A STUDY OF THE EFFECT OF POOR QUALITY IRRIGATION WATER ON SOIL CHEMICAL PROPERTIES

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A STUDY OF THE EFFECT OF POOR QUALITY IRRIGATION WATER ON SOIL CHEMICAL PROPERTIES

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CHAPTER I

INTRODUCTION

The present need for more food and fibre entails reclamation and development of new land resources apart from an increase in the agricultural inputs necessary for greater production.

Irrigated agriculture plays, and will continue to play, a major role in increasing the food supply--especially in arid and semi-arid regions. However, crop production under arid conditions is often limited by soil salinization.

The accumulation of excessive amounts of soluble salts in soils is a characteristic of arid and semi-arid regions, although not entirely limited to such areas. Rainfall in the arid zones is inadequate to remove salts released by weathering of rock or initially present in the soil-forming materials, or added through high salinity irrigation water.

According to estimates by the UN and affiliated agencies (FAO, UNESCO, etc.) more than 50% of all irrigated lands of the world have been damaged by secondary salinization, alkalization and waterlogging. In the same estimation, many millions of productive hectares in irrigation systems have had to be abandoned yearly owing to these causes.

Although the soils of some irrigated areas are nonsaline, the accumulation of salt is a continuing threat to crop production on much of the irrigated land. The lack of awareness of the problems of salt affected soils where conditions permit their formation, and of the need for necessary reclamation measures is one of the main factors for the failure of irrigated projects.

The increasing possibility of using brackish or saline water for supplemental irrigation in different parts of the world has created a need for a better understanding of the effects of salinity on the chemical variations and the salt accumulations which take place in soils.

Salt movement may be considered as a fundamental process behind all phenomena of salt accumulation and therefore, management of irrigated soils or the reclamation of saline soils require a knowledge of the way salts move through the soil profile.

It was the purpose of this study to obtain a preliminary evaluation of the effects of the frequency of irrigation with water that has high soluble salts and high sodium adsorption ratio (SAR) on soil salinity, and the exchangeable and water soluble cations and anions. Also their distributions and variations due to treatments in the soil profile under field conditions.

CHAPTER II

REVIEW OF LITERATURE

Distribution of Saline and Sodic Soils

This planet of ours is a very salty place. About 70 percent of the surface of the globe is covered by saline oceans, a third of the land area is semi-arid, and half of that area has highly saline soils.

The distribution of soils affected by salt at present is closely related to environmental factors such as arid or semi-arid climate, although not limited to it. The salt-affected soils cover large areas in many countries in Asia, Africa, South and North America, and Australia; and they cause considerable problems regarding not only the natural environment of these areas, but also the national economy. Saline soils account for 3.4 percent of the land area of the USSR, or more than 75 million hectares. Twenty million hectares of land in China are salt-affected. Yugoslavia has more than half a million hectares of salt-affected land. Saline and sodic soils occur in Egypt on land regularly irrigated. The salinity problem is common to nearly all irrigated lands in the western part of the United States. The salt ponds of North Africa are typically hydro-halic. The salt concentration in soils is the principal factor limiting plant growth in these areas. During the winter, when the wadies of North Africa carry runoff water into the permeable soil basins, the accumulated salt in the soil is moved downward but, during the summer, the salt usually moves back to the surface. In Western Australia salt-affected lands in the wheatbelt are estimated at one million hectares.

Salinity and Sodicity

Among the most important problems in the management of subhumid and arid soils are soil salinity and alkalinity. Salinity as defined (Richards, 1954) is the presence of excessive concentrations of soluble salts. Soils are regarded as saline if they contain enough soluble salts to harm plants. Chloride, sulfate, and bicarbonate salts of sodium, calcium, and magnesium contribute in varying degrees to soil salinity. For purpose of definition, the lower limit for saline soil has been set at four millimhos per centimetre (electrical conductivity of the saturation extract at 25^{o}C.).

Sodicity is defined as the presence of excessive amounts of sodium ions on the exchange complex or clay minerals in the soil sufficient to affect plant growth adversely. The lower limit for sodic soils has been set at 15 percent exchangeable sodium (Richards, 1954). Ehrlich and Smith (1958) examined 11 halomorphic profiles in order to characterize the sodic soils of Manitoba, Canada. They concluded that the high level of exchangeable sodium is not essential for the development of characteristic sodic soil features and that the exchangeable magnesium may function in a similar way to exchangeable sodium in soils which are low in sodium. They further concluded that strong sodic soil features may develop even though exchangeable calcium remains quite high. It appears that there is, in this case, an undue insistence on a minimal exchangeable sodium percentage (ESP) of 15 percent in order to qualify a soil as sodic. The meaning of the combined terms saline-sodic and non-saline-sodic is self evident.

The predominant effect of salinity appears to be osmotic, and specific injury symptoms and nutritional disorders are probably rare under most saline conditions in the field. Crop yields may be reduced by as much as 25 percent due to salinity without visible symptoms of crop reduction. Bernstein and Hayward (1958) concluded that salinity restricts top growth relatively more than root growth except when poor physical condition in salt-affected soils restricts root development. The salinity effects are more severe at lower moisture contents than at higher contents because soil suction and osmotic pressure exert additive effects.

Sodicity or alkalinity affects soils and plants quite differently from salinity. Excessive sodium in soil may be particularly damaging to plant growth because of the unfavourable effects of exchangeable sodium on soil structure. It renders the soil impermeable to water either by dispersion of clay or by swelling of clay minerals. This, in turn, makes it impossible to leach excess salt from the root zone. Except for those crops most sensitive to exchangeable sodium, such as beans (phaseolus vulgaris), the poor physical conditions of sodic soils restricts growth of most crops long before any nutritional effects begin to be observed (Bernstein and Pearson, 1956).

Rice growing on flooded soils is rather insensitive to the physical factors in sodic soils and provides an exception to the above rule (Pearson and Bernstein, 1958). Bower et al. (1968) concluded that it is more logical and feasible to relate the sodium hazard of irrigation water to the sodium adsorption ratio (SAR) of the water draining from the root zone.

The numerical limits for salinity and sodicity are not intended to be rigid. The final arbiter is the plant. Richards (1954) has recognized that severe salinity effects may occur at salinities as low as two millimhos per centimeter (electrical conductivity of the saturation extract at 25°C.) with such salt-sensitive species as beans and strawberries. Nieman and Shannon (1976) reported that salts of low solubility, such as magnesium carbonate, calcium carbonate, calcium bicarbonate, and calcium sulfate need not be considered harmful. Arany (1956a) has pointed out the importance of the anion associated with sodium in the formation of alkali soils. The alkaline salts (bicarbonate, carbonate, silicate) favour complete displacement of calcium by sodium because of the low solubility of the corresponding calcium salts. The sulphate and chloride of sodium, on the other hand, produce only partial replacement of calcium by sodium, the rate of alkalization is, therefore, quite different for the basic and neutral salts. The magnesium ion also influences the rate of alkalization by mediating the replacement of calcium by sodium on the exchange complex and hence may result in an increase in exchangeable sodium. Hipp and Gerard (1973) found that salt accumulation in irrigated vertisols was greater under continuous cotton than with continuous sorghum. They claimed that because of the rainfall distribution, changing quality of irrigation water, and management practices there is a lack of equilibrium between soils and irrigation water.

Kelley et al. (1940) concluded that with soils high in replaceable magnesium and calcium, comparatively little sodium was absorbed by plants, on the other hand, with soils high in replaceable magnesium, much more sodium is likely to be absorbed. They further concluded that the absorption of sodium from irrigation water will be substantially less when applied to calcareous soil than to a noncalcareous soil due to the presence of calcium carbonate which tends to yield calcium ions to the solution, which in turn will repress the absorption of sodium. Harper and Stout (1950) studied the relation of soil texture to soluble salt accumulation in irrigated soils of Oklahoma, they found that as the salt content of the water and the clay content of the soil increased, more salt was found in the soil profile. Eaton (1950) has indicated that irrigation water containing an excess of carbonates and bicarbonates may precipitate much of the calcium and magnesium and thus cause sodium to become the predominant cation in the soil solution. In a study by Kelley et al. (1940) to investigate the chemical effects of saline irrigation water on soils, they reported that the soluble salts of irrigation water are very important due to their effect on the concentration and composition of the soil solution, and their effect on the absorbed bases of the soil. Sinha and Singh (1976) concluded that the influence of prevailing evaporative demand should be considered when fixing soil salinity tolerance limits for plants. They claimed that under moderate to high evaporative conditions plant roots in salt-containing soils may be exposed to much higher salt concentration than that anticipated from the analysis of the bulk soil. Oliver and Barber (1966) and Sinha (1974) have made similar observations while growing soybeans and maize respectively. Agarwala et al. (1964) and Mass et al. (1972) observed better yields in saline-sodic soils than sodic soils, indicating that addition of soluble salts with high exchangeable sodium improved growth probably by improving physical conditions of the soil.

Flach (1976) observed that in very dry soils, highly soluble sodium and potassium salts are retained in the soil. Brewster and Tinker (1970) excluded any possibility of sodium accumulation at the root surface because of the diffusion-mediated back transport during the night when transpiration ceases. However, Sinha and Singh (1974) reported in a related study that the accumulation of sodium in the vicinity of plant roots occurs especially under high evaporative demand.

Development of Salinity and Alkalinity in Soils

Salinity and sodicity problems are most common in irrigated agriculture. However, they may occur under dryland farming. If there is a long dry season followed by a wet season, saline soils may form in any place where ground water is close enough to the soil surface to allow upward movement of water by capillarity during the dry season.

The process of salt movement may vary from the simple displacement, ion exchange, solubilization and precipitation reactions to biological oxidation and reduction, etc. Stoneman (1958c) claimed that salt movement in a soil can occur only when the salt is dissolved in water. He indicated that in Western Australia the spring period is normally the time of most rapid salt rise because the soil is still moist after the winter rains and temperatures are rising which is the ideal condition for salt movement from the subsoil to the surface.

The failure of irrigation systems in many parts of the world has been mostly attributed to careless management. In much of the world, farmers still irrigate as they did 5,000 years ago--either by flooding their fields or by furrow irrigation. Black (1976) claimed that plants take up only 30 to 60 percent of the water that is applied. The adoption of drip or trickle irrigation has been claimed to be advantageous to control the buildup of salts by what is effectively continuous leaching. Salinity problems have also been encountered in dryland farming systems where the introduction of a grain-fallow rotation has decreased water consumption. Groenewegen (1957) discussed salinization in the Mirrool Irrigation District (Australia) in relation to topography, soil permeability, and management factors. Despite an excellent quality irrigation water and an annual rainfall of 15 inches, salt accumulates because saline ground-waters move readily through the underlying permeable strata to the surface. Soil surveys of Central Iraq (Smith and Robertson, 1956) indicated that the lack of drainage is responsible for salinity of soils in ancient, as in modern times. Cover crops are claimed to decrease salt accumulation by intercepting the capillary rise of water and by lowering the water table. Overgrazing or fallowing has accelerated accumulation of salts. Both of these practices have the effect of removing plant cover. Furrow irrigation is known to be more conducive to salt accumulation than flood irrigation.

The cutting of eucalyptus forests in Victoria, Australia, on saline and sodic soils in the 20-30 inch rainfall belt has resulted in salinization of slopes and basins (Cope, 1958). The wadies of North Africa carrying rainfall into shallow depressions salinize these areas in just this way. Wind-blown sea-spray, or "cyclic salt", can cause general damage to shore plants and even impair the soil, under some conditions. Cope (1958) claimed that the sea-spray brings in up to 40 pounds or more of chloride per acre per year in Australia.

The activities of man extend the range of possible salinity effects to all agricultural enterprises. It has been reported by Harding et al. (1958) that a continued application of sodium nitrate or ammonium sulphate in a 27-year fertilizer experiment at the Citrus Experimental Station, Riverside, California, has produced marked effects on soil structure and on salt accumulation. In contrast, they claimed that calcium nitrate, manure, and other organics did not impair soil structure. The sodium nitrate treatment increased the soluble sodium percentage in the soil and the exchangeable sodium was estimated at 20-30 percent, compared to the initial value of 2 percent. The impaired permeability associated with increase in exchangeable sodium also caused an increase in salinity to 8.4 mmhos/cm in the top six inches. They reported that lime and gypsum applications, in the case of ammonium sulphate and sodium nitrate fertilized plots, respectively, tended to offset the damaging effects of these fertilizers.

Although many salt problems are man-made, Richards (1954) claimed that the occurrence of saline and alkali areas is related fundamentally to changes in climatic conditions, the chemical composition of soil-forming materials in the primary rocks, and to geologic changes that have taken place with time due to deposition, erosion, weathering and other processes.

Measures for Reclamation of Saline and Alkali Soils

It was recognized very early that the problem of soil salinity as it affects plant growth, is one of an undesirably high salt concentration occurring within the root zone of the plants concerned and, in particular, near or at the soil surface. From a practical point of view then, it doesn't matter greatly what concentration of salt exists below the root zone, as long as the salt can be kept there. Miyamoto et al. (1975) stated that in practice, the depth of soils to be treated for reducing exchangeable sodium percentage (ESP) is usually limited to less than 40 cm or the depths of the major root zone rather than the depth of the entire root zone.

Amendments required for reclamation of saline-alkali soils may vary depending upon various conditions. Oster et al. (19) compared the effectiveness of continuous ponding, intermittent ponding and intermittent sprinkling for leaching under field conditions. They found that half as much water was required with intermittent flooding as with continuous flooding for the same reduction in salinity. Organic matter was found to decrease exchangeable sodium not only by solubilizing calcium from lime but also by removing sodium as the humate salt of sodium. In Western Australia, gypsum is not recommended for reclamation because saline-sodic conditions are relatively rare compared to the more dominant saline conditions; also water to leach the saline soil is not generally available.

The leaching of affected soils is often a time consuming process, and recurrent leachings may be required. Rice production has become an important phase of land management with many salt-affected soils. Overstreet and Schulz (1958) described how three years of rice culture improved a non-saline-sodic soil of the Fresno Series in California (USA), so that dryland crops could be grown. For the salt-affected areas, which are usually spotty in distribution, they recommended cultivation. The loosened surface causes improved moisture penetration. On more severely salt-affected spots, roughened strips of soil will catch seed and thus promote the growth of the native salt-tolerant plants. The application of acid into alkaline irrigation waters may serve as a means of preventing a bicarbonate-induced sodium hazard. The use of acid on sodium-affected soils has proved to be advantageous over the conventional gypsum amendment (Miyamoto et al., 1975). Ravikovitch and Navrot (1976) mentioned that fertilization with micronutrients has to be taken into account when considering the factors which might accelerate growth in salt-affected soils. They claimed that the addition of manganese and/or zinc to saline soil may accelerate plant growth and has significantly increased yield in saline soil (7-13 mmhos/cm).

A major technique employed by Soviet physiologists for increasing the salt tolerance of plants consists of soaking seed in a salt solution. Hafiz (1958) mentioned that this technique has not been effective when applied to wheat and barley in Pakistan.

The literature on the effects of fertilizing saline soils appears to be contradictory. Ravikovitch and Yoles (1971) claim to have observed increased salt tolerance of millet and clover by phosphorus fertilization. On the other hand, Khalil et al. (1967) noted that fertilizing with nitrogen increased the sensitivity of corn and cotton to salinity. Fine and Carson (1954) also observed greater sensitivity to salinity of barley and oats on phosphorus-fertilized soil than on the unfertilized soil.

Reclamation and drainage projects are exceedingly expensive operations, in terms of dollars, energy, and water, all of which are required in prodigious amounts. This observation has led to more research to find other alternatives and to adopt new strategies for coping with the problem of saline and alkali soils.

Probably the greatest hope for future utilization of problem areas for crop production (arid, semi-arid regions) is the adoption of a new strategy which is the direct use of sea-water for irrigation purposes. The successful and amazing results obtained by many investigators (Iyerengar et al., 1965; Boyko et al., 1965; Ivan Hoorn et al., 1965) by the application of oceanic or sea-water to many vegetable and grain crops in India, Spain, Palestine and other countries represent a new era for better life and more food for the ever-growing population.

CHAPTER III

METHODS AND MATERIALS

The study reported here was located on the Agronomy Research Station, Oklahoma State University, Stillwater, Oklahoma (Figure 6). The station is located at 36° 07' north latitude and 97° 05' west longitude at an altitude of 273 m above sea level. The study was conducted under field conditions on a Renfrow silt loam complex. The complete description of this soil series is given in the Appendix. The area selected was level and the layout of the experiment consisted of four plots, each plot was one square meter, and surrounded with a frame of wood (redwood) 30 x 100 cm and 2.5 cm thick. The wood, which was covered with plastic material to prevent water seepage, was installed perpendicular in the soil so as 15 cm of the total width was buried under soil to prevent water movement to the adjacent plot after infiltration, and the other 15 cm appeared on top of the soil surface to prevent water from running off during irrigation. The data analyzed was for a split plot design in which samples are main plot and depth was the subplot. There was one replication of each treatment. The treatments consisted of one irrigation, two irrigations, three irrigations, and blank. The irrigation water used for all treatments was 12.11 SAR, and 2000 ppm of soluble salts. This water was synthesized as described in the Appendix. Each irrigation consisted of 100 liters of this water. The first treatment was applied to Plots I, II, and III on June 11, 1976. The second treatment was applied to Plots II and III on June 21, 1976. The third treatment was applied to Plot III on July 2, 1976. Plot IV was left blank. By the end of the treatments:

Plot I had received one irrigation; total 100 liters of the described water.

Plot II had received two irrigations; total 200 liters of the described water.

Plot III had received three irrigations; total 300 liters of the described water.

Plot IV had received no irrigation.

During the experiment, the experimental plots had a vegetation cover consisting of wild oats and other annual grasses.

On July 12, 1976, soil samples were taken using a 7 cm auger, three samples from each plot were taken at five depths (0-20 cm, 20-40 cm, 40-60 cm, 60-70 cm, and 70-80 cm). The soil samples were placed in plastic bags and samples were oven-dried, ground, sieved and analyzed in the laboratory.

During the duration of the experiment rainfall and temperature data from the OSU Agronomy Research Station in Stillwater was collected. These data are presented in the Appendix.

The weight of NaCl salt and $CaCl_2$ salt in grams that was required for preparation of the irrigation water of SAR 12.11 and 2000 ppm soluble salts is given in the Appendix. A standard curve shows the relationship between gm. of NaCl and $CaCl_2$ for 2000 ppm and SAR.

Chemical Analyses

1. Soluble salts by Electrical Conductivity: 1:1 soil-water extract as described by Richards et al. (1954).

2. Total Dissolved Solids TDS: From experiment (1), take 5 ml of the soil extract. Place in a weighed aluminum evaporation pan. Oven dry, (100°C.), reweigh. Then determine the weight of the salts deposited in gm. and ppm.
3. Water-Soluble Chlorine: 5 ml aliquot of the soil extract obtained in experiment (1). Titrate with silver nitrate (Mohr titration) as described by Richards et al. (1954).
4. Water-Soluble Cations: The extraction of these cations was done as outlined by Richards et al. (1954):
   (a) Calcium (Ca^{++}): 8 ml of the extract from experiment (1) + 2 ml of $LaCl_3$ 5%. The ppm of water soluble calcium was determined using atomic absorption techniques.
   (b) Magnesium (Mg^{++}): For magnesium the same samples and the same techniques as were used for calcium.
   (c) Sodium (Na^+): 5 ml of the extract of experiment (1). Read ppm of Sodium using the atomic absorption technique.
   (d) Potassium (K^+): No dilution was required. The ppm of potassium were obtained by using atomic absorption technique.
5. Sulfate Determination: By precipitation as Barium Sulfate ($BaSo_4$), as outlined by Richards et al. (1954).
6. Ammonium acetate (NH_4 OAc) extractable cations: The cations that were determined were--Calcium (Ca^{++}), Magnesium (Mg^{++}), Sodium (Na^+), and Potassium (K^+). For the extraction of these cations the techniques used were as outlined by Richards et al. (1954). The determination of ppm of these cations was as de-

scribed by Black et al. (1965). However, the atomic absorption technique was used instead of the flame photometry technique.

7. Cation exchange capacity (C.E.C.): The method used to determine C.E.C. was described by Reed (1974). Twenty grams of soil were shaken with 50 ml of 1N $CaCl_2$. The sample was rinsed with deionized water, and leached three times with 50 ml of 1N $NaNO_3$. The $NaNO_3$ leachate was analyzed for Ca by E.D.T.A. titration and chloride in the $NaNO_3$ solution was analyzed for chloride by Mohr titration.

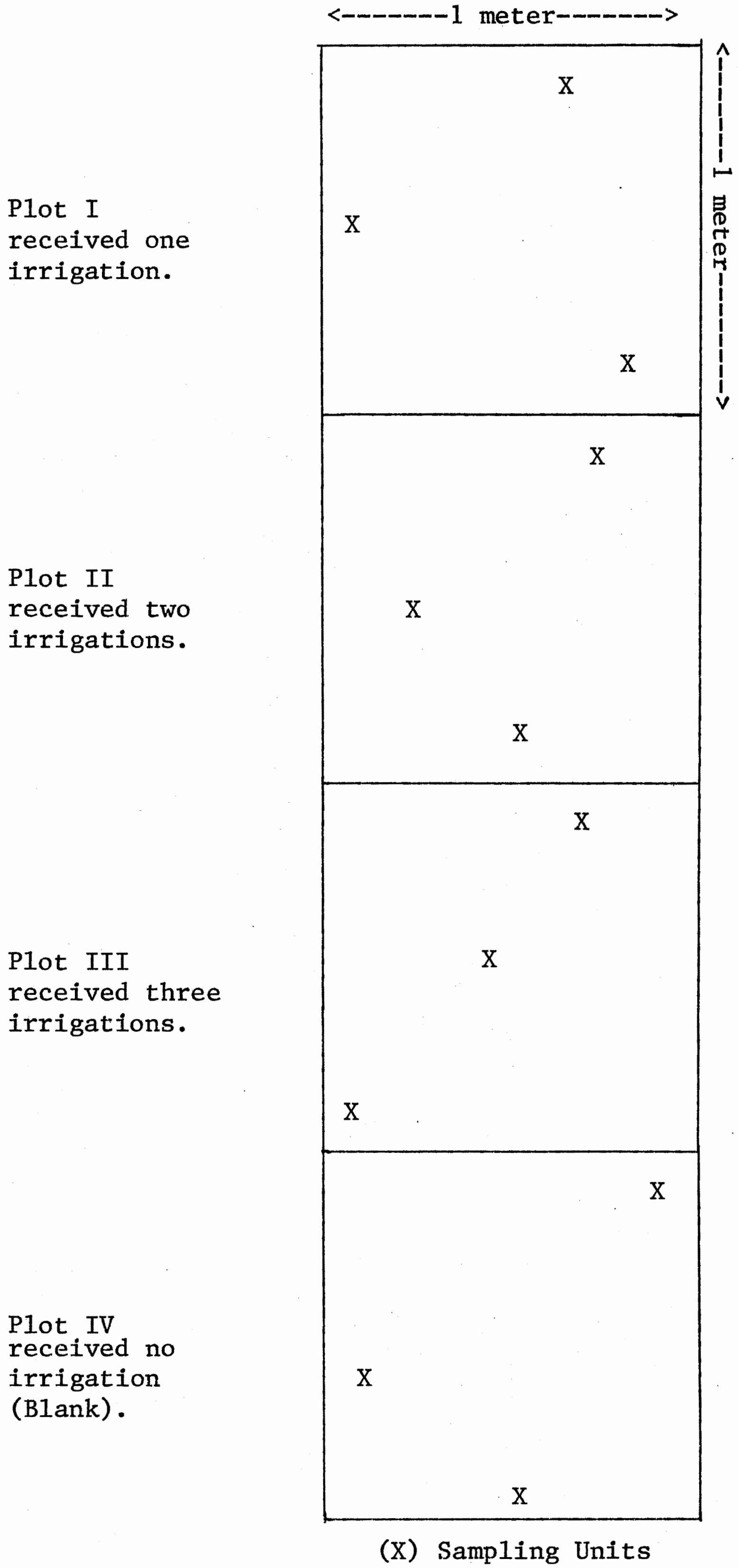

Figure 1. The Experimental Layout

CHAPTER IV

RESULTS AND DISCUSSION

Data regarding depth distribution and variability of salinity, and total soluble solids for different plots are presented in Tables I through V.

A preliminary statistical analysis showed an interaction between treatments and depth for many of the variables. Therefore, the differences among treatments for each depth were analyzed. This was done by obtaining an LSD between two treatments at the same depth. The LSD was found by the expression given in the Appendix.

Soil salinity, expressed as (the electrical conductivity of the saturation extract) in the 0-20 cm zone of Plot IV (did not receive any irrigation) was 407 micromhos compared to EC of 1153 for Plot III that received three irrigations (10 cm each). Data presented in Figure 2 indicates an increase in salinity of the top soil 0-20 cm with the highest increase in Plot III. The EC in Plots I, II, and III decreased at the 20-40 cm depth and the differences in salinity with different treatments probably was not significant. This might be attributed to the leaching of salts as water infiltrated through the soil as compared to a significant difference between treatments as shown by salt in the top 0-20 cm of the soil. This is probably related to the evaporation of water at the surface and the deposition of salts and hence an increase in the salinity as the number of irrigations were increased.

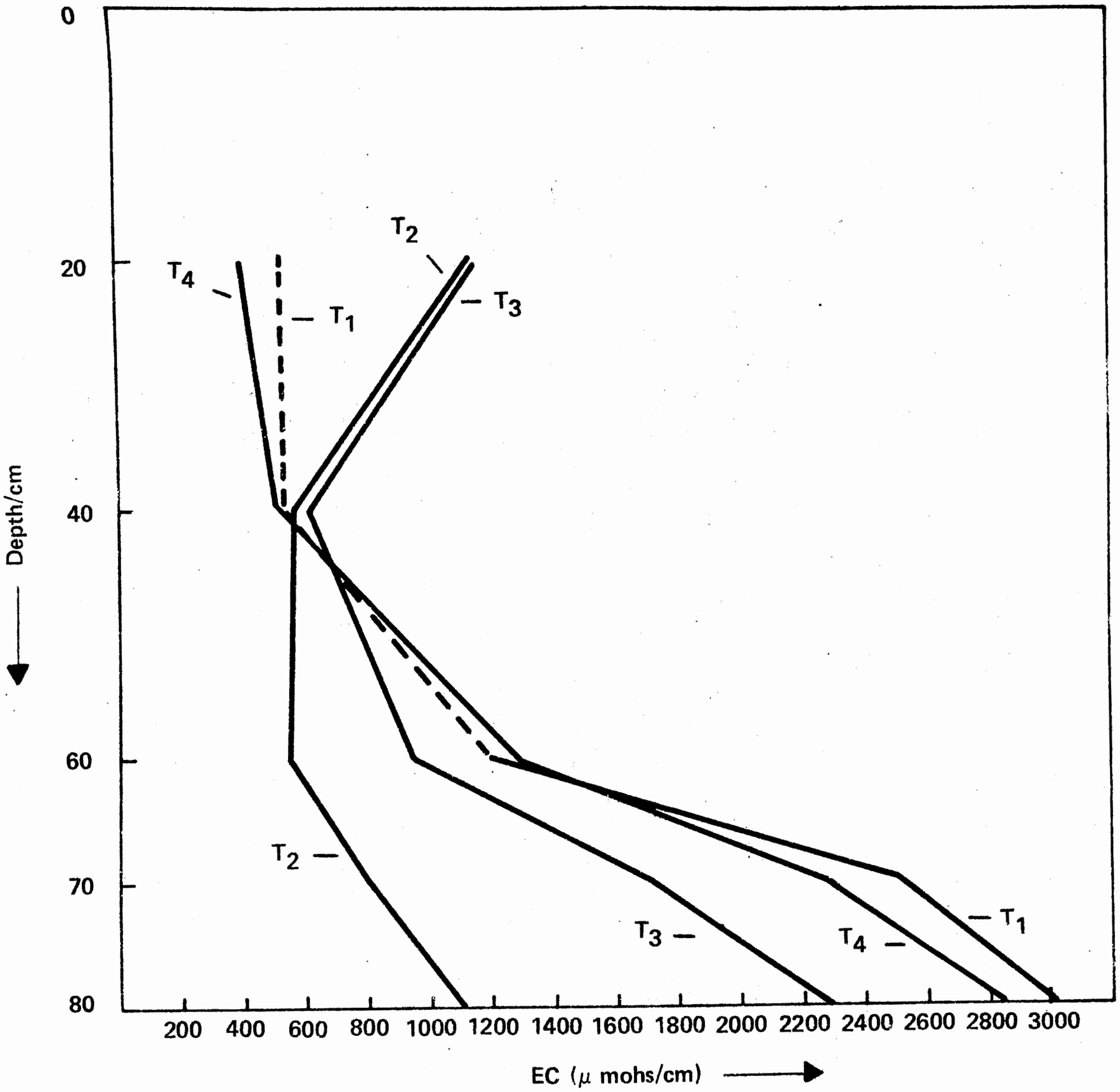

Figure 2. Effect of Frequency of Irrigation, with the Predescribed Water, on Soil Salinity of Different Plots.

The leaching of salts through the soil is more evident at the 40-60 cm depth where the irrigated plots had a lesser EC value than the plot that did not receive any irrigation. The EC of soils of different treatments showed an increasing trend at 60 cm and deeper.

The analysis of variance for the variable EC indicated a significant difference due to an interaction between treatments and depths. The statistical analyses of the data shows there was s significant difference in EC in the upper 0-20 cm of the soil profile of Plot IV and that of Plots II and III; also there was an apparent significant difference between EC of Plots I, II, and III. The statistical analysis also revealed that the EC of all plots was not significantly different at the 20-40 cm depth.

It might be interesting to observe that the EC as well as the total soluble salts in the soil of Plots I and IV were not significantly different throughout the soil profile of both plots. This may indicate that a supplemental irrigation with water of poor quality would not raise the salinity of the soil to a hazardous level under the set of conditions with which this study was carried out.

As was expected, the total soluble solids showed a similar trend as EC. Also, the statistical analysis caused similar conclusions to be made.

Water Extractable Cations

Results regarding water extractable cation (sodium, calcium, magnesium, and potassium) levels, depth distribution and variations due to treatments are given in Tables I through V.

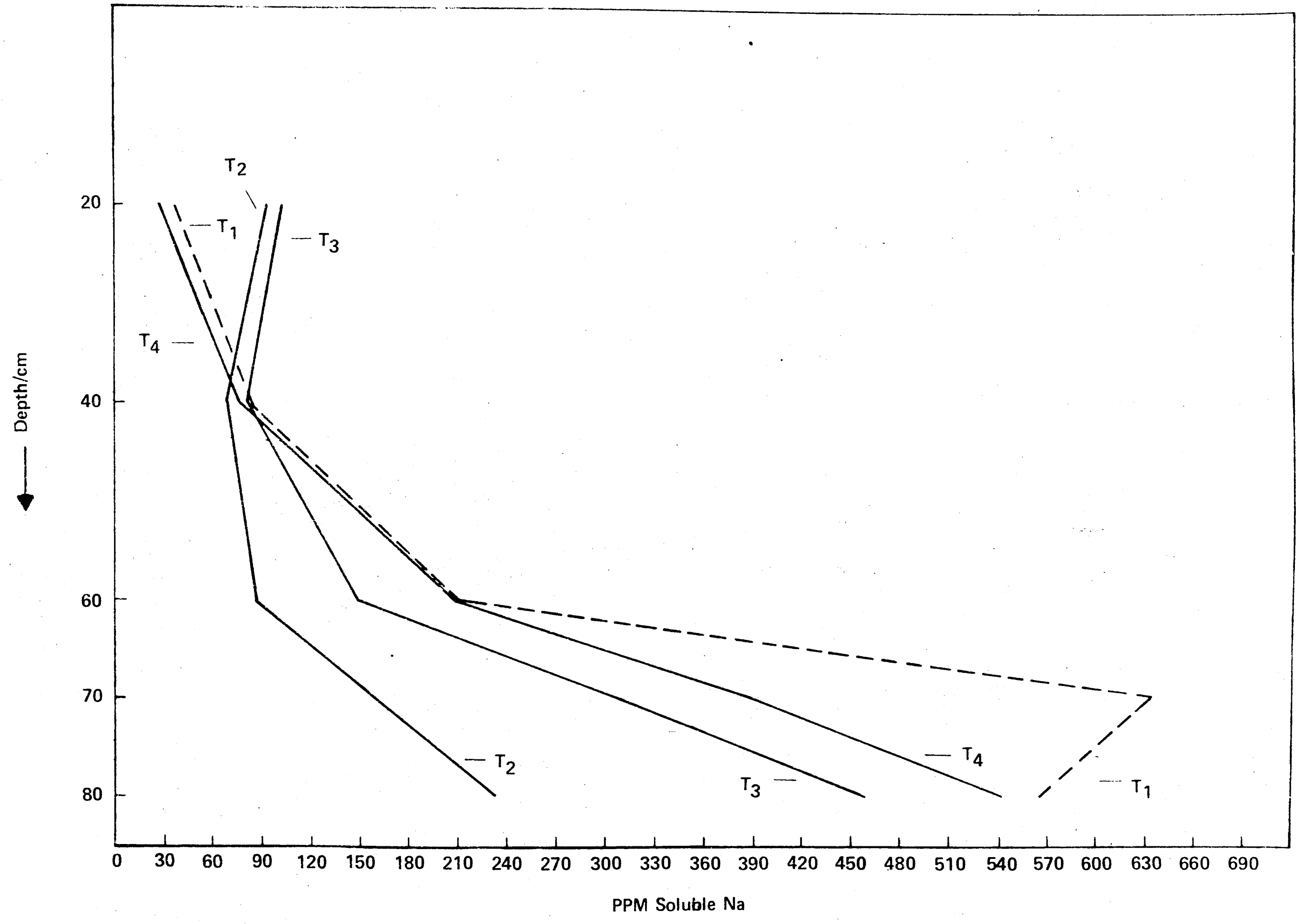

Figure 3. Effect of Frequency of Irrigation, with the Predescribed Water, on Levels and Distribution of Water Soluble Sodium in Soil Profile of Different Plots.

The levels of water extractable sodium were higher in Plot III in the top 0-20 cm of the soil as compared to all other plots. This was predictable since the irrigation water used in this study had a high sodium content; however, as shown in Figure 3, it is noticeable that the sodium content in Plot IV which received no irrigation was increasing at 20-40 cm depth, whereas for Plots II and III the water soluble sodium was decreasing at that depth. This indicates the leaching of this cation with the irrigation water in spite of its high sodium content.

The water-extractable sodium of Plot III below 40 cm was lower than that of Plot IV. This verifies that leaching the soil moves the sodium deeper into the soil profile. However, when only one irrigation was applied the amount of sodium added by irrigation water was higher than what was leached out as indicated by the higher sodium content of Plot I at 60-80 cm as compared to Plot IV.

The analysis of variance for water extractable sodium indicated an interaction between depths and treatments.

It was concluded that the water extractable sodium for all treatments was not significantly different in the upper 0-60 cm depth of the soil profile.

At the conclusion of this study, the water-extractable calcium for all plots were determined and the data are presented in Tables I through V. The highest water-extractable calcium in the top 20 cm of soil was found in Plot III. This was expected based on the fact that the irrigation water had appreciable amount of this cation. The level of calcium expressed as ppm declined in the 20-40 cm depth and then a gradual increase at deeper depths. The water-soluble calcium in Plot III, which received three irrigations, was higher in the top 0-20 cm than at the 80 cm depth. This may be attributed to the lower mobility of calcium and also as evaporation of water at the top of the soil column proceeds this cation will accumulate. On the other hand, the higher level of this cation at the 60-80 cm depth for Plot IV, which received no irrigation, as compared to other plots indicates leaching of this cation deep in the soil profile in spite of the high calcium content of the irrigation water.

The analysis of variance indicated a significant difference in water extractable calcium of Plot IV as compared to Plots II and III, except at 20-40 cm depth where all plots were not significantly different at the 0.05 level of probability. It was also concluded that the water-extractable calcium of Plot I and Plot IV were not significantly different at all soil profile depths.

The water extractable magnesium had, generally, a similar trend to that of calcium. However, the level of the former was much lower. The high level of water extractable magnesium in the top 0-20 cm of the soil for Plot III might be attributed to the solubilization or replacement of this cation on the clay exchange sites.

The statistical analysis showed a significant difference between Plot I and Plots II and III at 0-20 cm.

The AOV also indicated a nonsignificant difference in water extractable magnesium of soil which received one irrigation (Plot I) and soil which received no irrigation (Plot IV) for all depths.

As shown in Tables I through V very little water soluble potassium was present in all treatments.

The analysis of variance for water-soluble potassium indicated no significant differences between all plots, except at the top 0-20 cm of the soil profile where a significant difference in water-soluble potassium of the soil that received no irrigation and those which received two and three irrigations was indicated.

Water-Extractable Anions

Data reported in Tables I through V show the effect of the frequency of irrigation, with the irrigation water, on levels and distribution of chlorine in the soil profile of different plots. The highest level of chlorine in the 0-20 cm was obtained in Plot III, and the lowest in Plot IV.

The concentration of chlorine versus the number of irrigations was clearly demonstrated as shown by the data from the top 0-20 cm. A general trend for all plots (except Plot IV) was shown by a decrease in the level of water soluble chlorine at the 20-40 cm, and then an increase with depth.

The results indicate that the high solubility of the chlorine ion accounts for movement to greater depths with the infiltrated water, and also its deposition on the soil surface as a function of the capillary water rise.

The analysis of variance for water soluble chlorine indicated a significant difference due to interaction of treatments and depths.

It appeared that a 10-cm depth irrigation with the irrigation water did not cause a significant change in water extractable chlorine as indicated by the statistical analysis which showed a nonsignificant difference between Plots I and IV. However, an increase in number of irrigations resulted in a significant difference in the soil content of this anion in the top 0-20 cm of the soil profile.

The results reported in Tables I through V indicate that the sulfates were uniformly distributed in the top 0-40 cm of the soil profiles for all plots. The sulfates level showed a general increasing trend with depth.

The analysis of variance for sulfates indicated sufficient evidence for a probable interaction between treatments and depths.

It was concluded that no significant difference between sulfate level in all plots in the 0-60 cm depth of profile, however, a significant difference was observed between Plot III and the other plots at the 60-80 cm depth.

The values of SAR (sodium adsorption ratio) are given in Tables I through V together with the values of ESP (exchangeable sodium percentage). The SAR and ESP had shown a similar trend for all plots, Figures 4 and 5. There were occasional deviations; but generally low SAR values are associated with low ESP values, and high SAR values denote a high ESP value.

The highest SAR and ESP levels in the top 0-20 cm were obtained in soil receiving three irrigations (Plot III). However, at greater depths Plot I had the highest SAR as well as ESP.

The statistical analysis revealed a nonsignificant difference in SAR level of all plots in the top 0-40 cm, however, below the 40 cm zone in the soil profile a significant difference between Plot III and the other plots was evident.

It is interesting to note that there were no significant differences in the level of SAR and ESP of soil that received one irrigation

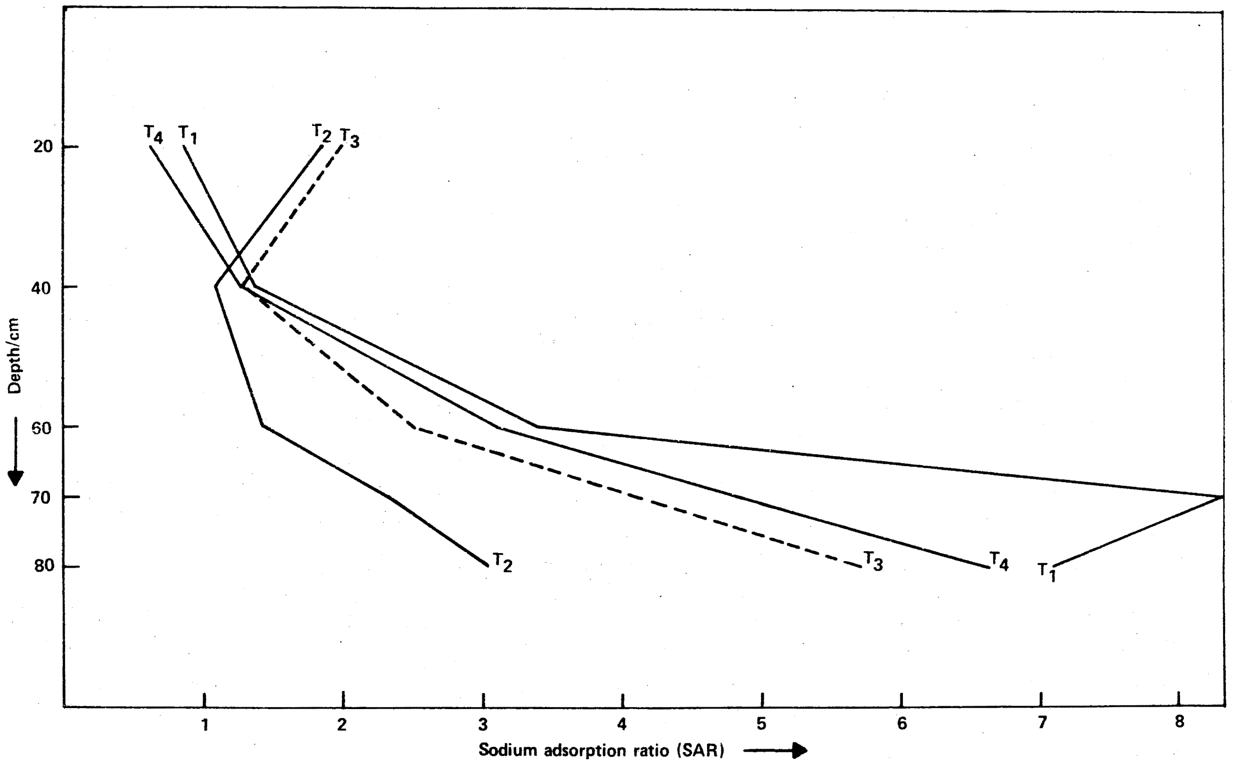

Figure 4. Effect of the Frequency of Irrigation, with the Predescribed Water, on Sodium Adsorption Ratio of Different Plots.

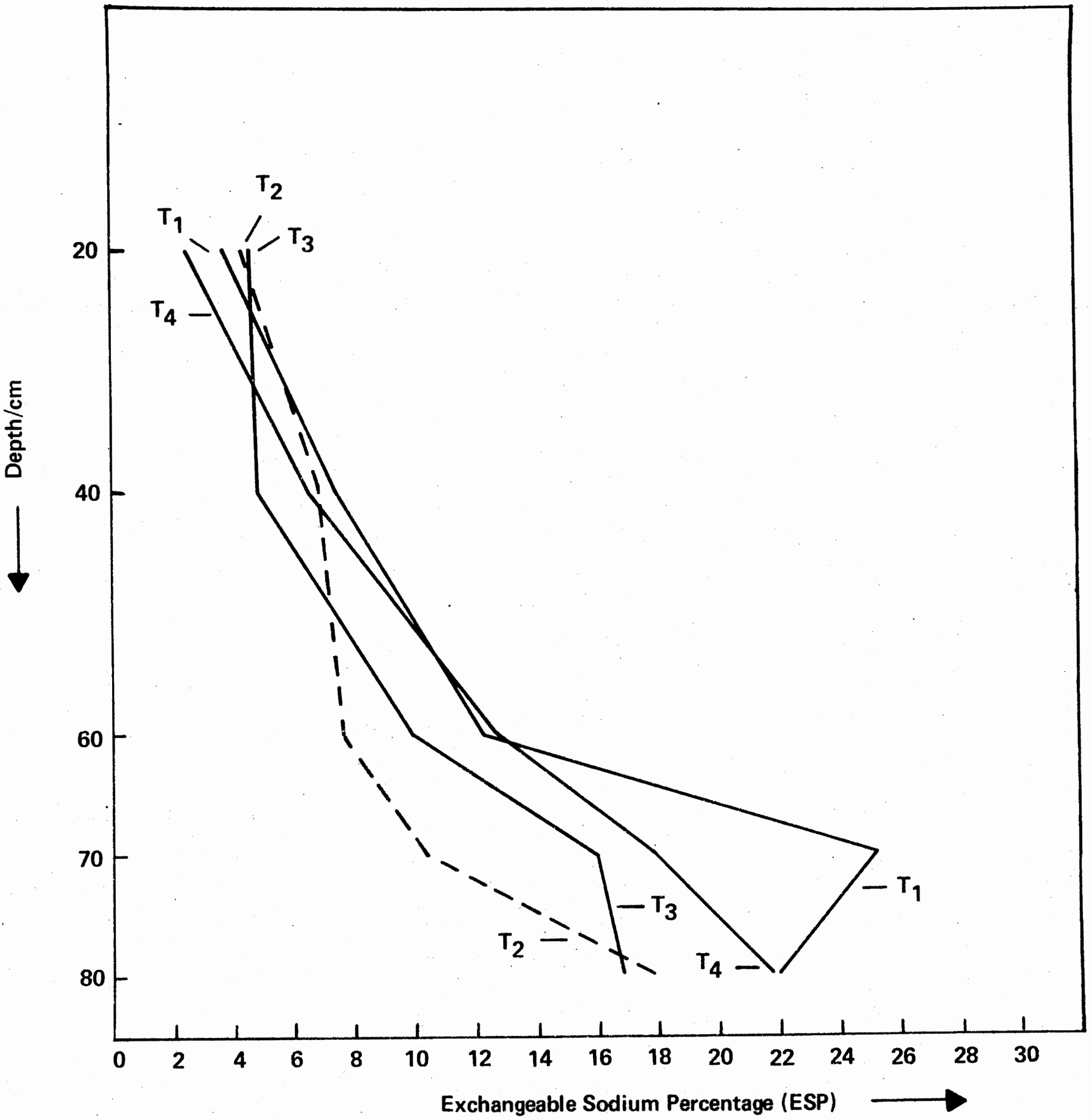

Figure 5. Effect of the Frequency of Irrigation, with the Predescribed Water, on Exchangeable Sodium Percentage of Different Plots.

TABLE I

WATER-SOLUBLE SALTS
(Depth 0-20 cm)

Plot No.	Moisture Percentage (oven-dry wt. basis)	E. C. µmhos/cm	SO_4 meq/l	ppm						SAR	ESP
				Total Soluble Solids	Cl	Na	Ca	Mg	K		
I	5.96	520	0.440	635	373	37	44	14	3	0.87	3.72
II	7.26	1130	0.834	1083	1330	93	94	31	5	1.84	4.38
III	9.71	1153	1.685	1347	1342	102	104	34	4	1.98	4.48
IV	6.26	407	1.371	693	163	29	53	15	3	0.62	2.53
Error (a), (df=8)	1.80964	277241.67	14.0553	150877.3	105207.1	12458.9	453.7	186.2	0.261	1.9853300	20.30024
Error (b), (df=32)	0.35632	57320.83	4.1997	33569.3	28568.0	5819.2	148.6	52.5	0.246	0.9821547	8.68084
LSD (from equation on page 55)	1.4369	567.7291	4.3748	425.0183	370.5927	146.8472	25.4638	15.7036	0.8512	1.8895	5.7876

NOTE: Every value is the average of three observations (Tables I through X).

TABLE II

WATER-SOLUBLE SALTS
(Depth 20-40 cm)

Plot No.	Moisture Percentage (oven-dry wt. basis)	E. C. µmhos/cm	SO_4 meq/l	ppm						SAR	ESP
				Total Soluble Solids	Cl	Na	Ca	Mg	K		
I	13.72	523	0.857	751	408	83	18	8	2	1.37	7.44
II	13.66	560	0.417	701	560	70	34	14	3	1.09	6.81
III	15.57	608	1.554	733	548	81	30	12	3	1.30	4.79
IV	12.77	516	0.954	651	455	77	26	8	2	1.27	6.59
Error (a), (df=8)	1.80964	277241.67	14.0553	150877.3	105207.1	12458.9	453.7	186.2	0.261	1.9853300	20.30024
Error (b), (df=32)	0.35632	57320.83	4.1997	33569.3	28568.0	5819.2	148.6	52.5	0.246	0.9821547	8.68084
LSD (from equation on page 55)	1.4369	567.7291	4.3748	425.0183	370.5927	146.8472	25.4638	15.7036	0.8512	1.8895	5.7876

TABLE III

WATER-SOLUBLE SALTS
(Depth 40-60 cm)

Plot No.	Moisture Percentage (oven-dry wt. basis)	E. C. µmhos/cm	SO_4 meq/l	ppm						SAR	ESP
				Total Soluble Solids	Cl	Na	Ca	Mg	K		
I	14.09	1193	3.239	1050	945	210	40	23	2	3.37	12.22
II	15.34	543	1.628	497	338	88	19	8	2	1.43	7.62
III	15.22	943	2.559	752	945	151	33	16	2	2.50	9.88
IV	14.94	1283	4.472	942	1213	208	47	23	2	3.10	12.72
Error (a), (df=8)	1.80964	277241.67	14.0553	150877.3	105207.1	12458.9	453.7	186.2	0.261	1.9853300	20.30024
Error (b), (df=32)	0.35632	57320.83	4.1997	33569.3	28568.0	5819.2	148.6	52.5	0.246	0.9821547	8.68084
LSD (from equation on Page 55)	1.4369	567.7291	4.3748	425.0183	370.5927	146.8472	25.4638	15.7036	0.8512	1.8895	5.7876

TABLE IV

WATER-SOLUBLE SALTS
(Depth 60-70 cm)

Plot No.	Moisture Percentage (oven-dry wt. basis)	E. C. µmhos/cm	SO_4 meq/l	ppm						SAR	ESP
				Total Soluble Solids	Cl	Na	Ca	Mg	K		
I	14.02	2517	14.440	2033	1575	637	86	58	2	8.31	25.22
II	14.84	813	1.097	885	432	158	29	13	2	2.32	10.35
III	15.56	1703	7.940	1339	1283	307	68	36	2	4.09	15.94
IV	14.43	2267	12.990	1787	1458	388	93	53	2	4.85	17.87
Error (a), (df=8)	1.80964	277241.67	14.0553	150877.3	105207.1	12458.9	453.7	186.2	0.261	1.9853300	20.30024
Error (b), (df=32)	0.35632	57320.83	4.1997	33569.3	28568.0	5819.2	148.6	52.5	0.246	0.9821547	8.68084
LSD (from equation on Page 55)	1.4369	567.7291	4.3748	425.0183	370.5927	146.8472	25.4638	15.7036	0.8512	1.8895	5.7876

TABLE V

WATER-SOLUBLE SALTS
(Depth 70-80 cm)

Plot No.	Moisture Percentage (oven-dry wt. basis)	E. C. µmhos/cm	SO_4 meq/l	ppm						SAR	ESP
				Total Soluble Solids	Cl	Na	Ca	Mg	K		
I	14.65	3000	22.008	2520	1703	567	110	70	2	7.09	21.98
II	14.76	1105	5.952	956	758	235	25	13	1	3.04	17.84
III	16.01	2283	13.286	1756	1412	460	78	46	2	5.72	16.80
IV	14.52	2833	18.861	2123	1587	542	108	58	2	6.62	21.81
Error (a), (df=8)	1.80964	277241.67	14.0553	150877.3	105207.1	12458.9	453.7	186.2	0.261	1.9853300	20.30024
Error (b), (df=32)	0.35632	57320.83	4.1997	33569.3	28568.0	5819.2	148.6	52.5	0.246	0.9821547	8.68084
LSD (from equation on page 55)	1.4369	567.7291	4.3748	425.0183	370.5927	146.8472	25.4638	15.7036	0.8512	1.8895	5.7876

and that received no irrigation. This is in substantial agreement with a study reported by Hanna (1976) that showed the possibility of using water of poor quality for supplemental irrigation without causing permanent hazardous effects.

Data regarding the cation exchange capacity of soil samples taken at different depths for all plots are shown in Tables VI through X. The CEC for different plots, generally, increased with depth. The CEC values were not affected by treatments in spite of the change in exchangeable cation composition.

The Exchangeable Cations

The exchangeable cation composition of the soil of different plots at the conclusion of this study is presented in Tables VI through X. It is noticeable that the exchangeable sodium of all plots was increasing with depth with the highest value at 80 cm depth. Data obtained show that the frequency of irrigation with the irrigation water increased the exchangeable sodium in the top 40 cm. However, the statistical analysis indicated that the increase was not significant at the 0.05 level of probability.

In spite of the high sodium content of the irrigation water, the non-irrigated soil showed a higher level of exchangeable sodium at the 40 cm depth and below. This may be due to the solubilization and then leaching of sodium cation from the soil by the irrigation water.

The analysis of variance for the exchangeable sodium indicated a significant effect due to interaction between treatments and depths.

It was concluded that the exchangeable sodium of Plot III, at 40 cm and below, was significantly different from that of Plots I and IV.

It was also found that the difference in exchangeable sodium between Plots I and IV was not significant at the 0.05 level of probability.

The irrigated and the non-irrigated soils show no significant difference in exchangeable calcium content. The exchangeable calcium consistently increased with depth. This might be due to the fact that the soil (Renfrow series) has some calcium carbonate at lower depths. (See Profile Description in the Appendix.)

Data regarding the exchangeable magnesium of the soil for all treatments is presented in Tables VI through X. The data show that the soil content of the exchangeable magnesium cation increased with depth until it reaches a maximum level at the 60 cm depth and then declines. This might be due to the predominance of calcium at the lower depths in the soil profile.

The analysis of variance indicated no significant difference in exchangeable magnesium among all plots, except at the 20-40 cm depth where a significant difference between exchangeable magnesium content of Plot IV and that of Plots I and III was observed at the 0.05 level of probability.

The statistical analysis for the exchangeable potassium indicated no significant difference due to treatments.

The exchangeable potassium content of the irrigated and the non-irrigated soils did not show a consistent pattern. There was an increasing trend in exchangeable potassium in the upper 40 cm, then a gradual decrease at the 40-70 cm, and finally it increased to a maximum level at the 80 cm depth.

TABLE VI

SOIL CHEMICAL ANALYSIS
(Depth 0-20 cm)

Plot No.	CEC meq/100 gr	Exchangeable Calcium		Exchangeable Magnesium		Exchangeable Sodium		Exchangeable Potassium	
		ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr
I	6	1090	5.433	310	2.556	50	0.217	50	0.14
II	8	1420	7.133	360	2.972	80	0.333	90	0.22
III	8	1440	7.217	370	3.083	90	0.377	80	0.21
IV	7	1400	6.983	380	3.139	40	0.188	80	0.21
Error (a), (df=8)	1.0974	3.86879		0.80509		0.24234		0.0528	
Error (b), (df=32)	1.5635	3.18827		0.30610		0.06126		0.0415	
LSD (from equation on page 55)	2.0521	3.1197		1.1135		0.5527		0.3586	

TABLE VII

SOIL CHEMICAL ANALYSIS
(Depth 20-40 cm)

Plot No.	CEC meq/100 gr	Exchangeable Calcium		Exchangeable Magnesium		Exchangeable Sodium		Exchangeable Potassium	
		ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100
I	16	2630	13.167	1140	9.528	280	1.217	160	0.42
II	16	2900	14.517	1010	8.417	240	1.058	150	0.39
III	17	2740	13.717	1140	9.472	190	0.826	190	0.49
IV	17	2590	12.967	990	8.278	250	1.101	170	0.44
Error (a), (df=8)	1.0974	3.86879		0.80509		0.24234		0.0528	
Error (b), (df=32)	1.5635	3.18827		0.30610		0.06126		0.0415	
LSD (from equation on page 55)	2.0521	3.1197		1.1135		0.5527		0.3586	

TABLE VIII

SOIL CHEMICAL ANALYSIS
(Depth 40-60 cm)

Plot No.	CEC meq/100 gr	Exchangeable Calcium		Exchangeable Magnesium		Exchangeable Sodium		Exchangeable Potassium	
		ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr
I	16	2530	12.667	1210	10.083	440	1.913	130	0.35
II	16	2760	13.833	1240	10.361	280	1.232	160	0.40
III	14	2420	12.100	1170	9.778	300	1.333	160	0.41
IV	16	2980	14.883	1280	10.694	450	1.971	160	0.41
Error (a), (df=8)	1.0974	3.86879		0.80509		0.24234		0.0528	
Error (b), (df=32)	1.5636	3.18827		0.30610		0.06126		0.0415	
LSD (from equation on page 55)	2.0521	3.1197		1.1135		0.5527		0.3586	

TABLE IX

SOIL CHEMICAL ANALYSIS
(Depth 60-70 cm)

Plot No.	CEC meq/100 gr	Exchangeable Calcium		Exchangeable Magnesium		Exchangeable Sodium		Exchangeable Potassium	
		ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr
I	12	3560	17.800	1090	9.056	640	2.797	120	0.31
II	15	3290	16.450	1100	9.194	360	1.580	150	0.39
III	14	3630	18.167	1060	8.861	520	2.275	140	0.36
IV	15	3940	19.717	1160	9.667	610	2.638	150	0.38
Error (a), (df=8)	1.0974	3.86879		0.80509		0.24234		0.0528	
Error (b), (df=32)	1.5635	3.18827		0.30610		0.06126		0.0415	
LSD (from equation on page 55)	2.0521	3.1197		1.1135		0.5527		0.3586	

TABLE X

SOIL CHEMICAL ANALYSIS
(Depth 70-80 cm)

Plot No.	CEC meq/100 gr	Exchangeable Calcium		Exchangeable Magnesium		Exchangeable Sodium		Exchangeable Potassium	
		ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr	ppm	meq/100 gr
I	14	3730	18.650	1060	8.806	690	3.000	120	0.31
II	13	4290	21.450	1080	8.972	550	2.391	330	0.85
III	15	4120	20.633	980	8.139	570	2.493	120	0.31
IV	14	4080	20.383	1070	8.917	700	3.043	150	0.38
Error (a), (df=8)	1.0974	3.86879		0.80509		0.24234		0.0528	
Error (b), (df=32)	1.5635	3.18827		0.30610		0.06126		0.0415	
LSD (from equation on page 55)	2.0521	3.1197		1.1135		0.5527		0.3586	

CHAPTER V

SUMMARY AND CONCLUSION

This study was located at the Agronomy Research Station, Oklahoma State University, Stillwater, Oklahoma. The study was conducted under field conditions on a Renfrow silt loam complex (fine, mixed, thermic, udertic, paleustoll). The layout of the experiment consisted of four plots; each plot was one square meter. The treatments consisted of varying quantities of irrigation water for each plot, with synthesized water that contained 2000 ppm soluble salts and 1:3 calcium to sodium ratio.

Soil samples taken at the termination of the study were oven dried, ground, sieved and analyzed chemically. Results of the chemical analysis are summarized as follows.

1. EC and total soluble salts:

   Soil salinity, expressed as the electrical conductivity of the saturation extract in the 0-20 cm zone of Plot IV which did not receive any irrigation was 407 micromhos/cm compared to an EC of 1153 for Plot III that received three irrigations (10 cm depth each). However, the EC of Plot I (received one irrigation) was not significantly different from that of Plot IV. The total soluble salts showed a similar trend.

   The study showed that the Renfrow silt loam series has a tendency to accumulate salts. Also, the soil salinity values are generally affected by the amount of saline water applied.

The data obtained in this study show the range of soil salinity values which may be obtained as a result of irrigation with saline water under a given set of conditions.

2. Water extractable cations:
   a) Sodium - The level of water extractable sodium was increased in the 0-20 cm of the soil profile due to treatments. However, this increase was not significant.
   b) Calcium - The water extractable calcium was highest in the top 20 cm of Plot III and the difference in water extractable calcium content of Plot IV was significantly different from Plots II and III.
   c) Magnesium - showed a similar trend as calcium.
   d) Potassium - Very little water extractable potassium was present in all plots and treatments had no significant effect.
3. Water extractable anions:
   a) Chlorine: The highest level of the chloride ion in the 0-20 cm depth was indicated in Plot III. However, the lowest level was obtained in Plot IV.
   b) Sulfates: Treatments had no significant effect on sulfates content of the soil.
4. SAR and ESP:

The SAR (Sodium Adsorption Ratio) and the ESP (Exchangeable Sodium Percentage) showed a similar trend for all treatments. The highest SAR and ESP levels in the top 0-20 cm depth were obtained in the soil which received three irrigations (Plot III). The SAR values for all treatments in the top 0-40 cm were not significantly different.

5. CEC:

   The CEC (Cation Exchange Capacity) values were not affected by treatments in spite of the change in exchangeable cation composition.

6. The exchangeable cations:

   No significant difference was observed in the soil exchangeable potassium, calcium, and magnesium due to treatments. However, exchangeable sodium in Plot III was significantly different than exchangeable sodium in Plots I and and IV at 40 cm depth and higher.

Data obtained in this study may be used to evaluate further the extent to which water with high soluble salts and high sodium:calcium can be used for supplemental irrigation. The results indicate that one irrigation may not cause hazardous effects to plants and soils under similar conditions, however, water of this type eventually will harm the physical structure of the soil by dispersing the clay particles if exchangeable calcium is not present in sufficient quantities to counteract the undesirable effect of the sodium.

The successful use of poor quality water for supplemental irrigation depends upon careful consideration that must be given to the salt concentration in the soil, the salt content of the water to be applied, the salt tolerance of the specific crop, and effective soil drainage.

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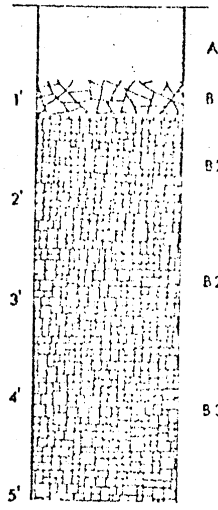
APPENDIX

PROFILE DESCRIPTION OF RENFROW SERIES

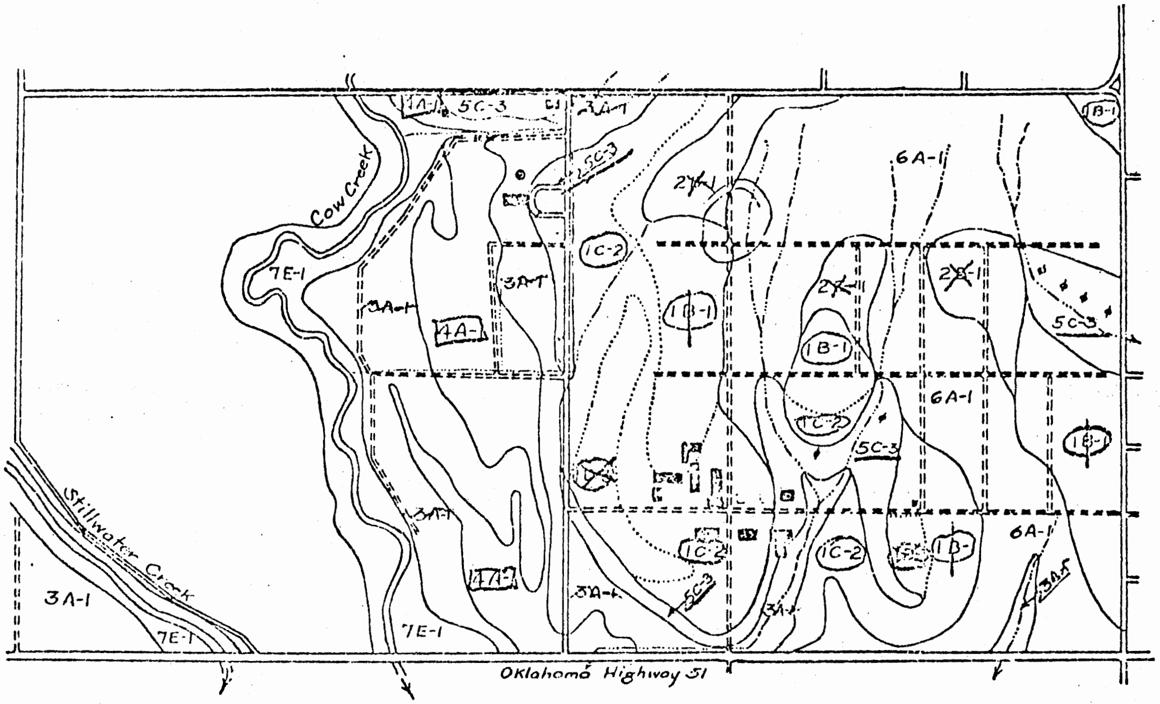
The Renfrow series is a member of the fine, mixed, thermic family of Udertic Paleustolls. These soils have brown silt loam A horizons and reddish brown clay B2t horizons that grade to red clay C horizons. Renfrow soils are on nearly level through gently sloping uplands. Slopes are mainly between 0 and 5 percent. The soil formed in material weathered from clay or shale. The climate is dry or moist subhumid. Mean annual temperature is 57° to 65°F.; average annual precipitation is 26 to 40 inches. Thornthwaite P-E indices of 44 to 64. Renfrow soils are well drained, have slow or medium runoff, and have very slow permeability. They were formerly classified in the Reddish Prairie great soil group.

Paleustoll



A1	0-9"	Brown silt loam; granules
B1	9-13"	Reddish brown clay loam; subangular blocks
B21t	13-25"	Reddish brown clay; blocks
B22t	25-40"	Reddish brown clay; blocks; calcareous
B3	40-65"	Red clay, blocks; $CaCO_3$ concretions; calcareous

MAIN USES AND LIMITATIONS: Cropland; pasture on slopes; very slow permeability; high shrink-swell potential; erosion on slopes; droughty.



Scale in Feet

0 1320 2640

Symbol	
1 B-1	Norge loam, (1 to 3% slopes)
1 C-2	Norge loam, (3 to 5% slopes)
1 D-3	Norge loam, eroded (4 to 6% slopes)
2 B-1	Bethany silt loam (1 to 3% slopes)
3 A-1	Port loamy soils (0-1% slopes)
4 A-1	Port silty clay loam (0 to 1% slopes)
5 C-3	Renfrow complex (3 to 5% slopes)
6 A-1	Kirkland silt loam (0 to 2% slopes)
7 E-1	Broken alluvial land (5 to 12% slopes)

Figure 6. Soil Map of the Agronomy Farm Oklahoma A&M College, Stillwater, Oklahoma.

Synthesis of the Water Used for Irrigation

For SAR 12.11 use 1.5 grams of NaCl per liter of distilled water and 0.5 grams of $CaCl_2$ per liter of distilled water.

For NaCl 1 ml of 20% stock solution which contained 0.2 gm of NaCl and for one liter of the final treatment solution take 7.5 ml of the 20% solution and for 20 liters use 150 ml of the 20% NaCl solution.

For $CaCl_2$ 1 ml of the 20% stock solution will contain 0.2 gm of $CaCl_2$/ml and for one liter of the final treatment solution use 2.5 ml of the 20% $CaCl_2$ and for 20 liters use 50 ml of the $CaCl_2$ solution.

Mathematical Manipulation for Preparation

Molecular weight of Sodium Chloride (NaCl) = 58.45.
Molecular weight of Calcium Chloride ($CaCl_2$) = 111.00.

Millequivalent weight of Sodium Chloride (m.e. NaCl) = 0.05845.
Millequivalent weight of Calcium Chloride (m.e. $CaCl_2$) = 0.0555.

$$\frac{\text{grams of NaCl}}{\text{meq. wt. of NaCl}} = \text{millequivalent of NaCl}$$

Therefore for 1.5 gm NaCl:

$$\frac{1.5}{0.05845} = 25.66 \text{ millequivalent of Na}$$

$$\frac{\text{grams of } CaCl_2}{\text{meq. wt. of } CaCl_2} = \text{millequivalents of } CaCl_2$$

Therefore for 0.5 gm of $CaCl_2$:

$$\frac{0.5}{0.555} = 9.00 \text{ millequivalents of Ca}$$

$$\text{Hence SAR} = \frac{\text{meq. of Na}}{\sqrt{\frac{\text{meq. of Ca} + \text{meq. of Mg}}{2}}} \quad \text{(expressed in meq. per liter)}$$

$$\text{Then SAR} = \frac{25.66}{\sqrt{\frac{9}{2}}} = 12.11$$

To get other points to draw curve shown in Figure 7, we need to calculate other SAR values using different proportions of NaCl and $CaCl_2$. As another example:

Suppose we used 1 gm of NaCl and 1 gm of $CaCl_2$, then:

$$\frac{1}{0.05845} = 17.1 \text{ m.e. Na}$$

$$\text{and} \quad \frac{1}{0.0555} = 18.01 \text{ m.e. Ca}$$

$$\text{then SAR} = \frac{17.1}{\sqrt{\frac{18.01}{2}}} = 5.7$$

SAR of soil was calculated as follows:

$$\text{SAR} = \frac{\text{EPM of water soluble Na}}{\sqrt{\frac{\text{EPM of water soluble Ca} + \text{EPM of water soluble Mg}}{2}}}$$

$$\text{where EPM} = \frac{\text{ppm of Cation}}{\text{Equivalent wt.}}$$

ESP was calculated using the formula

$$\text{ESP} = \frac{\text{Meq. of exchangeable Na/100 gr}}{\text{CEC}} \times 100$$

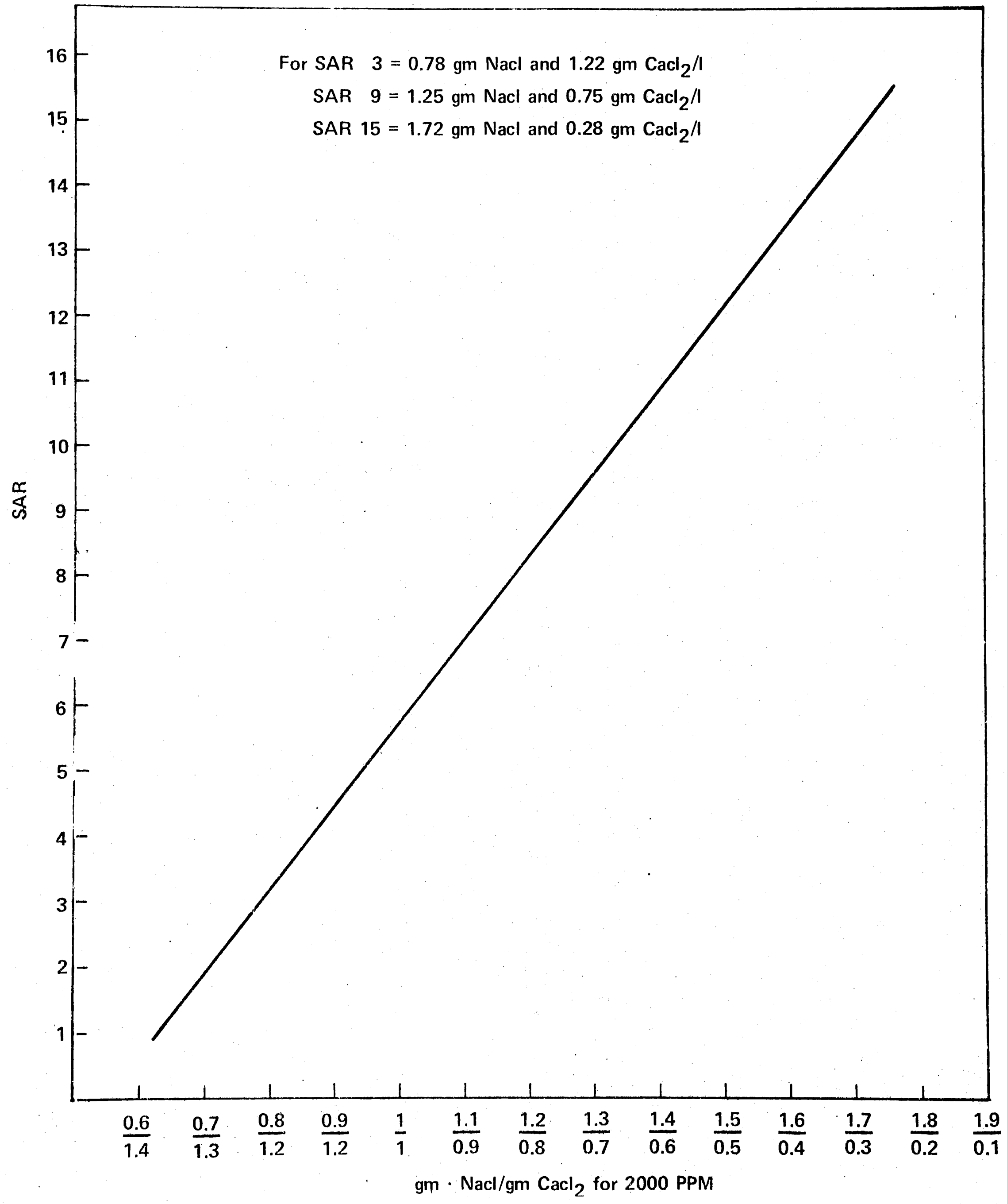


Figure 7. Relationship Between gm. of NaCl, $CaCl_2$ for 2000 ppm and SAR.

The LSD between two treatments at the same depth was obtained by the expression:

$$\mathrm{LSD} = t'\sqrt{\frac{2(b-1)E_b + E_a}{rb}}$$

let b = number of depth levels = 5

r = number of samples in a treatment at a given depth

E_a = main plot error

E_b = subplot error

$t' = \dfrac{(b-1)\ E_b t_b + E_a t_a}{(b-1)\ E_b + E_a}$

t_b = tabulated $t_{0.05}$ with 32 df = 2.0378

t_a = tabulated $t_{0.05}$ with 8 df = 2.306.

TABLE IX

MONTH: MAY, 1976

Day	Air Temperature ^oF		Rainfall per inches and hundredths
	Max.	Min.	
6	78	65	
7	79	66	
8	81	61	
9	84	60	
10	86	67	
11	88	70	
12	89	70	
13	90	73	
14	91	75	
15	86	60	
16	87	59	
17	90	60	
18	90	65	0.28
19	77	55	
20	81	55	
21	86	64	
22	87	65	
23	85	75	
24	88	70	0.35
25	85	61	
26	87	70	
27	90	74	
28	96	68	
29	99	67	0.16
30	95	69	

TABLE X

MONTH: JULY, 1976

Day	Temperature ^{o}F		Rainfall per inches and hundredths
	Max.	Min.	
1	98	65	0.08
2	83	64	0.07
3	81	70	
4	87	68	
5	80	64	
6	84	63	
7	89	58	
8	90	66	
9	95	65	
10	94	64	
11	92	64	
12	94	61	

VITA 2

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