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SPATIAL VARIABILITY OF NITRATE IN IRRIGATED COTTON

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SPATIAL VARIABILITY OF NITRATE IN IRRIGATED COTTON

by

Joseph Anthony Tabor

A Thesis Submitted to the Faculty of the

DEPARTMENT OF SOILS, WATER AND ENGINEERING

In Partial Fulfillment of the Requirements
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In the Graduate College

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A. W. Warrick

A. W. WARRICK
Professor of Soils, Water and Engineering

April 18, 1983

DATE

To family and friends,

past, present and future.

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ABSTRACT

Cotton petiole and soil samples were collected from 31 production fields and used to evaluate the reliability of a commercial cotton petiole sampling program and the spatial variability of petiole and soil nitrate. Standard statistical tests, multivariate analysis and variograms were used to evaluate the data.

It was determined that spatial dependence of nitrate ranges from strongly dependent to essentially independent and both spatial dependence and variability are mainly influenced by the soil properties and cultural practices. The best estimate of the field average for a field of unknown spatial structure is achieved by having sampling areas as far apart as possible and not occuring on the same row.

Bias, caused by the choice of petioles sampled, can be reduced by collecting petioles of the first fully extended leaves and if the degree of maturity is in question the petiole from the next older fully extended leaf should be sampled.

CHAPTER 1

INTRODUCTION

Twenty cotton farmers, members of Growers Pest Management (GPM) in southern Arizona, started a petiole analysis program during the summer of 1981. This presented an opportunity to study nitrogen variability in production fields, evaluate GPM's petiole program and determine more efficient methods of sampling. Petiole analysis is commonly used to monitor the nitrogen supply to the plant, allowing the grower to optimize their fertility program during the growing season by inseason adjustments.

The cotton fields in the program were located in the Casa Grande and Cooledge area, 100 kilometers south of Phoenix and part of the Central Arizona Basin and Range. The growing season is long and two peak flowering periods occur during the growing season. Most of the cotton grown in this area is short staple. The average of the five highest yields between 1965 and 1981 for cotton grown in the area was 1290 kg/ha.

The 196 fields in the GPM program were sampled once a week early in the season, tapering to once every two weeks near the end. Around 20 petioles, the stem-like portion of the leaf, were collected from two to four representative 0.5 ha areas in each field, combined and sent to a commercial lab for nitrate analysis. The sampling method followed that suggested by Tucker (1965). The cost of the program was 5 dollars per hectare or 4.7% of the seasons fertility costs.

For this study 900 plant and soil samples were collected from 31 fields. Objectives were to examine the variability of nitrate in different-aged petioles on individual plants and determine an optimum maturity to sample for minimizing bias and maximizing consistency. Objectives also included how to best estimate field averages and determine the spatial variability of petiole and soil nitrate in the field by use of variograms. Thus, the overall objective is to optimize sampling techniques.

CHAPTER 2

LITERATURE REVIEW

Petiole Nitrate

The petiole has been found to be the best part of a cotton plant to determine nitrogen status (Johan, 1951; Burhan and Babikir, 1968; Bates, 1971). Nitrate analysis lets one determine if nitrogen is deficient or predict an approaching deficiency. Other nutrients or enviromental conditions may limit production, so nitrate alone does not determine the health or yield of the plant. But by using the "Liebig's Law of the Minimum", a critical level of around 2000 ppm nitrate nitrogen has been determined for furrow irrigated cotton. Lower concentrations indicate a likely reduction in yield caused by nitrogen deficency (MacKenzie et al., 1963; Gardner and Tucker, 1967; Bates, 1971). In general, nitrate levels start out greater than 15000 ppm and decrease to around 4000 ppm by the end of the growing season. Petioles from the first mature leaves were shown to be the best indicators although the degree of maturity is somewhat subjective.

Complete agreement on the effect of cultivars on the nitrate concentration in the plants has not been reached (Bates, 1971). But it has been suggested that influence due to cultivar is less than that caused by time, row spacing or nitrogen application rates (Sunderman, Onken and Hossner, 1979). Since most fields are planted with the same cultivar spatial variability due to cultivar is assumed to be insignificant.

Batra (1961) studied the effect of time of day on petiole nitrate concentration at 3 hour intervals. Although the number of petioles per sample were not stated, it can be inferred that with adequate to high nitrate concentration in petioles, the sampling variation is more important than variation due to time of day. Batra also studied the differences of nitrate concentration caused by soil moisture. Comparing petiole nitrate levels before and after irrigation, within a 3 day period, he showed only minor differences. MacKenzie et al. (1963) also found that effects due to soil moisture were small.

Burhan and Babikir (1968) found difference of nitrate concentration could not be clearly distinguished during the first month of growth for plants grown at different nitrogen levels. Petiole nitrate monotoring in Arizona is believed informative between first square and the second peak-bloom period (which occurs in areas with long growing seasons).

In previous studies, samples were composites of large numbers of petioles over small areas. Directly transferring this sampling method to a production situation with large fields would be unrealistic. Tucker (1965) suggested sampling at a number of random areas from representative portions of the field. This has produced acceptable results in Arizona. (The implicit assumption with random samples is that sample sites are independent).

Soil Nitrate

Errors due to soil sampling are generally greater than those due to laboratory analysis (Cline, 1944). The soil test results have little value if the soil sample is unrepresentative, even when the analytical aspect of soil testing correlates perfectly with crop response (James and Dow, 1972).

Turjoman (1960) found nitrate concentrations highest in the surface 30 cm of Arizona soils and decreasing with depth. Ludwick, Soltampour and Reuss (1977) showed that reliable information about the total soil nitrate content could be obtained from shallow soil samples. This was due to the high proportion of total soil nitrate near the surface.

Since nitrate is a mobile ion its movement and distribution in the soil can be expected to follow the pattern of other soluble salts (Gardner and Tucker, 1967). Al Sanabani (1982) measured the eletricial conductivity

(EC), i.e. soluble salts, of 101 samples from a 10 ha irrigated field in Arizona and found the data closely approximated a lognormal frequency distribution. Soil nitrate samples from 24 irrigated Colorado fields approximated a lognormal distribution better than that of a normal distribution (Reuss, Soltampour and Ludwick, 1977). Frequency histograms of Leo's (1963) soil-nitrogen data shows positively skewed distributions for three out of four fields studied.

To help explain the high degree of soil nitrate variability, Jenson and Pesek (1962) modeled nonuniform nitrogen fertilizer applications and its resulting affect on production, assuming a homogenous soil. This resulted in banding of similar nitrogen concentrations in the direction of application with higher levels of variability perpendicular to application direction. Reuss, Soltampour and Ludwick (1977) using an analysis of variance, evaluated directional gradients in nitrate concentrations of subplots for some irrigated fields in Colorado and found significant directional effects both along and across rows.

Statistics: Independence and Dependence

Classical statistical analysis is often based on the assumption of random or independent samples. For dependent samples the variance of the mean $\bar{X}$ based on n observations of x_i is,

$$\begin{aligned} Var[\bar{X}] &= Var[(1/n)\sum_{i=1}^{n} x_i] \\ &= (1/n)^2\, Var[\sum_{i=1}^{n} x_i] \\ &= (1/n)^2\, (\sum_{i=1}^{n} Var[x_i] + 2\sum\sum_{i<j} Cov[x_i, x_j]). \end{aligned}$$

For independent samples, $x_1,\ldots,x_n$ are uncorrelated, $Cov[x_i,x_j]$ equals 0, and the result is that for independent sampling,

$$\begin{aligned} Var[\bar{X}] &= (1/n)^2 \sum_{i=1}^{n} Var[x_i] \\ &= \sigma^2/n, \end{aligned}$$

where σ^2 is the population variance. Also the usual estimation of variance with sample variance requires independence.

$$\begin{aligned} E[s^2] &= E[\sum_{i=1}^{n}(x_i-\bar{X})^2/(n-1)] \\ &= E[\sum_{i=1}^{n}(x_i-\mu)^2 - n(\bar{X}-\mu)^2]/(n-1) \\ &= \{\sum_{i=1}^{n}E[(x_i-\mu)^2] - n\,E[(\bar{X}-\mu)^2]\}/(n-1) \\ &= \{\sum_{i=1}^{n}\sigma^2 - n\,Var[\bar{X}]\}/(n-1). \end{aligned}$$

If the variables are uncorrelated then $Var[\bar{X}] = \sigma^2/n$, as shown above, and

$$\begin{aligned} E[s^2] &= (n\sigma^2 - n\,\sigma^2/n)/(n-1) \\ &= \sigma^2. \end{aligned}$$

This demonstrates that when the variables are dependent, i.e. correlated, σ^2/n does not equal $Var[\bar{X}]$ and s^2 does not approximate σ^2 (Mood, Graybill and Boes, 1974).

Geostatistics

Geostatistics is based on the theory of regionalized variables. A variable distributed in space and/or time is said to be regionalized. Corresponding to random function Z(X) a random variable $Z(x_1)$ can be compared to another random variable $Z(x_1 + h)$ which is a distance or time h away from $Z(x_1)$. The variable Z(x) is a regionalized variable.

Unlike most classical statistics, the assumption of independence is not made, thus the random variables Z(x) and Z(x + h) may or may not be dependent. Using regionalized variables, the variogram function (which is basic to geostatistics) is defined as

$$2\,\gamma(h) = \mathrm{Var}[Z(x) - Z(x + h)]$$

and the semivariance defined as $\gamma(h)$ (Journel and Huijbregts, 1978).

Taking a simplistic one-dimensional case, e.g. along a transect, and assuming stationarity (i.e. E[Z(x)] equals a constant) we define the variogram by

$$\gamma(h) = 1/2\ E[Z(x) - Z(x + h)]^2$$

and the sample variogram by

$$\gamma(h) = (1/2n) \sum_{i=1}^{n} [Z(x_i) - Z(x_i - h)]^2$$

where γ is a function of h, the distance between samples.

The variogram is developed by plotting semivariance with respect to h. Since h can be a vector quantity one can evaluate directional effects and determine if semivariance is anisotropic.

The resulting variograms can be fitted to mathematical models which are necessary for subsequent applications, e.g. kriging. Valid possibilities include linear, spherical, exponential, Gaussian and power models. To date, there is not a fool-proof, purely objective method for fitting models to sample variograms. As a result, models are fitted subjectively by weighting more heavily where large numbers of sample pairs are available and pairs relatively close together, thus avoiding edge effects of the plot or transect. Davis (1973) suggested that in evaluating correlograms (discussed below) for regular transects, the number of data pairs should exceed 50 and the distance between sample pairs should not exceed 1/4 of the largest data pair distance.

The linear variogram model is given as Figure 1. The semivariance starts at C_0 for $h = 0$, where the "nugget" value C_0 is due to inherent variability of the characteristic, type of sampling and/or laboratory analysis error. From C_0 the value increases linearly with distance between samples, h, to a maximum "sill" value, $C_0 + \Delta C$, where ΔC is the h dependent change in semivariance. The sill value remains constant with intersample distances greater than or equal to the "range", a. Thus, samples

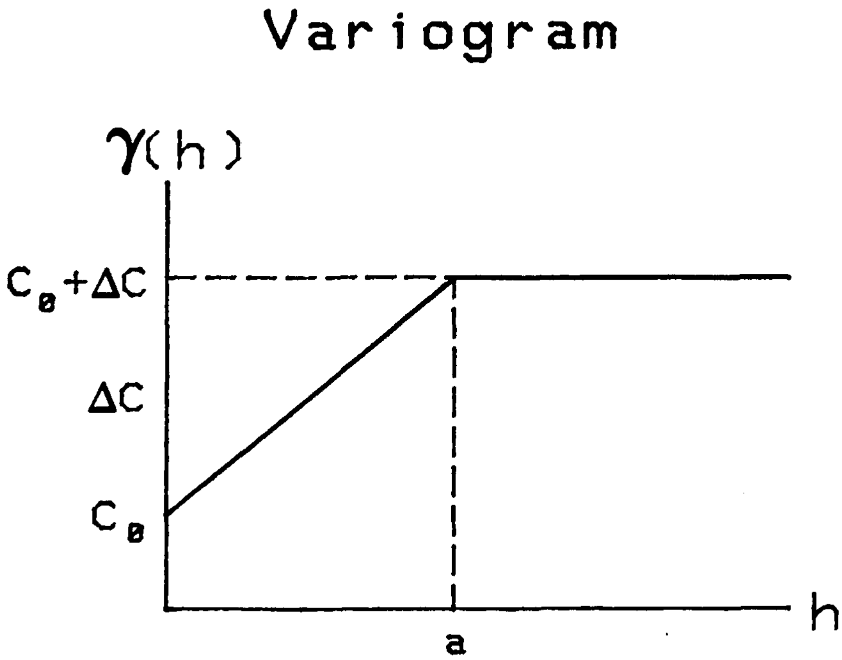


Figure 1. Linear variogram example.

close together have smaller semivariances and are more alike than samples further apart which have larger semivariance. Samples are dependent for distances up to range "a" where semivariance then remains constant with increasing distances between samples and samples achieve independence.

Semivariance is related theoretically to variance by the equations,

$$\gamma(h) = \sigma^2 - \sigma(h)$$

or,

$$\gamma(h) = Var[Z(x)] - Cov[Z(x + h), Z(x)],$$

under the condition of second order stationarity, i.e. $E[Z(x)]$ equals a constant and the $Cov[Z(x + h), Z(x)]$ exists. It follows that either covariance or the variogram can be used to characterize the auto-correlation between two variables $Z(x + h)$ and $Z(x)$. Thus the correlogram, $\rho(h)$ is defined (Journel and Huijbregts, 1978),

$$\rho(h) = \sigma(h)/\sigma^2 = 1 - \gamma(h)/\sigma^2.$$

The estimated sill may not equal the variance due to incomplete sampling or invalid conditions.

CHAPTER 3

METHODS

Sampling and laboratory analysis were carried out under conditions that would be expected under a commercial operation. Intensive sampling, both plant and soil, with a variety of soil sample analysies were also carried out to better understand the system.

Sampling

Sampling was begun by accompanying the GPM program sampler over 4 consecutive days, 15-18 June 1981. Intensive sampling was continued during a 3 day period, 29-31 July 1981. A total of 37 fields were sampled.

Field Samples

In 28 fields two to four 0.5 hectare areas were sampled, each sample being a composite of 20 petioles. These samples were collected with the program sampler in order to duplicate the sampling used in the program. These will be refered to as field samples. (The farm, field number, size and maturity of plants sampled are listed in Table 2 of the "Variability of Field Samples" section in the "Statistical Analysis" chapter below.)

Area Samples

In five fields, 0.5 hectare areas were intensively sampled in a combination of one, two or three ways by collecting a composite of 40 petioles over the 0.5 hectare area, by collecting 40 individual petiole samples over the 0.5 hectare area or by dividing the 0.5 hectare area into quarters and sampling a composite of ten petioles from each sub-area. These samples will be referred to as area samples. The farms and field numbers are listed in Table 1 (in "Variability of Area Samples" section in the "Statistical Analysis" chapter below) along with data and statistics. The maturity of the plants sampled are listed under the appropiate field number in Table 2.

Transects

In seven fields, ten transects were run in a variety of ways. Six transects (Nalbandion's field #28, M & W Miller's field #67, Marietta's field #14, Brown's field #7, Goldson's field #11-45-10 and D. Prechel's field #B1) were run across the center of the field collecting a composite sample of three or four petioles at 10 meter intervals over the width of the fields. The seventh transect (Nalbandion's field #28) was across the center of the field collecting a composite sample of two petioles every meter (row) for 100 meters. The eighth transect (D.

Prechel's field #B1) was down a furrow in the center of a field taking a composite sample of four petioles every 10 meters over the length of the field. The ninth transect (Nalbandion's field #4) was by collecting a petiole from every plant up 3 meters of a row. The last transect (Nalbandion's field #28) was by collecting single petioles of different maturity from the same plant for seven plants up 5 meters of row. Plant parts sampled were the apex, the petioles of the shiny and dull but not fully extended leaves and the petioles of the first, second and third fully extended mature leaves. These samples will be refered to as transect samples.

Grid Samples

An apparently uniform field was selected for intensive sampling of both leaf petioles and soil. A 360 by 360 meter plot was set up within the 15 hectares. The irrigation furrows were on a 1 meter row spacing. By using a random-number generator, 197 sites were chosen from the intersections of a 180 by 180 regular grid resulting in the locations given in Figure 2. A regular grid was chosen because of the ease of layout and sampling. Random sites were used to avoid bias caused by systematic variations with cycles greater than 4 meters and to sample from sites that are close together while still covering a large area.

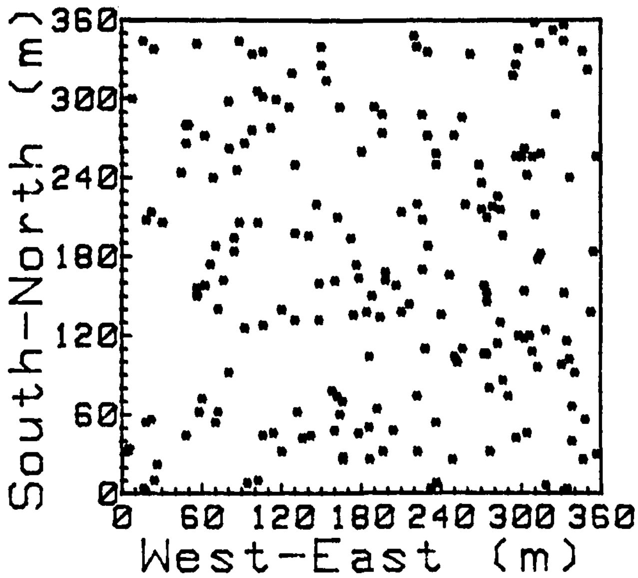


Figure 2. Location of 197 petiole grid-samples in the 360 by 360 meter plot.

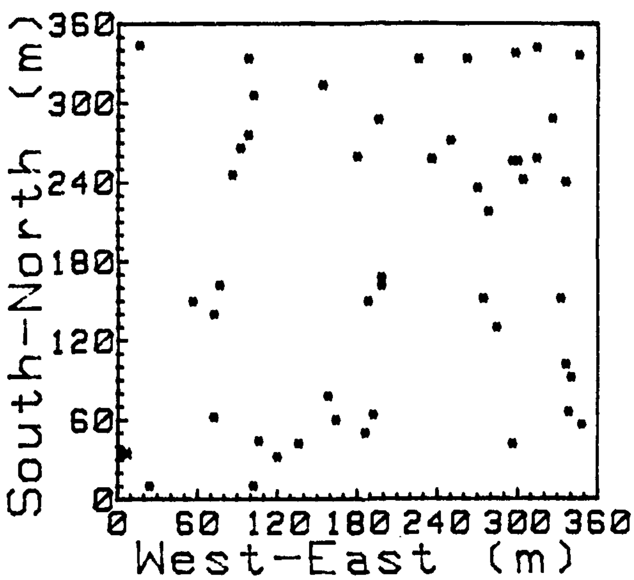


Figure 3. Location of 49 soil grid-samples in the 360 by 360 meter plot.

At each 2 by 2 meter site a composite of ten petioles were collected, five from each row. From the first 49 of the 197 random sites (Figure 3), a composite of eight surface soil samples were collected, two from each side of the row to a depth of 15 to 20 cm. Soil samples were collected with a 2.5 cm diameter probe. These samples will be referred to as grid samples.

A second order soil survey of the grid-sample field (Figure 4) was made by Steve Levine, former USDA Soil Conservation Service Soil Scientist with 5 years of mapping experience in the area. A description of the soils mapped is given in Appendix B. The mapping was completed based on information readily available to any field scientist.

The petioles collected for the above samples unless otherwise stated were picked from the first dull but not fully extended leaves by the author in an effort to minimize bias and maximize consistency.

Laboratory Analysis

Laboratory analysis consisted of determining the nitrate-nitrogen (NO_3-N) concentration of the petiole samples. Also for the 49 soil samples, analysis was done to determine texture, pH, electrical conductivity (EC), NO_3-N, carbonic acid extractable orthophosphate-phosphorus, water extractable sodium and potassium.

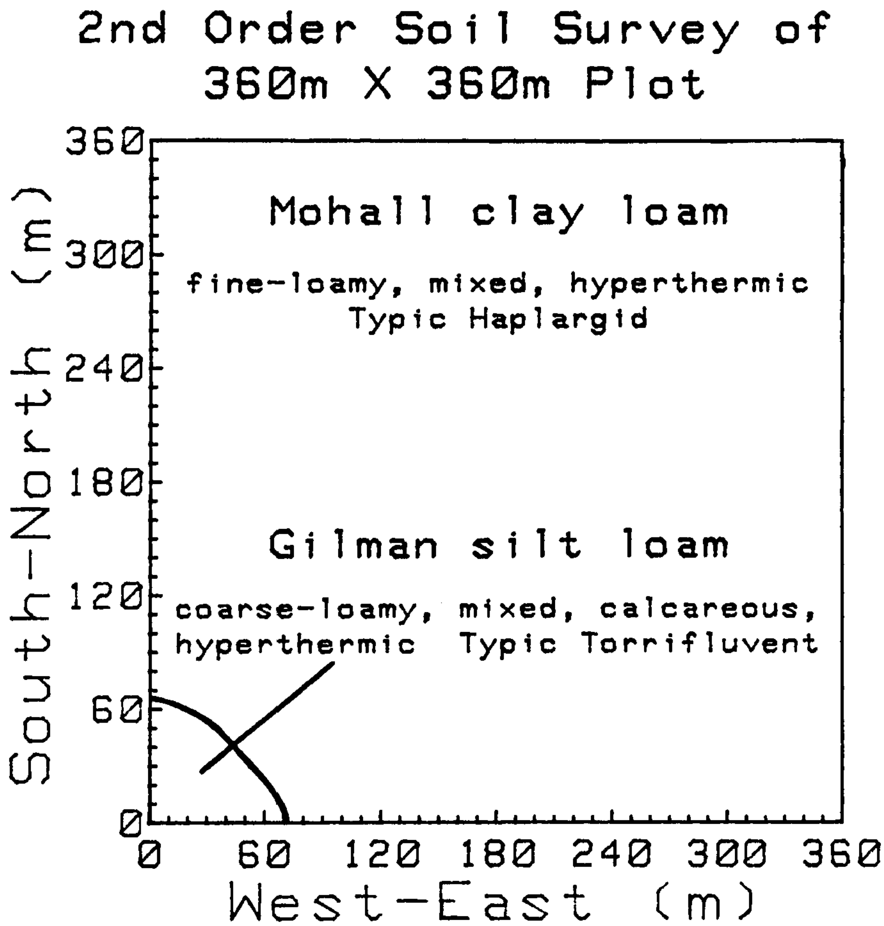


Figure 4. Intensive soils map of 360 by 360 meter plot.

Petiole Nitrate

Petiole NO_3-N was determined by an Orion nitrate electrode (model 93-07-01) with an Orion double junction reference electrode (model 90-02-00). The samples were collected in small coin envelopes, oven dried at 60° Celsius and then shattered with a leather mallet while in the envelope. The pulverized tissue was weighed on an analytical balance and extracted with aluminium-sulfate solution (Appendix C). The extraction solution was added to 15-dram vials with an automatic dispenser which had a reproducibility of 0.09% CV (coefficent of variation) at 23 ml.

Standard solutions in the 1 to 100 ppm NO_3-N range verified the meter reading from the nitrate electrode. Samples were shaken for 1 hour based on preliminary extraction tests. Filtered and unfiltered extracts showed no apparent effect on meter readings, so unfiltered extract were used in the analysis.

Soil Nitrate

Soil NO_3-N was analysed by using the nitrate electrode, as described above, and through the University of Arizona Soil, Water and Plant Tissue Testing Lab (Testing Lab) which used a nitrate reduction and colorimetric determination of nitrite procedure.

For the nitrate electrode, air-dried soil was extracted with a $CaSO_4$-Ag_2SO_4 solution (Appendix C), filtered and analysed. The electrode calibration was difficult to maintain for the soil-nitrate determination so the samples were also analysed by the Testing Lab as a check.

A Technicon AutoAnalyzer II was used by the Testing Lab to determine soil NO_3-N. The procedure is described in "Nitrate and Nitrite in Water and Waste Water" Technicon AutoAnalyzer II Industral Method No. 100-70W/B which is a distilled water extraction, a reduction of nitrate to nitrite in the extract and then a reaction of nitrite forming a redish-purple azo dye. The concentration is determined colorimetricaly at the 0.520 μm wavelength. Manufacturers specifications on reproducibility is ±0.31% CV at 1 ppm nitrogen. Nitrite concentration in the soil is assumed to be insignificant.

Results of the two methods show acceptable agreement. The average values of the two methods were used for further analysis (Appendix E).

Soil Ortho-Phosphate

Soil phosphorus was determined through the Testing Lab by using the Technicon AutoAnalyzer II and the manufactures procedure "Ortho-Phosphate in Water and Waste

Water", Industrial Methods No. 94-70W/B. Extraction was carried out by bubbling CO_2 in a 5:1 distilled water and soil mixture as described in McGeorge (1939). The ortho-phospate in the extract is reacted in acid with ammonium molybdate and then it is reduced with ascorbic acid to form a molybedenum blue complex. The concentration is determined colormetricaly at 0.660 µm. The manufactures specification for reproduceability is ±0.4% CV at 5 ppm phosphorus.

Soil Sodium and Potassium

Water extractable sodium and potassium were determined by the Testing Lab from a distilled-deionized water saturated paste extract as described in Black et al. (1965). The concentrations of sodium and potassium in the extract were determined by flame emission according to the proceedure recommended by Emmel et al. (1976). The sodium concentration was determined from the 0.589 µm wavelength and the potassium from the 0.7665 µm wavelength.

Soil pH and Electrical Conductivity

Soil pH was determined by the Testing Lab from a saturated paste with a standard pH electrode. Soil EC was determined from the extract of the saturated paste using a conductivity bridge. Both analyses followed the procedures as described in Black et al. (1965).

Soil Texture

Soil texture was determined by the hydrometer method using a standard hydrometer, ASTM No. 152H, according to the procedures in Black et al. (1965). Since the proportions of sand, silt and clay were similar for all samples, readings at 0.7 and 1.0 minutes bracketed the silt + clay concentrations and 620 and 1080 minutes bracketed the clay concentration. This provided two values close to each fraction boundary and linear interpolations of the bracketed values were used to estimate the percentages of sand, silt and clay (USDA classification).

CHAPTER 4

STATISTICAL ANALYSIS

Various statistical tools were used in this study. Standard statistical tests, multivariate analysis (Webster, 1977) and variograms were used to describe the structure of the variables. Sources of variation examined were that due to laboratory analysis, that due to maturity of plant tissue and that due to spatial position.

Variability of Laboratory Analysis

Samples from a finely-ground batch of cotton petiole tissue, where samples sizes ranged from 0.01 g (the size of the smaller petioles) to 0.1 g, were analysed and showed no detectable difference in NO_3-N concentration due to sample size (Figure 5).

Three subsamples were taken from 194 different samples, each containing pulverized tissue from ten petioles (see the "Grid Samples" subsection of the "Methods" chapter). Analysis of the subsamples were run in groups of 97 on separate days. No two subsamples from the same main sample were analysed on the same run. The resulting coefficient of variation (CV) from the family of three subsamples for each of the 194 different samples are plotted

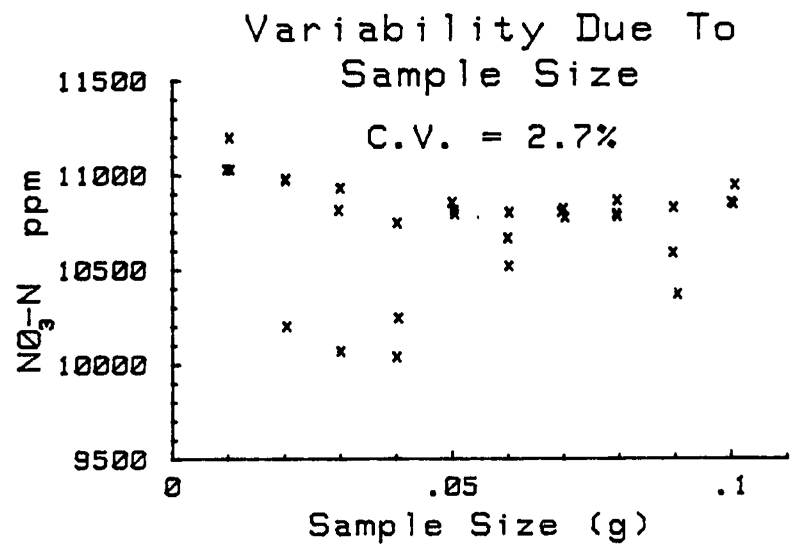


Figure 5. Plot of NO_3-N concentration due to sample size and the CV from all of the batch samples.

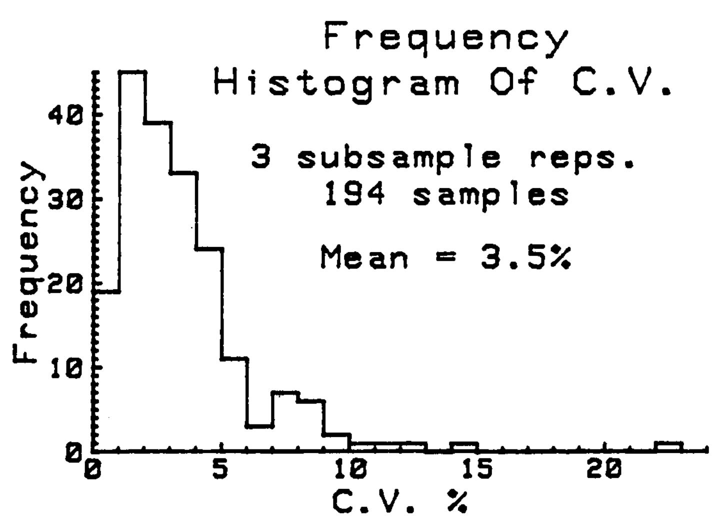


Figure 6. Frequency histogram of the CV of three subsample replications from 194 different samples.

as a frequency histogram (Figure 6). The average of 3.5% CV is very close to the precision expected, 2% CV as listed in the manufactures specifications for the nitrate electrode.

Other than comparing meter readings of the electrode with standard solutions, which agreed, no attempt to check the accuracy was made. Any small but relatively constant bias that affects the accuracy will not affect the conclusions of this study.

The methods of laboratory analysis used in this study showed sufficent sensitivity that variability due to sampling and other factors could be studied.

Variability of Petioles on the Plant

Petiole variability on the plant was determined by evaluating single petioles of different ages from individual plants along a 5 meter transect. Analysis was done on the apex tissue, the petioles of the shiny and dull immature leaves, and the petioles of the first, second and third mature leaves. See Figure 7 for position of plant parts and plot of concentarations for individual plant parts over distance.

The null hypothesis of equal means from different age of plant parts could not be rejected at the 0.80 level for the first, second and third mature leaf petioles with

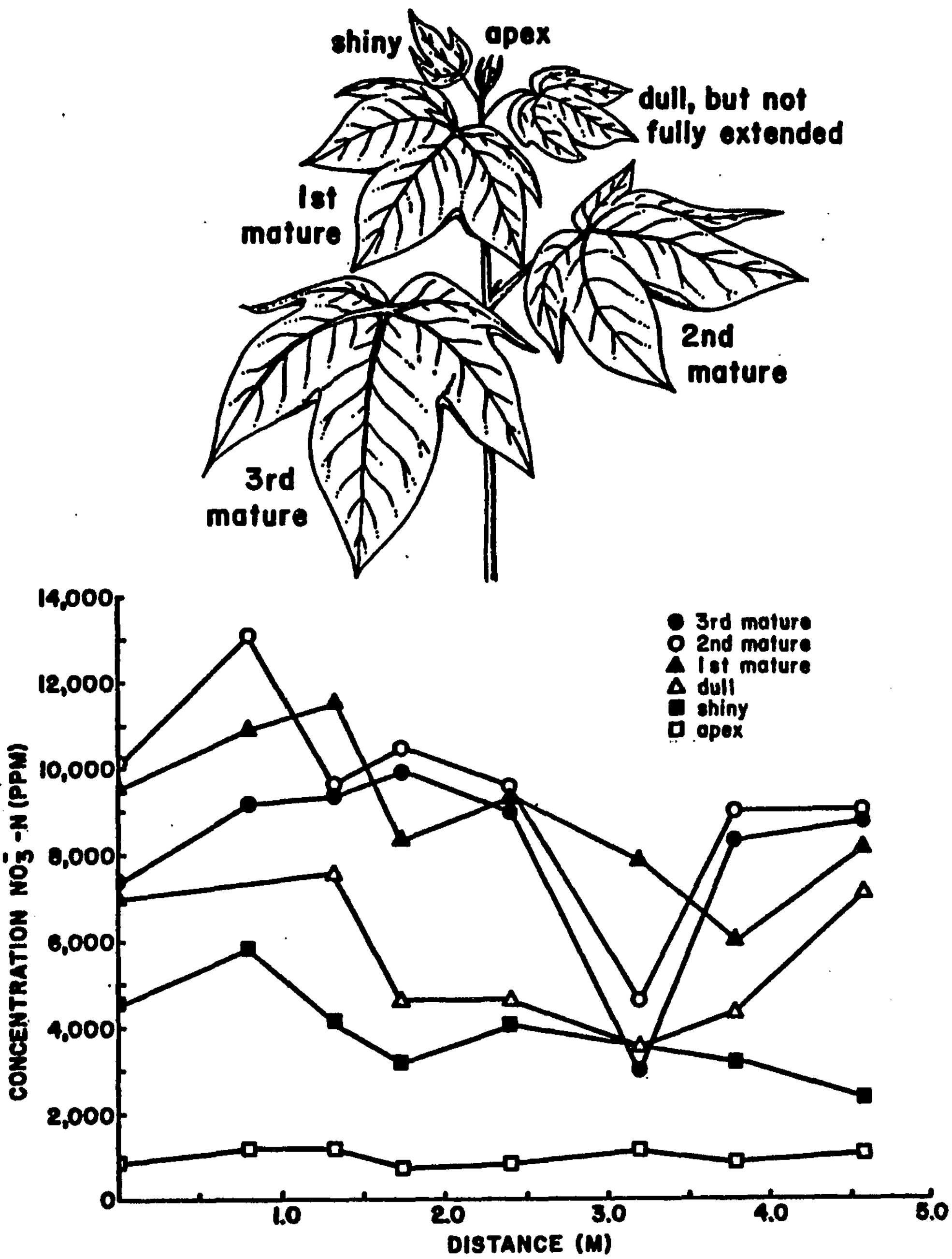


Figure 7. Sample position on plant and plot of NO_3-N concentrations of plant parts on individual plants over 5 meters of row.

the Student's t statistic. Petioles of the first mature leaves could be seperated from non-fully extended dull leaves at the 0.99 level as could the dull from the shiny non-fully extended leaves, and the shiny leaves from the apex tissue.

As indicated by other studies the apex tissue shows the least sensitivity to plant nitrate concentration and would not be an appropriate part to predict nitrogen deficiency. The shiny and dull, non-fully extended leaves show an increasing sensitivity to plant nitrate concentration but do not have the same mean concentrations and are difficult to differentiate in the field. The first, second and third fully extended mature leaf petioles have similar sensitivity and means. This agrees with previous studies suggesting petioles from the first fully extended leaf should be picked and also indicates the next older leaf should be picked if the degree of maturity is in question.

Composite samples of two petioles from the dull, non-fully extended leaves were collected from 100 sites along a transect (refer to the every row transect from Nalbandion's field #28 in the "Petiole-Nitrate Transects and Variograms" section below) and the two petioles were analyzed separately. The mean of the smaller of the two petioles was 4880 ppm and the mean of the larger petioles was 5670 ppm, indicating the level of bias that can occur when sampling within a maturity class.

Variability of Area Samples

Assuming sample independence and a normal distribution the number of petioles needed to achieve an average within 1000 ppm NO_3-N of the mean are listed in Table 1 at various confidence levels by using the standard normal statistic. Also listed are confidence levels for the average to be within the indicated range of the mean by using the Student's t statistic. These values were determined from the sample variances of 40 individual petiole samples, four composite sub-area samples and several composite samplings of 0.5 ha areas.

The table values indicate a wide range of petiole nitrate variability and sample number requirements for the 0.5 ha areas. The assumption of sample independence can not alway be made and will be discussed in the "Petiole-Nitrate Transects and Variograms" section below. The sample distributions of petiole nitrate approximate normal distributions.

Variability of Field Samples

The number of 0.5 ha areas required for the field average to be within 1000 ppm NO_3-N of the field mean and the confidence levels of the average occuring within a

Table 1. Summary of Area Sample Data and Statistics

Field		Samples	Petioles per sample	$\bar{X}$ ppm	s ppm	CV %	Sample # Req.[1] .99	.90	.80	Confidence Levels[2] ±1000	±2000	±3000
C. Brown	7	40	1	10600	2740	25.9	50	21	4	.95	.999	.999
		4	10	11030	1040	9.5	8	3	2	.8	.95	.98
		2	40	10810	308	2.9	1	1	1	.8	.9	.95
Goldson	11-45-10	4	10	9070	109	2.4	1	1	1	.999	.999	.999
		2	40	9170	141	0.01	1	1	1	.9	.95	.95
M. Marietta	14	40	1	4840	2480	51.3	41	17	11	.98	.999	.999
		4	10	4490	1480	33.1	15	6	4	.6	.9	.95
		2	40	4460	245	5.2	1	1	1	.8	.9	.95
M & W Miller	67	40	1	8820	3400	38.6	78	32	19	.9	.999	.999
		4	10	8280	1280	15.4	11	5	3	.6	.9	.98
		3	40	8390	386	4.6	1	1	1	.95	.98	.99
Nalbandion	28	40	1	6120	1950	31.9	26	11	7	.99	.999	.999
		4	10	6120	428	7.0	2	1	1	.98	.99	.999
		3	40	5980	228	3.8	1	1	1	.98	.99	.99

1 Sample requirements using std. normal statistic for the mean to be within ±1000 ppm NO_3-N of the average at given confidence levels with the assumption s^2 equals σ^2.

2 Confidence levels using the Student's t statistic for the mean to be within the given concentration ranges of the sample average in ppm NO_3-N.

given range of the field mean were determined by using the same assumptions and analysis techniques as in the above section. The 28 fields sampled show a wide range in sample variances and sample number requirements as listed in Table 2. Any influence of variability caused by field size, plant maturity (up to late square) and management from different farms were masked by other factors. This indicates that the soil may be the dominate influence.

In general, sampling methods used in the GPM program resulted in field averages occurring within 1000 ppm $N0_3$-N at greater than 0.50 confidence level for over half of the fields, within 2000 ppm NO_3-N at greater than 0.60 confidence level for over half of the fields and within 3000 ppm NO_3-N at greater than 0.80 confidence level for over half the fields.

Petiole-Nitrate Transects and Variograms

Transects are useful in obtaining preliminary information about the spatial variability in a field without the time and expense of more elaborate sampling programs. Nine transects were analysed.

The transect, frequency histogram and variogram for Nalbandion field #4 are illustrated in Figure 8. Histograms are useful in evaluating whether the variables need transforming for further analysis and to predict

Table 2. Summary of Field Sample Data and Statistics

Field		Area ha.	Age[1] #/#	# Areas Sampled	$\bar{X}$ ppm	s ppm	CV %	Sample # Req.[2] .99	.90	.80	Confidence Levels[3] ±1000	±2000	±3000
C. Brown	7	15.4	10/ 6	4	14880	784	5.3	5	2	1	.9	.98	.9
	12	16.2	11/10	2	8840	777	8.8	5	2	1	.6	.8	.8
	13	8.1	10/ 4	3	11120	1878	16.9	24	10	6	.5	.6	.8
Goldson	11-45-11	-	11/ 9	3	11160	902	8.1	5	3	2	.8	.9	.95
M. Marietta	14	-	12/10	3	7240	2100	29.0	30	12	8	.5	.6	.8
	16	-	12/10	3	7480	2294	30.7	36	15	9	.1	.6	.8
	MM	-	11/ 7	4	5140	2546	49.5	44	18	11	.5	.6	.8
M & W Earley	41N	15.4	12/12	3	12770	3369	26.4	76	31	19	.1	.5	.6
	41S	15.4	12/ 8	3	11440	828	7.2	5	2	2	.8	.9	.95
	42	13.0	13/14	2	8070	213	2.6	1	1	1	.9	.95	.95
	43	14.2	12/12	4	7200	2320	32.2	36	15	9	.5	.8	.9
	44N	24.3	9/ 6	3	12860	868	6.8	6	3	2	.8	.9	.95
	44S	24.3	—	2	7460	1016	13.6	7	3	2	.6	.6	.8
	45W	24.3	14/11	3	10400	3712	35.7	92	38	23	.1	.5	.6
	47	12.4	8/ 4	3	13090	3154	24.1	67	27	17	.1	.6	.6
	48	30.5	7/ 4	3	4780	5240	110.0	183	75	45	.1	.1	.5
	49	29.7	5/ 1	3	13900	3145	22.6	66	27	17	.1	.6	.6
	51	14.4	6/ 1	2	15790	1050	6.7	8	3	2	.5	.6	.8
	52	14.3	6/ 1	3	15160	620	4.1	3	2	1	.8	.95	.98
	53	17.6	9/ 4	3	14210	1428	10.0	14	6	4	.5	.6	.8
	54	26.7	7/ 2	2	13440	1257	9.4	11	5	3	.5	.6	.8
M & W Miller	67	36.5	12/ 9	3	10060	1632	16.2	18	8	5	.6	.8	.9
Nalbandion	28	15.4	14/18	3	10380	1985	19.1	27	11	7	.5	.6	.8
D. Prechel	B1	17.5	9/ 6	3	12640	1733	13.7	20	9	5	.5	.8	.9
P. Prechel	10E	-	11/12	2	11600	1655	14.3	19	8	5	.1	.6	.6
	10W	-	11/8	3	11100	2861	25.8	55	23	14	.1	.6	.6
	2B	-	15/bolls	3	11850	1721	14.5	20	9	5	.5	.8	.9
	5A	-	13/19	2	13160	2273	17.3	35	14	9	.1	.5	.6

1 Age of plants in the field are given by the # of nodes / # of squares.

2 Sample requirements using std. normal statistic for ±1000 ppm NO_3-N at given C.L.

3 Confidence levels using Student's t statistic for given concentration ranges in ppm N.

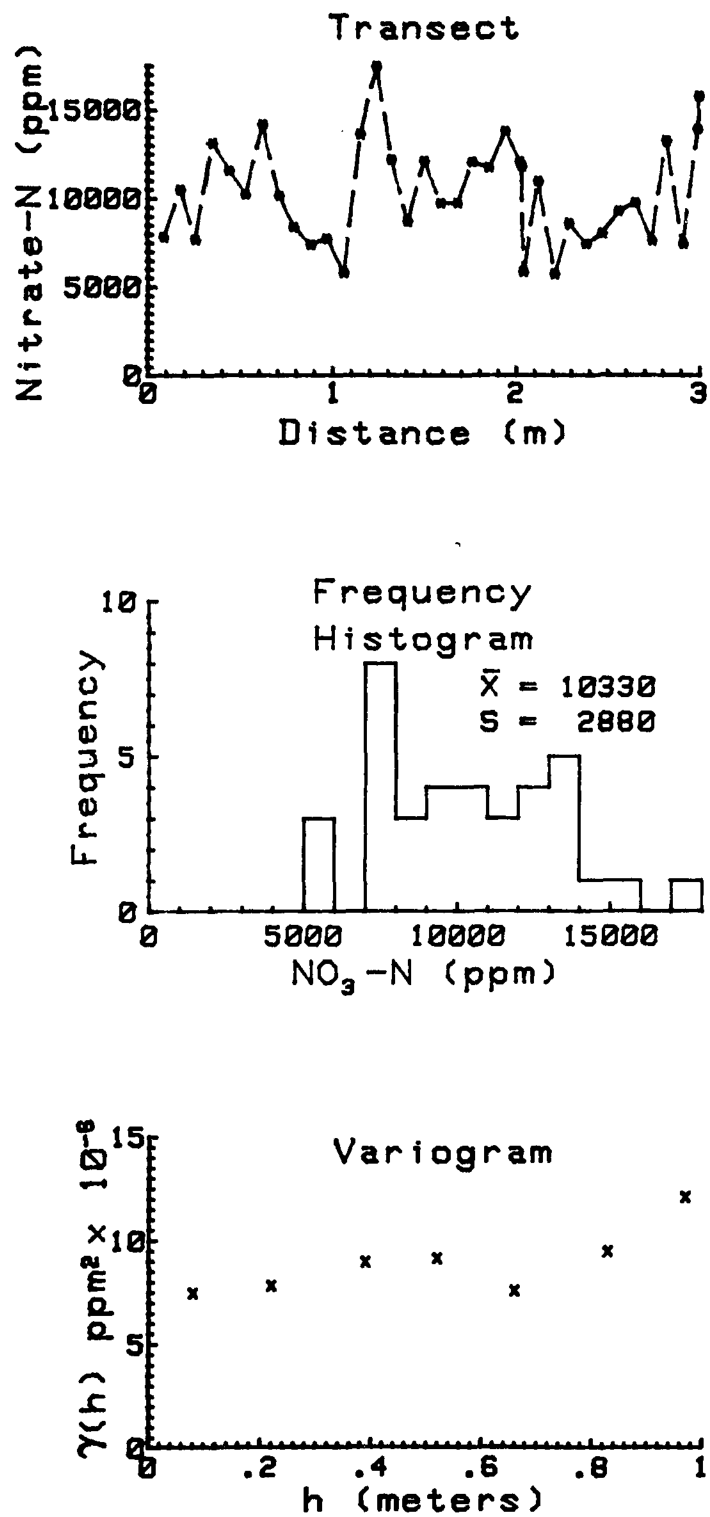


Figure 8. Transect, frequency histogram and variogram of Nalbandion's field #4 where single-petiole samples were collected every plant.

problems that may occur in analysis, especially with widely spaced multimodal distributions. This histogram sufficiently approximates a normal distribution and transformation is not needed.

The variogram suggests spatial dependence by a somewhat linear increase of semivarance with increasing distance between samples. The relatively large "nugget" effect indicates that when sampling plants within 1 meter of each other the inherent variability of sample values is more important than the variability due to distance between samples.

Transects, frequency histograms and variograms for Nalbandion field #28 are illustrated in Figures 9 and 10. The variogram from the every row transect (Figure 9) suggests a linear increase of semivariance until the range of 4 meters where an apparent sill is achieved indicating that samples greater than 4 meters apart along the transect can be considered random samples.

A second transect with samplings every 10 m and tracing the same path as above across the entire field (370 m) is illustrated in Figure 10. The first 100 meters of this transect represents the same portion of the field as the above transect. This variogram indicates a linear increase in semivariance with increasing distance between samples at least to 80 meters. Due to edge effects and

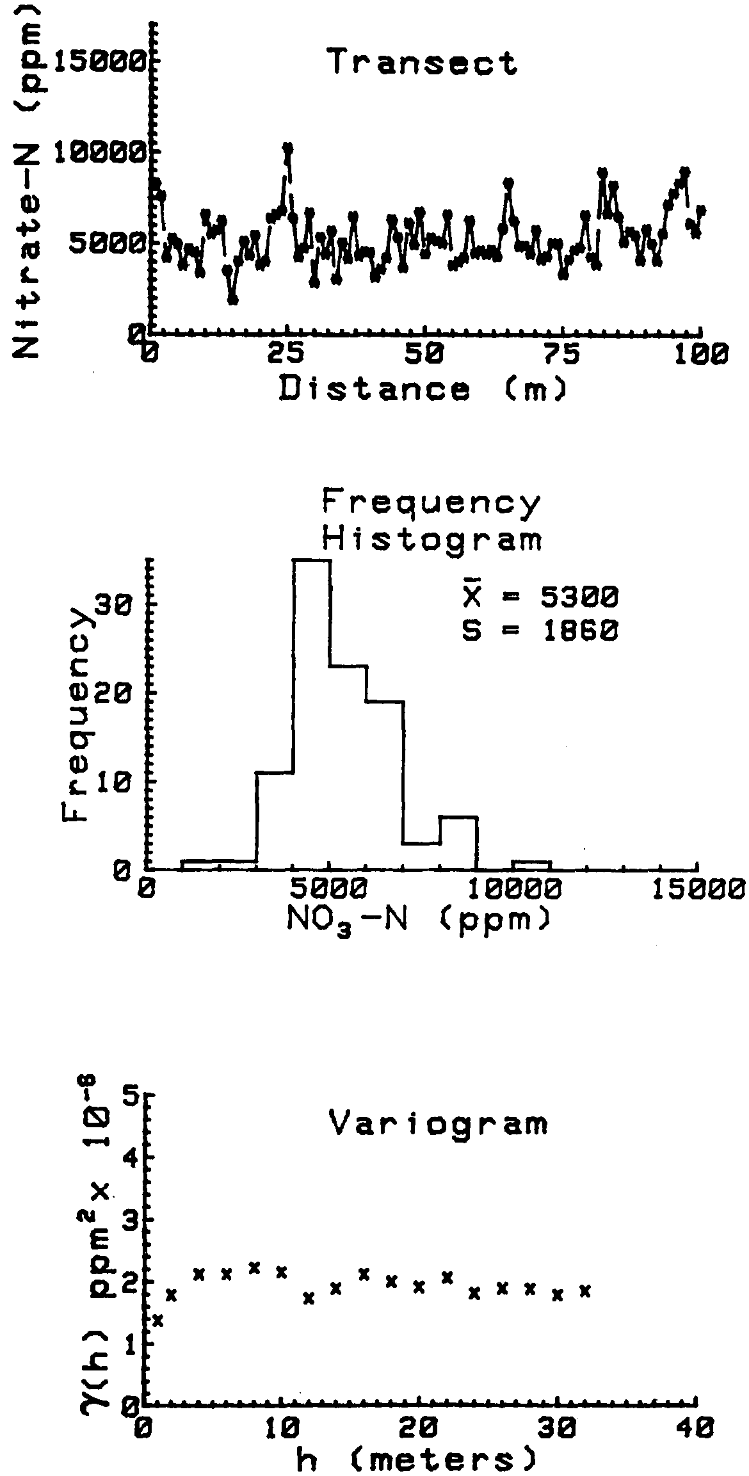


Figure 9. Transect, frequency histogram and variogram of Nalbandion's field #28 where composite samples of 2 petioles were collected every meter.

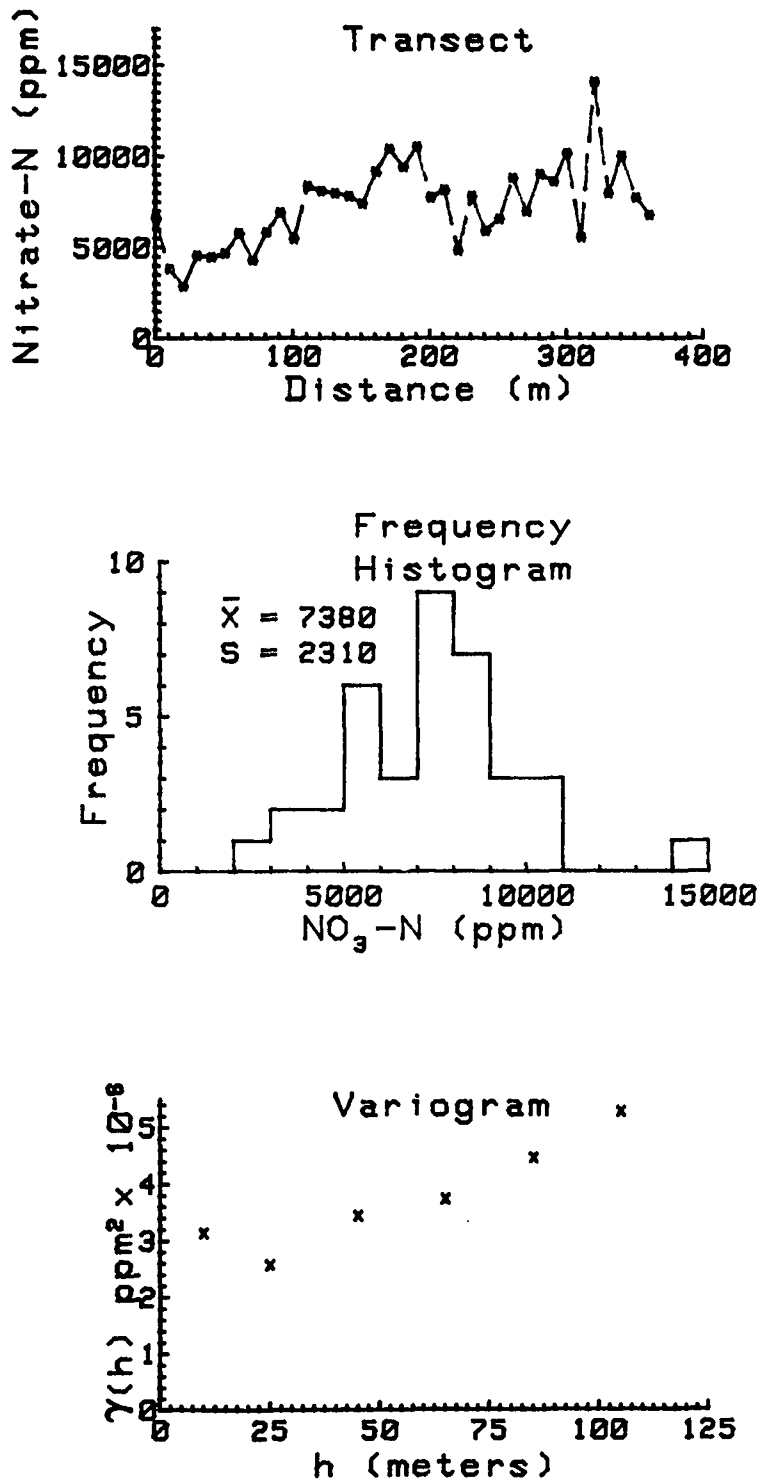


Figure 10. Transect, frequency histogram and variogram of Nalbandion's field #28 where composite samples of 3 petioles were collected every 10 meters.

lower numbers of sample pairs the semivariance for larger relative distances are unreliable.

The discrepancy between the two variograms can be attributed to a structure of the factors affecting petiole nitrates in the field. The 100-meter transect could have been over soil with uniform properties relative to the total field and was composed of smaller units of soil that graded between each other over an average distance of 3 meters, e.g. two rows irrigated and/or fertilized the same.

The remaining transect variograms (Figures 11-16) show various degrees of spatial dependence and "nugget" effects with several variograms indicating samples are independent at distances greater than 10 meters between each other.

A repeating cycle of increasing and decreasing sample values in a transect or other sampling scheme can result in a sinusoidal shape of the variogram. Figures 12 and 14 show a repeating cycle in the transect and a resulting sinusoidial shape of the variogram. The repeating cycle may be a chance occurrence or a repeating pattern of soil characteristics or cultural practices. This also illustrates the sensitivity of the variogram to edge effects.

Variograms of transects run in different direction in the field as in the Prechel transects, Figures 15 and

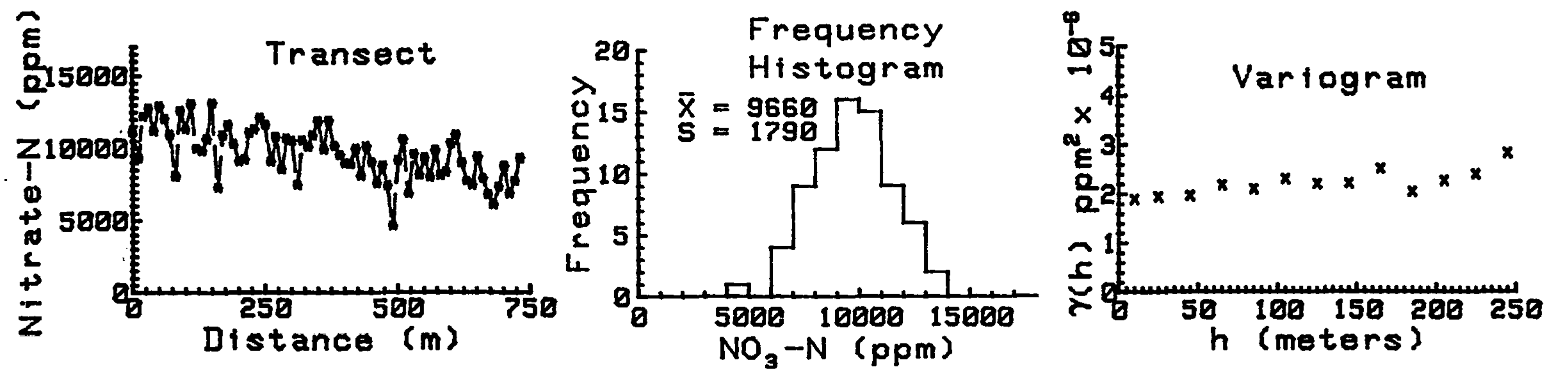


Figure 11. Transect, frequency histogram and variogram of M & W Miller's field #67 where composite samples of 3 petioles were collected every 10 meters across the rows.

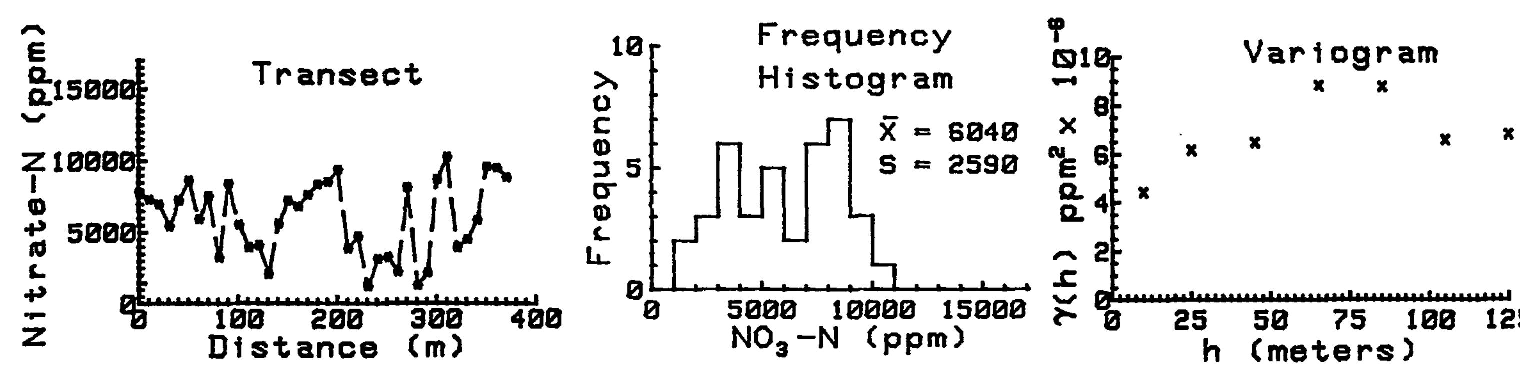


Figure 12. Transect, frequency histogram and variogram of Marietta's field #14 where composite samples of 4 petioles were collected every 10 meters across the rows.

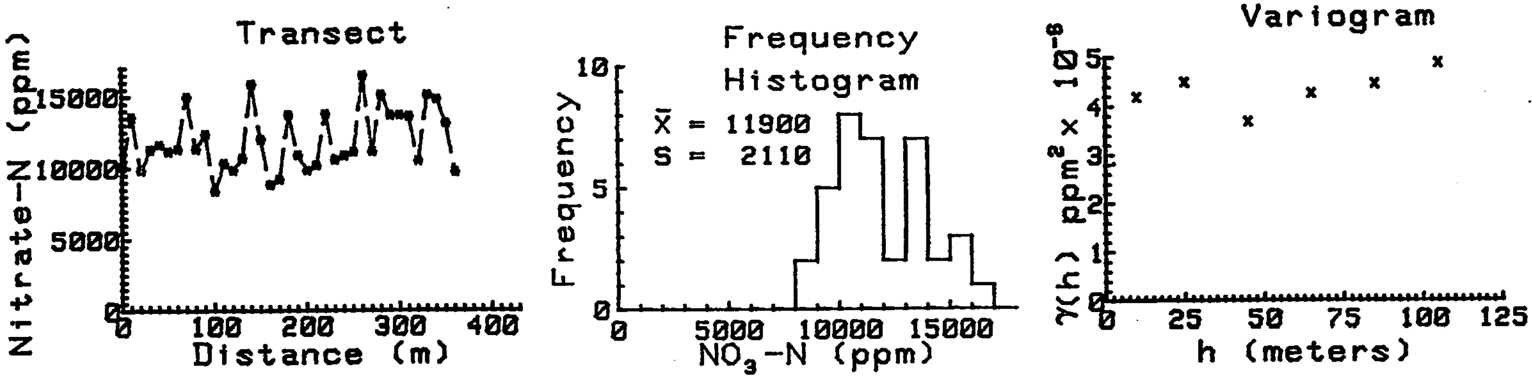


Figure 13. Transect, frequency histogram and variogram of C. Brown's field #7 where composite samples of 4 petioles were collected every 10 meters across the rows.

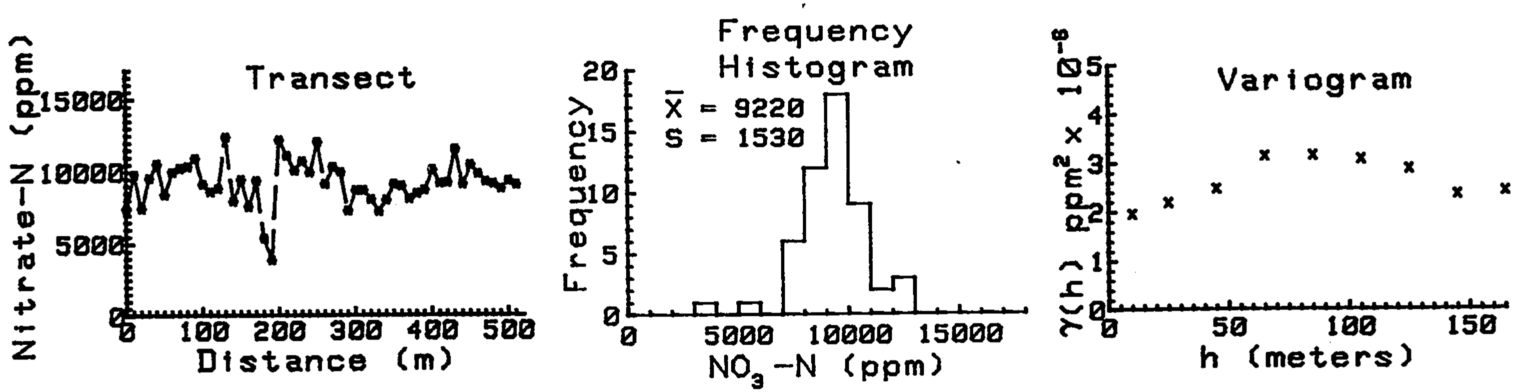


Figure 14. Transect, frequency histogram and variogram of Goldson's field #11-45-10 where composite samples of 4 petioles were collected every 10 meters across the rows.

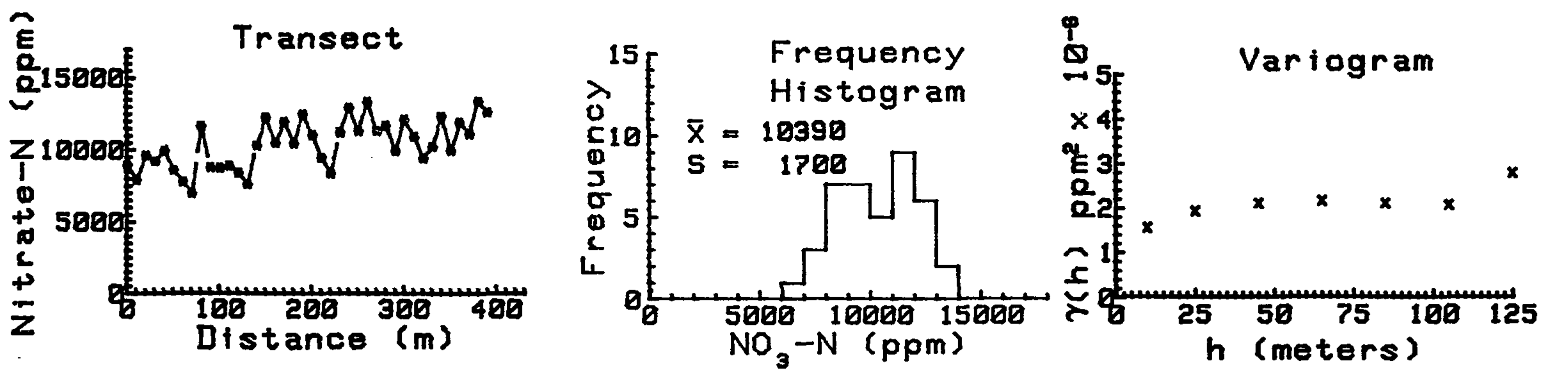


Figure 15. Transect, frequency histogram and variogram of D. Prechel's field #B1 where composite samples of 4 petioles were collected every 10 meters across the rows.

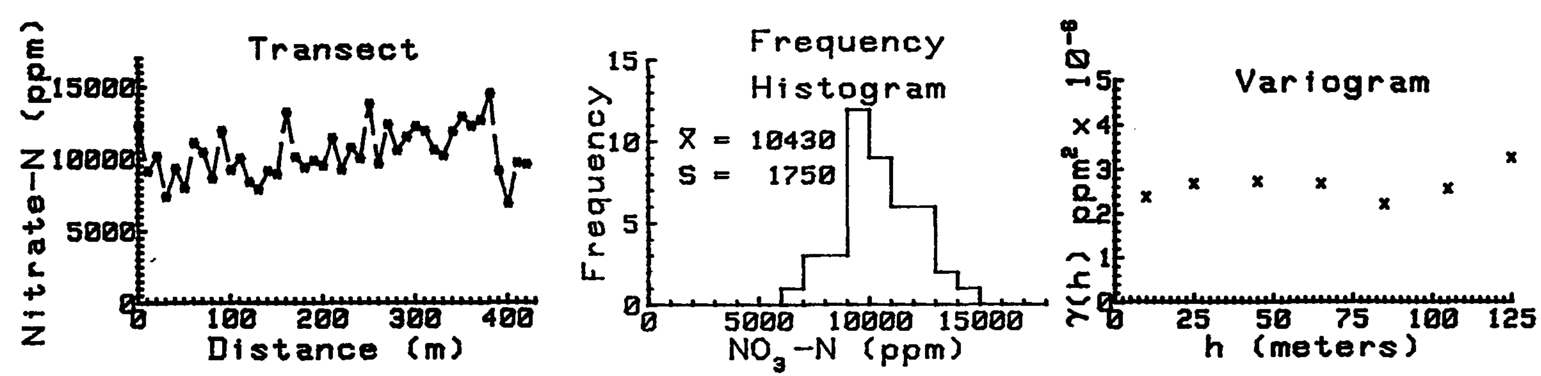


Figure 16. Transect, frequency histogram and variogram of D. Prechel's field #B1 where composite samples of 4 petioles were collected every 10 meters down a row.

16, can indicate directional effects on semivariance. Two transects were run; one across rows and the other down a row. The variograms are similar indicating an isotropic condition, that is spatial dependence is only a factor of distance and not direction.

Variograms of petiole-nitrate from different fields (Figures 10 to 16) show different degrees of spatial dependence and variability. The spatial dependence in M & W Miller's field #67 (Figure 11), C. Brown's field #7 (Figure 13) and D. Prechel's field #B1 (Figures 15 and 16) can be considered insignificant during the particular time of sampling. Comparing the field-sample data and statistics in Table 2 of the spatially "independent" fields with the "dependent" fields (Goldson's field #11-45-11, M. Marietta's field #14 and Nalbandion's field #28) shows no relationships. On the other hand, the variability of M. Marietta's field #14 was significantly higher in both field samples and variogram than the other fields.

Petiole Grid-Samples and Variograms

Sampling from a grid has the advantage over transects in that a better two-dimensional picture of the spatial variability of the area can be formed.

The frequency histogram of the 197 samples (Figure 17) approximates that of a normal distribution. Applying a

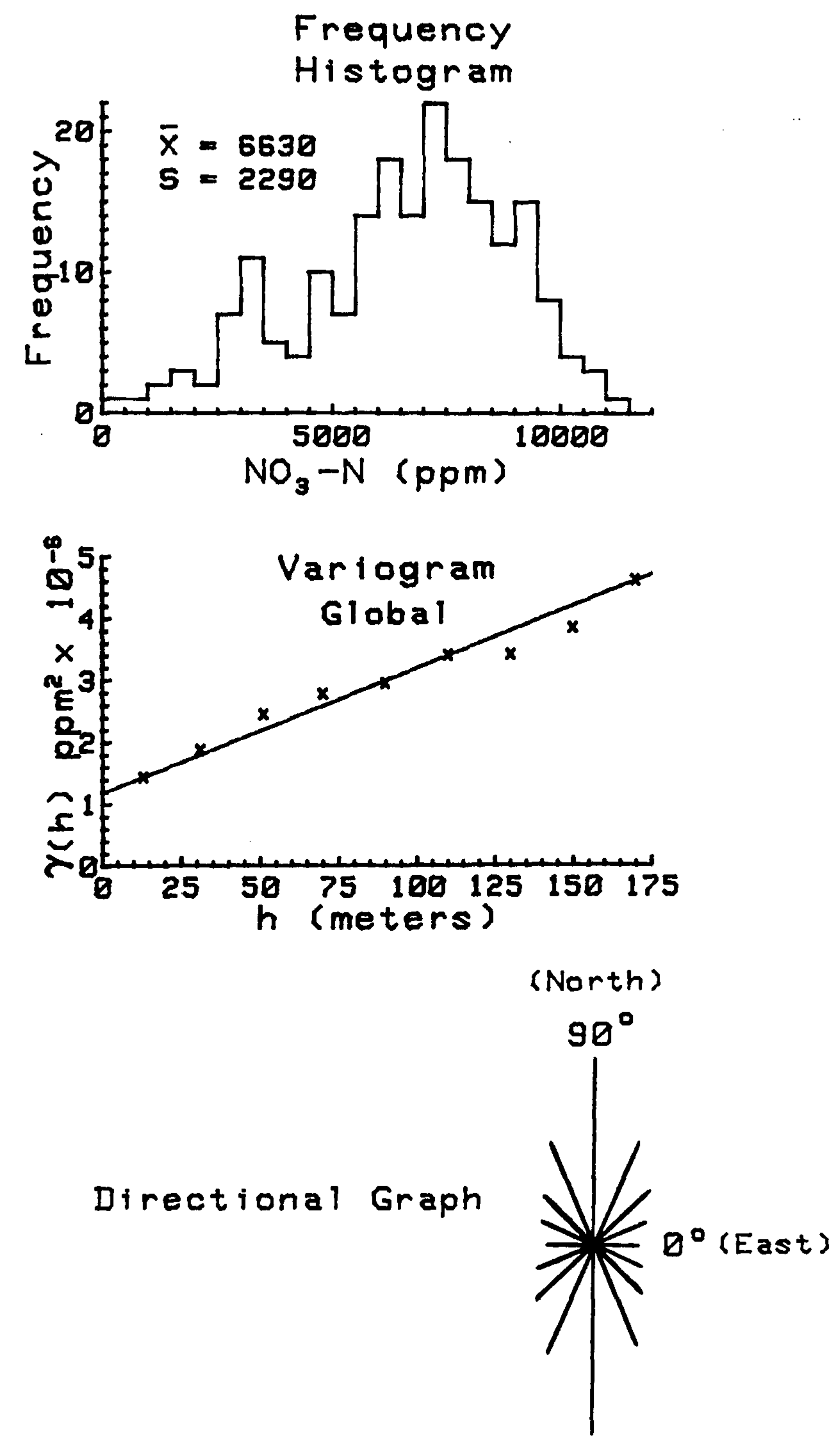


Figure 17. Frequency histogram, global variogram and directional graph of petiole-nitrate concentration from grid-samples.

goodness-of-fit test resulted in a Chi-squared value of 25.9 with 15 degrees of freedom. The hypothesis that petiole nitrate is a normally-distributed variable can not be rejected at the .975 level.

The global (isotropic) variogram (Figure 17) shows semivariance increasing linearly with increasing distance to at least 130 meters. To determine if anisotropy exists, 8 directional variograms were run at 90°, 68°, 45°, 23°, 0°, -23°, -45° and -68° with a ±11° window. They are illustrated in Figure D.1 of Appendix D. A directional graph can be drawn for geometrical anisotropy (Figure 17) by taking the recipical of the slope of each directional variogram and letting them represent the magnitude of vectors pointed in the direction of the corresponding variogram. This shows the relative sampling distances from a central sample needed to achieve the same semivariance and illustrates anisotropy (Journel and Huijbregts, 1978, esp. p. 179). The directional graph has a "peanut" shape which is different from the elliptical anisotropy commonly described in the literature. The graph shows indentations at directions across rows (0°) and indicates the direction of maximum change of γ with distance. Also the graph shows maximum extension along rows (90°) and indicates the direction of minimum change of γ with distance.

An interpretation is that petiole nitrate variability is also a function of cultural practices which, assuming otherwise uniform conditions, will result in less variability in the direction of fertilizer application and irrigation along rows (i.e. north and south). Also maximum variability will occur perpendicular to the direction of fertilizer application and irrigation across rows.

Intuitively one would expect that nitrate concentrations would be more similar along rows than across rows due to irrigation and fertilization along rows. This will result in a banding effect of similar values along rows. Kriging was used by Tabor, Warrick and Pennington (1983) on the petiole-nitrate values from the grid-sample field by using the fitted variogram models and an elipitical anisotropy model. (Kriging is a geostatistical technique where maps can be made using incomplete data from an area by optimumly interpolating estimated values between known data). The kriged map showed a definite banding along rows of similar nitrate concentrations.

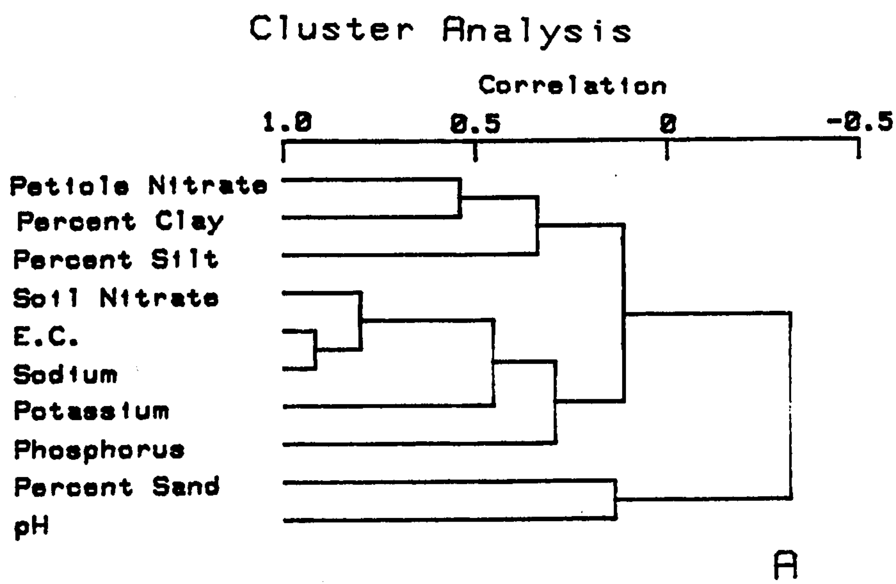
This anisotropic variability can be modeled by seperating the effects due to cultural practices. This anisotropic effect can be approximated by a two-petal, rose model while the anisotropy, if any, caused by other factors can be approximated by an ellipse. The sum of these two models can approximate the anisotropy observed better than the common elliptical model but may not be worth the trouble.

Soil Grid-Samples and Variograms

The 49 soil sample locations are plotted in Figure 3. The samples were analysed for percent sand, silt and clay, soil nitrate, pH, EC, sodium, potassium and CO_3-extractable phosphate. Three types of multivariate analysis were performed on the data; factor (Nie et al., 1975), correspondence (David, Dagbert and Beauchemin, 1977) and cluster analyses (Dixon et al., 1981). All three types had the same general results which are best graphically illustrated by the cluster analysis results (Figure 18).

Cluster analysis measures the similarity between variables and groups of variables, in this case by use of correlation. The progression is pairs of similar variables are grouped to form clusters, these clusters are then grouped according to their similarity, and so on. The heirarchy developed can be represented by a tree diagram. There are many ways to measure similarity of clusters. In this study average distance and minimum distance methods were used and produced similar results for both correlation and absolute correlation (not shown).

Soil nitrate and EC show high correlation and can be grouped into the same factor as can petiole nitrate with



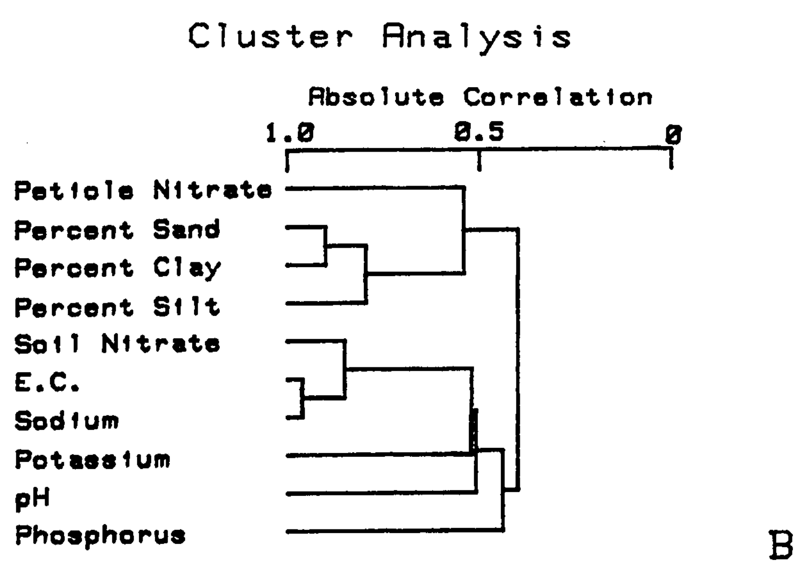


Figure 18. Cluster analyses of plant and soil characteristics from 48 grid-samples.

Figure "A" shows correlation measured by average distance method and figure "B" shows absolute correlation measured by minimum distance method.

clay percentage. For this reason the variograms of soil nitrate and EC are compared and also the variograms of clay percentage with petiole nitrate.

A frequency histogram of soil nitrate data approximates a lognormal distribution (Figure 19) so for the variogram information to be optimally useful in other geostatistical analyses, e.g. kriging, the data needs to be transformed, e.g. ln $Z(x) = Y(x)$. The lognormal variable $Z(x)$ is transformed to a normal variable $Y(x)$ (Journel and Huijbregts, 1978).

The resulting global variogram, illustrated in Figure 19, indicates that soil nitrate is spatially dependent. Semivariance appears to have a linear relationship with distance between samples up to at least 100 meters. Directional variograms are illustrated in Figure D.2 of Appendix D. The directional graph from the the variograms (Figure 19) indicate an anisotropic structure with samples more similar along rows than across rows and a possible indentation directly across rows. The poorly behaved directional variograms may be the result of a low sampling density.

EC, a closely correlated variable, was compared to soil nitrate. A frequency histogram of EC also approximates that of a lognormal distribution so the data was logarithmically transformed. The global variogram (Figure

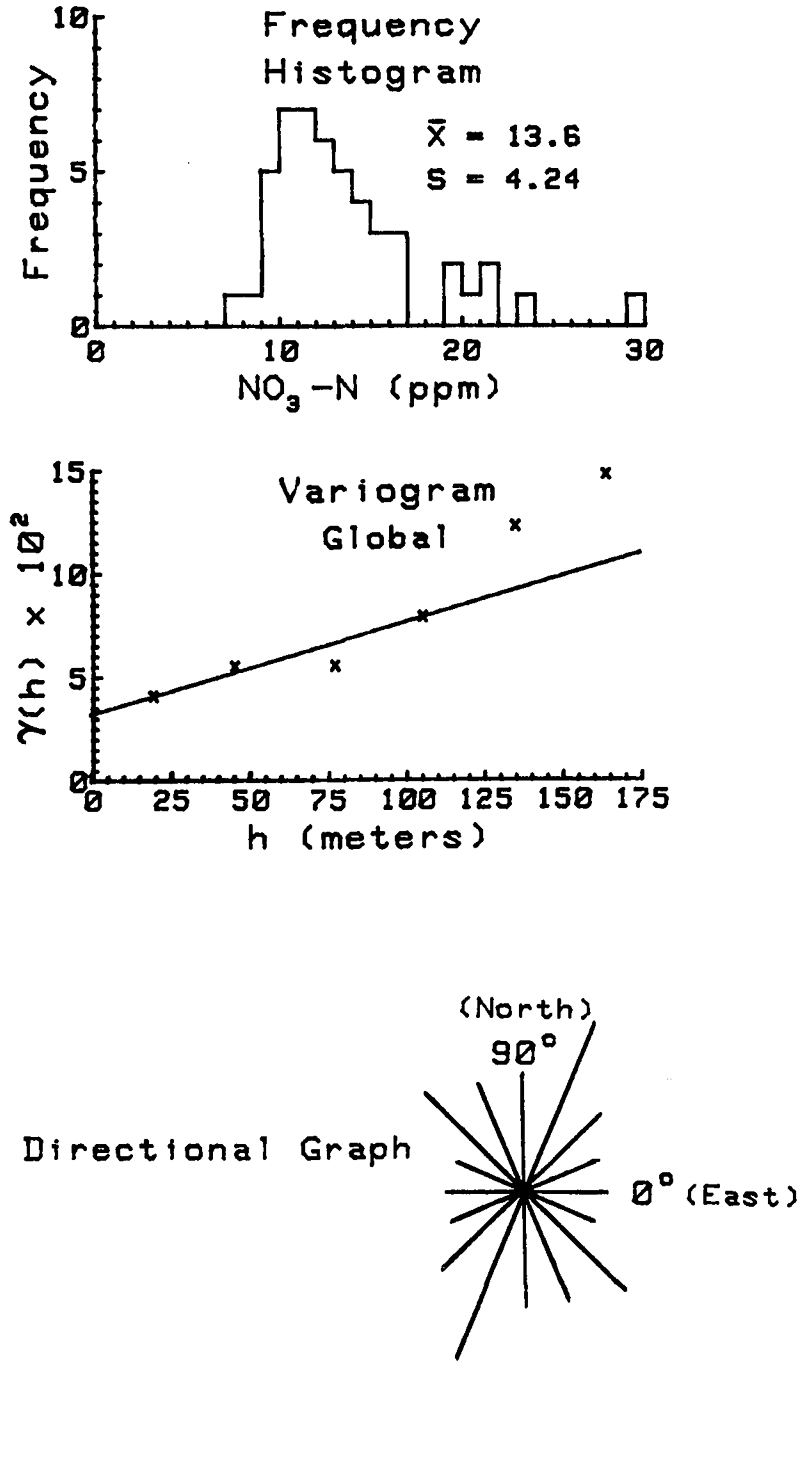
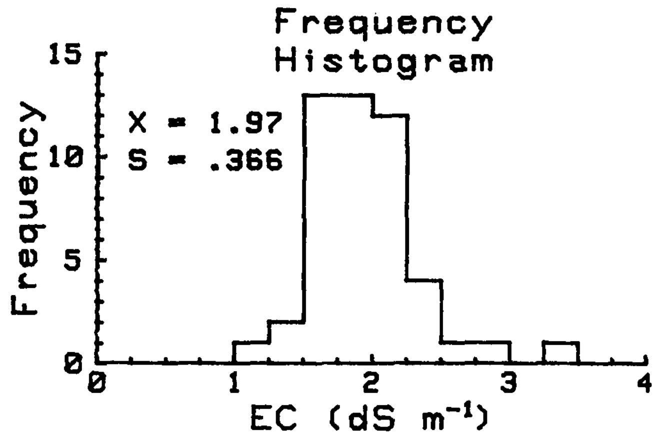


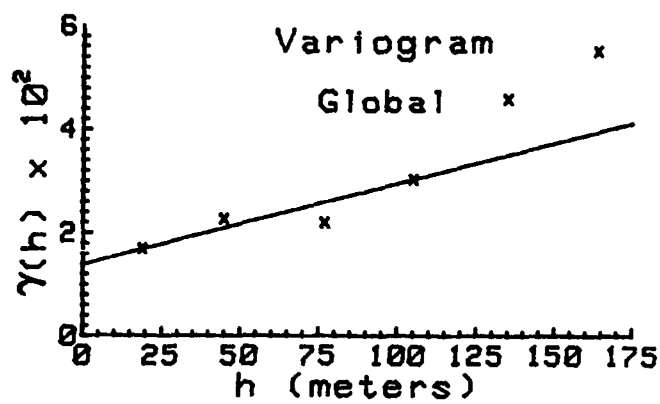
Figure 19. Frequency histogram, global variogram and directional graph of soil-nitrate concentration from grid-samples.

20) indicates spatial dependence with semivariance having a linear relationship with sample distance up to 100 meters. Al Sanabani (1982) found the EC variogram, from an irrigated Arizona soil, best fit a spherical model. His sampling density was greater with 101 samples per 10 ha compared to this study's 49 samples per 13 ha.

The directional variograms are illustrated in Figure D.3 of Appendix D. The resulting directional graph (Figure 20) indicates a slightly different anisotropy than soil nitrate but, in general, samples for both variables are more similar along rows than across rows. The global variograms of soil nitrate and EC are very similar and higher sampling densities may show a spherical model is more appropiate for the soil-nitrate sample variogram as EC was shown to be by Al Sanabani.

A frequency histogram of the clay percentage data approximates a normal distribution (Figure 21). The global variogram indicates spatial dependence with semivariance increasing linearly with distance between samples. The directional variograms of clay percentage (Figure D.4 in Appendix D) are marginally better behaved than soil nitrate or EC variograms and result in stronger conclusions about the variable's anisotropic structure. The directional graph (Figure 21) indicates that samples of clay percentage are more similar in a 113° orentation with the field and





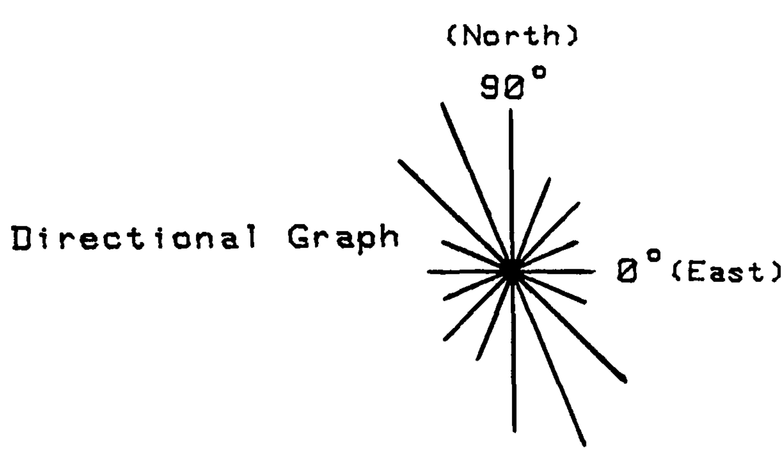


Figure 20. Frequency histogram, global variogram and directional graph of soil EC from grid-samples.

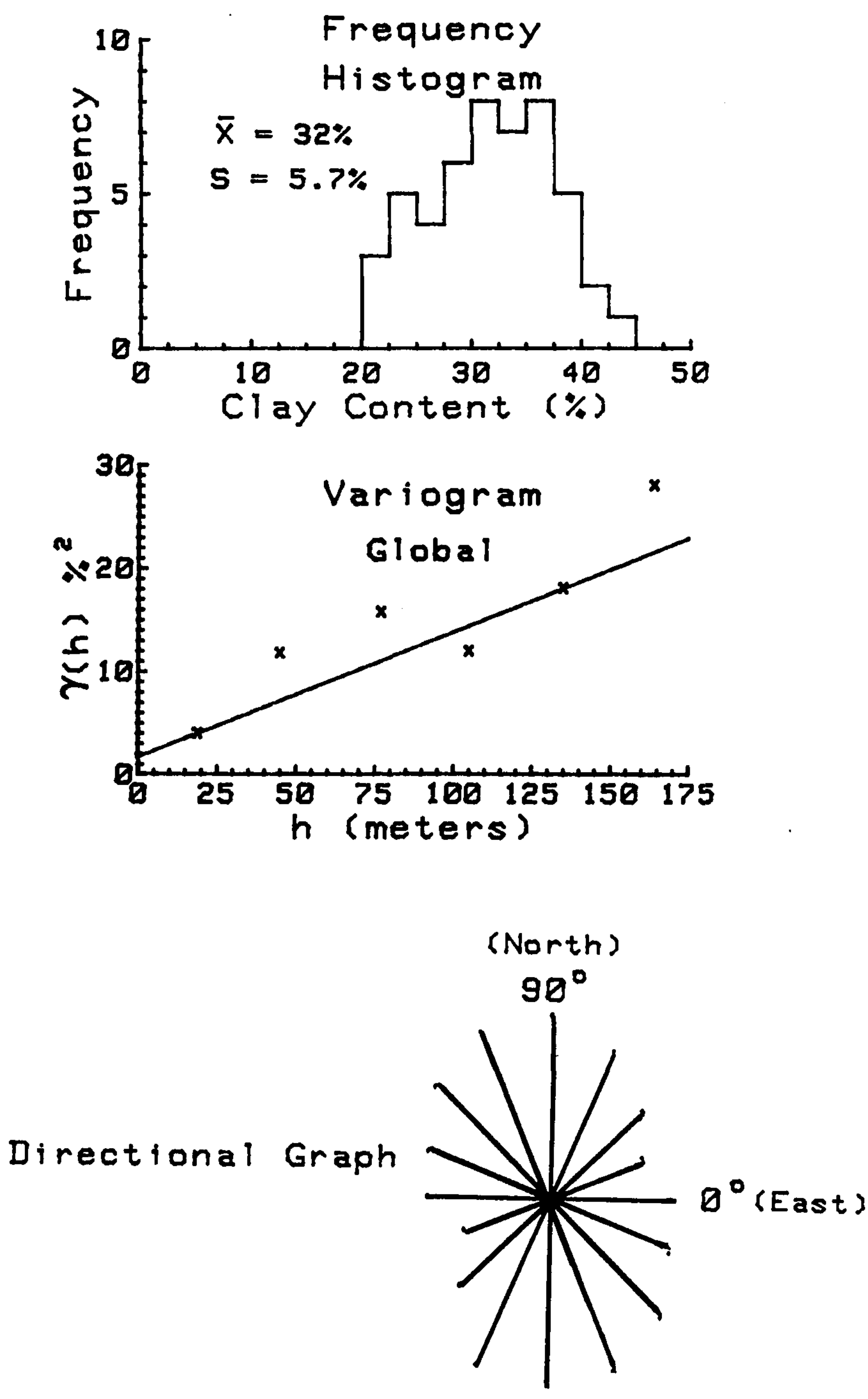


Figure 21. Frequency histogram, global variogram and directional graph of clay percentage from grid-samples.

more dissimilar in a 23° orientation with the field. It is assumed that this anisotropy is independent of cultural factors.

The variograms of petiole nitrate, soil nitrate, EC and clay percentage indicate all variables are spatially dependent to at least 100 meter between samples. Petiole nitrates and soil nitrates show similar anisotropic orientation as does EC with clay percentage. In general all four variables can be said to be more similar along rows and more dissimilar across rows.

CHAPTER 5

CONCLUSIONS

During field sampling for a production situation the sampler can not afford the luxury of thorough sampling so from past experience and intuition the GPM sampling program was developed. The field samples were collected by simulating the sampling method and resulted in the data and statistics in Table 2. By extrapolating from the data, it seems reasonable to expect that 80% of the time, the sample average will be within 2000 ppm NO_3-N of the true average by collecting from five 0.5 ha area samples and within 1000 ppm of the true average by collecting from 15 0.5 ha area samples in the field. Also the analysis of the 0.5 ha area samples indicates that by collecting 20 petioles over the area, the sample average will be within 1000 ppm NO_3-N of the true average 90% of the time and by collecting 40 petioles over the area, the sample average is within 1000 ppm NO_3-N of the true average 95% of the time. Thus, increasing the number of areas sampled will result in better estimates of the field average compared to increasing the total number of petioles collected from the same areas.

Improvement of sampling results can be accomplished by sampling petioles on the plant in one of two ways. In order to reduce bias and maintain consistancy, sampling should be from the first, fully expanded mature leaf but if the degree of maturity is in question the next older leaf should be picked. A simpler approach is to sample from the second, fully mature leaf. This will insure only the first or second mature leaf is picked because degree of maturity is subjective and samplers sometimes collect younger-than-optimum petioles.

Sampling for small areas (1 m^2) can be appraoched with the only concern of getting sample numbers large enough to provide the desired confidence level for the local sample average since spatial dependence at this distance is insignificant.

It was found that petiole and soil nitrate in the field can be spatially dependent for intersample distances greater than 150 meters. Therefore when sampling from a field or large area with unknown spatial structure, samples should be as far apart as possible to avoid biasing the field average with samples that represent one section of a field more than an other.

Soil properties and cultural practices are major influences in the spatial variability of petiole and soil nitrate. A field with a single soil type does not indicate uniform soil conditions as indicated by comparing the intensive soil map (Figure 4) with the directional graph of clay percentage (Figure 21). A soil mapping unit and associated soil inclusions (see Appendix B) may have characteristics with particular spatial structure which needs to be characterized at the mapping unit level so management can be optimized. On the other hand, the petiole and soil nitrate variability that is influenced by cultural practices is dependent on the uniformity of cultural practices and therefore is more predictable. Non-uniformity of irrigation and fertilization will result in a banding along the rows of similar petiole and soil nitrate concentrations. Thus to optimize sampling and to avoid bias due to cultural factors, sampling should be more thorough across the rows than down. The degree of which depends on the uniformity of fertilizer application and irrigation.

APPENDIX A

NOTATIONS

ASTM	American Society for Testing and Materials
CL	Confidence level
Cov	Covariance of...
CV	Coefficient of variation
E	Expected value of...
EC	Electrical conductivity (by saturated paste extract)
γ	Semivariance
Global	Isotropic (direction not taken into account)
GPM	Growers Pest Management
ln	Natural lograrithm of...
M	Molar
NO_3^--N	Nitrate-nitrogen
#	Number (of)
s^2	Sample variance
Testing Lab	University of Arizona Soil, Water and Plant Tissue Testing Lab
USDA	United States Department of Agriculture
Var	Variance of...
$\bar{X}$	Sample mean

APPENDIX B

SOIL MAPPING UNIT DESCRIPTIONS

By Steve Levine

Mohall clay loam: This unit is approximately 85 percent Mohall clay loam. Also included in this unit are Mohall loam and Contine clay. Included soils make up 15 percent of the total area. The slope is 0 to 1 percent.

Mohall soils are deep and well-drained. Typically they have a brown and dark brown clay loam surface layers about 6 inches thick. This is underlain by reddish brown clay loam and sandy clay loam subsurface layers about 25 to 30 inches thick. Below that to a depth of 60 inches is a brown and light reddish brown loam lower subsoil and substratum. Common soft lime masses are found between 20 and 60 inches. The profile ranges from slightly alkaline to strongly alkaline.

Mohall soils have moderately slow permeability and high available water capacity. Effective rooting depth is 60 inches or more. Runoff is slow and the hazard of erosion is slight.

Capability class is I-1.

Gilman silt loam: This unit is approximately 85 percent Gilman silt loam. Also included in the unit are Gilman very fine sandy loam, Mohall loam and Laveen loam. Included soils make up 15 percent of the total area. Slope is 0 to 1 percent.

Gilman soils are deep and well-drained. Typically they have a pale brown silt loam surface about 12 inches thick. The underlying material to a depth of 60 inches is light yellowish brown loam and very fine sandy loam. The profile is moderately alkaline and calcareous throughout. Few soft lime masses are common between 30 and 60 inches.

Gilman soils have moderate permeability and high available water capacity. Effective rooting depth is 60 inches or more. Runoff is slow and the hazard of erosion is slight.

Capability class is I-1.

APPENDIX C

PETIOLE AND SOIL EXTRACTION SOLUTIONS

Petiole Extraction Solution

Preservative solution: Dissolve 0.1g of phenylmercuric acetate in 20 ml of dioxane and dilute to 100 ml with distilled water.

Extraction solution: Dilute 100 ml of 0.5 M $Al_2(SO_4)_3$ solution and 2 ml of preservative solution to 2000 ml with distilled water.

Soil Extraction Solution

Extraction solution: Dissolve 1 g Ag_2SO_4 in 300 ml of deionized water. Dissolve 2.25 g of $CaSO_4$ in 500 ml of dionized water. Mix both solutions and dilute to 1000 ml with deionized water.

APPENDIX D

DIRECTIONAL VARIOGRAMS

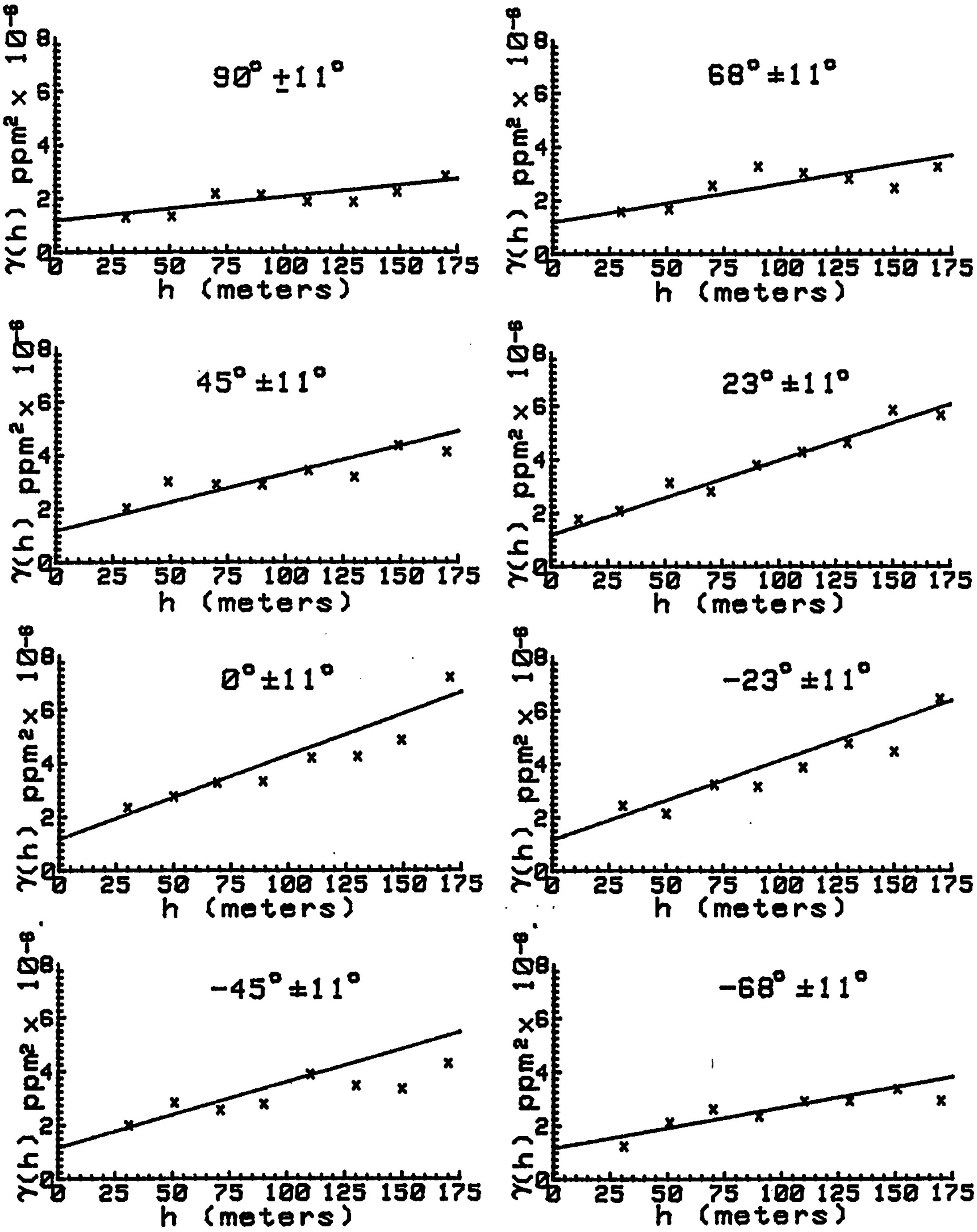


Figure D.1. Family of directional variograms for petiole NO_3-N.

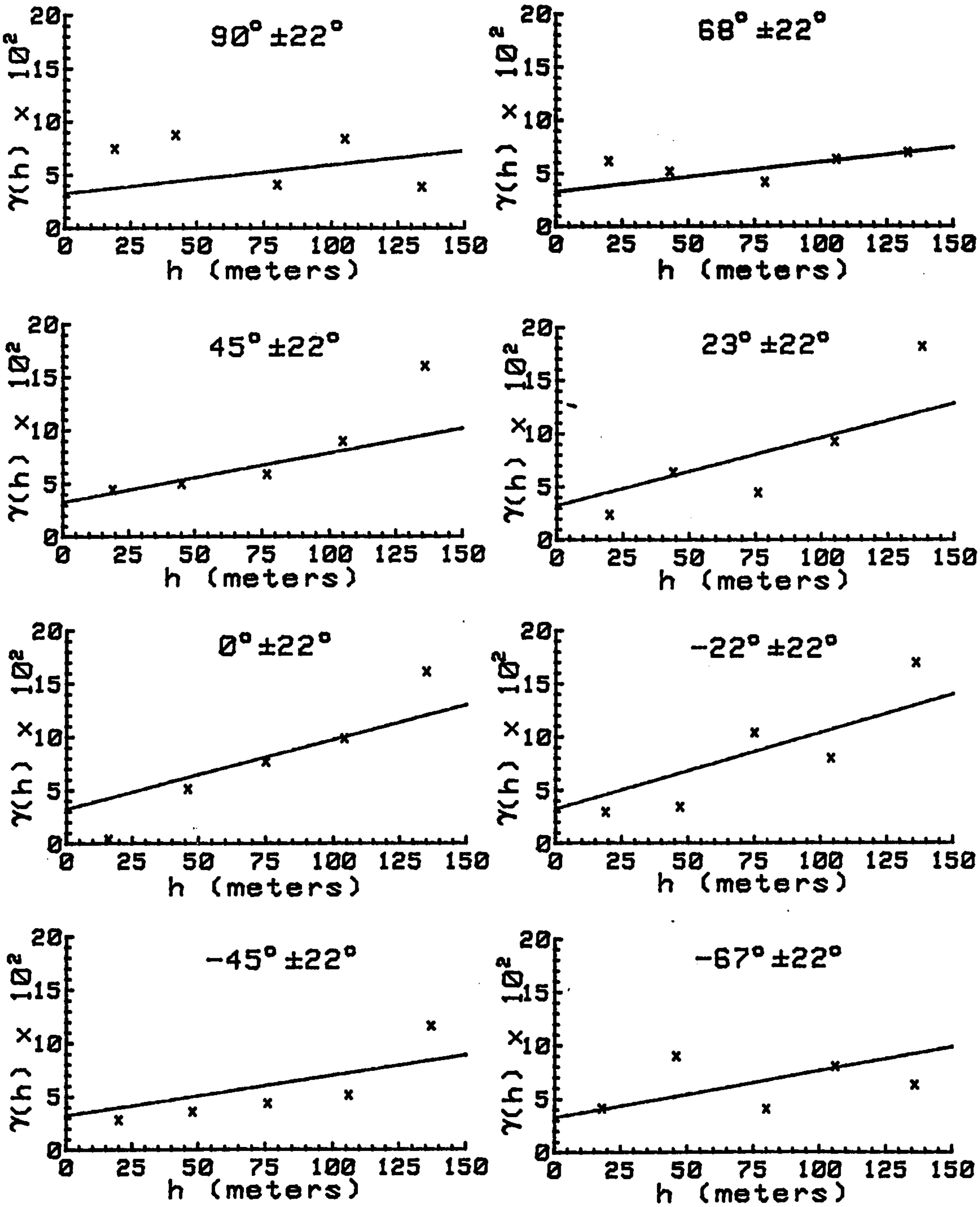


Figure D.2. Family of directional variograms for soil NO_3-N (γ(h) is in ppm^2).

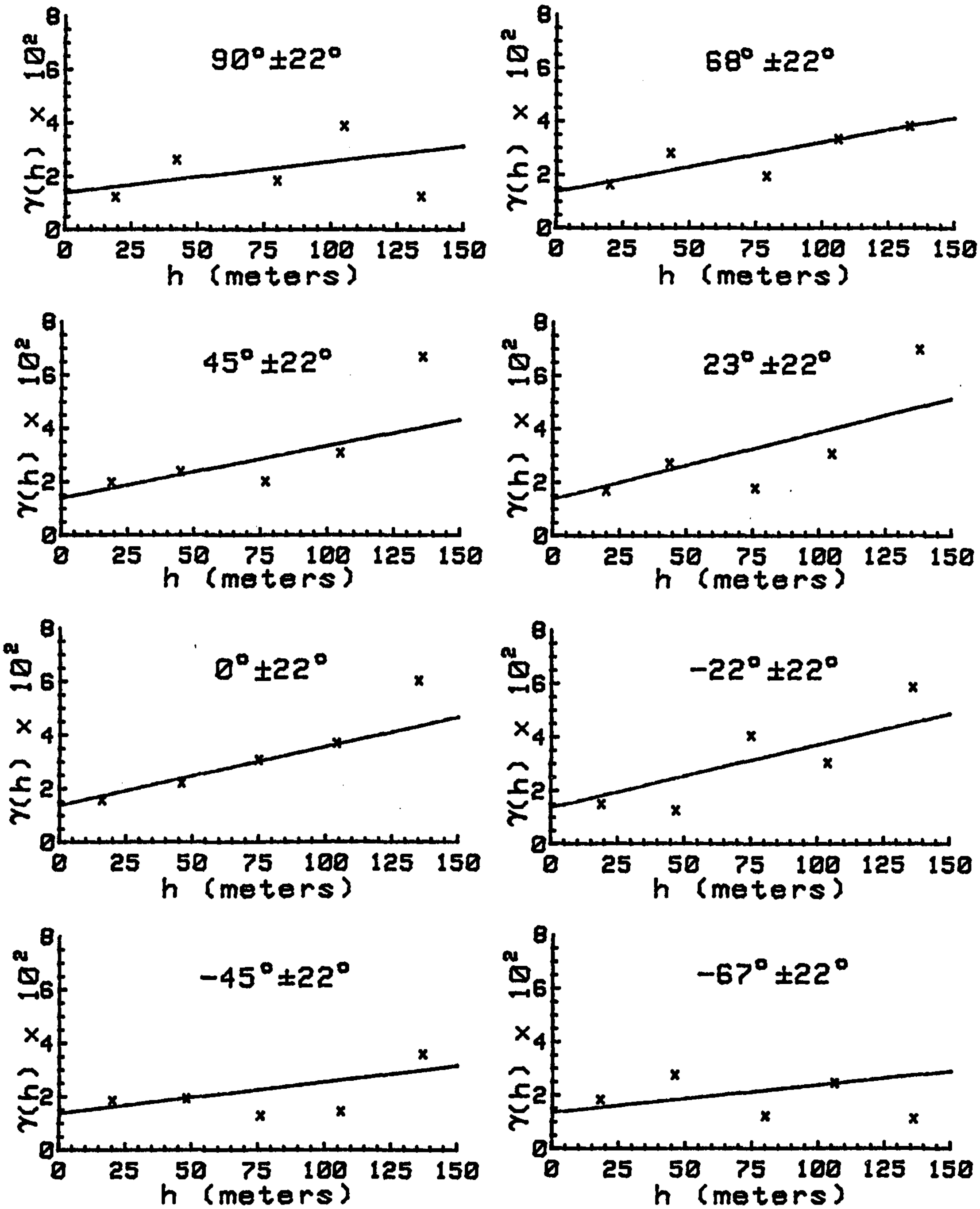


Figure D.3. Family of directional variograms for electrical conductivity ($\gamma(h)$ is in $(dS\ m^{-1})^2$).

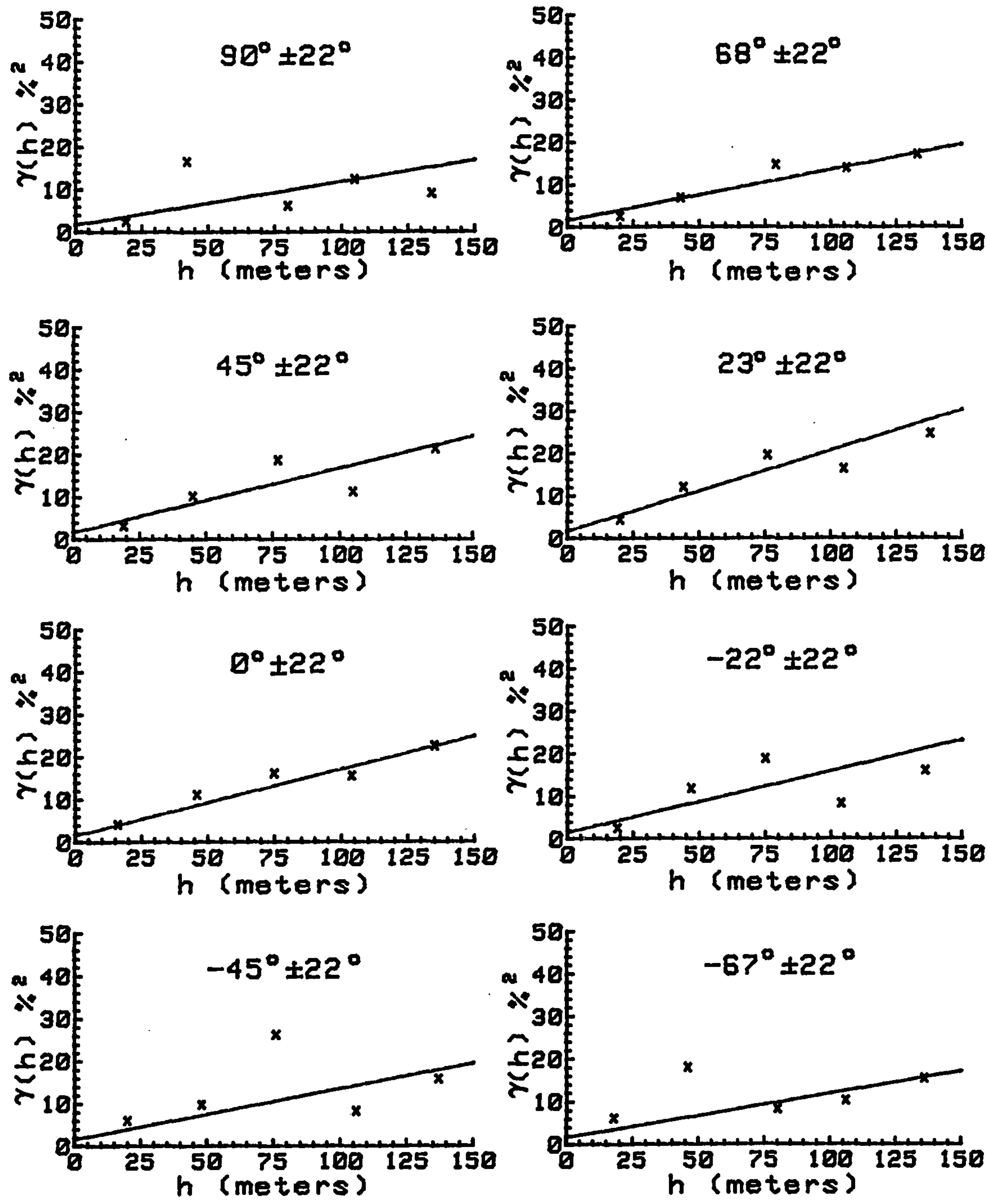


Figure D.4. Family of directional variograms for clay percentage.

APPENDIX E

TRANSECT AND GRID-SAMPLE DATA

Table E.1. Transect of C. Brown's field #7. Each sample is a composite of four petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
1.	10071.	131.	10691.	261.	16464.
11.	13561.	141.	15850.	271.	11139.
21.	9848.	151.	12010.	281.	15115.
31.	11291.	161.	8834.	291.	13673.
41.	11640.	171.	9203.	301.	13681.
51.	11154.	181.	13721.	311.	13593.
61.	11323.	191.	10889.	321.	10470.
71.	14961.	201.	9817.	331.	15101.
81.	11327.	211.	10197.	341.	14789.
91.	12363.	221.	13781.	351.	13108.
101.	8384.	231.	10556.	361.	9702.
111.	10339.	241.	10868.		
121.	9850.	251.	11117.		

Table E.2. Transect of Goldson's field #11. Each sample is a composite of four petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
1.	7424.	181.	5428.	361.	8981.
11.	9817.	191.	3900.	371.	8094.
21.	7476.	201.	12206.	381.	8454.
31.	9564.	211.	11117.	391.	8687.
41.	10551.	221.	10089.	402.	10097.
51.	8433.	231.	10730.	411.	9163.
61.	9990.	241.	9945.	421.	9202.
71.	10263.	251.	12070.	431.	11498.
81.	10379.	261.	9160.	441.	9087.
91.	10933.	271.	10318.	451.	10418.
101.	9138.	281.	9981.	461.	9800.
111.	8641.	291.	7300.	471.	9270.
121.	8870.	301.	8702.	481.	9114.
131.	12414.	311.	8700.	491.	8796.
141.	7972.	321.	8059.	501.	9325.
151.	9480.	331.	7228.	511.	9051.
161.	7598.	341.	8023.		
171.	9406.	351.	9107.		

Table E.3. Transect of M. Marietta's field #14. Each sample is a composite of four petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
1.	7818.	131.	2109.	261.	2241.
11.	7304.	141.	5642.	271.	8139.
21.	6969.	151.	7244.	281.	1295.
31.	5445.	161.	6833.	291.	2167.
41.	7265.	171.	7636.	301.	8713.
51.	8655.	181.	8383.	311.	10265.
61.	5956.	191.	8545.	321.	3938.
71.	7571.	201.	9413.	331.	4500.
81.	3283.	211.	3897.	341.	5854.
91.	8435.	221.	4719.	351.	9577.
101.	5533.	231.	1251.	361.	9487.
111.	3978.	241.	3164.	371.	8828.
121.	4117.	251.	3289.		

Table E.4. Transect of M & W Miller's field #67. Each sample is a composite of three petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
1.	11074.	251.	11616.	501.	9153.
11.	9331.	261.	9083.	511.	10577.
21.	12205.	271.	10765.	521.	6872.
31.	12757.	281.	8564.	531.	9567.
41.	11182.	291.	10674.	541.	8157.
51.	12907.	301.	10508.	551.	9338.
61.	12031.	311.	7469.	561.	8018.
71.	10928.	321.	10513.	571.	9829.
81.	8069.	331.	10091.	581.	8134.
91.	12591.	341.	10878.	591.	8370.
101.	11297.	351.	11854.	601.	10308.
111.	13067.	361.	9913.	611.	10920.
121.	9956.	371.	11894.	621.	8996.
131.	9816.	382.	10137.	631.	7745.
141.	10626.	391.	9511.	641.	7477.
151.	13090.	401.	8970.	651.	9412.
161.	7290.	411.	8931.	661.	7924.
171.	10890.	421.	9958.	671.	6816.
181.	11608.	431.	8110.	681.	6116.
191.	10275.	441.	10121.	691.	7345.
201.	9075.	451.	9037.	701.	8760.
211.	9212.	461.	7609.	711.	6876.
221.	11052.	471.	8816.	721.	7746.
231.	11299.	481.	7436.	731.	9312.
241.	12091.	491.	4649.		

Table E.5. Soil grid-samples from Nalbandion's field #28.

SAMPLE	COORDINATES		NITRATE-N (PPM)		TEXTURE (USDA)			PH	EC	SODIUM	POTASSIUM	PHOSPHORUS
NUMBER	X	Y	ELECTRODE	T. LAB	S	SI	C		DS/M	MEQ/L	MEQ/L	PPM
1	296.	256.	10.26	11.75	47.2	23.1	29.7	7.35	1.87	7.37	.44	1.26
2	154.	314.	15.99	14.86	36.6	29.8	33.6	7.25	2.44	9.35	.67	2.50
3	236.	258.	17.79	20.30	44.6	24.4	31.0	7.20	2.53	10.74	.85	14.05
4	332.	152.	7.58	10.97	54.5	22.1	23.4	7.35	1.83	7.50	.51	2.25
5	300.	256.	8.71	10.97	51.7	21.1	27.2	7.40	1.66	6.79	.42	1.36
6	278.	218.	10.68	13.82	44.5	23.3	32.2	7.15	2.09	9.07	.69	2.50
7	72.	140.	9.72	13.30	32.4	27.8	39.8	7.35	1.98	8.95	.67	1.50
8	336.	240.	9.00	12.30	60.3	16.4	23.3	7.35	1.87	7.67	.46	2.00
9	106.	44.	10.86	12.30	26.1	30.3	43.6	7.00	1.72	7.29	.63	7.50
10	336.	102.	11.02	14.10	56.1	22.9	21.0	7.40	1.96	7.66	.48	1.50
11	274.	152.	10.14	13.30	42.6	23.9	33.5	7.30	2.14	9.33	.69	10.00
12	56.	150.	10.41	13.05	31.3	27.6	41.1	7.50	1.74	8.05	.62	3.26
13	192.	64.	12.96	16.20	36.7	31.0	32.3	7.10	2.05	8.20	.65	4.00
14	314.	342.	14.24	17.20	55.0	20.3	24.7	7.45	2.16	8.53	.48	1.75
15	270.	236.	11.22	13.82	44.5	22.0	33.5	7.15	2.14	8.51	.60	4.76
16	24.	10.	9.14	12.00	34.6	31.8	33.6	7.40	1.70	7.89	1.60	4.50
17	158.	78.	19.32	22.70	31.3	28.8	39.9	7.00	2.44	9.41	.79	3.26
18	348.	56.	17.42	23.70	44.4	24.5	31.1	7.10	2.46	9.46	.66	16.00
19	326.	288.	14.92	18.24	44.4	25.8	29.8	7.40	2.22	8.39	.43	2.50
20	120.	32.	18.04	20.84	31.2	28.9	39.9	7.00	2.09	7.98	.66	5.25
21	338.	66.	11.36	16.70	47.2	26.8	26.0	7.30	1.66	6.52	.43	4.50
22	188.	150.	21.40	24.70	39.2	28.5	32.3	7.00	2.44	9.48	.81	5.50
23	262.	334.	10.85	17.20	51.6	26.1	22.3	7.30	1.70	6.87	.47	4.76
24	98.	334.	12.00	14.86	34.4	30.6	35.0	7.45	2.01	8.69	.59	2.00
25	186.	50.	13.34	13.54	34.5	29.6	35.9	7.40	1.96	8.71	.79	8.26

Table E.5. Continued

SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N (PPM) ELECTRODE	T. LAB	TEXTURE (USDA) S	SI	C	PH	EC DS/M	SODIUM MEQ/L	POTASSIUM MEQ/L	PHOSPHORUS PPM
26	92.	266.	14.00	14.54	34.5	28.2	37.3	7.50	1.91	8.83	.68	1.55
27	16.	344.	9.96	10.28	31.9	27.0	41.1	7.60	1.66	7.72	.50	3.04
28	136.	42.	16.74	16.04	31.8	30.9	37.3	7.30	2.03	9.26	.70	6.27
29	250.	272.	11.34	11.28	45.3	27.8	26.9	7.25	1.87	8.18	.58	6.52
30	296.	42.	8.26	8.52	38.1	28.5	33.3	7.25	1.49	7.42	.45	5.03
31	164.	60.	15.52	14.78	51.9	12.1	36.0	7.10	1.87	8.43	.65	5.53
32	298.	338.	13.60	14.04	52.8	24.2	23.0	7.40	1.83	7.75	.41	3.54
33	196.	288.	17.10	15.79	38.8	30.4	30.8	7.20	2.32	10.41	.69	11.50
34	102.	10.	9.80	10.78	30.6	33.5	35.9	7.20	1.66	7.99	.57	5.53
35	314.	258.	9.70	11.78	50.7	23.7	25.6	7.70	1.41	6.86	.36	1.80
36	346.	336.	11.93	12.00	49.6	21.8	28.6	7.60	2.20	9.62	.37	5.03
37	226.	334.	12.54	12.53	44.4	25.8	29.8	7.40	1.91	7.94	.57	4.29
38	2.	34.	9.76	9.27	36.4	31.1	32.5	7.60	1.20	6.03	.38	2.80
39	284.	130.	13.43	13.03	46.9	24.5	28.6	7.40	2.08	9.19	.66	4.54
40	102.	306.	9.69	10.28	36.5	28.6	34.9	7.70	1.72	7.76	.54	1.80
41	98.	276.	13.24	12.03	36.4	24.9	38.7	7.50	2.16	9.12	.68	3.04
42	304.	242.	9.79	10.28	52.2	23.0	24.8	7.50	1.87	7.70	.42	2.05
43	180.	260.	11.11	10.78	41.7	28.4	29.9	7.40	1.74	7.70	.55	4.29
44	198.	162.	29.94	28.83	44.4	23.3	32.3	7.20	3.28	12.49	1.03	3.54
45	198.	168.	21.36	21.81	41.8	25.9	32.3	7.25	2.82	11.34	.86	2.30
46	72.	62.	13.20	13.80	31.3	31.3	37.4	7.30	1.62	7.46	.64	7.02
47	340.	92.	6.62	8.02	52.3	25.4	22.3	7.30	1.66	7.20	.46	2.30
48	86.	246.	8.89	9.77	33.3	30.6	36.1	7.40	1.62	7.61	.69	1.31
49	76.	162.	11.19	11.03	33.8	26.3	39.9	7.50	1.83	8.46	.66	2.80

Table E.6. Petiole grid-samples from Nalbandion's field #28. Plants in the field were .8 m tall with an average of 13 bolls, some were starting to open.

SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM	SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM
1	296.	256.	2125.	41	98.	276.	7434.
2	154.	314.	6082.	42	304.	242.	4555.
3	236.	258.	7189.	43	180.	260.	6255.
4	332.	152.	5169.	44	198.	162.	7079.
5	300.	256.	3097.	45	198.	168.	5547.
6	278.	218.	3693.	46	72.	62.	9462.
7	72.	140.	9032.	47	340.	92.	2575.
8	336.	240.	7894.	48	86.	246.	7248.
9	106.	44.	9575.	49	76.	162.	9408.
10	336.	102.	8600.	50	68.	240.	10788.
11	274.	152.	6648.	51	58.	62.	9970.
12	56.	150.	9839.	52	56.	152.	8233.
13	192.	64.	5923.	53	240.	136.	6245.
14	314.	342.	5837.	54	338.	40.	1905.
15	270.	236.	5561.	55	222.	220.	8469.
16	24.	10.	9647.	56	302.	154.	2404.
17	158.	78.	9593.	57	246.	166.	6262.
18	348.	56.	4227.	58	298.	120.	2902.
19	326.	288.	9274.	59	274.	106.	6171.
20	120.	32.	7644.	60	308.	256.	1929.
21	338.	66.	5649.	61	66.	174.	11107.
22	188.	150.	7700.	62	324.	352.	7247.
23	262.	334.	6443.	63	210.	138.	8081.
24	98.	334.	6427.	64	272.	158.	6289.
25	186.	50.	7976.	65	222.	32.	5033.
26	92.	266.	7589.	66	216.	144.	6917.
27	16.	344.	6973.	67	128.	320.	7551.
28	136.	42.	8633.	68	94.	8.	6322.
29	250.	272.	6771.	69	172.	194.	7479.
30	296.	42.	3203.	70	106.	336.	7250.
31	164.	60.	9329.	71	60.	72.	9040.
32	298.	338.	2871.	72	270.	216.	6711.
33	196.	288.	4542.	73	290.	74.	1149.
34	102.	10.	7344.	74	274.	146.	6419.
35	314.	258.	5267.	75	140.	196.	7544.
36	346.	336.	7444.	76	286.	196.	4858.
37	226.	334.	--	77	248.	26.	6280.
38	2.	34.	9220.	78	258.	220.	6215.
39	284.	130.	6397.	79	70.	188.	8778.
40	102.	306.	6602.	80	220.	348.	5533.

Table E.6. Continued

SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM	SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM
81	276.	80.	2696.	121	106.	128.	8094.
82	106.	302.	7017.	122	162.	74.	8166.
83	22.	214.	6890.	123	190.	294.	5897.
84	222.	74.	5950.	124	148.	132.	8347.
85	194.	134.	4735.	125	150.	340.	6569.
86	88.	206.	10248.	126	130.	250.	8416.
87	318.	124.	3908.	127	312.	96.	3643.
88	272.	106.	4406.	128	286.	86.	5098.
89	332.	344.	8888.	129	226.	288.	6035.
90	114.	46.	7318.	130	48.	280.	8036.
91	236.	250.	7657.	131	230.	336.	7254.
92	62.	158.	9305.	132	318.	6.	471.
93	306.	120.	3328.	133	16.	4.	8747.
94	228.	110.	5669.	134	210.	214.	8967.
95	308.	108.	3054.	135	356.	256.	9993.
96	282.	114.	4143.	136	164.	294.	4876.
97	48.	266.	8765.	137	70.	54.	9171.
98	310.	358.	3444.	138	304.	46.	3521.
99	206.	158.	7508.	139	80.	262.	8748.
100	166.	26.	8672.	140	130.	132.	8395.
101	184.	138.	6400.	141	196.	274.	6707.
102	160.	162.	6530.	142	302.	262.	3441.
103	204.	48.	8405.	143	116.	300.	9748.
104	222.	340.	4921.	144	354.	184.	4690.
105	56.	342.	5973.	145	350.	322.	5561.
106	50.	280.	8708.	146	284.	216.	2737.
107	282.	226.	3284.	147	160.	48.	8220.
108	256.	286.	7115.	148	268.	250.	4932.
109	48.	44.	7494.	149	102.	206.	9403.
110	178.	164.	7386.	150	256.	110.	4668.
111	296.	326.	4032.	151	148.	160.	7720.
112	274.	210.	6723.	152	226.	170.	7987.
113	346.	26.	1785.	153	250.	104.	6762.
114	126.	294.	7224.	154	330.	98.	5543.
115	166.	70.	8400.	155	80.	298.	9717.
116	294.	318.	2701.	156	236.	8.	5669.
117	24.	338.	6447.	157	186.	104.	5454.
118	130.	198.	8773.	158	196.	32.	6446.
119	56.	156.	8455.	159	146.	220.	6531.
120	174.	136.	5254.	160	302.	118.	3487.

Table E.6. Continued

SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM	SAMPLE NUMBER	COORDINATES X	Y	NITRATE-N PPM
161	332.	356.	9378.	180	18.	208.	10255.
162	80.	92.	10012.	181	142.	44.	8204.
163	178.	46.	9009.	182	334.	116.	6372.
164	226.	208.	7655.	183	314.	182.	3701.
165	120.	140.	7367.	184	166.	28.	7778.
166	276.	32.	1407.	185	176.	174.	7469.
167	30.	206.	7538.	186	236.	54.	5750.
168	230.	272.	7498.	187	150.	326.	7481.
169	92.	126.	9241.	188	230.	188.	7445.
170	310.	212.	3342.	189	132.	62.	7806.
171	252.	100.	5491.	190	186.	26.	7737.
172	356.	30.	2502.	191	352.	138.	3207.
173	312.	178.	3375.	192	22.	56.	8506.
174	62.	272.	7914.	193	18.	54.	10574.
175	26.	22.	10846.	194	8.	300.	9068.
176	44.	244.	7890.	195	162.	210.	6623.
177	112.	278.	7420.	196	232.	4.	4916.
178	84.	194.	10208.	197	88.	344.	8464.
179	334.	4.	910.	198	84.	184.	9468.

Table E.7. Transect of Nalbandion's field #28. The two petioles of the composite samples were analysed seperately.

COORDINATES X	Y	NITRATE-N (PPM) SMALL	LARGE	COORDINATES X	Y	NITRATE-N (PPM) SMALL	LARGE
261	200	5769.	3907.	271	200	7328.	5522.
262	200	5392.	5850.	272	200	4868.	3377.
263	200	5205.	6966.	273	200	4156.	6825.
264	200	5077.	12919.	274	200	3893.	7538.
265	200	6379.	10277.	275	200	4161.	6050.
266	200	7782.	7756.	276	200	4230.	8801.
267	200	6336.	8010.	277	200	9966.	6465.
268	200	4686.	6447.	278	200	5667.	7701.
269	200	3689.	4445.	279	200	8168.	9737.
270	200	5469.	4571.	280	200	3492.	4260.

Table E.7. Continued

COORDINATES X	Y	NITRATE-N (PPM) SMALL	LARGE	COORDINATES X	Y	NITRATE-N (PPM) SMALL	LARGE
281	200	2325.	6278.	321	200	3750.	4191.
282	200	6361.	6814.	322	200	3555.	5565.
283	200	4554.	5052.	323	200	2413.	6194.
284	200	4828.	4494.	324	200	6245.	6710.
285	200	4385.	3957.	325	200	3360.	5028.
286	200	2546.	4183.	326	200	4540.	5576.
287	200	3654.	6475.	327	200	3184.	2904.
288	200	3908.	6220.	328	200	5440.	5927.
289	200	4161.	4538.	329	200	4008.	4790.
290	200	2954.	5364.	330	200	6676.	4018.
291	200	3518.	5473.	331	200	1778.	2565.
292	200	3578.	5363.	332	200	6360	6964.
293	200	4629.	5195.	333	200	4460.	4996.
294	200	3409.	6310.	334	200	3920.	4564.
295	200	5575.	6936.	335	200	7905.	4794.
296	200	8684.	8022.	336	200	8824.	11621.
297	200	5339.	6349.	337	200	6382.	7131.
298	200	3352.	5305.	338	200	5765.	7388.
299	200	5333.	4048.	339	200	6194.	6516.
300	200	4367.	4578.	340	200	5706.	2302.
301	200	5286.	6384.	341	200	4768.	5437.
302	200	5087.	3859.	342	200	4868.	5982.
303	200	4812.	7769.	343	200	4312.	--
304	200	4167.	4349.	344	200	5033.	5149.
305	200	2872.	5178.	345	200	3723.	4299.
306	200	4355.	3299.	346	200	1714.	2020.
307	200	5663.	7504.	347	200	3264.	3721.
308	200	4127.	5899.	348	200	6154.	6265.
309	200	5606.	4730.	349	200	5608.	5807.
310	200	4325.	6317.	350	200	5884.	5032.
311	200	3130.	4318.	351	200	4840.	7068.
312	200	6435.	7075.	352	200	3718.	3054.
313	200	5318.	4626.	353	200	3642.	5419.
314	200	5270.	7035.	354	200	5336.	4047.
315	200	3561.	3859.	355	200	4375.	3196.
316	200	4534.	6184.	356	200	3732.	6160.
317	200	3775.	8851.	357	200	5204.	5273.
318	200	5429.	3022.	358	200	3697.	4682.
319	200	3094.	4133.	359	200	8750.	6383.
320	200	3366.	2982.	360	200	9220.	7286.

Table E.8. Transect of Nalbandion's field #28. Each sample is a composite of three petioles.

COORDINATES X	Y	NITRATE-N PPM	COORDINATES X	Y	NITRATE-N PPM	COORDINATES X	Y	NITRATE-N PPM
1.	200.	6772.	131.	200.	7786.	261.	200.	5451.
11.	200.	7706.	141.	200.	4811.	271.	200.	6893.
21.	200.	9989.	151.	200.	8120.	281.	200.	5821.
31.	200.	7942.	161.	200.	7701.	291.	200.	4293.
41.	200.	14085.	171.	200.	10486.	301.	200.	5770.
51.	200.	5526.	181.	200.	9378.	311.	200.	4656.
61.	200.	10131.	191.	200.	10373.	321.	200.	4461.
71.	200.	8582.	201.	200.	9125.	331.	200.	4540.
81.	200.	8996.	211.	200.	7380.	341.	200.	2845.
91.	200.	6961.	221.	200.	7795.	351.	200.	3784.
101.	200.	8785.	231.	200.	7948.	361.	200.	6580.
111.	200.	6550.	241.	200.	8070.			
121.	200.	5892.	251.	200.	8331.			

Table E.9. Transect of petioles of different maturities from Nalbandion's field #28. Plants in the field were .8 m tall with an average of 13 bolls, some were starting to open.

	RELATIVE DISTANCE IN METERS							
	0	.8	1.3	1.7	2.4	3.2	3.8	4.6
APEX	833.	1254.	1242.	756.	855.	1082.	820.	1040.
SHINY	4576.	5826.	4154.	3309.	4075.	--	3300.	2302.
DULL	6998.	--	5635.	4664.	4636.	3534.	4386.	6592.
1ST MATURE	9668.	10960.	11521.	8397.	9422.	7880.	5950.	8234.
2ND MATURE	10062.	13105.	9677.	10466.	9583.	4575.	9051.	9021.
3RD MATURE	7491.	9113.	9305.	9881.	8953.	3004.	8370.	8767.

Table E.10. Transect of Nalbandion's field #4. Single petioles were collected every plant. Plants had an average of 13 nodes and 15 squares.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
.09	7788.	1.24	17434.	2.21	5708.
.18	10473.	1.32	12170.	2.29	8563.
.26	7643.	1.41	8672.	2.38	7390.
.35	13091.	1.50	12091.	2.47	7987.
.44	11538.	1.59	9700.	2.56	9238.
.53	10195.	1.68	9712.	2.65	9726.
.62	14138.	1.76	12015.	2.74	7586.
.71	10116.	1.85	11705.	2.82	13245.
.79	8349.	1.94	13768.	2.91	7403.
.88	7364.	2.02	12047.	2.99	13882.
.97	7704.	2.03	11762.	3.00	15764.
1.06	5772.	2.04	5824.		
1.15	13592.	2.12	10932.		

Table E.11. Transect across rows of P. Prechel's field #B1. Samples were a composite of four petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
10.	8932.	150.	10316.	290.	11695.
20.	7916.	160.	12249.	300.	9943.
30.	9632.	170.	10489.	310.	12107.
40.	9220.	180.	11950.	320.	10936.
50.	9957.	190.	10472.	330.	9446.
60.	8575.	200.	12482.	340.	10233.
70.	7763.	210.	11056.	350.	12341.
80.	6944.	220.	9481.	360.	9957.
90.	11643.	230.	8357.	370.	11910.
100.	8762.	240.	11220.	380.	11128.
110.	8747.	250.	12938.	390.	13363.
120.	8887.	260.	11330.	400.	12601.
130.	8408.	270.	13335.		
140.	7604.	280.	11334.		

Table E.12. Transect down a row of P. Prechel's field #Bl. Samples were a composite of four petioles.

POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM	POSITION M	NITRATE-N PPM
10.	12308.	160.	8953.	310.	12285.
20.	9128.	170.	13230.	320.	11944.
30.	10195.	180.	10119.	330.	10628.
40.	7379.	190.	9402.	340.	10239.
50.	9290.	200.	9883.	350.	11913.
60.	7951.	210.	9560.	360.	12956.
70.	11090.	220.	11434.	370.	12282.
80.	10409.	230.	9248.	380.	12702.
90.	8634.	240.	10785.	390.	14540.
100.	11941.	250.	10040.	400.	9152.
110.	9226.	260.	13848.	410.	6887.
120.	10015.	270.	9673.	420.	9713.
130.	8393.	280.	12411.	430.	9602.
140.	7879.	290.	10590.		
150.	9168.	300.	11554.		

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