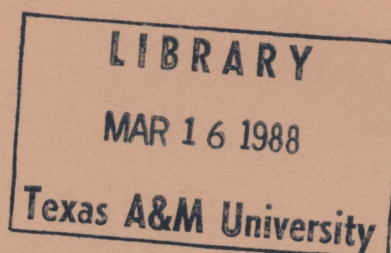


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February 1988



# Sampling Irrigated Soils for Salinity Appraisal



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## Summary

This report outlines the distribution and variation characteristics of soil salinity in irrigated fields, statistical treatments of the variability, and sampling strategies for salinity appraisal. The data were obtained from five border- or basin-irrigated and four furrow-irrigated fields in the El Paso Valley, Texas.

The coefficient of variability (CV) for salinity ranged from 17 to 47 percent with a mean CV of 30 percent in 0.5 to 6.2 hectare (ha) areas of the border- or basin-irrigated fields. The CV values for 103 to 178 meters (m) of furrow-irrigated crop beds immediately before preplant irrigation were comparatively low (19 percent) but increased with repeated irrigations to an average value of 31 percent. The CV values for sodicity were somewhat smaller. The saturation water content (a measure of soil texture) accounted for 62 percent of salinity variation in a border-irrigated orchard and less than 40 percent in the furrow-irrigated fields. In both cases, the distance from irrigation ditches was not the substantial factor gov-

erning salinity distribution. The analysis of autocorrelation showed that soil salinity in one of the furrow-irrigated fields was spatially dependent up to 46 m, but the distance of dependence decreased to less than 15 m when salinity readings were stratified by soil type. The frequency distribution of salinity and sodicity averaged over sampling depths and stratified by soil type conformed to the normal distribution. The number of soil samples required to obtain the mean value within 15 percent of the true mean averaged 13 per 0.5 to 3.4 ha areas of the border- or basin-irrigated fields, and 6 per tested row lengths. The sampling requirement generally increased with increasing sampling depth.

For routine appraisal, soil samples (of the quantities specified above) can be collected on the basis of soil type or crop growth. The measured mean salinity plus the standard deviation may serve as a practical index for appraising salt effects on crop performance in the sampled area.

—S. Miyamoto



# Sampling Irrigated Soils for Salinity Appraisal

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# Introduction

Soil salinity is among the most variable properties of soils, and its variation within a sampled field is ordinarily much greater than analytical errors. Thus, the reliability of soil salinity data for appraisal is often controlled at the time of sampling. Kelley (1922) described it realistically, "It is evident that the analysis of a single soil drawn from one place in the area studied has very little value. . . . If similar variation exists in alkali soils generally, it may be safe to conclude that the analysis of samples such as are commonly submitted by practical farmers is a waste of time."

Since Kelley's statement appeared in 1922, analytical capabilities have advanced greatly, but the knowledge of soil sampling for salinity appraisal has not kept pace. Existing guidelines for soil sampling are primarily for testing fertility levels or for mapping soils, and those for salinity and alkalinity appraisal have not been adequately developed.

In studying salinity and sodicity distributions in unirrigated fields, Sayegh et al. (1958) confirmed that salinity of soil samples collected from different soil series was significantly different. More recently, Wagenet and Jurinak (1978) and Hajrasuliha et al. (1980) described salinity distribution in a large watershed or in irrigation districts using conventional and/or geostatistics. These analyses were purely statistical since no reference was made to soil characteristics or soil mapping units. Bresler et al. (1984) pointed out that soil salinity varies manifold even within one-hectare areas of a fallow field consisting of a single soil type. This finding is important since soil characteristics within the same soil type (the lowest soil unit used for mapping) are considered sufficiently uniform to allow efficient management.

This publication outlines the distribution and variation characteristics of soil salinity in border- (including basin) and furrow-irrigated fields consisting of Torrifluvents (flood plain soils). The guidelines for soil sampling for salinity appraisal are also presented.

## Soil Salinity Distribution and Variation

### Border- or Basin-Irrigated

This method of irrigation is used widely for cultivation of forage and tree crops. Soil salinity is ordinarily low near the soil surface and increases with depth in the crop root zone. Figure 1 shows an example of salinity distribution in two 0.6-hectare sections of an orchard irrigated with waters of 1.1 and 4.3 decisiemens per meter ( $\text{dSm}^{-1}$ )<sup>1</sup> (Miyamoto et al. 1986b). In these examples, the salinity of the surface layer was approximately equal to that of irrigation waters; then it increased almost linearly with depth.

<sup>1</sup> A unit of  $\text{dSm}^{-1}$  is equal to the conventional unit of  $\text{mmho/cm}$ .

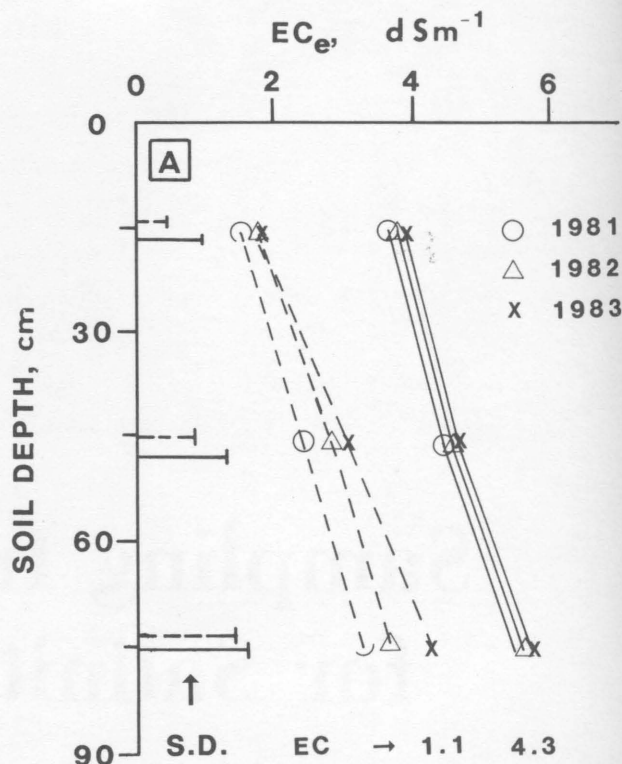


Figure 1. The vertical distribution of soil salinity measured in 1981, 1982, and 1983 in two sections of pecan orchards basin-irrigated with waters of 1.1 and 4.3  $\text{dSm}^{-1}$  (equal to  $\text{mmho/cm}$ ). Both sections consisted of Saneli silty clay loam (Vertic Torrifluvents). The standard deviation (S.D.) is shown by the horizontal bars.

The salt distribution pattern shown in Figure 1 is typical for silty clay loam and silty clay soils. In sandy soils, salinity tends to increase exponentially with depth. The salt distribution as measured in the soil saturation extract may not be continuous in stratified soils. When a clay stratum overlies a sandy stratum, high salinity is sometimes observed in the clay stratum, as the sand deters water penetration.

The horizontal distribution of soil salinity is often irregular and unpredictable. Figure 2 shows an example of soil salinity distribution (0 to 60 cm depth) in a pecan orchard located in the El Paso Valley. This orchard (a 13.6-hectare block; 292 × 465 m) was established during 1970-73, laser-leveled in 1979, and border-irrigated ever since, using water from the Rio Grande which has salinity of 1.1  $\text{dSm}^{-1}$  and sodicity of 3.5. Soil salinity readings varied widely (0.7 to greater than 6  $\text{dSm}^{-1}$ ), and the salinity distribution generally followed the soil type distribution. A statistical analysis indicated that the soil type accounted for 73 percent of the variability in salinity in this field, and the saturation water content (a measure of soil texture), 62 percent of the variability (Miyamoto and Cruz 1986).

An example of salinity and sodicity variation observed within an area consisting of the single soil type is given in Figure 1. The large standard deviation (ranging from 1 to 2  $\text{dSm}^{-1}$ ) indicates that both saline and nonsaline



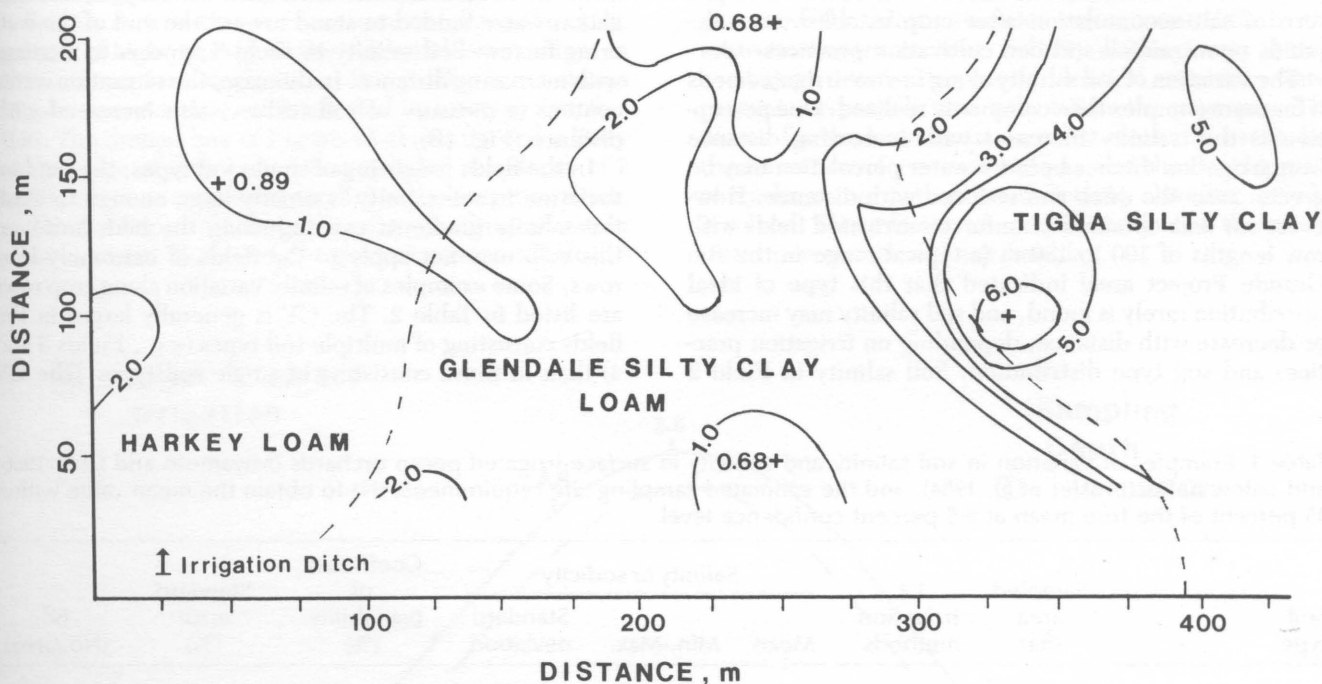


Figure 2. The horizontal distribution of soil salinity in  $\text{dSm}^{-1}$  at 0 to 60 cm in a 13.6-hectare, border-irrigated pecan orchard and the boundaries of three different soil types shown by the dashed lines. Irrigation borders run perpendicular to the horizontal axis.

sites appear within the 0.6-hectare section of the field irrigated with water of  $4.3 \text{ dSm}^{-1}$ . Similar results were obtained in a 0.5-hectare area of Glendale silty clay where salinity of the saturation extract ranged from 2.3 to  $5.0 \text{ dSm}^{-1}$  (Table 1). This orchard has been irrigated with water of  $1.1 \text{ dSm}^{-1}$ . As reported elsewhere (Miyamoto et al. 1986b), these sections of the orchards were selected for soil sampling, primarily because tree growth in these sections was observed to be "uniformly poor." However, soil salinity data show the large variation with a CV averaging 30 percent (Table 1). These CV values are smaller than those reported by Bresler et al. (1984) in a salt-affected fallow field (Table 1). It appears that soil salinity variation is so large that the analysis of one sample drawn from a so-called "poor growth area" does not have much credibility.

The reason for the large variability within a soil type may be related in part to the local difference in soil permeability which affects the leaching fraction. A small difference in leaching fraction causes a large difference in soil salinity, especially at depths toward the end of the root zone. Neither the distance from irrigation ditches nor the efficiency of surface water distribution was found to be a significant factor governing salt distribution in these laser-leveled small fields having low permeability (Miyamoto and Cruz 1986). The non-uniformity of water uptake by tree roots is a concern in small trees but not a major problem in nut-bearing trees which have overlapping root systems and fairly uniform water uptake patterns (Miyamoto 1983).

### Furrow-Irrigated

Under furrow-irrigated conditions, the salt distribution within crop beds, as well as its variation along and across crop rows, needs to be considered. The salt accumulation within crop beds occurs mainly at the ridge of the bed as soluble salts initially present in the dry soil are transferred by capillary water flow (e.g., Bernstein and Fireman 1957). Figure 3A shows an example of salt accumulation in the standard 1-meter single bed (40-inch bed) after preplant irrigation. The salinity increases toward the center of the bed. The salt concentration is highest at the surface and decreases to a background level about 5 cm from the surface (Miyamoto et al. 1985). The salt accumulated at the ridge (where crop seed is ordinarily planted) has been considered the cause for poor seed germination (e.g., Ayers and Wilcox 1976).

Cultural practices common to irrigated areas of the Southwest involve plowing, disking, bedding, preplant irrigation, deep seeding, capping, and decapping (Miyamoto et al. 1984). Under such practices, the salt accumulated at the ridge of the crop bed is removed during the decapping or bed-reshaping operation. Subsequent salt accumulation takes place in forms of salt deposition at the soil surface following water evaporation (Fig. 3B). The salt accumulation is limited to the soil surface, and salinity decreases to a background level at depths less than approximately 1 cm (Miyamoto et al. 1986a). The salinity at the soil surface can reach that of sea water in a matter of several weeks, and this surface salt crust can

become the cause for hypocotyl and seedling mortality (Miyamoto et al. 1985, Miyamoto et al. 1986a). The pattern of salt accumulation after crop establishment depends upon rainfall and bed cultivation practices.

The variation of soil salinity along furrow-irrigated beds is far more complex than commonly realized. One perception is that salinity increases with increasing distance from irrigation ditches because water percolation may be greater near the ditch and reduced with distance. However, our data obtained from furrow-irrigated fields with row lengths of 100 to 180 m (a typical range in the Rio Grande Project area) indicated that this type of ideal distribution rarely is found, and soil salinity may increase or decrease with distance, depending on irrigation practices and soil type distribution. Soil salinity in Field 2

(Fig. 4A), for instance, appears to decrease with distance from the irrigation ditch. This field was sloped, and irrigation water tended to stand toward the end of the watering furrow. Soil salinity in Field 3 appears to increase with increasing distance. In this case, the saturation water content (a measure of soil texture) also increased with distance (Fig. 4B).

In the fields consisting of single soil types, the random variation in soil salinity is usually large enough to mask the salinity gradients existing along the bed; however, this rule may not apply to the fields of extremely long rows. Some examples of salinity variation along crop rows are listed in Table 2. The CV is generally larger in the fields consisting of multiple soil types (e.g., Fields 3 and 4) than in those consisting of single soil types. The CV

Table 1. Examples of variation in soil salinity and sodicity in surface-irrigated pecan orchards (Miyamoto and Cruz 1986) and fallow fields (Bresler et al. 1984), and the estimated sampling site requirements (N) to obtain the mean value within 15 percent of the true mean at a 5 percent confidence level

Soil type	Sampled area (ha)	Irrigation methods	Salinity or sodicity			Coefficient of variability (%)	Standard error (%)	N <sup>1</sup> (No./area)
			Mean	Min.-Max.	Standard deviation			
SALINITY			dSm <sup>-1</sup>					
Harkey loam <sup>2</sup> 0-60 cm	4.0	border	1.5	0.8-2.1	0.4	30	6.6	12
Saneli silty clay loam		basin						
0-30 cm	0.66		1.1	0.7-1.7	0.2	27	10.9	11
0-60 cm	0.66		1.5	0.7-2.5	0.5	32	6.5	17
Glendale silty clay loam		border						
0-60 cm	6.2		1.7	0.7-3.7	0.8	47	6.7	38
Glendale silty clay								
0-60 cm	0.53	basin	3.6	2.3-5.0	0.6	17	6.5	5
0-60 cm	3.3	border	4.6	1.1-8.0	1.7	37	3.5	25
Tigua silty clay		border						
0-60 cm	3.4		4.5	2.1-6.3	1.1	24	6.1	10
Hamra Red Mediterranean soil		fallow						
0-30 cm	0.8		58	18-132	27	46	—	37
0-60 cm	0.8		39	12-84	18	47	—	37
0-90 cm	0.8		31	9-75	15	49	—	41
SODICITY			(mmol L <sup>-1</sup> ) <sup>1/2</sup>					
Harkey loam 0.60 cm	4.0	border	6.4	4.5-7.9	1.2	19	5.5	6
Glendale silty clay loam		basin						
0-60 cm	6.2		6.1	2.8-8.7	1.4	24	3.5	10
Glendale silty clay								
0-60 cm	0.53	basin	8.1	6.8-8.8	0.7	9	7.1	1
0-60 cm	3.3	border	10.0	5.0-17	2.6	26	6.4	12
Tigua silty clay		border						
0-60 cm	3.4		7.8	3.2-12.4	2.2	28	7.2	13

<sup>1</sup>The sampling requirements for the deviate ranges of 10 and 20 percent can be obtained by multiplying 2.25 and 0.562, respectively, to the listed values.

<sup>2</sup>Harkey, Glendale (Typic Torrifluvents); Saneli, Tigua (Vertic Torrifluvents), Hamra (Rhodoxeralf).

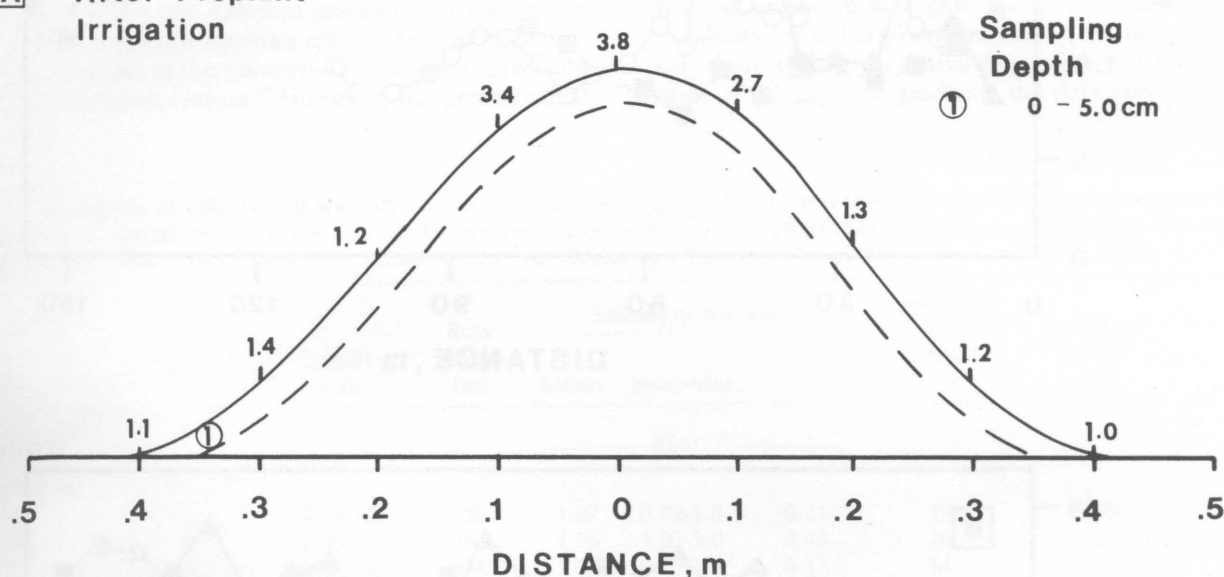


values are usually lowest when sampled after plowing and disking but before preplant irrigation.

Salinity distribution across crop rows follows the cyclic pattern of high readings at the ridge and low readings in the watering furrow. However, this pattern is not always regular or systematic and is affected by soil type distribution. The dashed line of Figure 4A shows the soil salinity at the ridge of crop beds when sampled at a depth of 2 to 30 cm across crop rows parallel to the irrigation ditch, and that of Figure 4B shows the corresponding saturation water content. Note that the general pattern of salt dis-

tribution follows the distribution pattern of saturation water content. The statistical analyses indicated that 41 percent of the salinity variation was accounted for by the saturation water content. Salinity readings vary widely even in an area having nearly identical saturation water contents, especially at depths below the plow pan. The reason for the large variation is not clear at present, but the formation of a compacted pan and the development of cracks, either natural or artificial by chiseling, may be involved. These factors can significantly alter the rate of water percolation and salt leaching.

### A After Preplant Irrigation



### B After Decapping

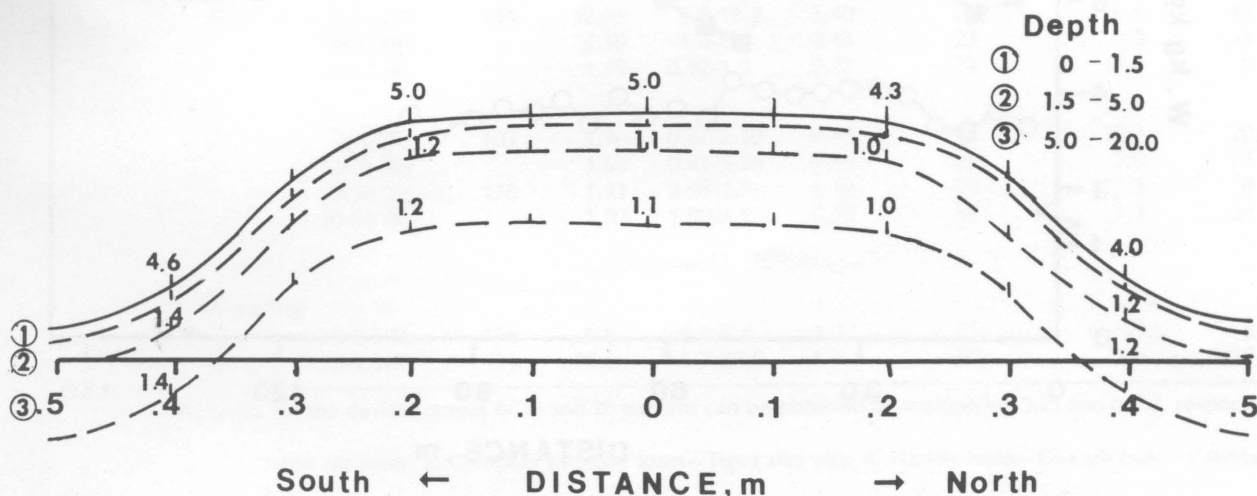


Figure 3. Soil salinity distribution in a furrow-irrigated crop bed after preirrigation (A) and after decapping (B).

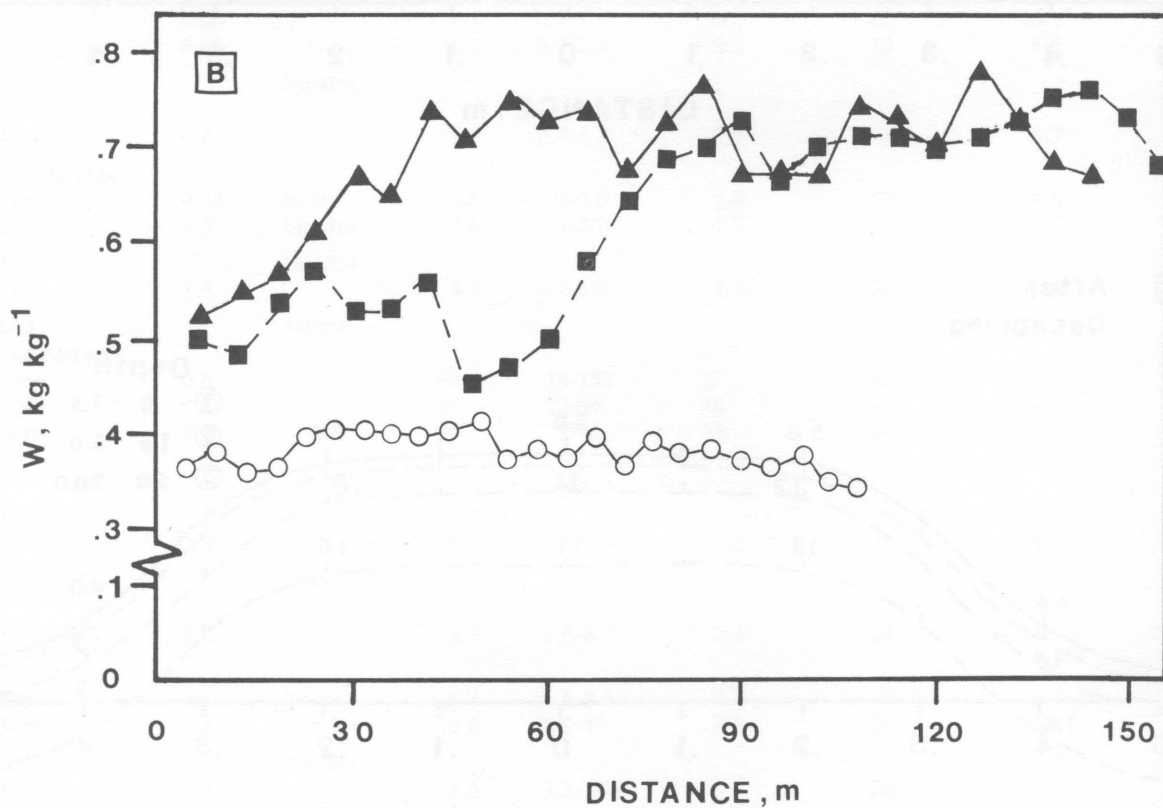
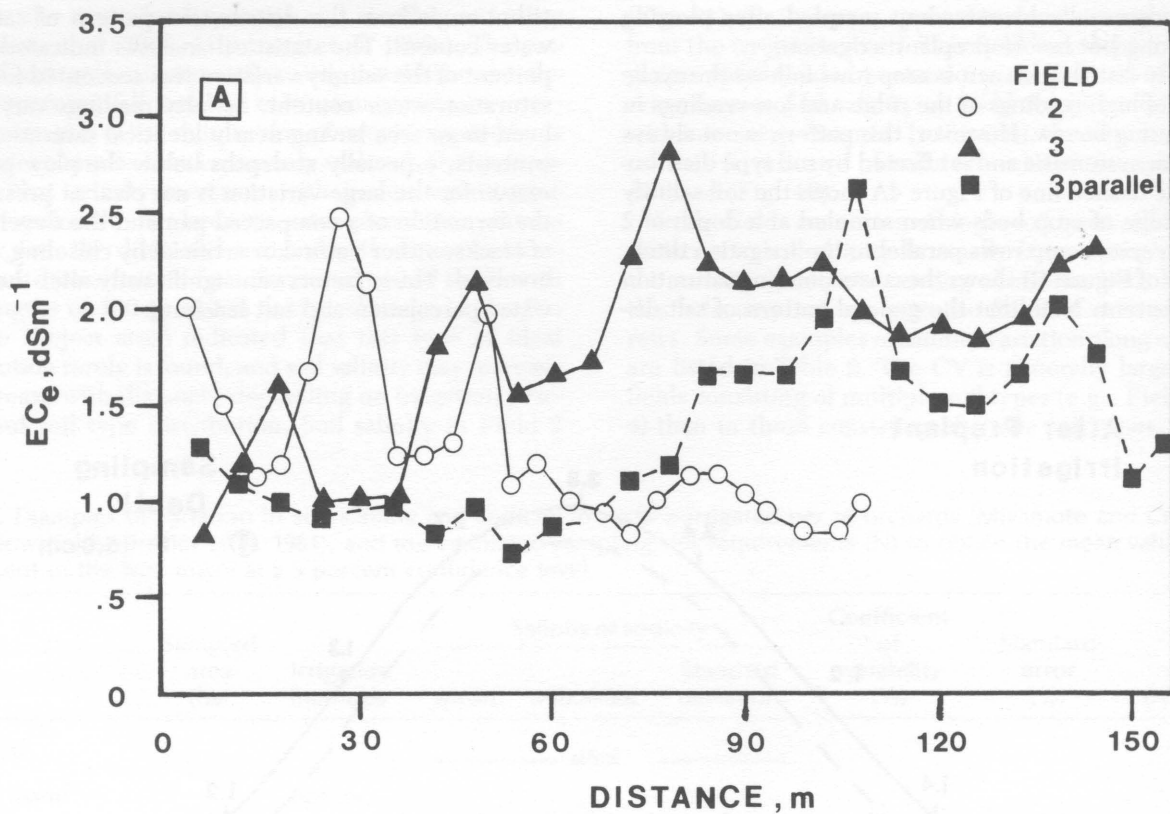


Figure 4. The distribution of soil salinity (A) and saturation water content (B) along the crop row and along the sampling transect across the crop rows parallel to the irrigation ditch.



# Statistical Treatment of Variability

Statistical treatment provides the quantitative assessment of variability. Currently, two types of statistics are used: conventional statistics and geostatistics, the latter increasing in popularity. With conventional statistics, the variates (salinity or sodicity values) must occur at random and be independent of each other. Geostatistics treats variates as spatially-dependent variables. Matheron (1963) pointed out, "It is not enough to know the frequency of samples in the deposit. . . . It is necessary to know in what way the different grades follow each other in the field. Common statistics can not take into account the spatial aspect of the phenomenon, which is precisely its most important feature." However, the geostatistical

approach generally demands large numbers of samples that growers can rarely afford to analyze. A reasonable sampling scheme can be developed using the stratification of salinity variables with soil type or crop growth.

## Spatial Dependence and Stratification

We examine spatial dependence mainly for two reasons: as a prerequisite for using conventional statistics and to provide an empirical relation used for kriging (a form of interpolation) to establish the horizontal distribution such as that shown in Figure 2. Several methods are available for determining the spatial dependence of measured data. One simple method is to plot salinity or sodicity readings against the distance along the sampling transect as shown in Figure 4A. If there is no gradient in salinity (or sodicity) readings along the sampling transect, there will be no spatial dependence. Conversely, if there is an apparent gradient, the data may be spatially

Table 2. Examples of salinity and sodicity variation in furrow-irrigated fields, and the estimated standard deviation (s), the coefficient of variability (CV), the standard error from the normal distribution (SE), and the sampling sites (N) required to obtain the mean value within 15 percent of the true mean at a 5 percent level (Miyamoto and Cruz 1987)

Field no.	Irrigation no.	Depth (cm)	Row length (m)	Salinity or sodicity			Coefficient of variability (%)	Standard error (%)	N <sup>1</sup>
				Mean	Min.-Max.	s			
SALINITY									
Preplanting									
———— dSm <sup>-1</sup> —————									
1 <sup>2</sup>	0	0-20 (R) <sup>3</sup>	156	1.07	0.72-1.8	0.21	19	6.9	6
3	0	0-20 (R)	162	1.96	1.02-3.0	0.48	26	3.6	11 (9) <sup>4</sup>
4	0	0-20 (R)	178	1.25	0.81-2.1	0.17	14	3.5	3 —
After preirrigation and before seeding									
3	1	0-5 (R)	162	3.52	1.5-5.9	1.38	39	7.4	26 (16)
		5-20 (R)	162	1.81	0.87-2.7	0.59	32	5.9	17 (9)
After seeding and decapping									
1	2	0-1.5(R)	156	4.44	2.2-6.5	1.08	24	7.2	10 —
		1.5-20 (R)		0.94	0.71-1.4	0.16	17	8.5	5 —
2	6	0-1.5(R)	103	12.51	6.5-19.0	3.40	27	7.0	13 —
		0-20 (R)		2.10	1.4-3.0	0.45	22	5.3	8 —
		0-20 (F)		1.19	0.92-1.9	0.27	23	14.0	9 —
After establishment									
2	11	3-30 (R)	103	1.30	0.87-2.50	0.45	35	13.1	20
		30-60 (R)		1.58	0.81-3.26	0.59	37	7.9	24
4	3	5-30 (R)	178	1.41	0.89-2.7	0.32	23	7.3	9 (7)
		30-60 (R)		1.92	1.09-4.1	0.73	38	8.1	24 (18)
SODICITY									
———— (mmol L <sup>-1</sup> ) <sup>1/2</sup> —————									
After seeding and decapping									
1	2	0-1.5(R)	156	6.6	4.0-9.4	1.38	21	3.9	8
2	6	0-1.5(R)	103	18.6	6.7-27.0	5.6	30	4.6	15

<sup>1</sup>The sampling requirements for the deviate ranges of 10 and 20 percent can be obtained by multiplying 2.25 and 0.562, respectively, to the listed numbers.

<sup>2</sup>Field 1: Gila silt loam, 2: Vinton silt loam, 3: Glendale silty clay loam—Tigua silty clay, 4: Harkey loam—Gila silt loam—Glendale silty clay loam.

<sup>3</sup>R: Ridge of the bed, F: Furrow of the bed.

<sup>4</sup>The sample number required when salinity or sodicity values are stratified by soil types or by saturating water content.

dependent. The determination of spatial dependence can be made using the following autocorrelation function,  $r(h)$ .

$$r(h) = \frac{1}{ns(x)s(x+h)} \sum_{i=1}^n [c(x) - \bar{c}(x)] [c(x+h) - \bar{c}(x+h)] \quad [1]$$

where  $c(x)$  and  $c(x+h)$  are the salinity values at positions  $x$  and  $x+h$ , respectively, and  $h$  the sampling distance,  $\bar{c}(x)$  and  $\bar{c}(x+h)$  are the mean of salinity at positions  $x$  and  $x+h$ , respectively,  $s$  and  $n$  denote the standard deviation and the number of samples, respectively.

Figure 5 shows examples of autocorrelograms for soil salinity collected at Fields 1, 3, and 4 prior to the preplant irrigation (the first three data sets of Table 2). The autocorrelogram indicates that the distance of spatial dependence at Field 3 is 46 m at the 5 percent level of confidence. In other fields, salinity values were independent of the distance as indicated by the scattered data points of low autocorrelation.

Soil samples collected at spacings greater than the distance of dependence are supposedly random samples. These samples can then be analyzed by conventional statistics. The distance of dependence is a site-specific parameter. Until now, we have not encountered a case where the distance of dependence obstructed random sampling, as long as soil samples were collected within an area consisting of a single soil type. The spatial dependence usually appears in the transient zone where a soil type changes in a gradual fashion such as Field 3 shown in Figure 4(A). The distance of dependence decreases when samples are grouped based on soil types. This process, called stratification, can be carried out using a detailed soil map supplemented with texture and profile examinations during soil sampling or using the observation of crop stands and growth.

If stratification is not used, spatially dependent variates are ordinarily analyzed for a semivariogram. In Field 3, for example, the semivariogram for salinity takes a linear form with a small nugget effect. Such a function is then used for kriging to draw the horizontal distribution of soil salinity similar to Figure 2. This type of approach is not discussed here, not only because of large numbers of samples required for analyses, but also because most soils do not reveal recognizable semivariograms when sampled within the same soil unit (Miyamoto and Cruz 1987). When soil properties are totally unknown and one must determine salinity distribution in a large area (e.g., for developing reclamation plans), geostatistics may prove quite useful. For details, readers should refer to Clark (1979) or Journel and Huijbregts (1978).

## Frequency Distribution

The frequency distribution of soil salinity was thought to be a skew distribution (Wagenet and Jurinak 1978). Recent studies, however, indicate that the frequency distribution of soil salinity averaged over depth within the

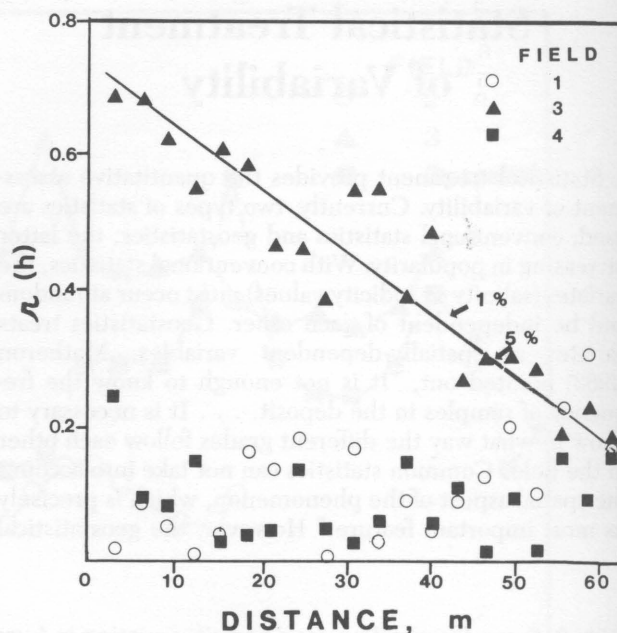


Figure 5. Examples of autocorrelogram for salinity distribution along the crop rows in three different fields.

same soil type follows the normal distribution (Miyamoto and Cruz 1986, Miyamoto and Cruz 1987).

$$P(c) = \frac{1}{\sqrt{2\pi} s} \int e^{-\frac{(c-\bar{c})^2}{2s^2}} dc \quad [2]$$

where  $P(c)$  is the cumulative frequency of variate  $c$  (in this case, salinity or sodicity), and  $s$ , the standard deviation. Examples of the frequency distribution are shown in Figure 6. The solid lines are the simulation using the above equation with the experimental value of  $s$ . The standard error of the estimates is usually less than 8 percent in both salinity and sodicity (Tables 1 and 2).

Salinity distribution can deviate from the normal distribution if samples are taken from an area consisting of multiple soil types. Salinity of a soil type from where the most samples were drawn tends to set the mode, and the distribution pattern may skew either positively or negatively depending on the relative numbers of samples collected from each area representing different soil types (Miyamoto and Cruz 1986). Salinity distribution also sometimes deviates from the normal distribution when samples are collected from a discrete depth such as a depth from 30 to 60 cm. When salinity values are averaged over a depth (e.g., 0 to 60 cm), the distribution conforms to the normal type. This is a reason why the sampling depth in Table 1 is taken as 0 to 60 cm or 0 to 90 cm.

## Sampling Adequacy

When the frequency distribution conforms to the normal type and the samples are collected with the spacings



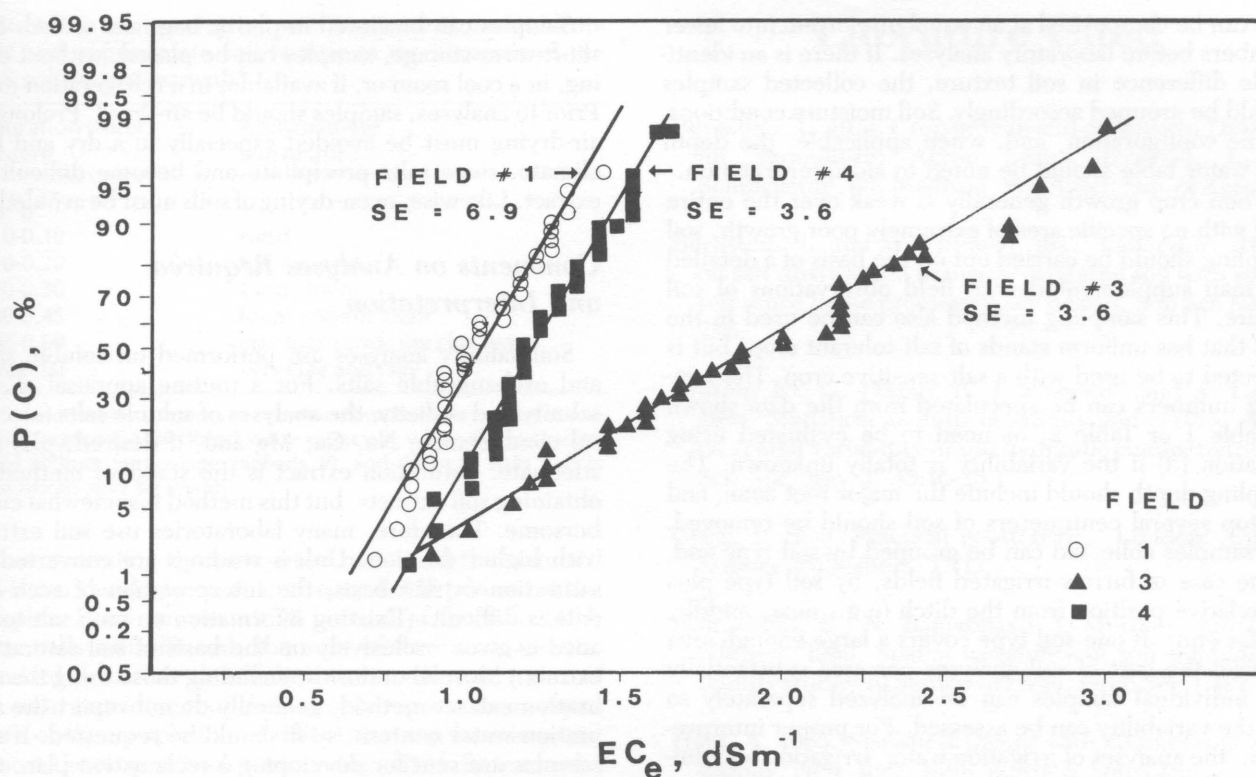


Figure 6. The frequency distribution,  $P(c)$ , of soil salinity,  $EC_e$ , plotted in the cumulative form of the normal distribution function with SE, the standard error of the estimate.

greater than the distance of spatial dependence, the number of samples required ( $N$ ) to estimate the mean within a desired accuracy can be computed by the following formula:

$$N = t_{\alpha}^2 s^2 / (d\bar{c})^2 \quad [3]$$

where  $t$  is the normalized deviate for a given confidence level; (e.g.,  $t = 1.96$  at a confidence level of 5 percent, and  $t = 1.64$  at 10 percent);  $s$ , the standard deviation;  $\bar{c}$ , the arithmetic mean; and  $d$ , the deviate range from the true mean. The number of samples is assumed to be large enough to satisfy the central limit theorem. Examples of computed  $N$  values are given in Tables 1 and 2. For these estimates, the deviate range was taken at 15 percent and the confidence level at 95 percent. The  $N$  values for the deviate range of 10 and 20 percent can be obtained by multiplying 2.25 and 0.562, respectively, to the listed values.

The sampling requirement averaged 13 per sampled area of 0.5 to 3.4 ha in surface-irrigated orchards, and 11 per row length of 103 to 178 m in furrow-irrigated fields, excluding the samples from a depth of 30 to 60 cm. The sampling numbers for furrow-irrigated fields are without stratification by soil type and without averaging over the depth from zero. Stratification reduces the sampling requirements (indicated by the numbers in parentheses) to an average of 6 per row. The large sampling numbers found in a few cases were associated with the presence

of a few extreme values. The presence of extreme values increases the standard deviation and causes  $N$  values to increase by Equation [3].

## Suggested Guidelines for Soil Sampling

### Sampling Strategies

Sampling strategies are dictated largely by purpose and economics. In general, the cost of chemical analysis is greater than the cost of taking a sample, and the reliability of the data is usually controlled at the time of sampling.

When an area or a portion of a field is not productive, soil samples can be collected at random or by using a systematic grid from the area of low productivity. For comparison, some samples from the adjacent productive areas also can be collected. The depth of sampling should include the major root zone. The sampling site requirement can be speculated from the data shown in Table 1 or Table 2, or can be evaluated by Equation [3] if the variability is totally unknown. The deviate range should be determined based on the sensitivity of a given crop to salinity, such as given by Maas and Hoffman (1977). Usually 15 percent at the surface and 20 percent at sub-surface are adequate. To reduce analyses costs, the sam-

ples can be composited at an equal proportion into fewer numbers before laboratory analyses. If there is an identifiable difference in soil texture, the collected samples should be grouped accordingly. Soil moisture conditions, profile configuration, and, when applicable, the depth to a water table should be noted to aid interpretation.

When crop growth generally is weak over the entire field with no specific area of extremely poor growth, soil sampling should be carried out on the basis of a detailed soil map supplemented with field observations of soil texture. This sampling method also can be used in the field that has uniform stands of salt-tolerant crops but is expected to be used with a salt-sensitive crop. The sampling numbers can be speculated from the data shown in Table 1 or Table 2, or need to be evaluated using Equation [3] if the variability is totally unknown. The sampling depth should include the major root zone, and the top several centimeters of soil should be removed. The samples collected can be grouped by soil type and, in the case of furrow-irrigated fields, by soil type plus the relative position from the ditch (e.g., near, middle, and far end). If one soil type covers a large enough area to make the cost of soil analyses per area substantially low, individual samples can be analyzed separately so that the variability can be assessed. For proper interpretation, the analyses of irrigation water, irrigation scheduling, and profile configuration are needed.

If crop establishment is the problem, soil salinity evaluation should be made before preplant irrigation to a depth of 20 to 30 cm. After seeding, but prior to expected seedling emergence, soil surface salinity at and above the seeding depth should be checked for assessing salt effects on seed germination and hypocotyl mortality. The number of soil samples required can be speculated from the data shown in Table 2. In addition, soil moisture, crusting, bed cultivation practice, and salinity of water need to be examined.

### ***Sampling Tools and Sample Handling***

Most sampling tools and equipment used for general soil sampling purposes are adaptable to saline and/or sodic soils. Tube samplers are most convenient when composite samples are to be made, since they provide samples of equal diameters. They come in different diameters and sizes. We have used a plexiglass tube of 90 mm inside diameter (ID) for sampling the surface at 0 to 1.5 cm and 0 to 5.0 cm; a tube sampler of 23 mm ID to a depth of 20 cm (the plow pan depth); and a 38 mm ID sampler to a depth greater than 20 cm. The use of samplers with a larger diameter may reduce variability. The amount of sample required for salinity analyses is about 200 g (7 oz) for clay soils and 400 g (14 oz) for sandy soils on the basis of moist weight, although this varies considerably depending on the methods of analyses employed.

Tube samplers with a view slot are adequate for sampling surface soils, usually not exceeding the depth of the plow pan in clay soils and about 50 cm in sandy soils. Sampling below these depths usually requires some sort of mechanical device, especially when dealing with a large number of samples.

Samples can be stored in plastic bags and sealed. For short-term storage, samples can be placed, without drying, in a cool room or, if available, in a refrigeration unit. Prior to analyses, samples should be air-dried. Prolonged air-drying must be avoided especially in a dry and hot climate, since salts precipitate and become difficult to extract. Likewise, oven-drying of soils must be avoided.

### ***Comments on Analyses Required and Interpretation***

Soil salinity analyses are performed on soluble salts and exchangeable salts. For a routine appraisal of soil salinity and sodicity, the analyses of soluble salts (electrical conductance, Na, Ca, Mg and, if desired, pH) are adequate. Saturation extract is the standard method of obtaining soil extracts, but this method is somewhat cumbersome. Therefore, many laboratories use soil extract with higher dilution. Unless readings are converted to saturation extract basis, the interpretation of such lab data is difficult. (Existing information on crop salt tolerance is given exclusively on the basis of soil saturation extract.) Most laboratories, including those using the saturation extract method, generally do not report the saturation water content, so it should be requested. If soil samples are sent for developing a reclamation plan, the analyses of cation exchange capacity and the content of soil lime and gypsum should be included.

Once laboratory results are obtained, electrical conductance (EC) should be examined against the sum of Na, Ca, and Mg concentrations. The measured EC in  $\text{dSm}^{-1}$  (equal to  $\text{mmho/cm}$ ) is approximately equal to the sum of Na, Ca, and Mg concentrations expressed in milliequivalent (meq) per liter and divided by 10. If not, the laboratory should be notified of a possible error. If this is within a reasonable range, the sodium adsorption ratio (SAR) is computed by the following formula:

$$\text{SAR} = \text{Na} / \sqrt{(\text{Ca} + \text{Mg})} \quad [4]$$

where Na, Ca, and Mg concentrations should be expressed in mmol per liter (see footnote 2). If samples were analyzed individually, the standard deviation and the mean can be computed. If not, the standard deviation can be approximated as 0.30 times the measured mean, assuming that the CV conforms to an average of 30 percent. In the next process, the value of saturation water contents relative to soil texture is examined using Table 3. The lab reports on the saturation water content and soil texture description should be in agreement.

When sample numbers are correctly estimated, salinity and sodicity readings of the composite samples should provide the mean value within a deviate range of 15 to 20 percent. The standard deviation would be in the range of 0.20 to 0.40 of the mean when dealing with the flood plain soils of the Rio Grande. Soil samples having salinity

<sup>2</sup>To convert ppm of Na, Ca, and Mg to mmol/L, divide by 23, 40, and 24.4, respectively.



Table 3. The relationship between the saturation water content and approximate soil texture (a modification of the SCS soil survey manual)<sup>1</sup>

Saturation water content	Approximate soil texture
kg kg <sup>-1</sup>	
0-0.10	sand
0.10-0.20	loamy sand
0.20-0.30	sandy loam
0.30-0.45	loam and silt loam
0.45-0.60	clay loam and silty clay loam
0.60-0.90	silty clay and clay

<sup>1</sup>Saturation water contents of montmorillonitic soils may be somewhat larger than the listed value especially when the exchangeable sodium percentage exceeds 10, and those of soils rich in ion oxides may be lower.

values exceeding the sum of the mean and the standard deviation should account, in theory, for 15 percent of the samples. If we can permit 15 percent of the field to be potentially salt affected, the sum of the mean and the standard deviation should be used as the salt index of the area, providing that each sample represents an equal share of the sampled area. This value can be compared against the crop salt tolerance values cited, for example, by Maas and Hoffman (1977).

When waters having conductance readings greater than 2 to 3 dSm<sup>-1</sup> are used for irrigation or when fields are irrigated with high frequency irrigation such as sprinklers and drips, the appraisal of salinity hazard based on salinity of saturation extract becomes inaccurate. The salinity of saturation extract cannot account for the effect of soil water depletion on the salinity of the soil solution. To improve the accuracy of appraisal, soil solution salinity, estimated by the following formula, can be used.

$$EC_s = \alpha EC_e W_{sat} / W_f \quad [5]$$

where  $EC_s$  is the estimated salinity of soil solution;  $EC_e$ , salinity of the saturation extract;  $W_{sat}$ , the saturation water content;  $W_f$ , the field soil water content which can be approximated by the mean soil water content within an irrigation cycle; and  $\alpha$ , the correction factor (approximately 0.70 in most soils of the Rio Grande). In general, the appraisal based on  $EC_e$  underestimates salinity hazards to crops when saline waters having EC of several dSm<sup>-1</sup> or greater are used for irrigation in sandy soils. Conversely, it may overestimate salinity hazards to crops grown with high frequency irrigation. Detailed discussion on salt hazard appraisal is beyond the scope of this report.

## Literature Cited

- Bernstein, L. 1974. Crop growth and salinity. In *Drainage for agriculture*. Agron Series 17:39-54, J. van Schilfgaarde, ed. Madison, WI: Amer. Soc. of Agron.
- Bernstein, L. and M. Fireman. 1957. Laboratory studies on salt distribution in furrow-irrigated soil with special reference to the preemergence period. *Soil Sci.* 83:249-256.
- Bresler, E., G. Dagan, R. J. Wagenet, and A. Laufer. 1984. Statistical analysis of salinity and texture effects on spatial variability of soil hydraulic conductivity. *Soil Sci. Soc. Am. J.* 48:16-25.
- Clark, I. 1979. *Practical geostatistics*. London: Applied Science Publishers, LTD.
- Hajrasuliha, S., N. Baniabbassi, J. Metthey, and D. R. Nielsen. 1980. Spatial variability of soil sampling for salinity studies in Southwest Iran. *Irrig. Sci.* 1:197-208.
- Hald, A. 1965. *Statistical theory with engineering applications*. New York: John Wiley & Sons, Inc.
- Hummadi, K. B., D. Fangmeier, and T. C. Tucker. 1978. Soluble salts and nitrate distribution in irrigated lettuce beds. *Trans. ASAE* 18:686-691.
- Journel, A. G. and C. J. Huijbregts. 1978. *Mining geostatistics*. New York: Academic Press.
- Maas, E. V. and G. J. Hoffman. 1977. Crop salt tolerance: current assessment. *J. Irrig. and Drainage Div. Proc. of ASCE*. 103:115-134.
- Matheron, G. 1963. Principles of geostatistics. *Econ. Geol.* 58:1246-1266.
- Miyamoto, S. 1983. Consumptive water use of irrigated pecans. *J. Hort. Sci.* 103:676-681.
- Miyamoto, S. and I. Cruz. 1986. Spatial variability and soil sampling for salinity and sodicity appraisal in surface-irrigated orchards. *Soil Sci. Soc. Am. J.* 50:1020-1026.
- Miyamoto, S. and I. Cruz. 1987. Spatial variability of soil salinity in furrow-irrigated Torrifluvents. *Soil Sci. Soc. Am. J.* 51:1019-1025.
- Miyamoto, S., J. Moore, and C. Stichler. 1984. Overview of saline water irrigation in Far West Texas. In *Proc. Specialty Conf. on Irrig. and Drainage Div. ASCE*, pp. 222-230. J. Reppogle, ed. July 24-26, Flagstaff, AZ.
- Miyamoto, S., K. Piela, and J. Petticrew. 1985. Salt effects on germination and seedling emergence of several vegetable crops and guayule. *Irrig. Sci.* 6:159-170.

- Miyamoto, S., K. Piela, and J. Petticrew. 1986a. Seedling mortality of several crops induced by root, stem or leaf exposure to salts. *Irrig. Sci.* 7:97-106.
- Miyamoto, S., T. Riley, G. Gobran, and J. Petticrew. 1986b. Effects of saline water irrigation on soil salinity, pecan tree growth and nut production. *Irrig. Sci.* 7:83-95.
- Sammi, T., D. Weeks, and E. Hanson. 1979. Influence of irrigation methods on salt accumulation in row crops. *Trans. ASAE* 22:791-796.
- Sayegh, A. H., L. A. Alban, and R. G. Petersen. 1958. A sampling study in a saline and alkali area. *Soil Sci. Soc. Am. Proc.* 22:252-254.
- U.S. Salinity Lab. Staff. 1954. Diagnosis and improvement of saline and alkali soils. *USDA Handbook* 60. L.A. Richards, ed. Washington, D.C.: U.S. Government Printing Office.
- Wagenet, R. J., and J. J. Jurinak. 1978. Spatial variability of soluble salt content in a Mancos shale watershed. *Soil Sci.* 126:342-349.

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