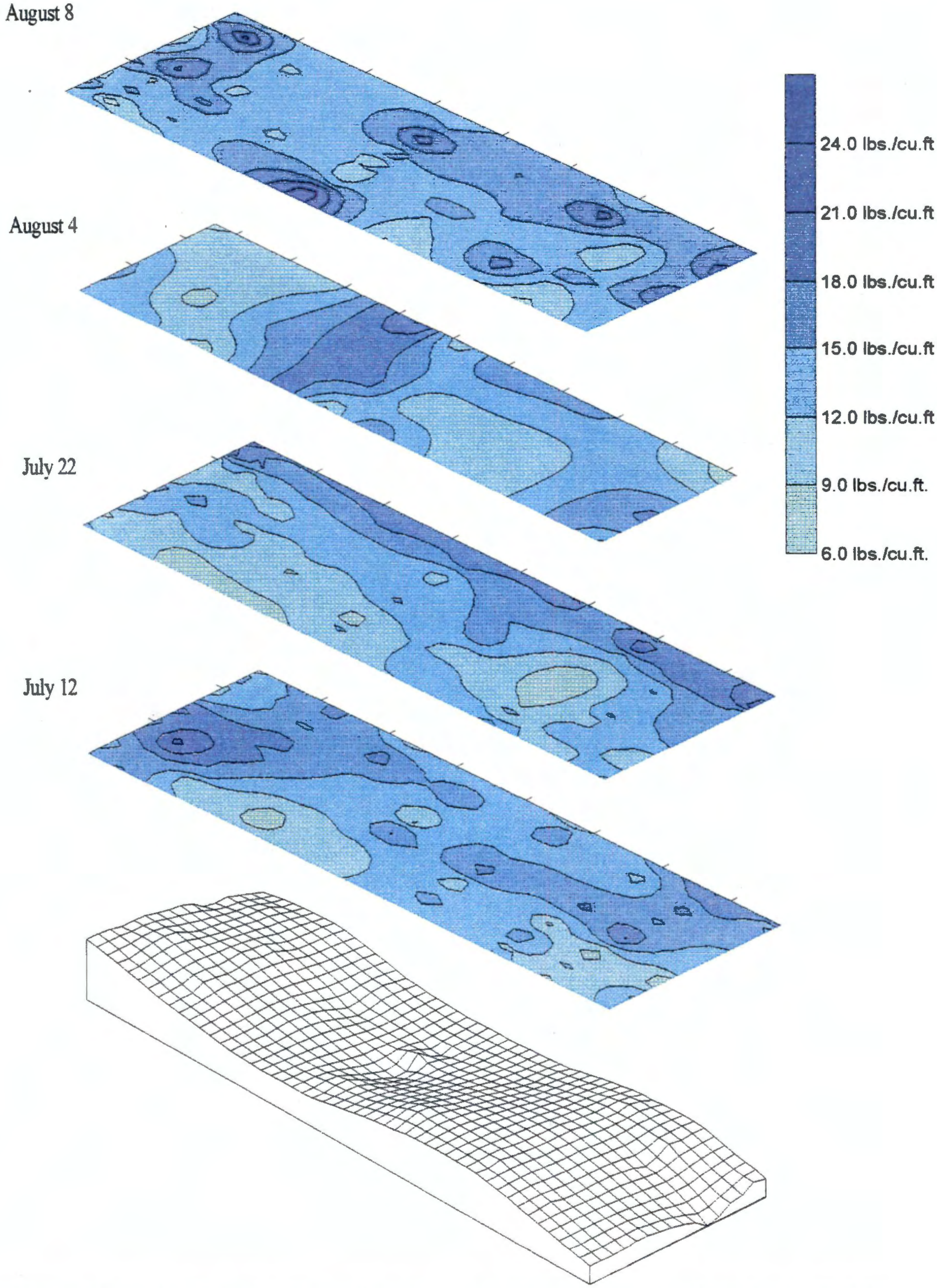

Figure 16: Moisture variability and movement on four consecutive dates in the E-field.

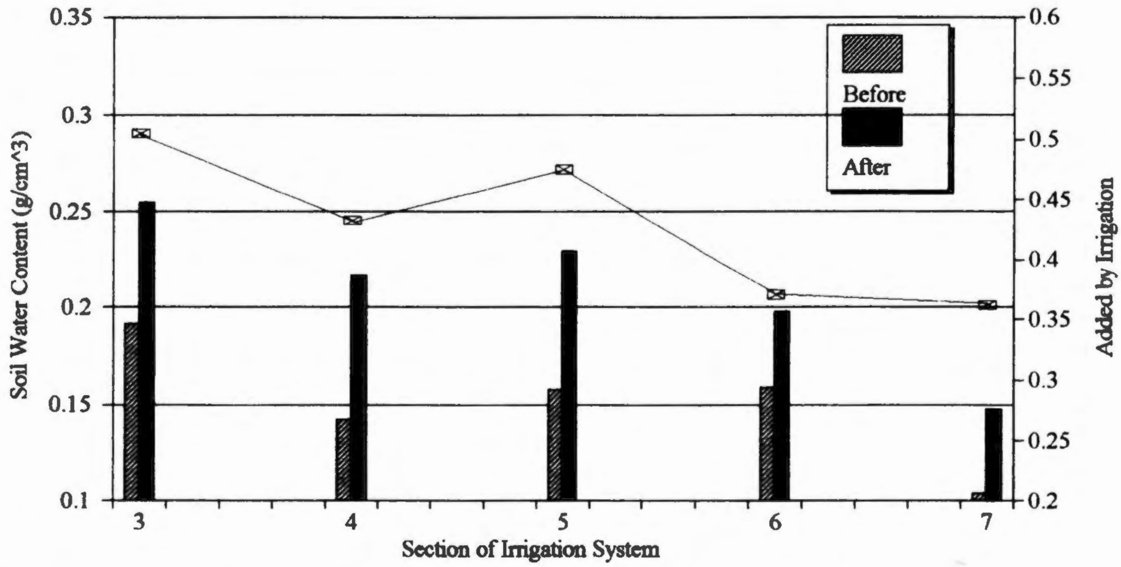

Figure 17: Soil moisture variability due to non-uniform water discharge rates along the length of an irrigation system.

Soil Fertility

Another source of variability observed in the study was soil nutrients. Soil variables Ca, K, Fe, Mg, Mn, P, along with pH were found to be statistically significant ($\alpha = 0.05$) as noted in Table 1. Graphs for each of these variables are included in Appendix C. Regression models were run for two- and three-way interactions. The only interaction found statistically significant ($\alpha = 0.05$) was calcium and magnesium.

Soil test results indicated a wide variation in fertility levels across the Morgan field. Figure 18 shows the variability in the distribution of potassium across the test area. The graph also shows the variation at depths of 0-6 and 6-12 inches. Not only was variation measured with depths, but also between the beds. Figure 19 illustrates the variation of fertilizer distribution between beds. Each bar on the graph represents the

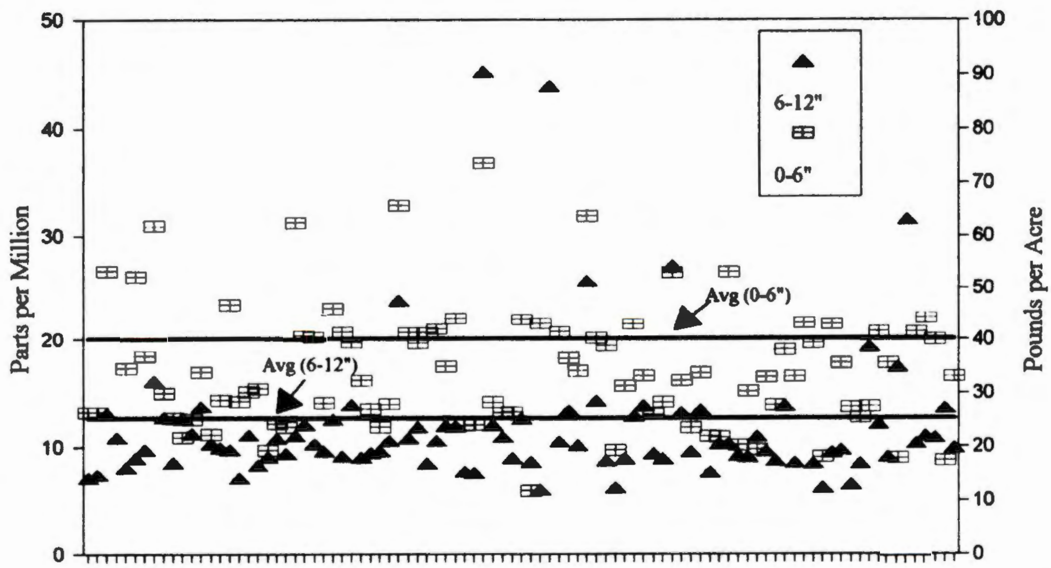

Figure 18: Distribution of Potassium across the Morgan field at germination.

average potassium level for 1000 feet of bed length. This graph is indicative of the bed-to-bed variation found for other elements.

Soil pH in the Morgan field varied from a low of 5.3 to a high of 7.4 with a plot average of 6.2. Soil pH was one of the variables that showed a correlation with yield. A correlation was also established between soil pH and plant height. Figure 20 shows that as the pH level increased, the average plant height also increased up to a certain point. The optimal pH level for plant height appears to be around 6.3. This is in-line with the recommended pH level reported by the Tennessee Agriculture Extension Service for green beans. This effect was apparent only in the Morgan field. Soil pH in the E-field did not vary by more than one-tenth across the entire study area. The average level for the field was 7.6 with a standard deviation of 0.18. Plant height varied sporadically across this

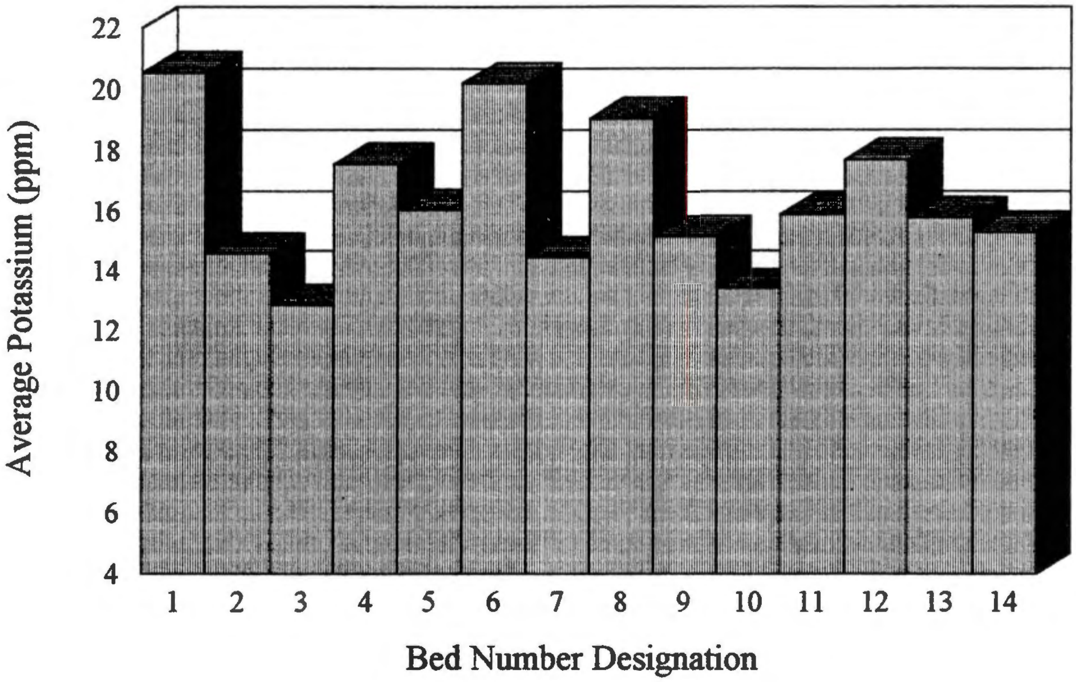

Figure 19: Average distribution per bed of potassium across the Morgan field.

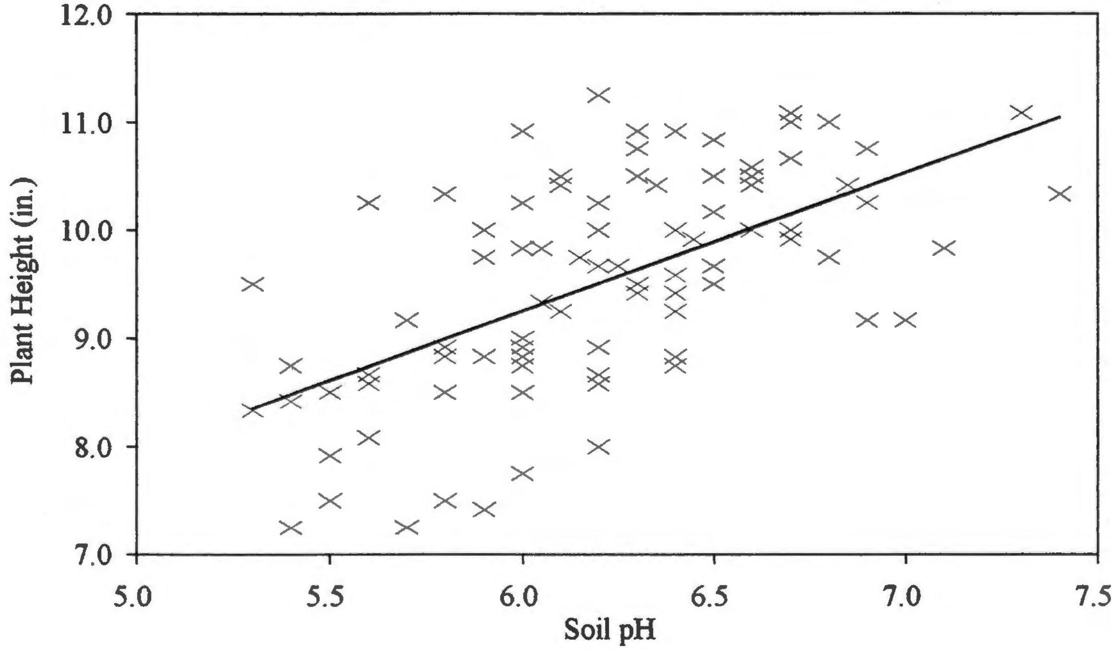

Figure 20: Effect of pH on plant height at maturity in the Morgan field.

field, however there was no statistical correlation between plant height and soil pH.

Other Sources of Variability

It became apparent that areas of the E-field which had high densities of Hornbean Copperleaf weeds also had low yield densities. At the end of the study, an attempt was made to verify the areas of the field which had high weed counts. A weed count showed that indeed high weed-density areas did in fact have the lowest yielding plots. It also became apparent that the areas abundant with weeds were also the areas affected by the mis-calibrated irrigation system. Figure 21 shows the effect of weed population on yield. Areas that had been over irrigated flourished with tall standing weeds and resulted in lower yields for butter beans. Figure 22 illustrates how bed rows and even plot marker flags even became over grown by the weeds.

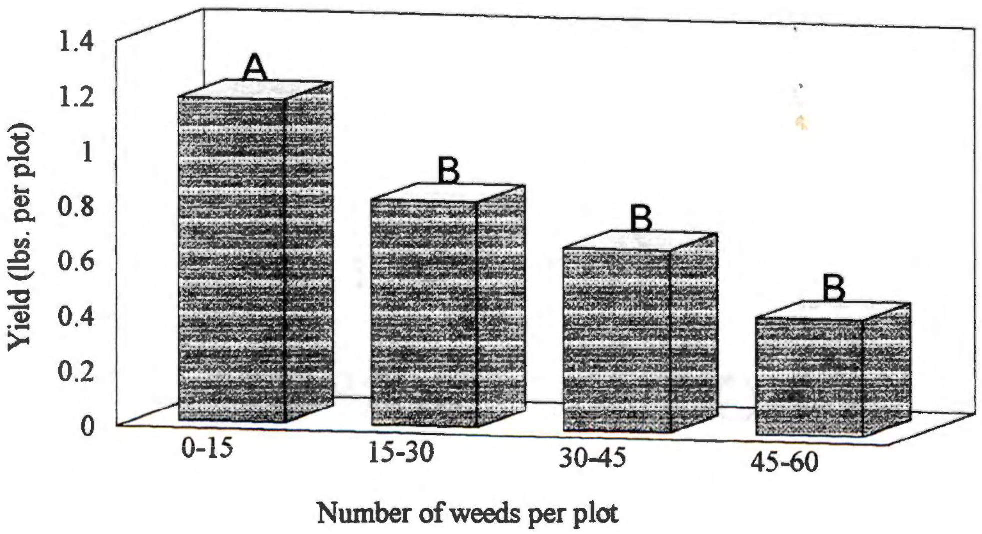

Figure 21: Yield in the E-field vs. Population of Hornbean Copperleaf weed.

Figure 22: Photo of butter beans (E-field) illustrating the weed pressure within the test area.

Chapter 5

CONCLUSIONS

This study was established to document the spatial variation in two vegetable fields in West Tennessee and determine whether the variation had a specific effect on yield. The following points were concluded from this study.

- Results suggests that there is no single factor that has a pronounced effect on yield. It became apparent during this study that there are many factors which do, in fact, affect the yield of a field when combined with other factors.
- This study has shown that the producer needs to be aware of all previous inputs applied to a field and existing soil fertility levels in a field in order to maximize yield.
- Visual assessment was not a good indicator of yield variability, in what appears to be a uniform yield.
- Soil analysis indicated a wide range of variability in soil nutrients. Soil nutrients Ca, Fe, K, Mg, Mn, P, along with pH were found to be statistically significant. However, these variables only account for 68% of the yield variability. These variables were not found significant when examined individually for explaining variations in yield.
- Soil moisture concentration varied spatially across the field and the

moisture levels changed over a period of the growing season in both crops.

- Variations in plant population in the green beans and butter beans significantly affected yields.
- During the course of the study additional factors, such as weed pressure, which were not initially accounted for, appeared to have an effect on the crop yield.

BIBLIOGRAPHY
AND
REFERENCES

BIBLIOGRAPHY

Auerhammer, H. and T. Muhr. 1991. GPS in a Basic Rule for Environment Protection in Agriculture. Automated Agriculture for the 21st Century. A.S.A.E. Proceedings of the 1991 symposium. December 16-17.

Bae, Y.H., J.K. Schueller, and B.A. Stout. 1987. Determination of Spatial Variability Yield Maps. 1987. A.S.A.E. paper number 87-1533. December 15-18.

Becker, H. and D. Senft. 1992. Satellites Key to New Farming Aids. Agricultural Research. February.

Borgelt, S.C. 1988. Geographic Information Systems for on Farm Use. A.S.A.E. paper number 88-1606. December 13-16.

Bresler, E. and G. Dagan. 1988. Variability of Yield of an Irrigated Crop and Its Causes 1. Statement of the Problem and Methodology. Water Resources Research, vol 24, 381-387.

Bresler, E., S. Dasberg, and G. Dagan. 1981. Spatial Variability of Crop Yield as a Stochastic Soil Process. Soil Sci. Soc. Am. J. 45:600-605.

Brown, N.W. and W.B. Saufferer. 1991. Integration of Site Specific Field Data into a Whole Farm Management System. Automated Agriculture for the 21st Century. A.S.A.E. Proceedings of the 1991 symposium. December 16-17.

Brownie, C., D.T. Bowman, and J.W. Burton. 1993. Estimating Spatial Variation in Analysis of Data from Yield Trials: a Comparison o f Methods. Agronomy Journal, vol. 85, Nov.-Dec.

Bunker, J.R., R.H. Lockerman, G.L. Westesen, and C.F. McGuire. 1989. ETPROBE: Computerized System for Processing Neutron Probe Soil-Water Data. Agronomy Journal. Vol. 81, Nov.-Dec.

Chanasyk, D.S. and R.H. McKenzie. 1986. Field Calibration of a Neutron Probe. Canadian Journal of Soil Science. 66: 173-176.

Comis, D. 1989. Alternative vs. Conventional Farming. Agriculture Research. October. 4-7.

Cooke, Linda. 1993. Fine Tuning Agriculture Inputs. Agriculture Research. January. 16-18.

Couch, D. 1993. Fishing by the Numbers. In-Fisherman. February. 39-53.

Gaultney, L.D., J.K. Schueller, J.L. Shonk, and Z. Yu. 1988. Automatic Soil Organic Matter Mapping. A.S.A.E. paper number 88-1607. December 13-16.

Gordon, G.P. and R.G. Holmes. Laser Positioning for Off Road Vehicles. 1988. A.S.A.E. paper number 88-1603. December 13-16.

Han, S. and C.E. Goering. 1992. Selection of Cell Size for Site-Specific Crop Management. A.S.A.E. paper number 927007. June 21-24.

He, B., C.L. Peterson, and R.L. Mahler. 1992. An Expert System Linked With a GIS Database for Spatially Fertilizer Application. A.S.A.E. paper number 92-3556. December 15-18.

Klemme, K.A., D.P. Froehlich, and J.A. Schumacher. 1992. Spatially Variable Technology for Crop Yield. A.S.A.E. paper number 921543. December 15-18.

Landers, A.J. and D. Steel. 1994. Precision Agriculture-A Variable Option for Future Arable Farming in Europe. A.S.A.E. paper number 94/1604.

Larsen, W.E., D.A. Tyler, and G.A. Nielsen. A 1991. Using the GPS Satellites for Precision Navigation. Automated Agriculture for the 21st Century. A.S.A.E. Proceedingsof the 1991 symposium. December 16-17.

Larson, W.E., D.A. Tyler, and G.A. Nielsen. B 1988. Field Navigation Using the Global Positioning System. A.S.A.E. paper number 88-1604.

Luellen, W.R. 1985. Fine Tuned Fertility, Tomorrows technology here today. Crops and Soils Magazine. Nov.

Matherson, G. 1963. Principles of Geostatistics. Economic Geology, Vol 58, 1246-1266.

McCauley, J.D. and A.D. Whittaker. 1993. Index for Describing Spatial Variability in Prescription Farming. A.S.A.E. Technical Notes. May\June.

Mulla, D.J. 1991. Using Geostatistics and GIS to Manage Spatial Patterns in Soil Fertility. Automated Agriculture for the 21st Century. A.S.A.E. Preceedings of the 1991 symposium. December 16-17.

Peitscher, A. 1992. Variable Rate Fliud Technology Arrives for Dealers. Equipment Technology. July\August.

Reichenberger, L., and J. Russnogle. 1989. Farm by the Foot. Farm Journal. March.

Scharf, P.C. and M.M. Alley. 1993. Accounting for Spatial Yield Variability in Field Experiments Increases Statistical Power. Agron. J. Vol. 85:1254-1256.

Schlotzhauer, S.D. and R.C. Littel. SAS Systems for Elementary Analysis. SAS Institute, Inc. Cary, NC.

Schoenecker, B. 1993. Variable Application Gets Variable Review. Farm Chemicals. December.

Schoenecker, B. 1994. Site-Specific Aplication. Farm Chemicals. May.

Shonk, J.L. and L.D. Gaultney. 1988. Spectroscopic Sensing for theDetermination of Organic Matter. A.S.A.E. paper number 88-2142. June 26-29.

Stafford, J.V. and B. Amber. 1990. Sensing Spatial Variability of Seedbed Structure. A.S.A.E. paper number 90-1624. December 18-21.

Stafford, J.V., B. Ambler, and M.P. Smith. 1991. Sensing and Mapping Yield Variation. Automated Agriculture for the 21st Century. A.S.A.E. Preceedings of the 1991 symposium. December 16-17.

Troxler Electronics Laboratories, Inc. 1983. 3300 Series Instruction Manual, Depth Moisture Guages. Research Triangle Park, NC. 27709.

Vanichen, R. and J. De Baerdemaeker. 1993. A Measurement Technique for Yield Mapping of Corn Silage. J. Agricultural Engineering Research. 55-1-10.

Warrick, A.W., D.E. Myers, and D.R. Nielsen. 1986. Geostatistical Methods Applied to Soil Science. Methods of Soil Analysis, Part I. 53-82.

Warrick, A.W. and W.R. Gardner. 1983. Crop Yield Affected by Spatial Variations of Soil and Irrigation. Water Resources Research, vol 19, 181-186.

REFERENCES

Beckett, P.H.T. and R. Webster. 1971. Soil Variability: A Review. Soil and Fertilizers, vol 34, 1-15.

Bhatti, A.U., D.J. Mulla, F.E. Koehler, and A.H. Gurmani. 1991. Identifying and Removing Spatial Correlation from Yield Experiments. Soil Sci. Soc. Am. J. 55:1523-15-28.

Burgess, T.M. and R. Webster. 1980. Optimal Interpolation and Isarithmic Mapping of Soil Properties, I The Semi-Variagram and Punctual Kriging. Journal of Soil Sci. 31, 315-331.

Carr, P.M., G.R. Carlson, J.S. Jacobson, G.A. Nielsen, and E.O.Skogley. 1991. Farming soils, Not Fields: A Strategy for Increasing Fertilizer Profitability. J. Prod. Agric. 4:57-61.

Chen, C., and M. Kocher. 1994. Better Utilization of Spatial Information for Agricultural Management. A.S.A.E. paper number 943077. June 19-22.

Colvin, T.S., D.L. Karlen, and N. Tischer. 1991. Yield Variability Within Fields in Central Iowa. Automated Agriculture for the 21st Century. A.S.A.E.Proceedingss of the 1991 symposium. December 16-17.

Costigan, P.A. and T. McBurney. 1983. Variation in Yield Between Two Similar Sandy Loam Soils. II. Causes of Yield Variation in Cabbage and Lettuce Crops. Journal of Soil Science. 34, 639-647.

Dorr, G.J. and D.J. Pannell. 1992. Economics of Improved Spatial Distribution of Herbicide for Weed Control in Crops. Crop Protection, vol 11, 385-390.

Evans, R. and J.A. Catt. 1987. Causes of Crop Patterns in Eastern England. J. of Soil Science. 38:309-324.

Gaultney, L.D. 1989. Prescription Farming Based on Soil Property Sensors. A.S.A.E. paper number 89-1036. June 25-28.

Han, S. and C.E. Goering. 1992. A Field Information System for Site Specific Crop Management. A.S.A.E. paper number 923608. December 15-18.

Holmes, B. 1993. Translating High-Tech to Real Fields. Dealer Progress. January, vol. 1, I-20-21.

Johnson, D.L. 1995. Soil Moisture Sensor Evaluation. Master's Thesis, University of Tennessee.

Karlen, D.L., E.J. Sadler, and W.J. Busscher. 1990. Crop Yield Variation Associated with Coastal Plain Soil Map Units. Soil Sci. Soc. Am. J. 54:859-865.

Klute, Arnold. 1986. Soil Sampling. In Methods of Soil Analysis Part I. Wisconsin : Soil Science Society of America.

Macy, T.S. 1991. Personal Site Specific Experiences. Automated Agriculture for the 21st Century. A.S.A.E. Preceedings of the 1991 symposium. December 16-17.

Ndiaye, J.P. and R.S. Yost. 1989. Influence of Fertilizer Application Nonuniformity on Crop Response. Soil Sci. Soc. Am. J. 53:1872-1878.

Oberle, S.L. and D.R. Keeney. 1990. Soil Type, Precipitation, and Fertilizer N Effects on Corn Yields. J. Prod. in Agric. 3:522-527.

Or, D. and R.J. Hanks. 1992. Soil Water and Crop Yield Spatial Variability Induced by Irrigation Nonuniformity. Soil Sci. Soc. Am. J. 56:226-233.

Polito, T.A. and R.D. Voss. 1991. Corn Response to Varied Producer Controlled Factors and Weather in High yield Environments. J. Prod. Agric. 4:51-57.

Pringle, J.L., M.D. Schrock, R.T. Hinnen, K.D. Howard, and D.L. Oard. 1993. Yield Variation in Grain Crops. A.S.A.E. paper number 931505. December.

Rennie, D.A. and J.S. Clayton. 1960. The Significance of Local Soil Types to Soil Fertility Studies. Can. J. of Soil Science. 40:146-155.

Roder, W., S.C. Mason, M.D. Clegg, and K.R. Kniep. 1989. Yield-Soil Water Relationships in Sorghum-Soybean Cropping Systems with Different Fertilizer Regimes. Agron. J. 81:470-475.

Schueller, J.K. 1988. Machinery and Systems for Spatially - Variable Crop Production. A.S.A.E. paper number 88-1608 December 13-16.

Wibawa, W.D., D.L. Dludlu, L.J. Swenson, D.G. Hopkins, and W.C. Dahnke. 1993. Variable Application Based on Yield Goal, Soil Fertility, and Soil Map Unit. Journal of Production Agriculture, Vol. 6, no2, 255-261.

APPENDICES

APPENDIX A

Table A1: Local coordinates and Elevation for the Morgan field

Vect.	Row	X (ft)	Y (ft)	Elev. (ft)
A	1	3.333	1238.5	1.05
B	1	3.333	1116.1	1.87
C	1	3.333	1014.4	2.46
D	1	3.333	857.2	3.72
E	1	3.333	789.2	3.25
F	1	3.333	706.6	3.58
G	1	3.333	525.4	5.18
H	1	3.333	351.4	5.65
I	1	3.333	280.5	6.20
A	2	13.333	1238.5	1.50
B	2	13.333	1116.1	2.15
C	2	13.333	1014.4	3.02
D	2	13.333	857.2	4.25
F	2	13.333	706.6	4.10
H	2	13.333	351.4	5.88
I	2	13.333	280.5	6.40
B	3	43.333	1116.1	2.35
D	3	43.333	857.2	4.36
E	3	43.333	789.2	3.95
G	3	43.333	525.4	6.03
H	3	43.333	351.4	6.05
A	4	53.333	1238.5	1.88
B	4	53.333	1014.4	3.62
D	4	53.333	857.2	4.9
F	4	53.333	706.6	4.68
G	4	53.333	525.4	6.40
I	4	53.333	280.5	6.80
B	5	83.333	1116.1	2.80
C	5	83.333	1014.4	3.40
D	5	83.333	857.2	5.18
E	5	83.333	789.2	4.88
F	5	83.333	706.6	5.08

Vect.	Row	X (ft)	Y (ft)	Elev. (ft)
H	5	83.333	351.4	6.38
C	6	93.333	1014.4	3.58
D	6	93.333	857.2	5.16
E	6	93.333	789.2	5.78
F	6	93.333	706.6	6.25
G	6	93.333	525.4	7.10
H	6	93.333	351.4	6.80
I	6	93.333	280.5	7.30
A	7	123.333	1238.5	1.88
B	7	123.333	1116.1	2.76
C	7	123.333	1014.4	3.46
D	7	123.333	857.2	4.94
E	7	123.333	789.2	5.72
H	7	123.333	351.4	6.95
I	7	123.333	280.5	7.35
A	8	133.333	1238.5	2.41
B	8	133.333	1116.1	3.05
C	8	133.333	1014.4	3.63
D	8	133.333	857.2	4.60
E	8	133.333	789.2	5.05
F	8	133.333	706.6	5.72
G	8	133.333	525.4	7.40
H	8	133.333	351.4	7.08
I	8	133.333	280.5	7.45
B	9	163.333	1116.1	3.25
D	9	163.333	857.2	4.66
F	9	163.333	706.6	5.70
G	9	163.333	525.4	7.40
H	9	163.333	351.4	7.18
I	9	163.333	280.5	8.55
C	10	173.333	1014.4	4.15
D	10	173.333	857.2	5.36

Vect.	Row	X (ft)	Y (ft)	Elev. (ft)
E	10	173.333	789.2	5.84
F	10	173.333	706.6	6.35
G	10	173.333	525.4	7.65
H	10	173.333	351.4	7.45
A	11	203.333	1238.5	2.79
B	11	203.333	1116.1	3.60
D	11	203.333	857.2	5.52
E	11	203.333	789.2	6.05
F	11	203.333	706.6	6.55
H	11	203.333	351.4	7.55
I	11	203.333	280.5	7.80
A	12	213.333	1238.5	2.79
C	12	213.333	1014.4	4.35
D	12	213.333	857.2	5.44
F	12	213.333	706.6	6.64
G	12	213.333	525.4	7.95
H	12	213.333	351.4	7.80
A	13	243.333	1238.5	2.95
B	13	243.333	1116.1	3.60
D	13	243.333	857.2	5.50
G	13	243.333	525.4	7.90
I	13	243.333	280.5	8.10
B	14	253.333	1116.1	3.88
C	14	253.333	1014.4	4.35
E	14	253.333	789.2	6.24
F	14	253.333	706.6	7.05
G	14	253.333	525.4	7.90
H	14	253.333	351.4	7.95
I	14	253.333	280.5	8.25

Table A2: Local coordinates and elevation for the E-field

Vect.	Row	X (ft)	Y (ft)	Elev. (ft)
A	1	3.333	1090.88	2.98
B	1	3.333	1041.92	2.85
C	1	3.333	972.39	2.62
D	1	3.333	867.02	2.38
F	1	3.333	627.57	2.63
G	1	3.333	499.58	2.73
H	1	3.333	424.07	2.48
I	1	3.333	327.65	2.17
A	2	13.333	1090.88	2.99
B	2	13.333	1041.92	2.80
D	2	13.333	867.02	2.38
E	2	13.333	752.101	2.35
G	2	13.333	499.58	2.68
A	3	43.333	1090.88	2.94
C	3	43.333	972.39	2.62
E	3	43.333	752.1	2.40
F	3	43.333	627.57	2.79
G	3	43.333	499.58	2.77
H	3	43.333	424.07	2.53
I	3	43.333	327.65	2.15
A	4	53.333	1090.88	2.89
B	4	53.333	1041.92	2.91
C	4	53.333	972.39	2.77
D	4	53.333	867.02	2.34
F	4	53.333	627.57	2.71
G	4	53.333	499.58	2.40
H	4	53.333	424.07	2.45
A	5	83.333	1090.88	2.89
B	5	83.333	1041.92	2.92
C	5	83.333	972.39	2.39
D	5	83.333	867.02	2.16
F	5	83.333	627.57	2.60
G	5	83.333	499.58	2.66
H	5	83.333	424.07	2.44
I	5	83.333	327.65	2.21
A	6	93.333	1090.88	2.84
B	6	93.333	1041.92	2.82
C	6	93.333	972.39	2.64
D	6	93.333	867.02	2.12
F	6	93.333	627.57	2.55
H	6	93.333	424.07	2.44
I	6	93.333	327.65	2.17
A	7	123.333	1090.88	2.74
B	7	123.333	1041.92	2.68
C	7	123.333	972.39	2.74
D	7	123.333	867.02	2.32
E	7	123.333	752.1	1.95
F	7	123.333	627.57	2.48
H	7	123.333	424.07	2.44
A	8	133.333	1090.88	2.75
C	8	133.333	972.39	2.65
D	8	133.333	867.02	1.92
G	8	133.333	499.58	2.65
I	8	133.333	327.65	2.09
A	9	163.333	1090.88	2.60
C	9	163.333	972.39	2.67
D	9	163.333	867.02	2.39
F	9	163.333	627.57	2.33
H	9	163.333	424.07	2.36
I	9	163.333	327.65	1.93
A	10	173.333	1090.88	1.73
C	10	173.333	972.39	1.55
D	10	173.333	867.02	0.88
E	10	173.333	752.1	0.56

Vect.	Row	X (ft)	Y (ft)	Elev. (ft)
H	10	173.333	424.07	0.40
I	10	173.333	327.65	13.98
A	11	203.333	1090.88	12.33
B	11	203.333	1041.92	0.20
D	11	203.333	867.02	0.44
E	11	203.333	752	0.33
F	11	203.333	627.57	0.07
G	11	203.333	499.58	14.17
H	11	203.333	424.07	0.06
I	11	203.333	327.65	3.22
A	12	213.333	1090.88	0.15
B	12	213.333	1041.92	0.13
D	12	213.333	867.02	0.04
E	12	213.333	752.1	0.04
F	12	213.333	627.57	1.07
G	12	213.333	499.58	0.10
H	12	213.333	424.07	2.45
I	12	213.333	327.65	1.45
A	13	243.333	1090.88	3.89
B	13	243.333	1041.92	2.68
C	13	243.333	972.39	2.86
F	13	243.333	627.57	2.49
G	13	243.333	499.58	2.86
H	13	243.333	424.07	0.21
I	13	243.333	327.65	0.26
A	14	253.333	1090.88	3.70
B	14	253.333	1041.92	3.23
D	14	253.333	867.02	3.08
E	14	253.333	752.1	2.00
F	14	253.333	627.57	2.58
G	14	253.333	499.58	2.76
I	14	253.333	327.65	4.12

APPENDIX B

Table B1: Plot information for the Morgan field.

Vector	Row	Population	Height 1 (in.)	Height 2 (in.)	Yield (lbs)
A	1	113	3.42	8.00	8.16
B	1	102	3.50	7.75	6.93
C	1	99	4.42	10.25	8.46
D	1	102	3.33	10.67	8.51
E	1	95	3.67	10.33	7.62
F	1	105	3.42	9.83	7.56
G	1	98	3.75	9.17	6.69
H	1	102	3.75	10.00	8.38
I	1	102	4.33	9.92	7.13
A	2	100	3.08	8.58	7.10
B	2	98	3.92	9.17	7.37
C	2	96	3.50	9.92	8.09
D	2	100	4.00	10.00	8.69
F	2	115	4.00	11.08	8.33
H	2	107	4.17	9.50	7.54
I	2	112	3.83	10.42	8.31
B	3	90	3.67	9.25	7.23
D	3	104	3.83	11.00	7.91
E	3	113	4.08	11.08	8.89
G	3	100	3.75	11.00	7.65
H	3	102	4.08	10.50	8.71
A	4	96	3.42	8.92	7.41
B	4	104	3.58	10.00	9.94
D	4	114	3.50	9.75	8.73
F	4	107	3.92	10.75	9.41
G	4	112	3.92	10.00	10.49
I	4	105	3.17	10.17	8.53
B	5	115	3.17	8.92	8.95
C	5	120	4.08	10.00	10.09
C	5	117	3.50	10.25	9.09
D	5	111	3.75	9.83	7.52
F	5	109	3.83	9.42	8.90
H	5	122	3.75	10.50	8.13
C	6	102	3.25	10.50	8.24

Vector	Row	Population	Height 1 (in.)	Height 2 (in.)	Yield (lbs)
C	6	116	3.50	10.92	8.94
D	6	101	4.08	10.50	7.98
F	6	102	4.33	10.58	9.54
G	6	100	3.83	10.75	8.51
H	6	105	3.75	11.25	7.64
I	6	101	4.42	10.42	9.18
A	7	100	2.92	7.25	4.06
B	7	85	2.92	7.42	6.91
C	7	98	3.42	9.67	8.58
C	7	93	3.58	10.83	8.34
D	7	95	3.75	10.00	7.65
H	7	101	3.50	9.58	7.56
I	7	90	4.00	10.92	7.79
A	8	97	2.67	8.50	7.52
B	8	109	3.58	8.42	6.81
C	8	104	3.08	8.33	7.60
C	8	120	4.17	9.67	10.35
D	8	118	3.50	10.25	10.90
F	8	120	3.50	9.25	10.27
G	8	115	4.33	10.92	11.50
H	8	121	3.75	10.50	10.07
I	8	126	4.00	9.67	8.74
B	9	105	2.92	7.50	5.62
D	9	93	3.00	10.33	10.32
F	9	98	3.58	10.42	9.35
G	9	72	3.17	8.75	8.59
H	9	76	4.42	10.42	8.17
I	9	73	3.67	9.75	8.35
C	10	65	3.25	8.67	5.73
D	10	72	3.25	8.83	6.64
E	10	68	3.25	8.75	5.27
F	10	60	3.33	8.83	5.85
G	10	66	3.33	9.00	5.48
H	10	74	4.00	9.75	7.95
A	11	67	3.58	8.58	5.67
B	11	71	3.17	7.25	4.20

Vector	Row	Population	Height 1 (in.)	Height 2 (in.)	Yield (lbs)
D	11	65	3.00	7.50	4.60
E	11	72	3.42	8.83	5.65
F	11	52	3.50	9.50	6.89
H	11	50	3.25	9.42	7.34
I	11	63	3.58	9.33	7.13
A	12	136	3.33	8.67	8.17
C	12	75	3.25	7.92	6.23
D	12	72	3.58	8.08	6.14
F	12	78	3.50	9.25	6.64
G	12	69	3.25	8.92	5.18
H	12	66	3.50	8.83	8.55
A	13	123	3.33	8.75	7.08
B	13	126	3.75	8.50	7.50
D	13	125	4.00	10.92	6.86
G	13	114	3.33	8.75	5.13
I	13	122	3.42	9.83	8.85
B	14	141	4.17	10.25	10.07
C	14	130	3.92	8.50	8.99
E	14	140	3.67	9.17	8.73
F	14	135	3.42	9.50	8.67
G	14	104	3.67	10.00	7.94
H	14	131	3.75	10.17	8.98
I	14	121	3.50	9.75	8.11

Table B2: Plot information for the E-field.

Vector	Row	Population	Height (in.)	Yield (lbs)
A	1	45	7.92	0.60
B	1	45	6.92	0.76
C	1	41	7.58	0.64
D	1	52	7.83	1.58
F	1	41	7.92	0.12
G	1	45	7.75	0.4
H	1	51	8.08	0.34
I	1	46	7.25	0.14
A	2	41	8.50	1.08
B	2	48	9.58	0.96
D	2	49	10.08	0.36
E	2	40	10.00	1.06
G	2	38	8.67	0.52
A	3	39	7.83	0.10
C	3	48	5.50	0.16
E	3	51	6.42	0.48
F	3	45	8.17	0.60
G	3	44	9.92	0.14
H	3	43	9.00	0.16
I	3	46	8.83	0.52
A	4	47	9.00	0.42
B	4	47	6.92	0.42
C	4	40	7.00	0.98
D	4	50	9.83	1.40
E	4	49	9.50	0.76
G	4	38	8.50	0.64
H	4	41	8.25	0.84
A	5	36	8.08	0.85
B	5	38	8.58	0.92
D	5	44	7.50	0.68
E	5	43	10.58	0.70
F	5	37	9.25	0.98
G	5	44	9.00	0.26
H	5	51	10.17	0.68

Vector	Row	Population	Height (in.)	Yield (lbs)
I	5	41	8.92	0.10
A	6	49	10.50	0.94
B	6	43	9.50	0.67
C	6	51	6.50	0.54
E	6	45	7.83	0.72
F	6	49	8.92	0.78
H	6	55	8.08	0.74
I	6	46	10.00	0.48
A	7	54	9.33	0.82
B	7	42	9.25	0.62
C	7	45	8.50	0.46
D	7	37	10.92	0.84
E	7	38	8.83	0.78
F	7	47	10.33	0.58
H	7	53	6.17	0.52
A	8	37	10.25	0.32
C	8	43	9.58	0.35
E	8	43	5.75	0.26
G	8	41	7.33	0.36
I	8	49	7.92	0.56
A	9	52	7.25	1.80
C	9	47	10.75	1.10
D	9	35	8.83	0.63
F	9	46	7.92	1.14
H	9	39	7.25	0.98
I	9	51	7.17	2.02
A	10	56	8.42	1.90
C	10	58	8.67	1.22
D	10	46	12.33	0.94
E	10	44	11.67	1.00
H	10	60	8.50	1.58
I	10	48	10.58	1.60
A	11	48	8.50	1.52
B	11	53	8.50	2.08
C	11	48	7.58	1.42
E	11	48	11.75	0.54

Vector	Row	Population	Height (in.)	Yield (lbs)
F	11	48	8.33	0.48
G	11	44	10.25	0.34
H	11	44	8.83	1.42
I	11	54	8.58	1.26
A	12	51	9.92	1.06
B	12	49	8.75	0.50
D	12	47	9.17	1.66
E	12	47	9.00	0.70
F	12	43	7.58	0.78
G	12	49	11.08	0.20
H	12	46	10.75	0.86
I	12	49	11.25	1.00
A	13	41	7.17	0.90
B	13	44	9.25	1.44
C	13	45	7.75	1.92
F	13	48	9.83	1.10
G	13	43	9.17	1.36
H	13	52	9.14	0.48
I	13	51	9.83	0.50
A	14	47	8.83	1.16
B	14	51	8.33	1.30
D	14	52	9.67	1.32
E	14	45	8.05	1.00
F	14	56	9.17	0.56
G	14	54	9.10	1.46
I	14	44	9.83	0.38

APPENDIX C

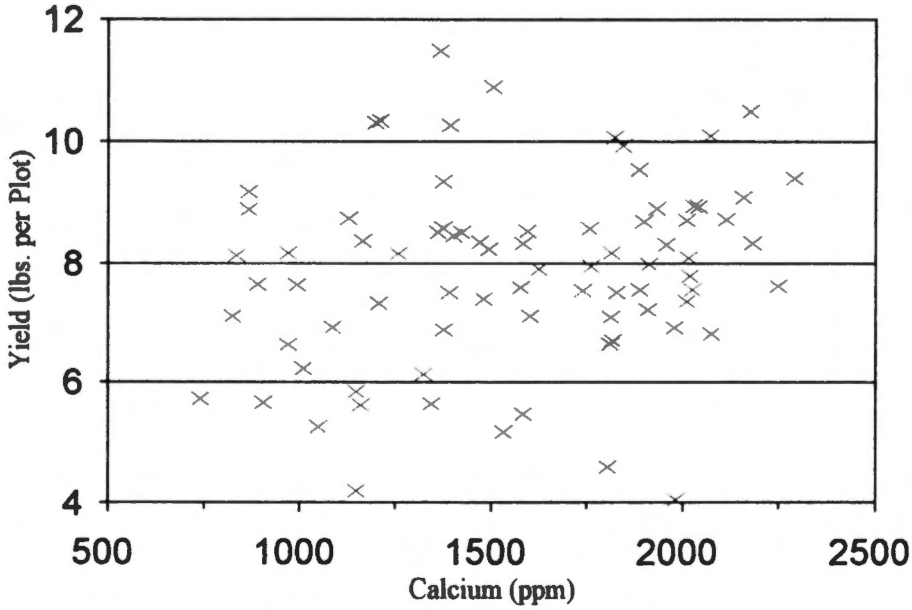

Figure C1: Calcium levels from 0-6 inches and yields for Italian green beans.

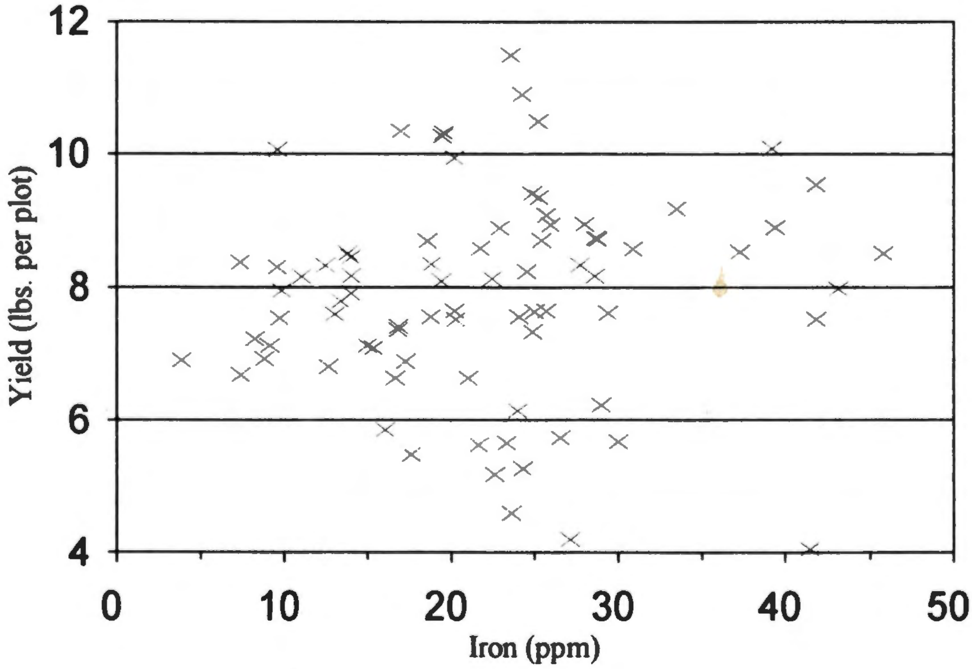

Figure C2: Iron levels from 0-6 inches and yield for Italian green beans.

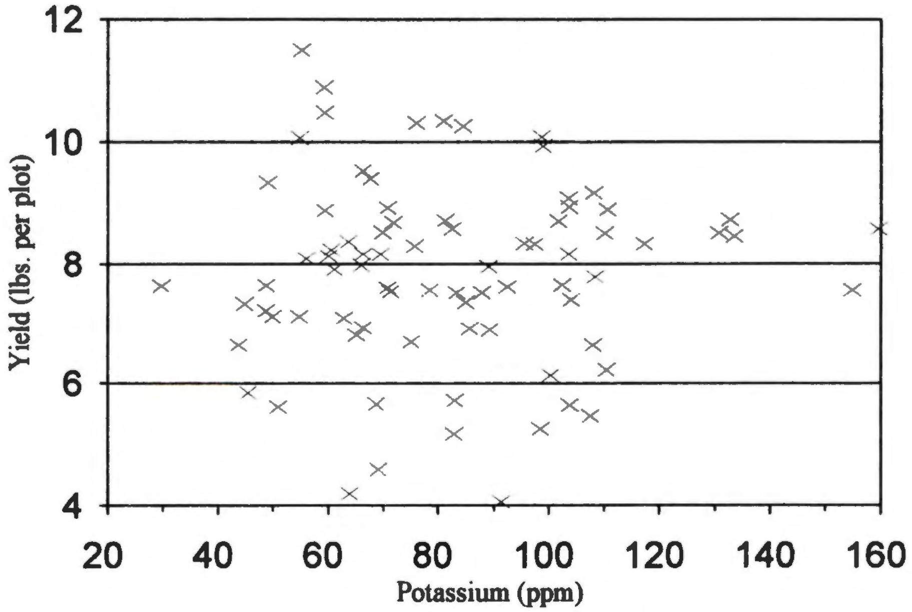

Figure C3: Potassium levels from 0-6 inches and yield for the Morgan field.

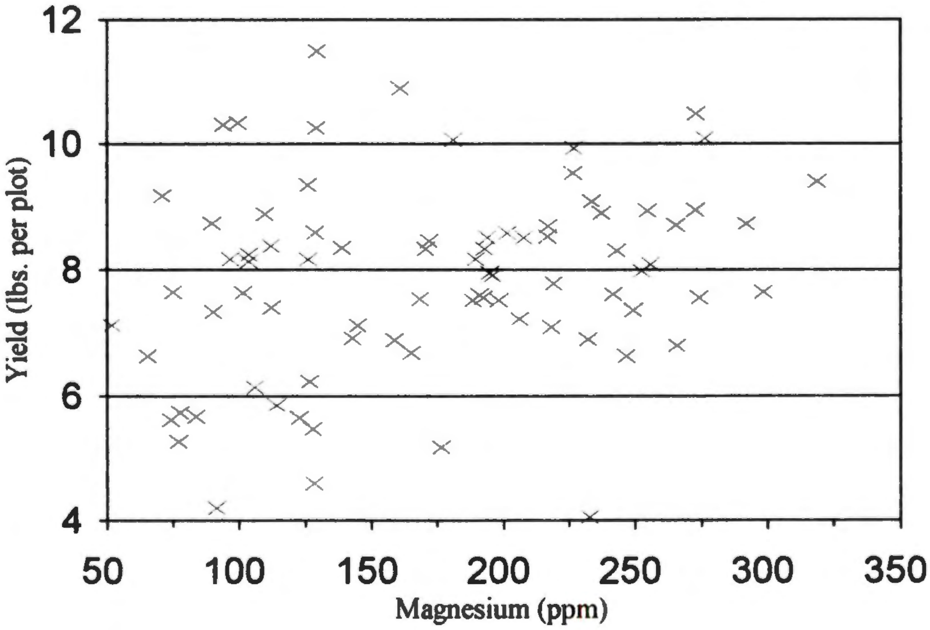

Figure C4: Magnesium levels from 0-6 inches and yield for Italian green beans.

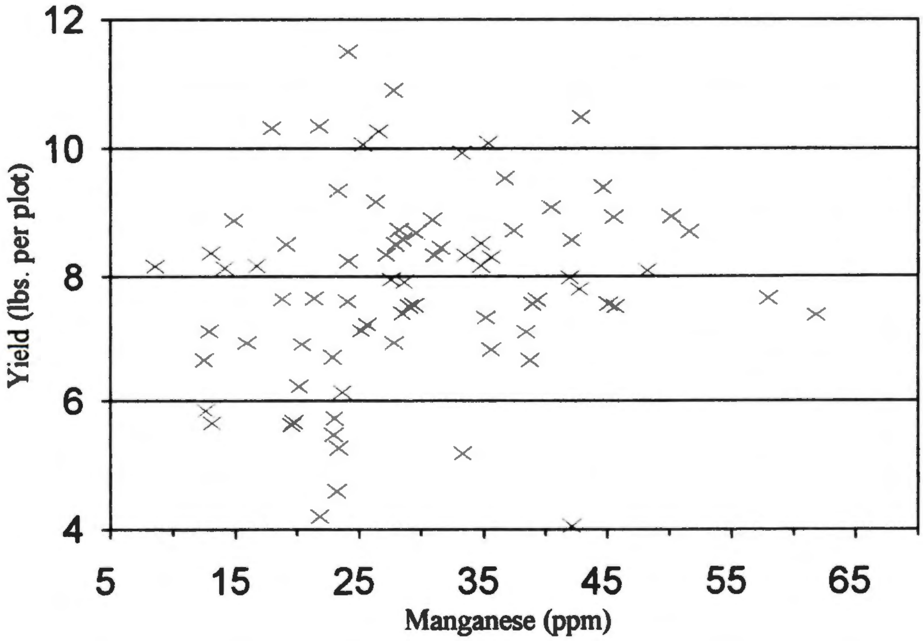

Figure C5: Manganese levels from 0-6 inches and yield for Italian green beans.

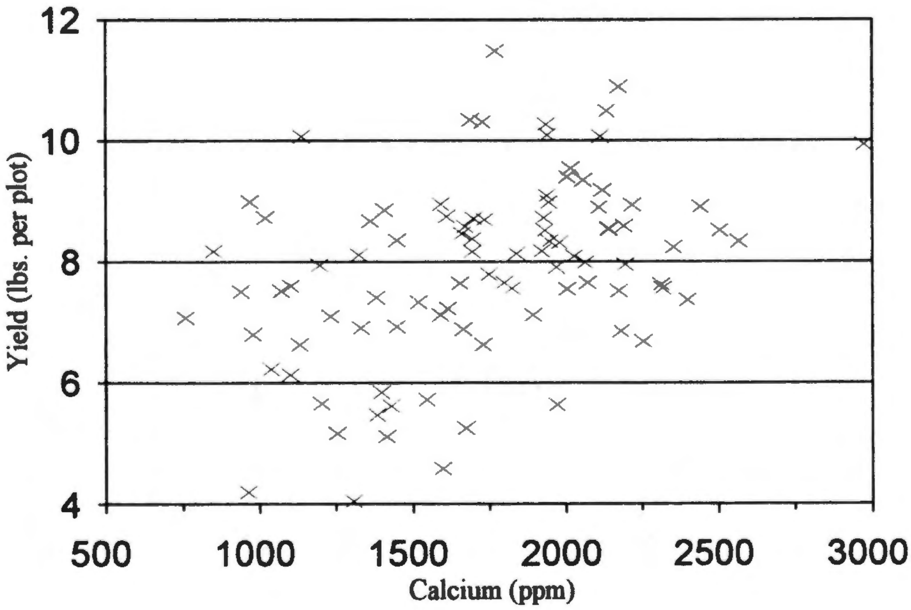

Figure C6: Calcium levels from 6-12 inches and yields for Italian green beans.

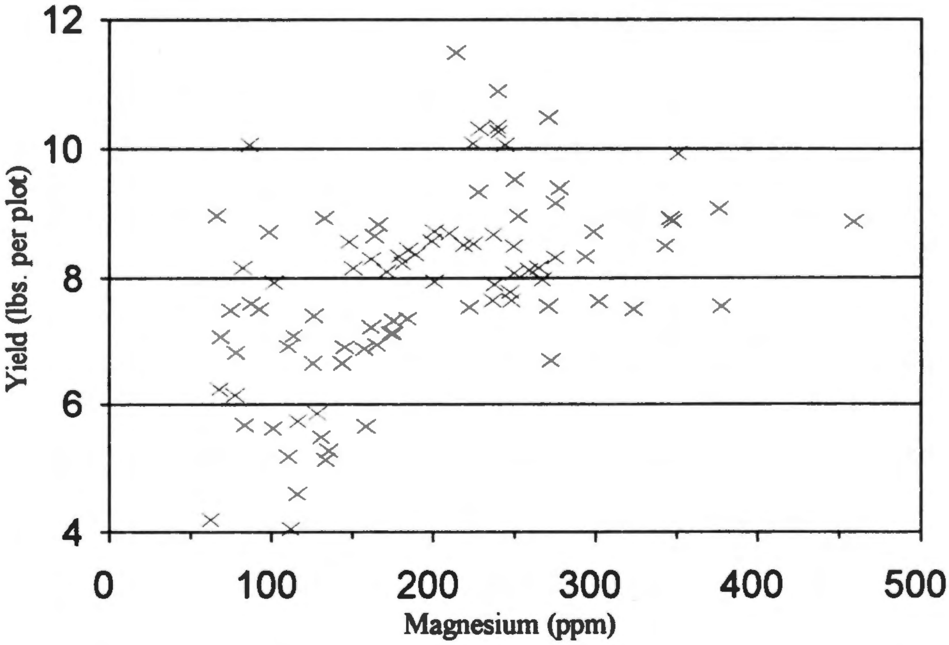

Figure C7: Magnesium levels from 6-12 inches and yields for Italian green beans.

APPENDIX D

Table D1

Effects on Yield from 0-6 inches

Soil Variables	Statistical Significance	Pr >f
Aluminum	Not Significant	0.8705
Calcium	Significant	0.0185
Copper	Not Significant	0.7343
Iron	Significant	0.0155
Potassium	Significant	0.0227
Magnesium	Significant	0.0096
Manganese	Significant	0.0007
Sodium	Not Significant	0.5705
Phosphorous	Not Significant	0.6420
Zinc	Not Significant	0.2730
pH	Not Significant	0.4196

Table D2

Effects on Yield from 6-12 inches

Soil Variables	Statistical Significant	Pr >f
Aluminum	Not Significant	0.5432
Calcium	Significant	0.0014
Copper	Not Significant	0.9940
Iron	Not Significant	0.9069
Potassium	Not Significant	0.3029
Magnesium	Significant	0.0084
Manganese	Not Significant	0.6751
Sodium	Not Significant	0.8703
Phosphorous	Not Significant	0.1660
Zinc	Not Significant	0.1640
pH	Significant	0.0510

Table D3

Variable	Statistical Significance	Pr>F
Plant Population	Significant	0.001
Soil Moisture		
June 8th (0-6")	Significant	0.051
June 11th (0-6")	Significant	0.0084
June 15th (0-6")	Not Significant	0.994
June 18th (0-6")	Not Significant	0.7535
June 8th (6-12")	Not Significant	0.6994
June 11th (6-12")	Not Significant	0.6617
June 15th (6-12")	Not Significant	0.5898
June 18th (6-12")	Not Significant	0.0741

VITA

Stephen Addison Schneiter was born November 17, 1964 in Louisville, Kentucky. He attended elementary school in Louisville, Kentucky and graduated from Trinity High School in 1984. Upon graduation Stephen work in various agricultural positions in Kentucky.

Stephen moved to Knoxville, Tennessee and entered The University of Tennessee in the spring of 1988. He received a Bachelors of Science degree in Animal Science in December, 1992. The following month he accepted a research assistantship and entered the University of Tennessee Graduate School. Stephen completed the requirements for a Masters of Science degree with a major in Agricultural Engineering Technology in December, 1995.