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SPATIAL VARIABILITY OF ELECTRICAL CONDUCTIVITY AND SODIUM  
CONDUCTIVITY AND SODIUM ADSORPTION RATIO IN AN ALFALFA  
FIELD (COOLIDGE)

THE UNIVERSITY OF ARIZONA

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SPATIAL VARIABILITY OF ELECTRICAL CONDUCTIVITY  
AND SODIUM ADSORPTION RATIO IN AN ALFALFA  
FIELD (COOLIDGE)

by

Solomon Afolabi Ajibogun

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A Thesis Submitted to the Faculty of the  
DEPARTMENT OF SOILS, WATER, AND ENGINEERING  
In Partial Fulfillment of the Requirements  
For the Degree of  
MASTER OF SCIENCE  
WITH A MAJOR IN SOIL AND WATER SCIENCE  
In the Graduate College  
THE UNIVERSITY OF ARIZONA

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## ABSTRACT

This research investigates the technology for soil sampling of agricultural fields which are inherently variable in both space and time. Soil samples were collected randomly from an alfalfa field (350.5 x 350.5 meters). Fifty points were sampled and saturation extracts made from which electrical conductivity,  $\text{Na}^+$ ,  $\text{Mg}^{++}$  and  $\text{Ca}^{++}$  were analyzed. Geostatistics and classical statistics were used to evaluate the data.

The EC and SAR were spatially dependent at distances less than 69 meters. From the semivariogram the SAR has a nugget effect of 0.5. The sills for SAR and EC were 0.5 mmhos/cm and 0.026 mmhos/cm. The EC values were approximately normal with a mean of 1.0 mmhos/cm. The SAR values were also approximately normal with a mean of 5.08 mmhos/cm.

Both spatial dependence and variability are mainly influenced by the soil properties and cultural practices. The high nugget effect of SAR may be due to error in Laboratory analysis.

## INTRODUCTION

This study reveals the technology for soil sampling of agricultural fields which are inherently variable in both space and time. One of the important factors that affects crop production is soil salinity. Since soil properties change slowly across the landscape, the need for investigation of the variability of soil salinity over distance becomes of great importance. Saline and alkali soils are a major problem in arid and semi-arid regions. They greatly affect the value and productivity of farming lands in every continent of the world. The salinity problem is salt accumulation in the root zone, which affects plant growth because of its osmotic effect. Salinity may reduce the yields of crops as much as 25 percent without visible symptoms.

Proper management and treatment of salt-affected soils depends upon accurate knowledge of the nature and severity of the salt problem at hand. Inadequate information may lead farmers to plant salt-sensitive crops where they should plant salt-tolerant ones, or to fail to apply chemical amendments where they are needed.

Population explosion justifies the need to expand farm land and productivity. With large cultivated farms; investigating for salinity variability will mean sampling many samples which is unnecessary, costly, and the time involved becomes of economic importance to us. Since we must learn to maximize our resource, the need

for improving the number of soil samples to be taken in an area becomes highly essential. One should, however, make sure that the number of samples taken is representative of the area in question.

The number of sampling locations in this study was 50. Saturated extracts were made from these 50 samples. Electrical conductivity (ECe), which is a measure of the salinity of the filtered solution, was measured for each sample. Also measured were the sodium, calcium and magnesium content of the solution. With the help of spatial study, similarity and dissimilarity between samples were determined using geostatistics. With this determination, instead of sampling 50 points, the next salinity appraisal may require only 25-30 sample points. In other words the sampling distance is increased as opposed to the initial sampling distance. This indeed saves money and time.

The objective of this research is to:

- a) evaluate the usefulness of geostatistics (semi-variogram) in studying variability in electrical conductivity (Ece), and sodium adsorption ratio (SAR) in an irrigated alfalfa field, and
- b) investigate the frequency distributions of electrical conductivity (ECe), and sodium absorption ratio of the assay data.

## LITERATURE REVIEW

The conductivity of the soil's saturation extract is recommended as a general method for appraising soil salinity in relation to plant growth (U.S. Salinity Laboratory Staff, 1954). The saturation extract method is somewhat slower than a resistance measurement of the soil paste, but the result is easier to relate to plant response. The saturation extract is used because it is easily reproducible and tends to cancel out the matric effects due to soil texture between different soils. The soil is saturated by adding distilled water gradually to a given amount of soil sample while stirring with a spatula. At saturation the soil paste glistens as it reflects light, flows slightly when the container is tipped, and the paste slides freely and cleanly off the spatula for all soils but those with a high clay content. After mixing, the sample should be allowed to stand for an hour or so, and then the criteria for saturation should be rechecked. Free water should not collect on the soil surface nor should the paste stiffen markedly or lose its glisten on standing. If paste is too wet, additional dry soil may be added and mixed again (Methods of Soil Analysis, 1965).

Pure water is a very poor conductor of electrical current, whereas water containing dissolved salts conduct current approximately in proportion to the amount of salt present. Based on this fact, the measurement of the electrical conductivity of an extract is an indication of the total concentration of ionized constituents (Methods of

Soil Analysis, 1965). Because most soil minerals are insulators, electrical conductivity of saline soils is primarily through the water, which contains dissolved electrolytes (salts). Exchangeable cations contribute to electrical conductivity only in a minor way in saline soils because these cations are less abundant and mobile than the soluble electrolytes (Rhoades and Halverson, 1977).

#### Saline and Alkali (Sodic) Soils

Saline and alkali (sodic) conditions lower the productivity of large areas of agricultural land in the United States - an estimated one fourth of our 29 million acres of irrigated land and less extensive acreages of nonirrigated crop and pasture lands (Yearbook of Agriculture, 1957).

Saline and alkali soils are soils that have been harmed by soluble salts, consisting mainly of sodium, calcium, magnesium, chloride, and sulfate and secondarily of potassium, bicarbonate, carbonate, nitrate and boron.

Salt-affected soils which poses a problem to soils require special treatment and management practices.

Soluble salts may harm soils by increasing the salt concentration of the soil solution and by increasing the percentage saturation of the soil adsorption complex with sodium.

The second effect occurs when sodium salts predominate. It is more permanent than the first because adsorbed sodium usually persists after most of the soluble salts are removed.

Salt-affected soils occur mostly in regions of an arid or a semiarid climate.

Under humid conditions, the soluble salts originally present in soil materials and those formed by the weathering of minerals generally are carried down-ward into the ground water and are transported ultimately by streams to the oceans.

Alkali soils contain excessive amounts of adsorbed sodium. The presence of negative electrical charges at their surfaces, soil particles adsorb and retain cations, such as calcium, magnesium, and sodium. While the adsorbed cations are combined chemically with the soil particles, they may be replaced or exchanged by other cations that are added to the soil solution.

Figure 2.1 shows calcium replacement by sodium when irrigation water containing a high proportion of sodium is applied to porous, aggregated soil on which calcium is adsorbed. Figure 2.2 is an example of the devastating effect of salt to crops.

The types of salt effects, as measured by the total salt concentration (ECe) and the Na concentration, as measured by exchangeable sodium percentage (ESP), can be classified into three groups: Sodic, Saline and Saline-Sodic Soils.

Sodic soils contain an amount of total salts which is usually less than 4 mmhos/cm in their saturation extract and more than 15 percent exchangeable sodium. The pH ranges from 8.0 to 9.0. Sodic soil is reclaimed by adding gypsum, sulfur or sulfuric acid to the soil.

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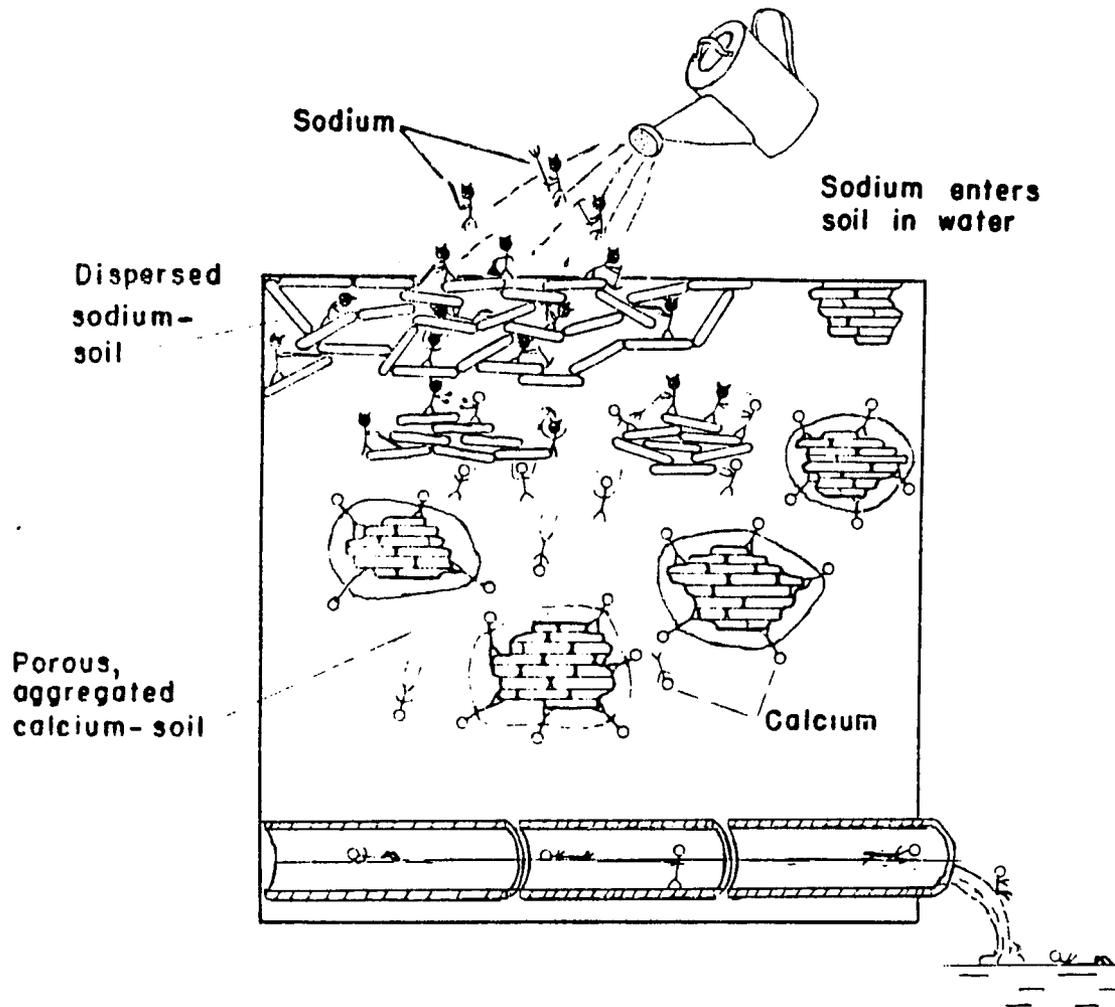


Figure 2.1. When irrigation water containing a high proportion of sodium is applied to porous, aggregated soil on which calcium is adsorbed, the sodium replaces the adsorbed calcium and causes the soil particles to rearrange so as to form small pores through which water moves slowly. This process is reversed when soluble calcium is applied to the soil and structure-building practices are employed.

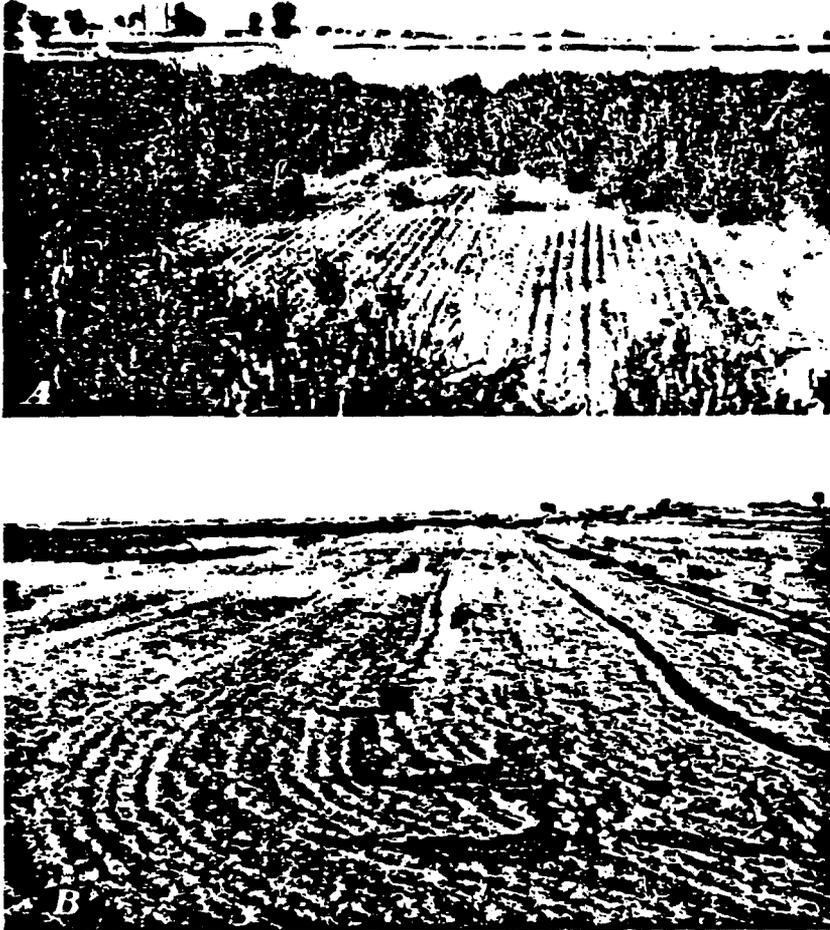


Figure 2.2. The effects of salinity are sometimes very striking as in the "salt spot" of 2.2A, B, the result of planting cotton on sandy loam with inadequate sub-soil drainage and excessive salinity. In many cases the salt is more uniformly distributed than in the fields shown, with no sharp line of demarcation between good plants and no plants. If the farmer has no point of reference, his entire crop, though actually stunted by excessive salt, may appear to him to be "normal".

Saline soils contain soluble salts in an amount high enough to interfere with plant growth, but not enough exchangeable sodium to alter the soil characteristics appreciably. Saline soils usually have electrical conductivity (ECe) that is greater than 4 mmhos/cm and ESP that is less than 15%. The pH is less than 8.5. Saline soils have normal physical properties.

Saline-Sodic soils contain significant amounts of total salts, usually greater than 4 mmhos/cm and greater than 15 percent exchangeable sodium. The pH is less than 8.5 and its properties are similar to those of saline and sodic soils.

#### Origin and Causes of Salt Buildup

Salt comes from the minerals of the earth's crust. Weathering decomposes the minerals and releases the salt in a soluble form.

In arid and semiarid areas in the Western States and elsewhere in the world soluble salts may accumulate in the soil in amounts harmful to crop production. In arid regions rainfall is too meager to leach the salt out of the soil. The rain is largely dissipated by evaporation and by plant transpiration.

Meager rainfall, evaporation, and plant use favor salt buildup in arid regions. A salt buildup caused by these processes under natural, well-drained conditions is usually not enough to cause trouble. When a field continually receives salt from other locations, a harmful buildup, or accumulation occurs. The salt is brought into the area by surface water or by ground water. Irrigation often speeds the process.

Salt problems are especially serious in 17 Western States, where more than 7 million acres of irrigated land is salt-affected. A similar condition exists in a less extensive acreage of nonirrigated crop and pasture land (Agriculture Information Bulletin No. 190).

It is estimated that an area of about 7 million ha in India alone is seriously affected by salinity and/or alkalinity. In Southern Russia and around the Yellow River in China large irrigated areas suffer from salinity problems. Another newly-cultivated land is Australia where some areas in the south already have a salinity problem.

#### The Semivariogram

The geostatistical ore reserve estimation method (or geostatistics in short) is a relatively new method developed by G. Matheron in France during the early 1960's for analyzing spatial variability. Historically the methodology for geostatistics began in mining engineering for assessment of ore bodies by D. G. Krige. The underlying mathematical basis of the method is called "The Theory of Regionalized Variables". The method somewhat similar to the classical statistical approach; although there is one fundamental difference between geostatistics and the classical statistics. In classical statistics, the sample population are assumed to be random samples. Also, they are assumed to be independent of each other; i.e., obtaining one sample does not give any information about the next sample. In geostatistics samples are not demanded to be independent. Instead, it assumes that adjoining samples are correlated to each other spatially (or in space).

It also assumes that the correlation can be analytically and statistically captured in a function known as variogram.

It is misleading to refer to geostatistics as simply a method of ore reserve estimation, when in actuality geostatistics can be applied to almost any research endeavor. For instance, Warrick et al. (1983) stated that methods can be used to analyze any number of soil properties (physical, chemical, biological) and can be extended to include plot response and crop yields.

The semi-variogram  $Y(h)$  is defined as:

$$Y(h) = (\frac{1}{2}) \text{Var. } [Z(x)-Z(x+h)] \quad (1)$$

Where "Var" is the variance of the argument. The  $Y(h)$  is the semi-variance which is equal to one-half the variance of the difference  $z(x)-z(x+h)$ . The vector  $h$  is known as the lag while  $z(x)$  is the value of the regionalized variable  $z$  at a point  $x$  in the transect and  $z(x+h)$  the value of  $Z$  at a point  $x+h$  at distance  $h$  from  $x$ , also in transect. Under the zero drift assumption  $E z(x+h) = E z(x)$  and equation (1) is equivalent to:

$$Y(h) = E [Z(x+h)-Z(x)]^2 \quad (2)$$

An estimate of  $Y$  is  $Y^*$  given by

$$Y^*(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(x_i+h) - Z(x_i)]^2 \quad (3)$$

Where  $n(h)$  is the number of couples separated by a distance  $h$ , and  $E$  is the expected value of  $Z(x+h)$ . If the strong stationarity conditions (which will be explained later) are met, then  $Y(h)$  exists.

Figure 2.3 shows several examples of different degrees of continuity (spatial dependence). The distance at which the variogram curve levels off is called the range and is simply the traditional geological notion of range of influence. Beyond this range of influence, the samples are said to have discontinuity; i.e., they are independent of each other.

The value of the variogram where the curve levels off is called the sill value. The value of the variogram at distance  $(h) = 0$  is called the nugget value. Ideally, this nugget value should have the same value. A positive nugget value, can have real physical meaning or be due to errors in sampling or assaying (Knudsen et al., 1978).

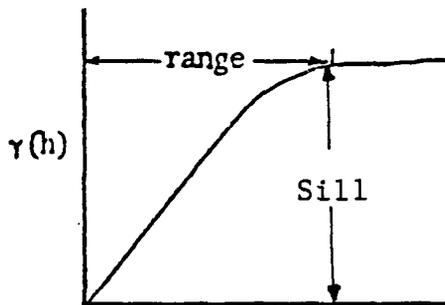
A third item of geological and soil interest is whether the property is anisotropic; i.e., is the property more continuous in one direction than another. Anisotropy is determined by comparing the range of influence of the variograms, computed along different directions.

Two common models of semivariograms are the spherical model and the linear model as shown on Figure 2.3. The semivariogram showed discontinuity between sample points at distances less than the lag  $h$  when it does not pass through the origin.

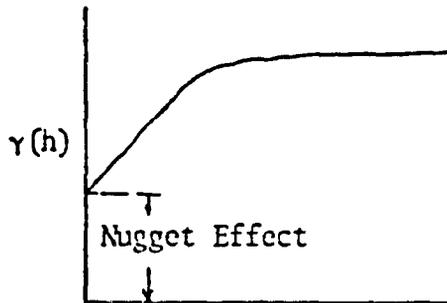
Spatial variations with interdependence are commonly described with a semivariogram. It considers a set of values  $z(x_1)$ ,  $z(x_2)$  ---,  $z(x_n)$  at  $x_1$ ,  $x_2$  ---,  $x_n$  where each location defines a point in 1, 2, or 3-dimensional space. The value need not be for an exact point,



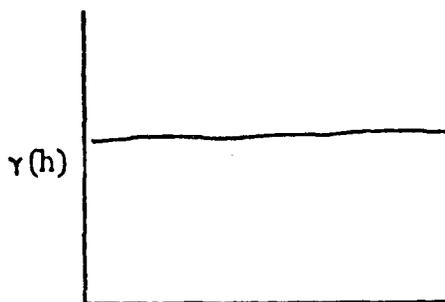
High degree of continuity. Can be approximated by parabola near the origin.



Average continuity. Almost linear near origin. Typical of many metal deposits.



Nugget effect. Discontinuity at the origin and thereafter much like above variogram.



Purely random.

Figure 2.3. Degrees of continuity expressed by variogram.

but rather represents a defined "support volume" which is centered at  $x$ . For the semivariogram, strong stationarity is required, that is

Strong Stationarity (stationarity of order 2)

- (i) The expected value of  $x(z)$  is independent of the point  $z$ , for any value of  $z_0$ .
- (ii) The semivariogram is independent of the point  $z$  for any vertical distance  $h$ .

The first condition implies that there is no drift (trend) in values but does not preclude the presence of high and low value areas.

The second condition implies stationarity of the variance as well as of the semivariogram; the variance of  $x(z)$  must be independent of the point  $z$ , and must be finite.

Weak Stationarity (the intrinsic hypothesis)

- (i) The expected value of  $x(z)$  is independent of the point  $z$ , for any value of  $z_0$ .
- (ii) For all vectors  $h$  the variance of  $z(x+h) - z(x)$  is defined and is a unique function of  $h$ . A system which satisfies the strong stationarity requirements also satisfies the intrinsic hypothesis but the vice-versa is not true.

The variogram is developed by plotting semivariance with respect to  $h$ . There are different types of semivariogram models. Some are without sills. Examples of these are Linear, Generalized Linear and DeWijsian model (Figure 2.4). The linear  $y$  is shown as the dotted line in Figure 2.4. A generalization of this model exists

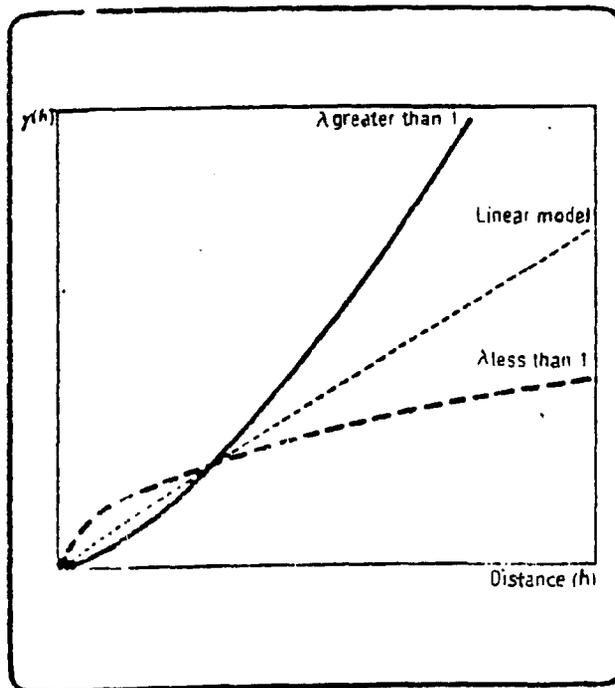


Figure 2.4 Model without sills.

in which the value of  $y$  is related to the distance  $h$  raised to some same power  $\lambda$  that lies between zero and 2 but never actually equals 2. The other two curves in Figure 2.4 show examples of the generalized linear model for specified values of  $\lambda$ . Only one other model is available without a sill - the DeWijsian model, which is essentially a straight line relationship between the  $y$  values and the logarithm of the distance  $h$ .

There are three models that possess a sill, although one of them is mentioned very rarely (Nugget effect). The two most commonly used are the spherical, or "Matheron", model and the exponential model (Figure 2.5).

Royle et al. (1979) state that the range of influence is essential in sampling programs, and when it is large, samples can be taken at relatively large intervals. If something is known of the range of influence, sampling spacing for global (total reserve) estimates for a deposit may initially approach 90% of the range, because the samples will be just correlated at this distance. When different ranges of influence occur in different directions, as commonly occurs in alluvial deposits, the sampling program can be optimized by varying the sampling intervals in proportion to the ranges.

Thus, if the range of influence is 500 ft (152 meters) from north to south and 250 ft (76 meters) from east to west, the minimum sampling interval from north to south could be 400 ft (122 meters) and that from east to west could be 200 ft (61 meters). In many cases, anisotropies of this nature, although qualitatively recognized, have been greatly exaggerated. Too small an interval in the other

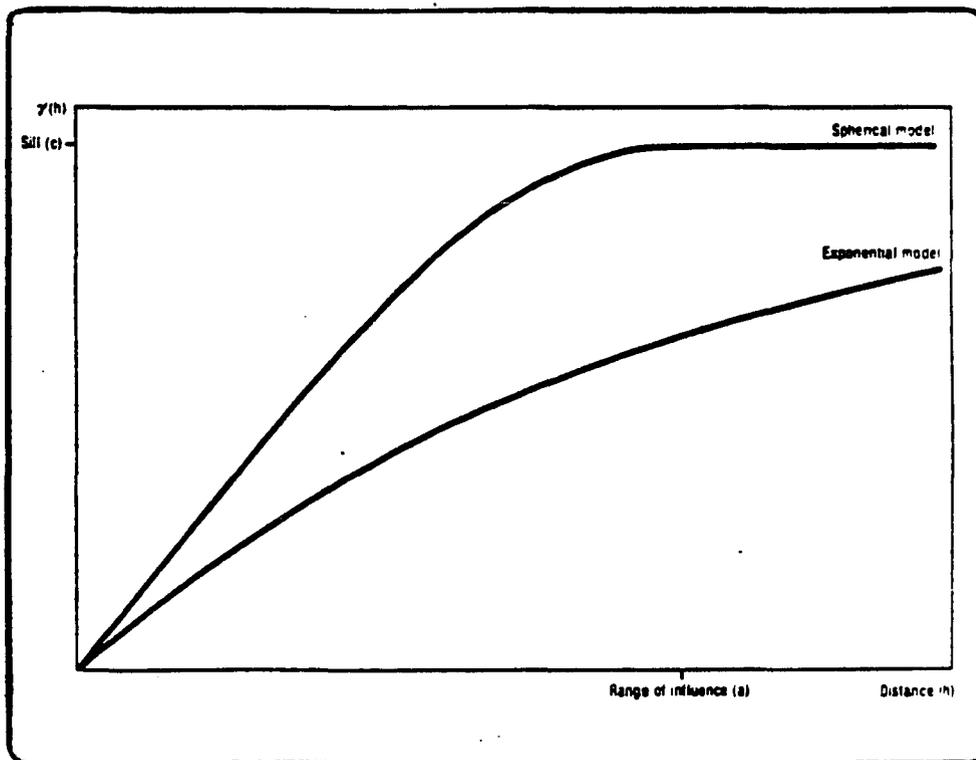


Figure 2.5. Model with sills.

geostatistics would have produced the maximum effect from the same number of samples by optimizing the ratio of the two sampling intervals. To do so, all that is needed is two variograms, one in each direction.

The diversity of physical and chemical properties of soil has prompted many researchers to carry out work in spatial variation studies of some soil parameters that needed to be defined and quantitatively predicted. Examples of these are spatial variation of salt (chief concern) and spatial variability of soil physical properties; to mention but a few.

Wagenet and Jurinak (1977) studied the spatial variability of soluble salt content in a Mancos shale watershed. A total of 35 samples were taken from a 777 km<sup>2</sup> area. The observed E<sub>c</sub> values were not normally distributed. The spatial distribution of salt in the watershed showed low salt content, although there were some interspersed high-salinity areas. Summarily, it was assumed that each E<sub>c</sub> measurement is independent of the other.

Hajrasuliha et al. (1980) studied the spatial variability of soil salinity in southwestern Iran. Three sites of 150, 440, and 455 ha were sampled respectively as site 1, site 2, site 3. The variogram for site 2 shows that the E<sub>c</sub> values were spatially related to each other for separation distances less than 800 m. Site 3 did not exhibit a range. It exhibited a nugget effect which may be related to the spacing of the data points, or errors of

measurement. Site 1 showed that the data were randomly distributed owing to the small physical size of each sample (80 to 320 m), and the large spacing between samples.

Hajrasuliha et al. (1980) stated that instead of arbitrarily selecting a grid spacing of 80 m, as seen in Figure 2.6, it would be advisable to sample fewer locations to identify the randomness of the field, and also determine the number of observations required for a given area.

Burgess and Webster (1980) studied the sodium content of a soil at Plas Gogerddan in Great Britain. Square sampling grids were considered at 15 m intervals. Semi-variograms for four directions were computed (Figure 2.7). The linear model was applied because it was found simple and adequate. The results showed that the isarithmic maps of sodium content had no continuities in the surface as a result of the large nugget variance. When a nugget exists, the estimation variance is correspondingly higher and cannot be reduced below the nugget value. In this study, the semi-variogram was assumed isotropic.

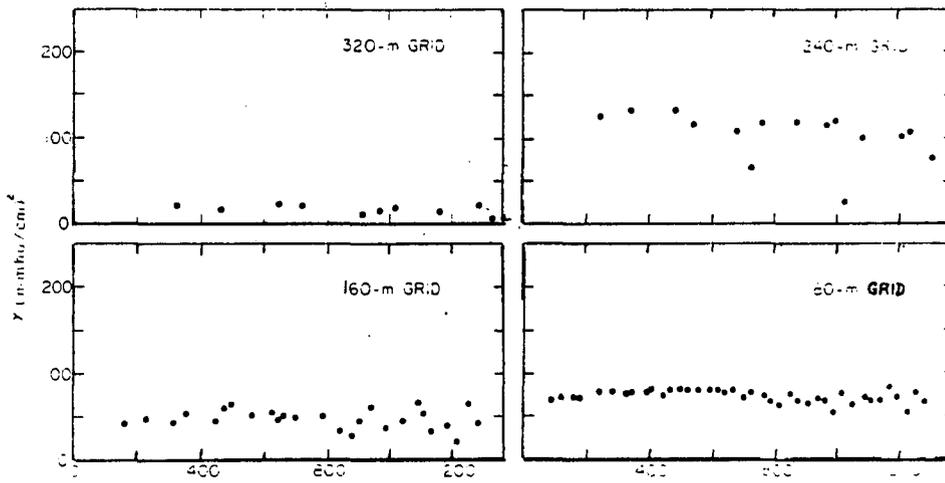


Figure 2.6. Semivariogram of 18, 32, 64, and 232 ECe observations (mmhos cm<sup>-1</sup>) for site 1.

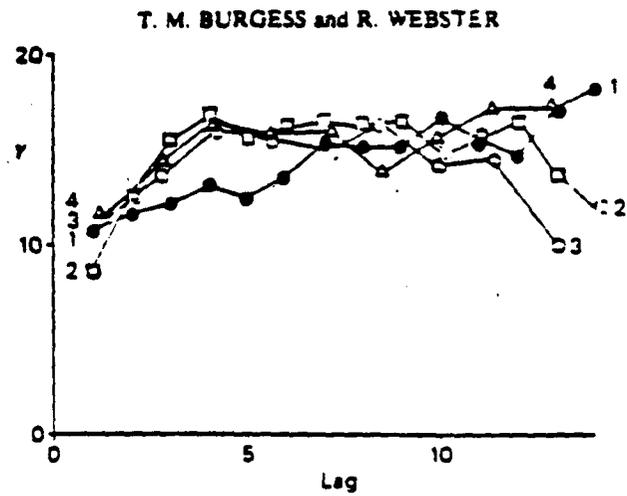


Figure 2.7. Semi-variograms of sodium content in Cae Ruel, Plas Gogerddan, for the four principal directions of the grid.  $\gamma$  is in units of  $(\text{meq}/10 \text{ kg})^2$ .

## AREA OF STUDY AND EXPERIMENT PROCEDURE

The area studied in this report lies between Casa Grande and Coolidge, Arizona. It was planted to alfalfa when samples were collected. Average annual precipitation is 150 to 200 millimeters and the mean annual temperature is 21°C. In extreme hot days during the summer, the temperature goes as high as 49°C.

There are 24 borders in this field. The area is 351 meters wide and 351 meters long, except for the last border which is narrower than the rest (Figure 3.1). On the North side of the field is a road and on the south is an irrigation ditch which floods the field through the help of siphon tubes from the ditch.

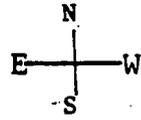
This field, according to Corinne Ross (personal communication, 1982) is producing well and the farmer has been content with its production. However, the field is beginning to show signs of non-uniformity, and if the poorer areas can be brought up to the yields of the rest of the field, a maximum yield will be achieved.

### Sampling Procedures

The field was divided into a grid system. Each border (15 m wide) was divided into 24, 15 meters by 15 meters, square blocks (see Figure 3.2). The blocks were assumed to be uniform throughout the one sample per blocks was representative of the entire block.

Fifty sampling units were sampled at a depth of 0 to 15 cm. These sampling points were randomly chosen. Sampling was done with

To  
← Coolidge



To  
→ Casa Grande

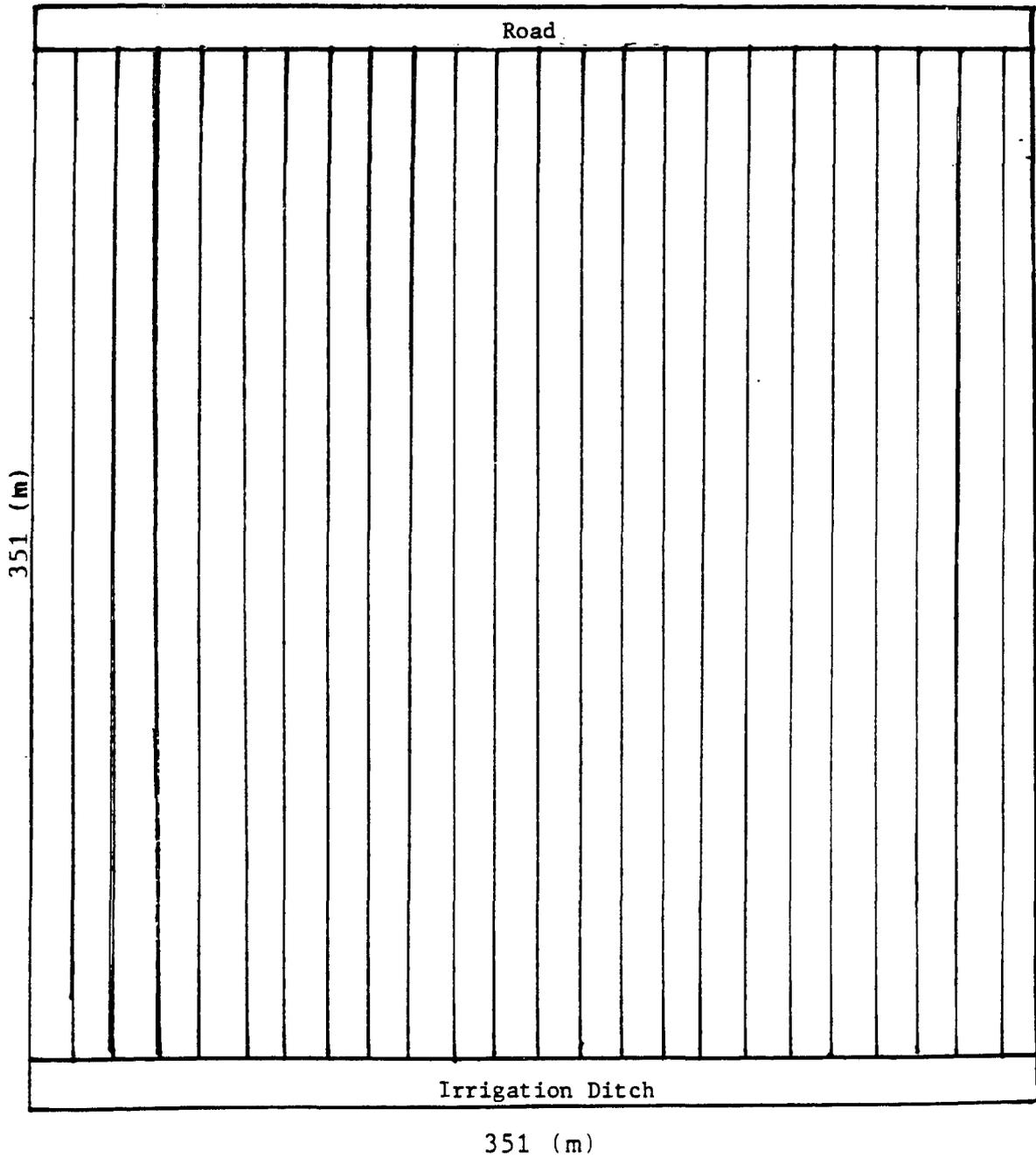


Figure 3.1. Map of field.

THE UNIVERSITY OF ARIZONA, TUCSON  
 MAP OF GRID SYSTEM  
 SMPL. PTS.  
 ALFALFA FIELD IN COOLIDGE AZ  
 03/14/84 PREPARED BY : S.A.AJIBOGUN SCALE 1:51

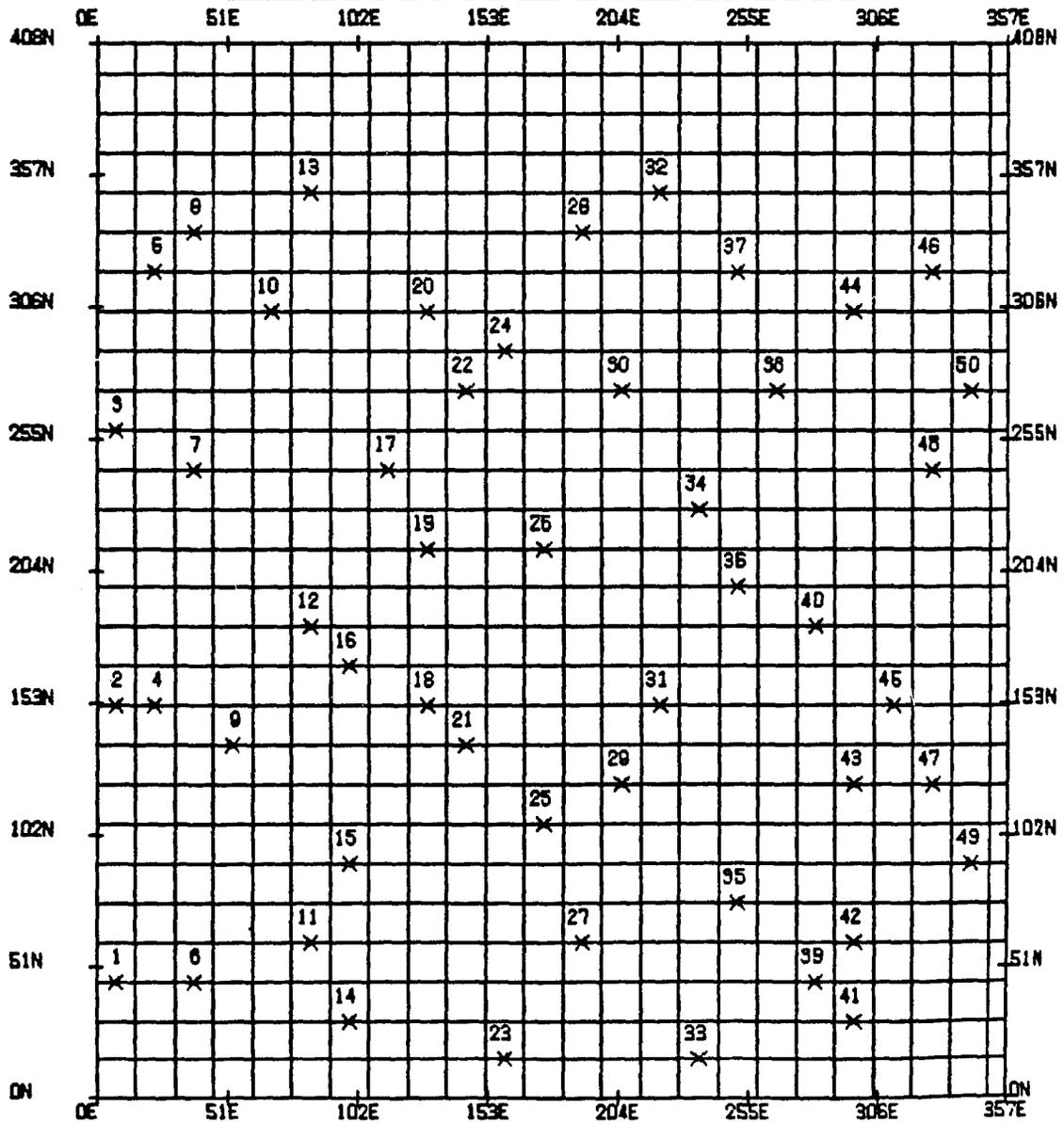


Figure 3.2. Map of grid system.

a bucket auger and a distance measuring device that consisted of a calibrated wheel to mark off the locations (X-, Y-coordinates). Samples were collected several days after irrigation of this field. Since salts are considered mobile at high moisture content, samples were collected at low moisture.

## MATERIALS AND METHODS

The direct Indicating Bridge (bridge and cell for measuring the conductivity of saturation extracts and irrigation water) described by Agricultural Handbook No. 60 (1954) has conductivity cell which has a constant of  $0.5 \text{ cm}^{-1}$  and a capacity of 2 to 3 ml of solution. With the help of this cell the bridge scale reads directly from 0.15 to 15 mmhos/cm. To operate the bridge, the current is alternated which makes use of a cathode ray tube null indicator. In order to read the electrical conductivity at  $25^{\circ}\text{C}$ , the temperature of the solution is set on the temperature-compensating dial, the main dial, at balance.

The accuracy of calibration of the bridge scale was checked by preparing a saturated solution of calcium sulfate. Adjusting the temperature-compensation dial properly, the bridge read 2.2 mmhos/ with the prepared saturated solution of calcium sulfate.

The equipment used to collect the soil samples tool for removing the soil, a bucket or similar container, waterproof sample containers that will hold roughly 400 to 500 grams of dry soils, and tags or labels for identification.

A sampling bucket auger was used to draw the samples. The waterproof containers used were plastic since the samples were collected four or five days after irrigation and were somewhat moist. If moist saline soil is placed in a container that is not

waterproof, salt will be absorbed by the container as the soil dries and the sample will be altered.

For the purpose of this experiment, 50 sample points were sampled, from 0-15 cm depth each.

To prepare a saturated soil paste, distilled water was added to the air-dried soil (250/gm) and the mixture stirred manually. Oven-dried soils should not be used because heating to 105°C partially converts Gypsum,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , to  $\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$ . The latter hydrate is more soluble in water than gypsum. The mixture was allowed to stand for several hours to permit the soil to imbibe water. After this imbibition period, more water was added so as to obtain a uniform saturated soil-water paste (free of partially wetted clumps). At this stage, the soil paste glistens as it reflects light, flows slightly when the container is tipped, slides freely and cleanly off the spatula, and consolidates easily when the container is jarred or tapped after a trench has been formed in the paste with the flat side of the spatula. After allowing the sample to stand for overnight, the criteria for saturation was rechecked. It should be ensured that no free water collects on the surface of soil nor should the paste stiffen markedly or lose its glisten. Should the paste get too dry, remix with more water. If the paste is too wet, additional dry soil should be added and the paste remixed.

After meeting the above criteria, the soil paste was filtered with vacuum pump and the extracted solution collected in small sample containers. Filtration was terminated when air passed through the filter-cake.

The saturated extracts were analyzed for the sodium, calcium, and magnesium concentrations in solution. To insure that the instrument for analyzing Na, Ca, and Mg was in the standard curve range, standard solutions of 0 to 50 ppm (Ca), 0 to 25 ppm (Na) were prepared. The instrument used in determining calcium, sodium, and magnesium was the atomic absorption spectrophotometer. This method is based on the ability of calcium or magnesium to selectively absorb radiation of a characteristic wavelength that it would normally emit if excited. The amount of light absorbed is proportional to the number of atoms in the ground state in the flame, i.e., proportional to the Ca or Mg concentration in the test solution.

Lanthanum chloride was added to the extracts as the internal masking ion. Lanthanum chloride prevents calcium and magnesium from forming complex compounds in the flame.

Sodium ion concentrations were measured with flame emission spectrometer. This method is based on the measurement of the amount of radiation emitted by atoms. The sample to be analyzed is sprayed into the flame, the water vaporizes, leaving a fine suspension of solid particules. At the high temperature of the flame some of the salt is converted to gaseous atoms. These atoms are excited in the hot part of the flame but they quickly come back to the ground state and emit light. The light emitted then passes to spectrometer where it is dispersed, a spectrum of the sample is formed, and the desired wavelength isolated and its intensity measured.

## RESULTS AND DISCUSSION

The ordinary concept of "statistics" usually includes the calculation of averages, percentages, standard deviation, variance, etc., and the presentation of data in tables and charts. Today, statisticians are mainly concerned with the development and application of methods for collecting and objectively interpreting quantitative data. Because such interpretation involves the process of inductive inference, from the particular to the general, statistics may be said to be technology of the scientific method. In classical statistics, certain assumptions are made if the parameters under study are intended to avoid bias. The assumptions are as follows: that the samples taken to infer the unknown population are always randomly selected and further more, they are assumed to be independent of each other. That is, obtaining one sample does not give any information about the next sample.

In the alfalfa field, the samples were randomly selected. This means that randomization gave each member of the population an equal chance of being included in the sample. The ECe values were recorded from direct indicating bridge and SAR calculated from their  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Na}^{+}$  as obtained from the saturated soil extracts. The formula used for SAR calculation is

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}}$$

The distribution of SAR over the field is shown in figure 5.2. It ranged from 3.5 to 7.5 with a mean of 5.08. The variance of the mean is 0.919 with a standard deviation of 0.959. The values of SAR in table 5.2 are approximately normally distributed. The resulting cumulative frequency, illustrated in Figure 5.4, was plotted on a probability scale and yielded an approximately straight line. Notice that the upper frequencies deviate to the right of the straight line. This is typical of data that are skewed to the right.

A further check was made to see if the distribution is actually normal. To do this, the mean standard deviation of the samples was rapidly estimated by graphically estimating the median and the points enclosed by the portion of a normal curve represented by  $U \pm 0$ . The median was estimated by dropping a perpendicular from the intersection of the 50% point on the ordinate and cumulative frequency curve to the abscissa. The estimate of the mean of 5.1 is quite close to the computed mean of 5.08. The standard deviation was estimated by dropping similar perpendiculars from the intersections of the 15.9% and the 84.1% points with the cumulative curve, respectively. By measuring the difference between these perpendiculars and dividing by 2, an estimate of one standard deviation is obtained. The estimate is  $S = 0.8$  which is close to the computed value of 0.959. These estimates indicate that the mean represents the actual mean of the population. For convenience, the SAR values were multiplied by 10 so that it could be graphed easily. The SAR coefficient of variation is 18.88.

Table 5.1. Calculated frequency distribution for ECe values.

ECe Range mmhos/cm	Class Boundaries	ECe x 100	Number of Spl in Class	Cum. Freq. # of Spl.	Cum. Freq. %
0.7-0.79	.696-.795	79.5	1	1	2.1
0.8-0.89	.795-.895	89.5	1	2	4.2
0.9-0.99	.895-.995	99.5	12	14	29.2
1.0-1.09	.995-1.095	109.5	13	27	56.2
1.09-1.19	1.095-1.195	119.5	6	33	68.7
1.20-1.29	1.195-1.295	129.5	7	40	83.3
1.3-1.39	1.295-1.395	139.5	6	46	95.8
1.4-1.49	1.395-1.495	149.5	1	47	97.9
1.5-1.59	1.495-1.595	159.5	1	48	100.0

Table 5.2. Calculated frequency distribution of SAR.

SAR Range	Class Boundaries	SAR x 10	# of Spl. in Class	Cum. Freq. # of Spl.	Cum. Freq. (%)
3.5-3.9	3.45-3.95	39.5	4	4	8
4.0-4.4	3.95-4.45	44.5	10	14	28
4.5-4.9	4.45-4.95	49.5	8	22	44
5.0-5.4	4.95-5.45	54.5	15	37	74
5.5-5.9	5.45-5.95	59.5	6	43	86
6.0-6.4	5.95-6.45	64.5	2	45	90
6.5-7.4	6.45-6.95	69.5	2	47	94
7.5-7.9	6.95-7.45	74.5	3	50	100

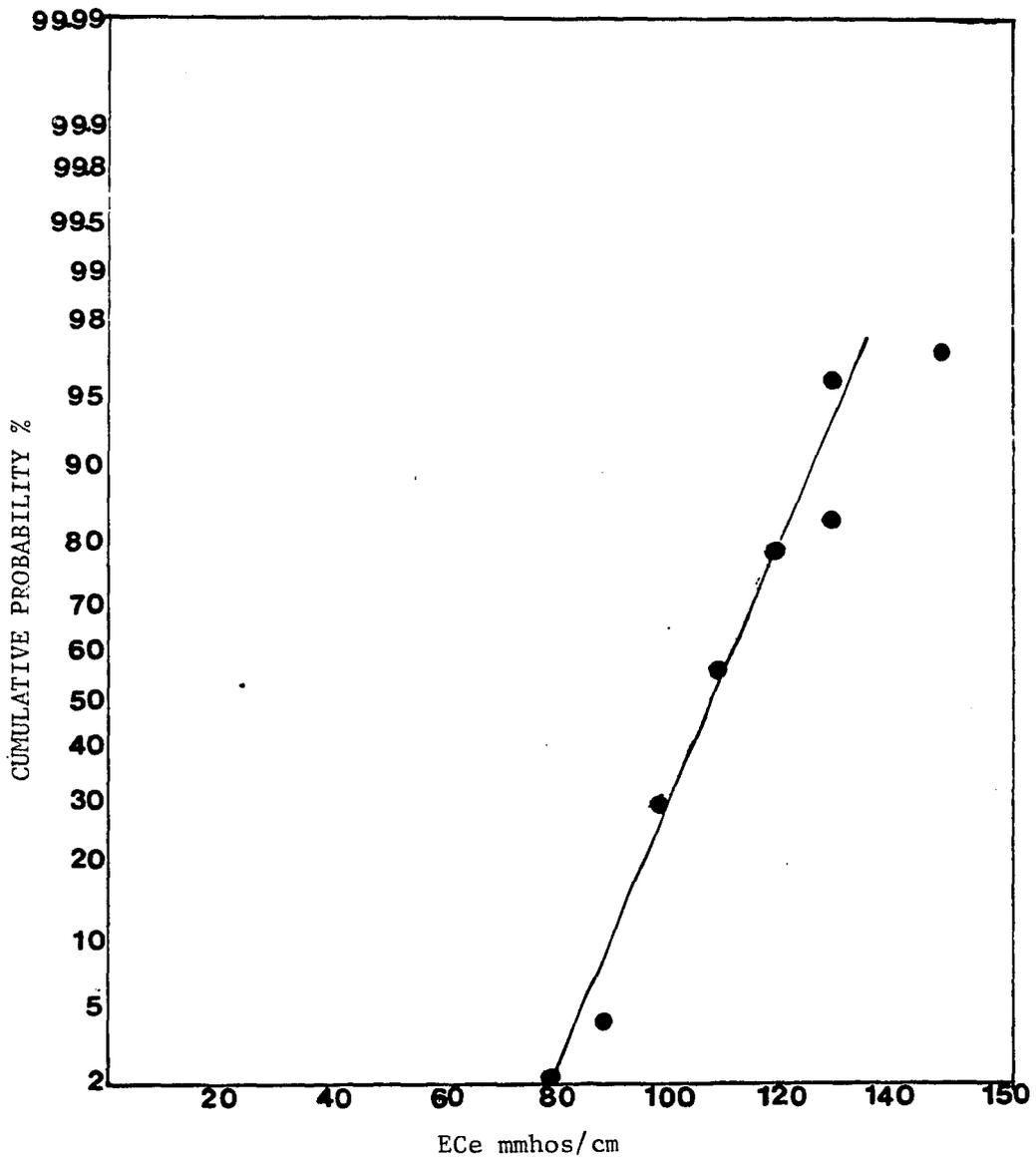


Figure 5.1. Cumulative frequency distribution (Probability scale) of ECe values.

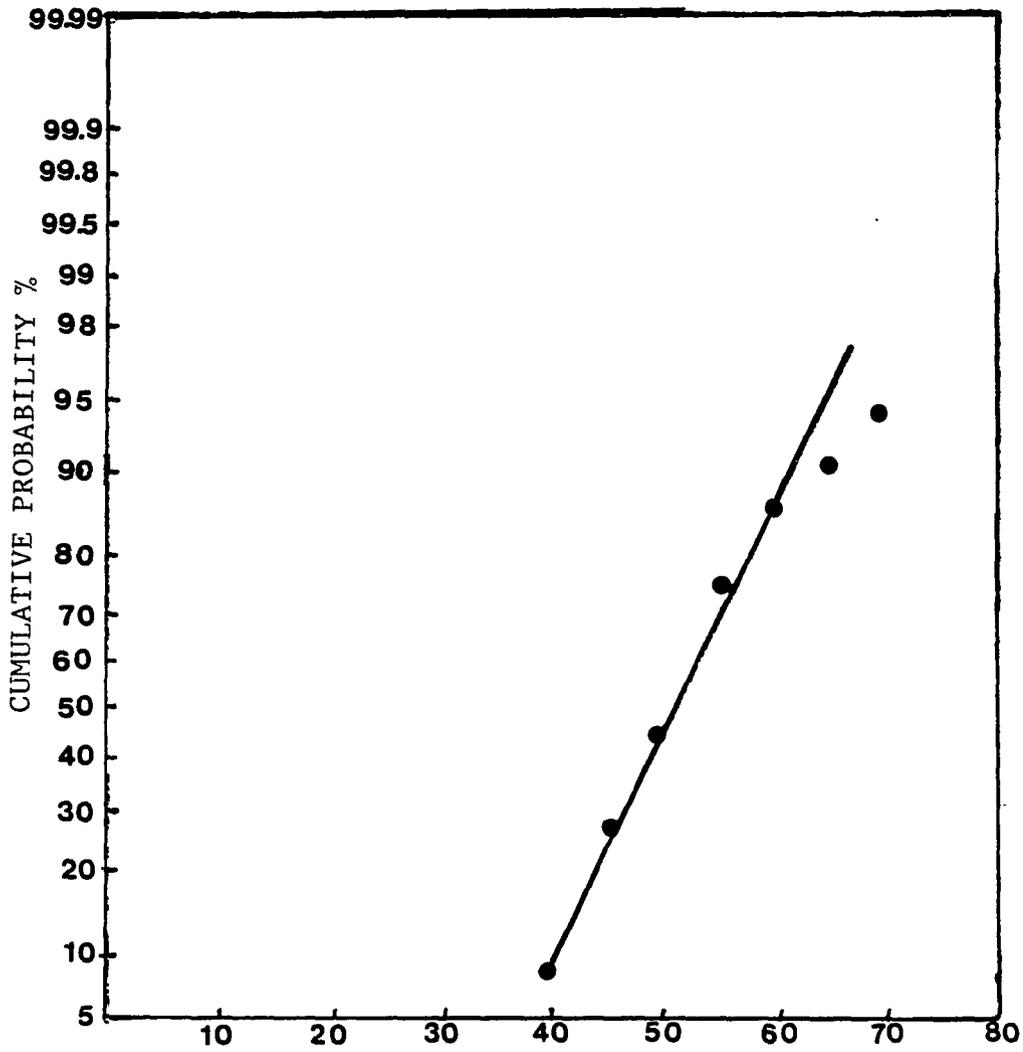
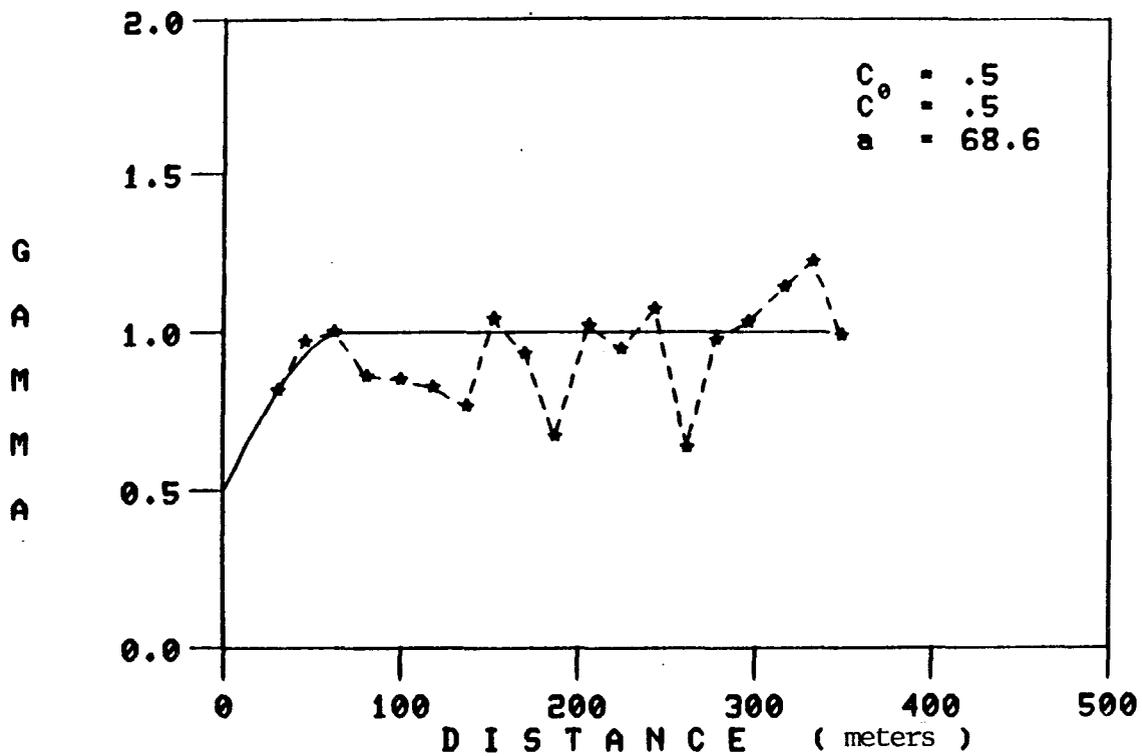


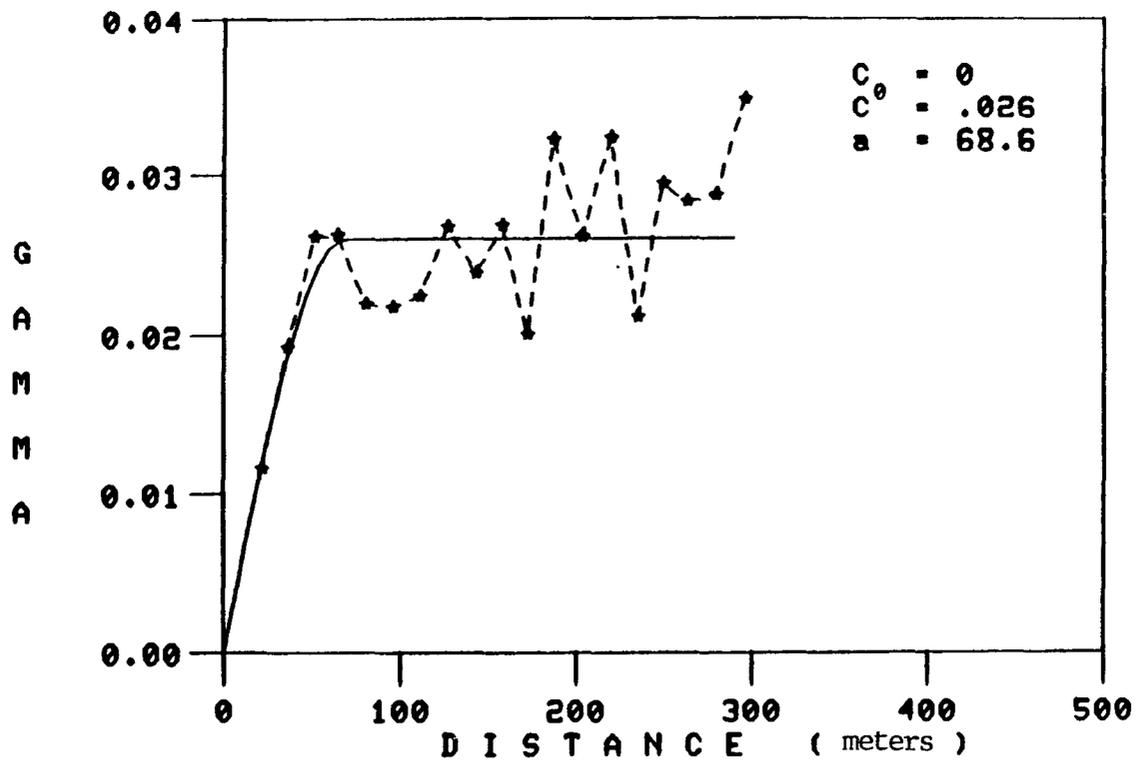
Figure 5.2. Cumulative frequency distribution of SAR values.



**SAR SEMI-VARIOGRAM**

DIRECTION	=	.000E+00	MEAN	=	.508E+01
WINDOW	=	.900E+02	VARIANCE	=	.919E+00
CLASS SIZE	=	.180E+02	NO.OF SAMPLES	=	49
LOGARITHMS:		NO			

Figure 5.3. Semi-variogram of SAR.



**EC VARIOGRAM**

DIRECTION	=	.000E+00	MEAN	=	.108E+01
WINDOW	=	.900E+02	VARIANCE	=	.270E-01
CLASS SIZE	=	.152E+02	NO.OF SAMPLES	=	50
LOGARITHMS:		NO			

Figure 5.4. Semi-variogram of EC.

The same statistical procedure that was used in analyzing SAR values was also applied to EC values. The EC values were multiplied by 100 for ease of graphing. The EC values ranged from 0.78 to 1.5 mmhos/cm with a mean of 1.00. The variance of the mean was 0.028 with a standard deviation of 0.167. The values were approximately normally distributed (Table 5.2). The values were plotted on a cumulative probability scale and it gave approximately a straight line. Estimation of the mean and standard deviation were obtained from the graph (Figure 5.4). The mean from this estimation is 1.08 which is very close to the calculated mean of 1.00. The estimated standard deviation is 0.140 which is also close to the calculated standard deviation of 0.167. Again the EC mean is a true mean of the population. The coefficient of variation of EC is 16.71.

To give some idea of precision of the experiment, the estimated deviation expressed as a percentage (CV) of the mean of EC and SAR was compared. It shows that the SAR values were more variable than the EC value. The sources of variation of SAR and EC examined were probably due to laboratory analysis and spatial position. The measuring error for EC was minimized by rinsing the cell several times with distilled water and rinsing with the next sample before each measurement.

In all, the values of EC and SAR were low and would not cause problems to alfalfa production in this field, although very sensitive crops might be affected.

In order to improve on similar studies in the future, more samples should be collected so as to increase the accuracy and precision, and also the spacing between samples should be reduced so as to increase the spatial dependence.

The summary of important parameters are in Table 5.3. The result of the chemical analysis and the values of EC and SAR are tabulated at the appendix.

In an attempt to obtain a good variogram, four different programs were used; they are: GAMMC, DUPL, VPLOT, and HPLOT2. Program HPLOT2 generates a map of the sample holes using Calcomp routines. The map can be drawn with a Calcomp or Printonix raster-type plotter. The program has the capability to draw the property grid lines, as well as the hole locations and associated values. Program DUPHL is a hole editing program. The program determines samples whose coordinates and identification names have been duplicated in a set of data. The program can also be used to select pairs of samples which are located within a specified distance. Program GAMMC is a variogram computation program. Variograms are calculated in any specified direction, using data that have coordinates and assay values. The program is designed to compute variograms in either two dimensions or three dimensions, depending on the input data file. Program VPLOT is an interactive Tektronix Plot-10 program for plotting experimental variograms on Tektronix graphic terminals.

At the early stage of the analysis, error resulted from mis-transcribing the data onto the coding sheet and mispunching of the

Table 5.3. Statistical summary of vital parameters of EC and SAR.

Parameters	EC mmhos/cm	SAR
Number of observations, N	50	49
Mean, M	1.00	5.08
Variance	0.028	0.919
Standard deviation	0.167	0.959
Range L, meters	68.6	68.6
Still, C	0.026	0.50
Length of unit lag, (meters)	15	18
Coefficient of variation, CV	16.71	18.88

data. Programs DUPL, and HPLLOT2 were used to solve these problems. It is highly essential that the data be coded carefully and legibly in order to minimize errors.

Another problem encountered was the computational aspect of the variogram. Program GAMMC was used to calculate the variogram. It proved useful in choosing the right direction along which to compute the variogram, the size of window and the class interval to use. Since the modeling of a variogram requires considerable subjective judgement, many trials are required prior to obtaining a satisfactory one.

Knudsen et al. (1978) stated that it is common to obtain a poor variogram at the initial trial. It was also common in the past to quit the modeling after the first trial, simply because of the poor results that one obtained. The final step in the "art" of capturing variograms is to find the theoretical variogram that best describes the experimental variograms. Choosing the model and estimating its parameters are quite subjective. The selection of a model can often be narrowed to the choice of either a spherical model or a Deklijsian model, with the spherical model being the most common. The  $E_{C_e}$  values in the alfalfa field are low. They range from 0.78 to 1.5 mmhos/cm.

In examining similarity or dissimilarity between pairs of samples in the area studied, semivariograms  $Y(h)$  for EC and SAR were calculated and spherical model fitted. Several semivariograms were constructed, one in each of several directions. The final direction, window and class size that fitted EC and SAR were  $0.0, 90^{\circ}, 50$ , and  $0.0, 90^{\circ}, 60$ , respectively. The semivariogram (Figure 5.4) as

calculated from EC assay data shows that the values are spatially correlated to each other for separation distance less than 70 m. Figure 5.4 also shows that beyond the range of influence the samples are no longer correlated. That is, they are independent of one another. The sill,  $C$  is 0.026 and there is no nugget effect. The shape of the EC semivariogram resemble that described in Figure 2.3. That is, Figure 5.4 has a spherical shape. Hajrasuliha et al. (1980) found that site 2 of the three sites under spatial variability study showed spatial dependence. They were spatially related to each other for separation distances less than 800 m.

The semivariogram of SAR (Figure 5.3) shows some spatial dependence. The range of influence for SAR is 70 meters. That is, values beyond the range of influence are independent of one another. The fact that the data does not extrapolate smoothly to the origin is called a "nugget effect". In Figure 5.2, the estimated nugget value is approximately 0.5 which is a relatively high value in relation to the sill value of 0.5. A relatively high nugget value is very common in the soils, thus indicating the difficulty of obtaining accurate assays from laboratory procedure and sampling error. Hajrasuliha et al. (1980) found that nugget effect reveals an absence of continuity between adjacent samples taken at distance less than 80 m and may be related to sampling and analytical procedure errors. The semivariogram of SAR is spherical.

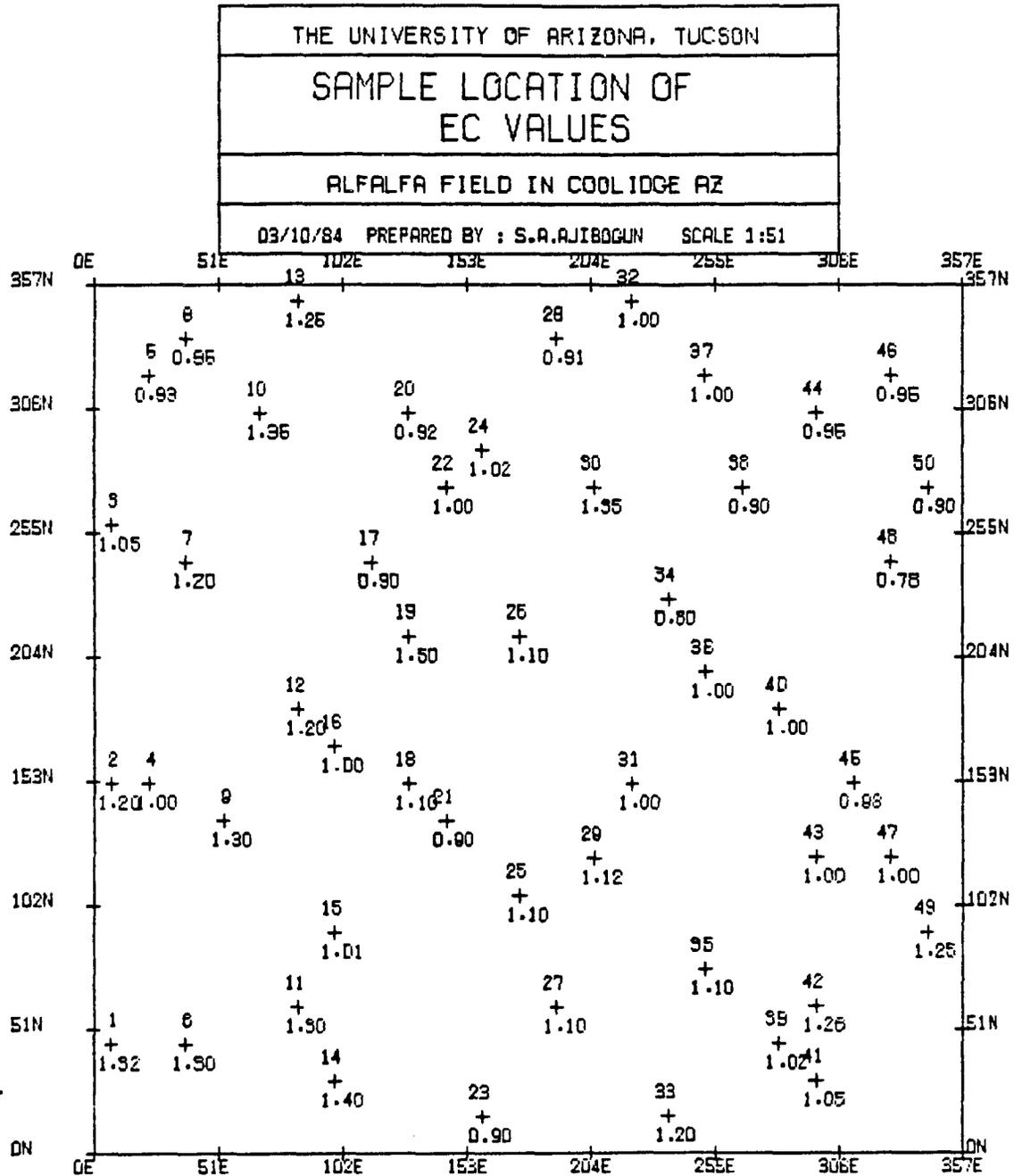


Figure 5.5. Sample location of EC values.

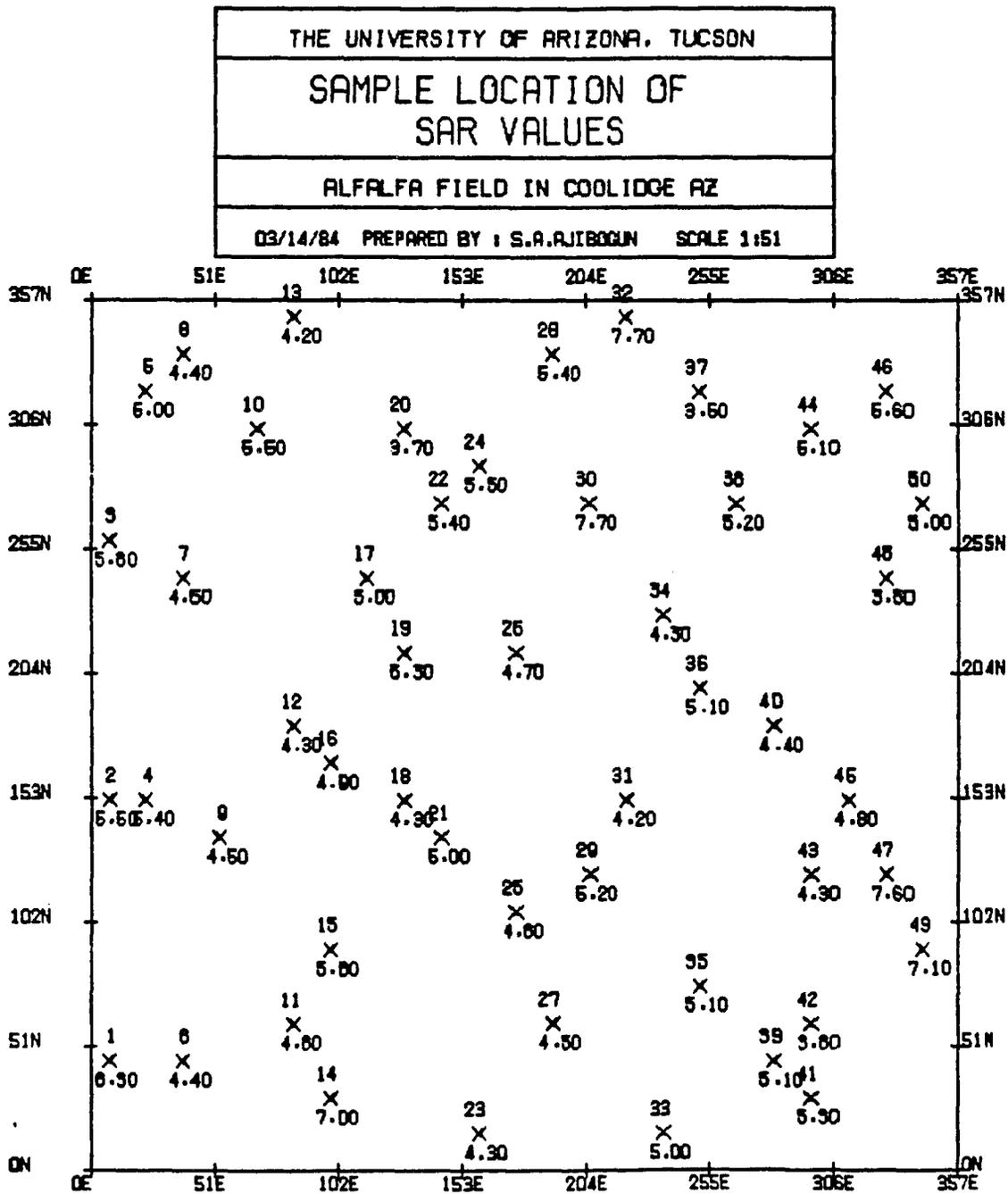


Figure 5.6. Sample location of SAR values.

## SUMMARY AND CONCLUSIONS

This study examined the usefulness of geostatistics and classical statistics to investigate the spatial dependence of electrical conductivity and sodium adsorption ratio in an alfalfa field.

The soil saturation extract method of measuring ECe,  $\text{Na}^+$ ,  $\text{Mg}^{++}$ , and  $\text{Ca}^{++}$  is a good method since it represents field conditions. The instruments for measuring ECe (direct indicating bridge) and  $\text{Na}^{++}$ ,  $\text{Mg}^{++}$ , and  $\text{Ca}^{++}$  (atomic absorption and flame emission spectrometer) are reliable.

Results from the spatial study showed that instead of the 15 m interval used in sampling, it could be increased to 90% of the range of influence (69 m) or greater. When the next salinity appraisal is needed in this area, a 62 m interval should be used. This also means that the number of sampling points will be reduced to 20 to 25 instead of 50 points initially used. The classical statistics revealed that the ECe and SAR are approximately normally distributed.

This method is very significant since money and time could be saved. Also methods can be used to analyze any number of soil properties (physical, chemical, biological) and can be extended to include plot response and crop yields (Warrick et al., 1983).

## APPENDIX A

### NOTATIONS

Ca <sup>++</sup>	Calcium
C	Sill
Co	Nugget effect
Cum.	Cumulative
CV	Coefficient of variation
E(·)	Expected value (·)
EC	Electrical conductivity
Freq.	Frequency
Meq/l	Milliequivalent/liter
Mg <sup>++</sup>	Magnesium
mmhos	Millihos
Na <sup>+</sup>	Sodium
#	Number
PPM	Parts per million
SAR	Sodium Adsorption Ratio
Spl	Sample
Y*	Estimate of Semi-variogram (Y)
σ	Standard deviation
VAR	Variance

APPENDIX B

RESULTS OF CHEMICAL ANALYSIS

Table B.1.

Sample No.	X Meter	Y Meter	EC mmho/cm	Na meq/l	Ca meq/l	Mg meq/l	SAR
1	8	46	1.32	8.78	2.68	1.20	6.30
2	8	152	1.20	10.28	2.82	1.21	5.50
3	8	259	1.05	7.68	2.48	1.06	5.80
4	23	152	1.00	7.59	3.03	0.91	5.40
5	23	320	0.93	6.59	2.41	1.06	5.00
6	38	46	1.30	7.19	3.93	1.35	4.40
7	38	244	1.20	6.87	3.36	1.15	4.60
8	38	335	0.95	6.34	3.05	1.16	4.40
9	53	137	1.30	7.89	4.52	1.64	4.50
10	69	305	1.35	9.88	4.83	1.63	5.50
11	84	61	1.30	8.63	4.69	1.73	4.80
12	84	183	1.20	7.63	4.66	1.59	4.30
13	84	351	1.25	7.20	4.32	1.58	4.20
14	99	30	1.40	10.14	2.70	1.56	7.00
15	99	91	1.01	7.97	2.93	0.87	5.80
16	99	168	1.00	6.75	2.97	1.08	4.90
17	114	244	0.90	6.81	2.86	0.84	5.00
18	130	152	1.10	7.33	4.73	1.16	4.30
19	130	213	1.50	8.98	2.91	1.15	6.30
20	130	305	0.92	5.64	2.82	1.75	3.70
21	145	137	0.90	6.76	2.41	1.16	5.00
22	145	274	1.00	7.53	2.91	1.00	5.40
23	160	15	0.90	6.80	3.81	1.10	4.30
24	160	290	1.02	7.10	2.23	1.06	5.50
25	175	107	1.10	7.25	3.25	1.81	4.60
26	175	213	1.10	7.35	3.64	1.28	4.70
27	190	61	1.10	6.86	3.48	1.28	4.50
28	190	335	0.91	6.04	2.49	1.70	5.40
29	206	122	1.12	7.78	3.27	1.15	5.20
30	206	274	1.35	11.49	3.03	1.36	7.70

Table B.1., Continued.

Sample No.	X Meter	Y Meter	EC mmho/cm	Na meq/l	Ca meq/l	Mg meq/l	SAR
31	221	152	1.00	6.60	3.50	1.35	4.20
32	221	351	2.00	11.84	3.68	1.01	7.70
33	236	15	1.20	7.42	2.17	2.26	5.00
34	236	229	0.80	5.86	2.29	1.46	4.30
35	251	76	1.10	8.31	4.26	1.01	5.10
36	251	198	1.00	7.41	2.91	1.29	5.10
37	251	320	1.00	5.41	3.31	1.42	3.50
38	267	274	0/90	7.09	2.56	1.13	5.20
39	282	46	1.02	7.40	3.11	1.04	5.10
40	282	183	1.00	5.97	2.70	0.99	4.40
41	297	30	1.05	7.45	2.99	1.03	5.30
42	297	61	1.26	8.63	3.72	1.30	3.80
43	297	122	1.00	6.05	2.59	1.43	4.30
44	297	305	0.95	7.48	2.46	0.98	5.10
45	312	152	0.98	6.65	3.05	0.80	4.80
46	328	320	0.95	7.47	2.68	0.84	5.60
47	328	122	2.00	10.95	3.39	0.75	7.60
48	328	244	0.78	6.04	2.97	2.13	3.80
49	343	91	1.25	9.94	3.23	0.67	7.10
50	343	274	0.90	6.41	2.48	0.87	5.00

Table B.1., Continued.

Sample No.	EC mmho/cm	Na ppm	Ca ppm	Mg ppm
1	1.32	201.9	53.7	14.6
2	1.20	236.3	56.6	14.8
3	1.05	176.6	49.6	12.9
4	1.00	174.5	60.7	11.0
5	0.93	151.4	48.4	12.9
6	1.30	165.3	78.7	16.4
7	1.20	157.9	67.2	14.0
8	0.95	145.7	61.1	14.1
9	1.30	181.4	90.6	20.0
10	1.35	227.2	96.8	19.9
11	1.30	198.5	93.9	21.0
12	1.20	175.6	93.3	19.3
13	1.25	165.5	86.5	19.2
14	1.40	233.1	54.1	18.9
15	1.01	183.1	58.6	10.6
16	1.00	155.2	59.5	13.2
17	0.90	156.5	57.4	10.3
18	1.10	168.6	94.7	14.1
19	1.50	206.4	58.2	14.0
20	0.92	129.6	56.6	21.2
21	0.90	155.4	48.4	14.1
22	1.00	173.0	58.2	12.1
23	0.90	156.2	76.3	13.4
24	1.02	163.2	44.7	12.9
25	1.10	166.7	65.2	22.0
26	1.10	168.9	72.9	15.6
27	1.10	157.7	69.7	15.6
28	0.91	138.8	50.8	20.7
29	1.12	178.9	65.6	13.9
30	1.35	263.8	60.7	16.5
31	1.00	151.8	70.1	16.5
32	2.00	272.2	73.8	12.3
33	1.20	170.5	43.5	27.5
34	0.80	134.6	45.9	17.7
35	1.10	191.1	85.3	12.3

Table B.1., Continued.

Sample No.	EC mmho/cm	Na ppm	Ca ppm	Mg ppm
36	1.00	170.3	58.2	15.7
37	1.00	124.3	66.4	17.2
38	0.90	162.9	51.3	13.7
39	1.02	170.1	62.3	12.7
40	1.00	137.3	54.1	12.1
41	1.05	171.4	59.7	12.5
42	1.26	198.5	74.6	15.8
43	1.00	139.0	52.9	17.3
44	0.95	171.9	49.2	11.9
45	0.98	152.9	61.1	9.7
46	0.95	171.8	53.7	10.2
47	2.00	251.8	67.9	9.1
48	0.78	138.8	59.5	25.9
49	1.25	228.5	64.8	8.1
50	0.90	147.4	49.6	10.6

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