WATER MANAGEMENT AND SALINITY CONTROL IN IRRIGATED SWELLING AND SHRINKING SOILS

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ABSTRACT

The influence of different irrigation management systems on crop production, water-use efficiency, and soil salinity was investigated for a swelling and shrinking soil in southwestern Oklahoma. Crop production increased significantly each year as the amount of irrigation water increased. Irrigation water-use efficiency decreased as the amount of water increased. No differences in salinity due to irrigation treatments were detected but salinity decreased over time for all treatments. Water content and potential measurements indicated that little irrigation water moved below the 30-cm depth. Therefore, little leaching occurred during the irrigation season. A field resistivity probe was developed and calibrated to facilitate future monitoring of soil salinity. The unsaturated hydraulic conductivity of this soil was measured *in situ* at 5 locations. These results are presented. Soil salinity was determined before and after applying 30 to 45 cm of water to each plot. Large salinity decreases were observed to depths of 60 cm in these plots. More research will be needed to evaluate this practice on a field scale.

ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of Mr. Rhea Foraker, Superintendent, Irrigation Research Station, his staff, and Mrs. Galene Freeman, Mr. Harold Gray, Mr. Tom Acre, and Mr. David Stone to this research. Appreciation is also expressed to Mrs. Joan Breazile for typing this manuscript.

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OBJECTIVES AND EXTENT OF ACHIEVEMENT OF THE OBJECTIVES

The objectives of this study were:

1. To determine the influence of different irrigation management systems on crop production, water-use efficiency, and soil salinity in swelling and shrinking soils.
2. To monitor seasonal and long term movement and accumulation of water and salt in these soils.
3. To develop irrigation management strategies for optimum water conservation and crop production without harmful saline intrusion.

The first two objectives were achieved satisfactorily. Three different irrigation management systems were used in this study. Cotton production and quality, water-use efficiency, and soil salinity were monitored or calculated for each management system. The systems resulted in different crop yields and water-use efficiencies but no differences in soil salinity were detected. Water movement in these soils were monitored by means of tensiometers and neutron scattering techniques. A field resistivity probe was developed and evaluated for measuring the apparent conductivity of soils in situ. Although the technique is not highly accurate, it appears to be suitable for characterizing soil salinity on a large scale.

This project has failed to meet the third objective because none of the irrigation systems used in objective 1 influenced the rate of salt accumulation in these soils. Therefore, one cannot deduce optimum irrigation strategies which can protect the soil from saline intrusion. This research indicates that none of the three management systems used here is extreme enough to influence the rate of salt accumulation.

BACKGROUND

Irrigation management systems capable of providing efficient utilization of water by plants while preventing harmful increases in soil salinity and excessive irrigation return flow are needed in many areas. Historically, many irrigation projects have suffered reduced crop production due to excessive soil salinity. This problem has been solved by applying excess irrigation water to leach the salts from the root zone. If more water is used than necessary to control salinity, the water is wasted. If less than the required amount of water is used, soil productivity is decreased. Thus, research is needed to determine the optimum water management system.

Two factors which influence the water management system are the climate and the soil. In arid regions, all the water needed for leaching must be irrigation water, while in sub-humid regions, rainfall provides part of the water. Soils which swell when wetted, and shrink and crack when dried, present special management problems. Significant amounts of water may enter these soils through the cracks. This will influence the movement and accumulation of salts. Also, water movement in wet swelling soils tends to be very slow (Ouattara, 1977). This means more time will be required for water to move deeply into these soil profiles.

Jackson County, Oklahoma, is an example of the need for improved irrigation management practices in shrinking and swelling soils of the Southern Great Plains. The irrigated land in Jackson County is primarily clay loam soil containing montmorillonitic clays which swell and shrink. The area has an average annual precipitation of 63 cm. Much of the soil has gone out of production due to high salt concentrations. Recent research in that area indicated that the concentration of salts in the productive soils has approximately doubled in a period of 10 years. If this trend continues much more land will go out of production. The present salinity problem in this area indicates a need for more information on the movement and accumulation of salts in the soils.

Stone et al. (1979) found that large amounts of irrigation water could be saved without yield reduction by irrigating with wide-spaced or alternate furrows instead of every furrow as is customary. This study included the swelling soils of Jackson County but it did not include salinity measurements there.

Water management in these soils is further complicated by canal seepage and the existence of perched water tables near the soil surface during the irrigation season. Nofziger et al. (1979) found that the canal seepage was sufficient to raise the water table one meter or more as was observed. The water tables are commonly 1 to 2 m from the soil surface.

At this time, no irrigation management systems have been found which are capable of significantly decreasing the soil salinity in these soils. Until such systems are found, the long term productivity of these soils is uncertain.

MATERIALS AND METHODS

This study was conducted on the Oklahoma Agricultural Experiment Station Irrigation Research Station, Altus, Oklahoma. The soil was a Hollister clay loam (fine, mixed, thermic Paleustoll). The experimental design was a randomized complete block with 5 replications. Plots were 75 m long (in a 300 m field) and 6.1 m wide. All plots were adjacent to the concrete irrigation canal. Each plot consisted of six rows and six furrows. The center 2 rows of each plot were harvested for yield. The harvested area began 30.5 m from the irrigation canal and was 30.5 m long.

Cotton (variety Westburn M) was planted in 100-cm rows on May 6, 1980, May 20, 1981, and May 19, 1982. Normal tillage, fertility, and pest management practices were used each year. The three irrigation treatments were designed to apply a wide range of irrigation water to these treatments. One treatment consisted of every furrow irrigation on a 14-day interval. This was selected because it represents the typical irrigation practice in these soils. The second treatment was the high frequency irrigation in which every furrow in the plots were irrigated on a 7-day interval. The third treatment received water in alternate furrows (3 per plot) on a 14-day interval. In 1980, irrigation began July 3 and ended September 4 with 5 complete irrigation cycles. In 1981, irrigation began July 20 and ended Aug. 12 with only 2 irrigation cycles. This reduction in irrigation was due to insufficient water in Lugert Lake. In 1982, irrigation began on July 20 and ended September 7 with 4 complete cycles.

Cotton quality was determined in the Oklahoma State University Agronomy Department Cotton Quality Research Laboratory. Fiber length was measured on the digital fibrograph as 2.5 percent span length and 50 percent span length. Fiber coarseness was measured on the Micronaire. Fiber strength was measured on the Stelometer at the 0 and 1/8 inch gauge settings.

Selected blocks of the experiment were instrumented with neutron access tubes and tensiometers for monitoring soil-water contents and potentials. Neutron tubes were placed 29 and 62 m from the canal. The alternate-furrow treatment had access tubes in both a wetted furrow and a dry furrow. A Troxler Model 3223 neutron probe was used for these measurements. Tensiometers were installed to depths of 30, 60, 90, and 120 cm at a distance of 26 m from the canal. Two tensiometers were installed at each depth in a wetted furrow and in a row of all treatments. Two additional tensiometers were placed at each depth in a dry furrow for the alternate-furrow treatment.

The quantity of irrigation water entering the soil was determined in 1982 from soil-water content measurements made approximately one-half day before and one day after irrigation. The difference between the quantity of water in the profile before irrigation and that after irrigation was taken as the amount of irrigation water entering the soil. Inspection of the water content - time curves indicates that little if any water moved below the 30-cm depth so this method was considered more reliable than any based on water leaving the irrigation canal. These values for 1980 and 1981 were calculated from the 1982 data assuming the same average recharge per irrigation.

Electrical conductivities of soil samples were determined by the Oklahoma State University Soil Testing Laboratory. Soil samples were collected from 0- to 30-, 30- to 60-, and 60- to 90-cm depths with a hand sampler or truck-mounted Giddings sampler. Each sample was dried and crushed to pass a 2-mm sieve. It was then thoroughly mixed and a small 100 g sample was analyzed. Ten samples were removed from each treatment at each depth in 1980 and 1982. Six samples were taken at each depth in 1981. Measurements were also made with a soil resistivity meter as described by Rhoades and Halvorson (1977). These results are presented in Section A of the Appendices.

In 1981, the in situ unsaturated hydraulic conductivity of this soil was determined for five sites. Three of the sites were along the southern edge of the cotton plots. The remaining two sites were approximately 1.5 km away. Details of the method are presented in Section B of the Appendices. The technique involved flooding a 3-m by 3-m plot for approximately 3 days. The surface water was then drained and the soil was covered with plastic to prevent evaporation. Water content and potential measurements were made during the drainage process. Soil samples were collected prior to wetting just outside the four corners of the plots at 15-cm depth intervals. Samples were collected from within the plots after drainage. The electrical conductivity of the soils were compared to determine the extent of change due to the extended flooding.

RESULTS AND DISCUSSION

The Influence of Irrigation Management Systems on Crop Production: The three irrigation treatments resulted in highly significant differences (at the 1% level) in lint and seed cotton yields each year of the study. These results are summarized in Figures 1 and 2. The alternate-furrow irrigation treatment consistently produced less lint and seed than the normal irrigation treatment. This is in contrast to the results of Stone et al. (1979) who reported four years of results on this soil with no yield reductions. However, they used a 9-day normal irrigation frequency rather than 14 as was done here. Each year of this study, the high frequency irrigation treatment produced the greatest yield.

Significant yield differences were also observed over time. Yields in 1981 were especially low because of the lack of irrigation water in the entire district. The exact reasons for the differences between 1980 and 1982 are not known but several possibilities exist. In the first place, daily high temperatures in June and July averaged 10 degrees warmer in 1980 than in 1982. Water was placed in the irrigation canal 17 days earlier in 1980 so one additional irrigation cycle was completed in 1980. It is not believed that the decrease in yield from 1980 to 1982 represents a trend in cotton production.

Irrigation treatments did not have very much influence on cotton quality. However, in 1980 and 1982, fiber length as measured on the digital fibrograph as 2.5 percent span differed significantly between treatments. The alternate-furrow treatment gave significantly (1% level) lower length in 1980 and the high frequency treatment produced significantly

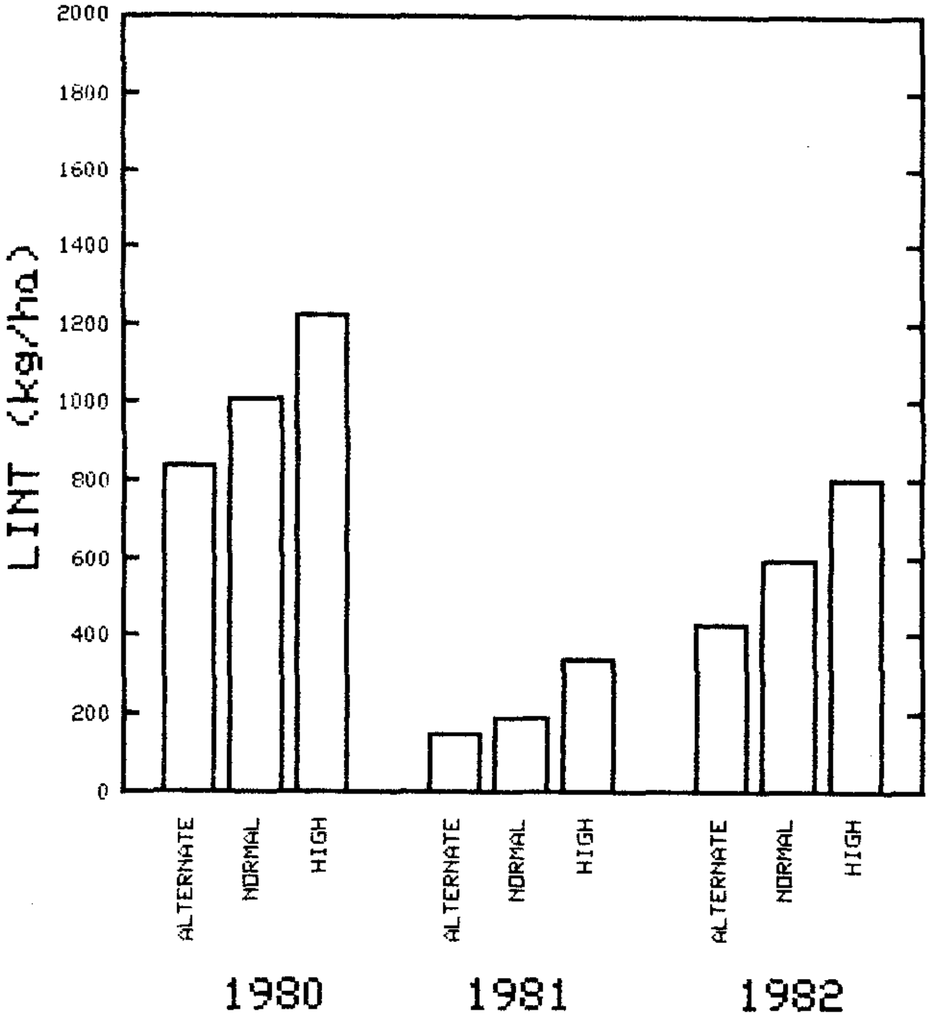

Figure 1. Lint yield for alternate-furrow, normal, and high-frequency irrigation treatments.

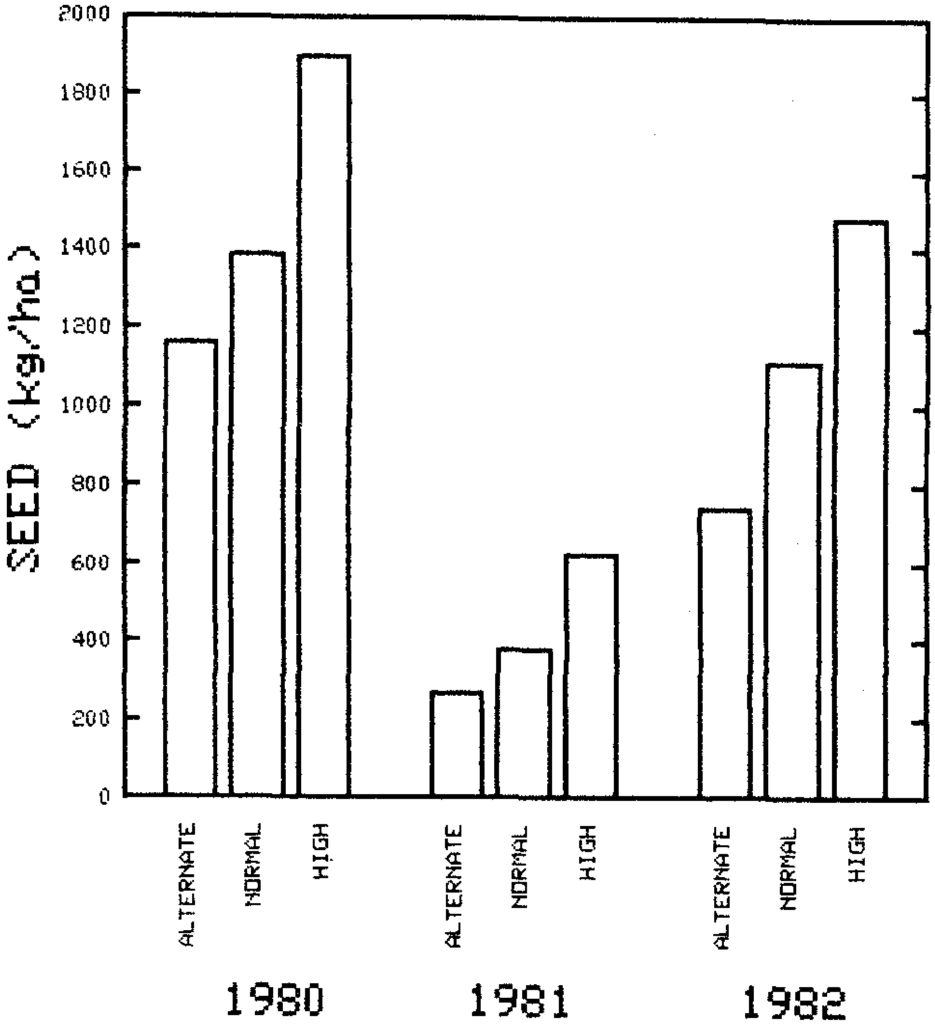

Figure 2. Seed yield for alternate-furrow, normal, and high-frequency irrigation treatments.

(1% level) greater length in 1982. In 1982 the fiber strength at the 0-in. gauge setting was significantly (5% level) greater for the high frequency treatment. In 1981, fiber coarseness was significantly (1% level) lower for the normal irrigation. No other quality differences were observed.

Water Use Efficiency: Figure 3 shows the lint yield as a function of quantity of soil water recharge due to irrigation. This recharge was determined from soil moisture readings made approximately one-half day before and one day after irrigation. The moisture data is presented in Figure 4 as the height of water as a function of time for 1982. Figure 3 indicates that the yield increases with the quantity of soil-water recharge in a nearly linear manner each year. This suggests that water is still limiting cotton production at the highest irrigation level. The slopes of the three curves are nearly the same. They indicate that each centimeter of water increase over the alternate-furrow treatment produced approximately 45 kg of lint per hectare each year. The irrigation water use efficiency for each treatment is the slope of a line connecting that point on the graph to the origin. Those values were 140, 65, and 135 kg/ha/cm for the alternate-furrow treatment, 105, 50, and 100 kg/ha/cm for the normal irrigation treatment, and 80, 55, and 75 kg/ha/cm for the high frequency treatment in 1980, 1981, and 1982 respectively. Each year the alternate-furrow treatment had the highest irrigation water use efficiency but also the smallest yield. This treatment may use the water more efficiently due to reduced evaporation. This treatment also depleted the stored soil water more than the other treatments (see Figure 4).

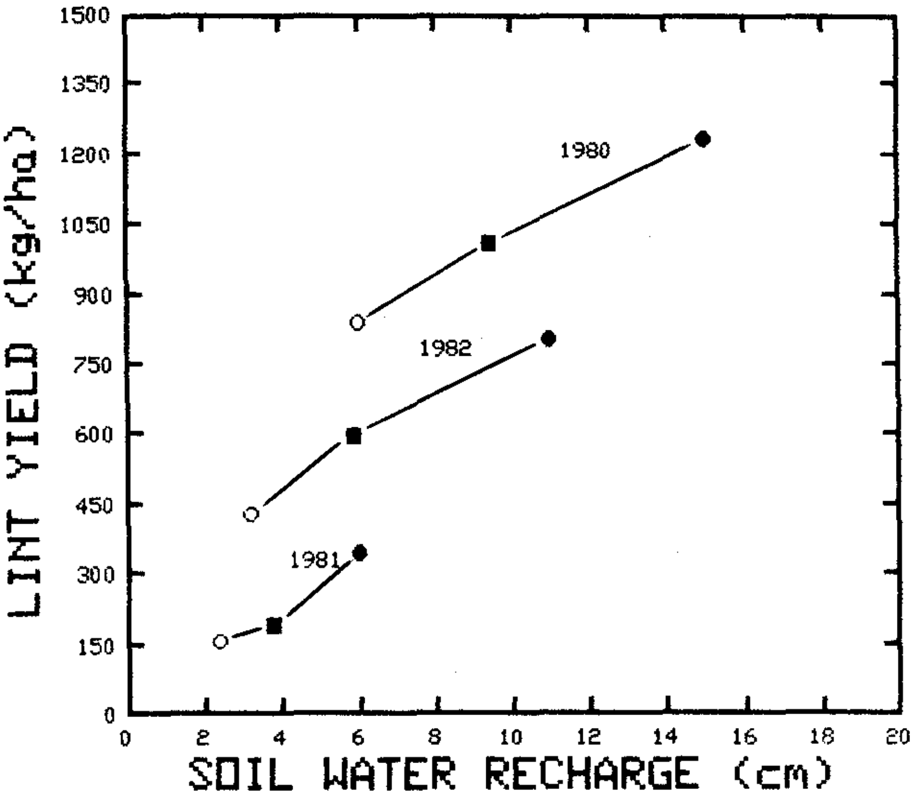

Figure 3. Lint yield as a function of soil-water recharge due to irrigation.

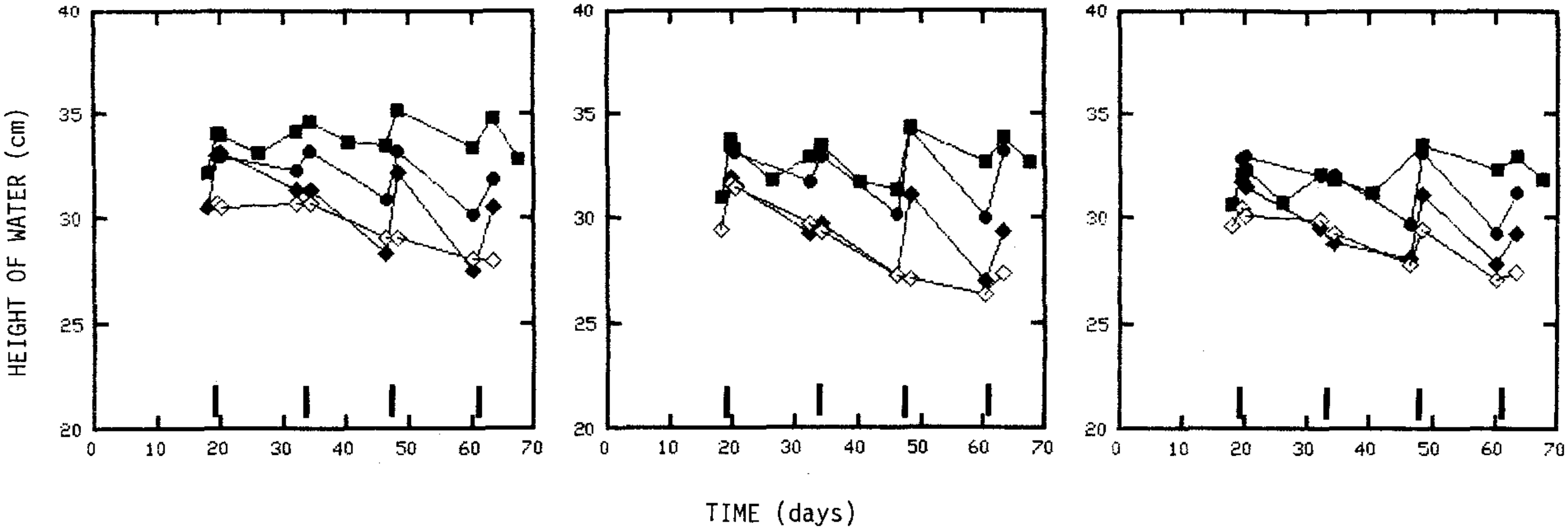

Figure 4. Quantity of water in soil profile to a depth of 105 cm as a function of time after July 1, 1982. Lines indicate dates when all treatments were irrigated.

Soil Salinity: The electrical conductivity of 1:1 soil extracts is shown as a function of treatment and time in Figure 5. No significant treatment effects were observed at any depth. Large variations in conductivity were observed for samples within one plot. Coefficients of variation were commonly in excess of 30% at shallow depths and 15% at deeper depths. This variation is due in part to the small samples used in the extraction process. The field probe discussed in Section A of the Appendices samples a much larger volume which is an advantage when characterizing salinity on a field scale.

From Figure 5, one can see that large changes in soil salinity occurred over time for all treatments. Near the soil surface, the conductivity increased from May to December of 1980 and then returned to its lower value by May of 1981. Deeper in the profile, the conductivity continually decreased from its value in May, 1980, to May, 1981, and then remained unchanged. This dramatic decrease in salinity is of interest but its cause is not understood. Clearly it was not due to the imposed irrigation treatment. No information is available on the change in electrical conductivity with time for many years so it is not possible to conclude if this is a long term decrease in salinity or if it is just a random fluctuation for some unknown reason. Periodic measurements with the field probe should help to answer this question.

Although the 1981 season was unusual in that very little irrigation water was available, it did provide some additional information. From Figure 5, one can observe that the salinity level of the soil at all

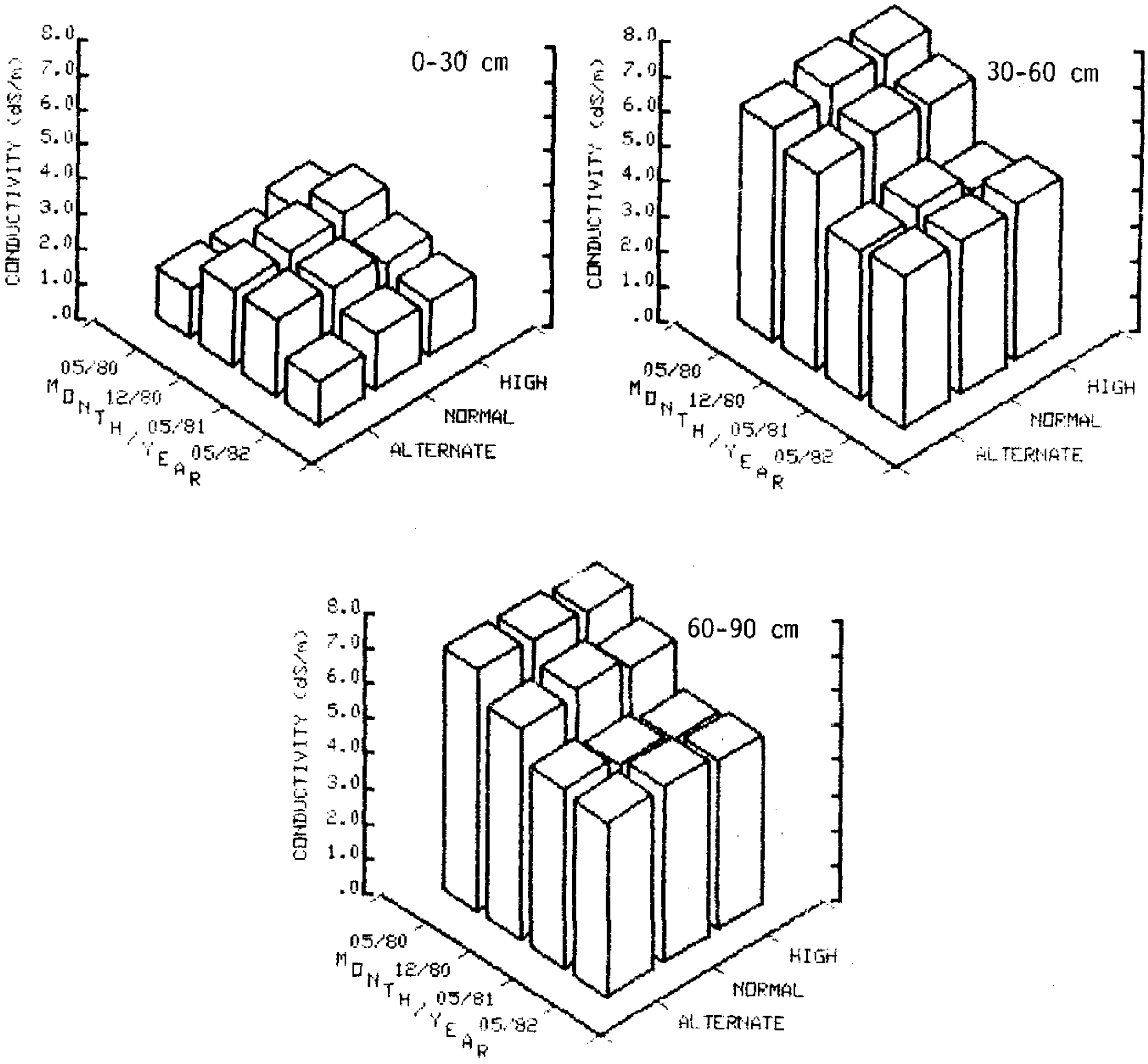

Figure 5. Electrical conductivity of 1:1 extract for the alternate-furrow, normal, and high-frequency irrigation treatments at four sampling dates.

depths was essentially unchanged between May of 1981 and May of 1982. Since there was little irrigation in 1981, little salt was applied to the soil. Winter and spring rainfalls had a chance to leach additional salts from the root zone and decrease the salinity levels. Clearly this did not happen. This suggests that reducing irrigation below the levels used in this experiment will not result in a significant rapid decrease in soil salts.

Soil-Water Content Changes with Time: Volumetric water content is shown as a function of time (in 1982) for various depths in Figure 6. Dates when all treatments were irrigated indicated in the Figure with arrows. Water content changes due to irrigation were approximately .08 to .14 cm^3/cm^3 at 15 cm, .04 to .06 cm^3/cm^3 at 30 cm and .01 cm^3/cm^3 or less at depths greater than 30 cm. At the 15-cm depth, the changes were greatest for the wet furrows in the alternate furrow treatment followed by the furrows in the normal and high frequency treatments. This behavior would be expected. Figure 6 also indicates that little recharge of the non-irrigated furrows occur in this soil. Thus, lateral water flow is not sufficient to wet the soil in this dry furrow. This would reduce evaporation at the surface and conserve water as reported by Stone et.al. (1979). The figure also indicates that the curves for all treatments tend to coalesce more and more as the depth increases. By the 90-cm depth, the curves overlap at random. This may be due to a lack of roots at this depth and hence no water uptake there. It may also be due to recharge of the soil-water from the perched water table observed in these soils during the irrigation season (Nofziger et.al., 1979).

These results indicate that very little downward movement of water

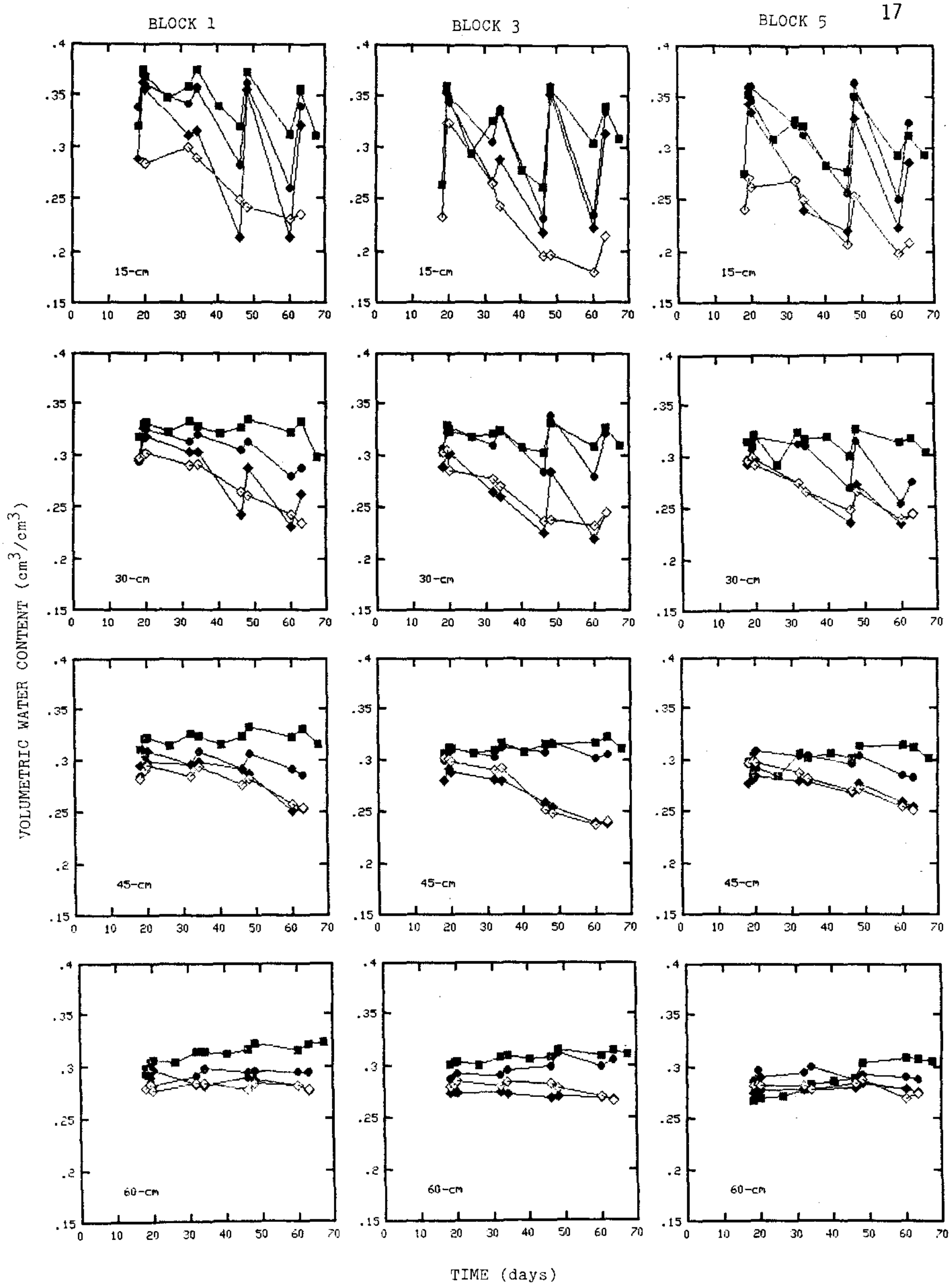

Figure 6. Volumetric water content at selected depths as a function of time after July 1, 1982.

below the 30-cm depth occurs in these soils during the irrigation season. Therefore, little leaching of salts occurred for any treatment.

Soil-Water Potentials and Gradients: Three of the five experimental blocks were equipped with tensiometers for measuring soil-water potential. Two tensiometers were placed at each of four depths in the furrows and in the rows. Although the duplicate tensiometers were separated by only 1.2 m, observed water potentials differed by as much as 700 cm of water. Frequently the tensiometers changed in phase with each other but the potentials differed by 100 to 300 cm. Tensiometers at shallow depths in the rows and at all locations in the alternate-furrow treatment showed the greatest differences. Some of these tensiometers did not even change in phase with each other. A thorough understanding of the cause of this behavior will require additional research. One possible explanation is that the water potentials in soils of this type are very heterogeneous due to cracks and soil lenses. A second possibility is that some tensiometers in the row were closer to roots and the soil was dryer near the roots. A third possibility is that the tensiometers malfunction in these soils as the soil drys out due to cracks and poor contact between the soil and porous cups.

For plots where the tensiometers were in good agreement, the gradients in total potential were upward throughout the irrigation season between the 30- and 60-cm depths for the normal and high frequency irrigations. That is, there is no evidence of downward water flow between these two depths. Below 60 cm, the gradients were downward with values close to unity. Thus, there is an indication of downward movement between the 60- and 90-cm depths and the 90- and 102-cm depths.

During the summer of 1981, the hydraulic conductivity of these soils were measured in situ. The technique involved and results obtained are described in Section B of the Appendices. Those results indicate that this soil has a conductivity of approximately .01 cm/day at a water content of 0.3 cm^3/cm^3 and depths below 60 cm. Combining this conductivity with the unity gradient using Darcy's equation results in a calculated flux density of .01 cm/day. This very low flux density indicates that only approximately .5 cm of water flow downward below the 60 cm depth during the entire irrigation season. This quantity of water is insignificant as a method of leaching salt through the profile.

Salinity Changes in Conductivity Plots: Figure 7 shows the mean electrical conductivity of the soil samples before and after applying 30 to 45 cm of water (and subsequent drainage) to the sites used for measuring the hydraulic conductivity of this soil. The electrical conductivity decreased significantly (at the 1% level) at all depths. Mean decreases in electrical conductivity were 1.0, 1.3, 1.0, and 1.2 dS/m for the 0- to 15-, 15- to 30-, 30- to 45-, and 45- to 60-cm depths, respectively. These results indicate that sustained flooding and drainage without evaporation can reduce the salinity of the soil to a depth of 60 cm or more. This is encouraging since none of the treatments used in this research decreased salinity. More research will be needed to determine if flooding like this could be successful on a field scale.

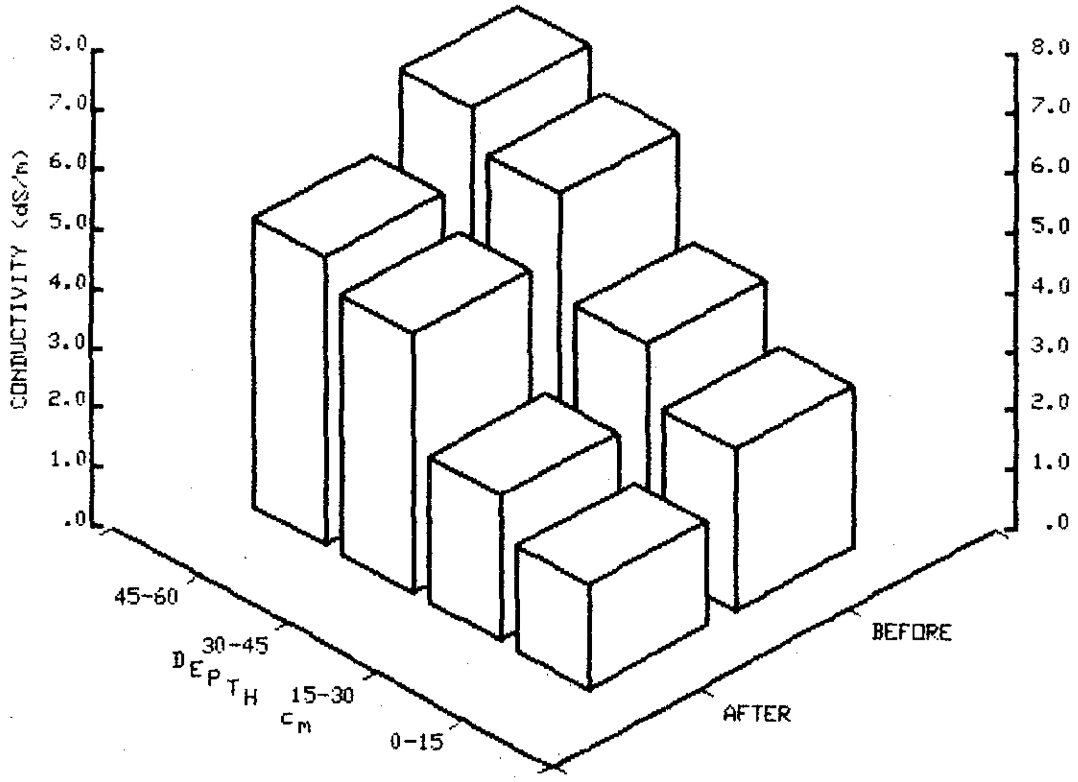

Figure 7. Mean electrical conductivity of 1:1 extract before and after flooding 5 sites with 30 to 45 cm of water.

CONCLUSIONS

1. Cotton lint and seed yields were significantly different for the three irrigation treatments. The yields increased as the quantity of irrigation water increased.
2. No differences in soil salinity were detected among the three irrigation treatments.
3. Soil salinity changes were observed between 1980 and 1981 but the cause of these changes is not known.
4. Very little irrigation water was applied in 1981. Since no change in salinity was detected between 1981 and 1982, this suggests that reducing irrigation water will not result in rapid salinity changes.
5. Application of 30 to 45 cm of water over 3 days resulted in a decrease in salinity of approximately 1 dS/m at depths to 60 cm for 5 small plots.
6. Water contents measured by neutron scattering were essentially unchanged by irrigation water at depths greater than 30 cm.
7. Soil-water potentials as measured by tensiometers varied greatly over short distances. This was especially true in the rows and at low matric potentials. Gradients in total potential indicate that little, if any, downward water movement occurred below the 30-cm depth during the irrigation season.
8. Additional research is needed to
    a. Develop an optimum irrigation management system which will control

CONCLUSIONS (continued)

soil salinity.

b. Monitor soil salinity changes on a field scale over long periods of time to detect potential saline soils.

c. Evaluate long term flooding as a means of salinity control and reclamation on a field scale.

d. Develop techniques to measure soil-water potential in these shrinking and swelling soils.

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Appendices

Appendix A

Field Determination of Electrical Conductivity

The four electrode Wenner array method for measuring soil electrical conductivity, EC_a has been used to determine field salinity (Rhoades and Ingvalson, 1971; Halvorson and Rhoades, 1974). The method is applied to soils at approximately field capacity or 1 to 2 days after a rain. The EC_a value is an average for the soil to a depth of approximately the inner electrode spacing, d. The volume of soil sampled in the Wenner technique is approximately πd^3. This large sample volume is desirable when working on field-scale projects. However, the method is sensitive to the soil-water content. Rhoades et al. (1976) report errors up to 14% in salinity can result from changes in water content between field capacity and saturation. Use of this method requires calibration for each soil. This section deals with the probes used in this research and their calibration. The existence of a valid field technique will enable farmers and researchers to monitor soil salinity more effectively and make necessary management decisions to control soil salts.

To measure the soil electrical conductivity, EC_a, four electrodes were placed equidistant apart in a straight line at a uniform depth of 5 cm. The electrical resistance between the inner electrodes was measured as a constant current was passed between the outer electrodes. The EC_a was calculated using the equation

$$EC_a = \frac{1000}{2\pi d} \frac{f_t}{R_t}$$

where EC_a is the bulk soil conductivity (dS/m), R_t is the measured resistance (ohms), d is the inner electrode spacing (cm), and f_t is a temperature correction factor. A model R-40C Strata-Scout resistivity meter from Soil Test Inc. was used for these measurements. Temperatures were measured by thermometer in 1981 and a thermistor probe in 1982.

In May of 1981, soil resistance measurements were made at selected sites in the cotton plots for 0- to 15-, 15- to 30-, 30- to 45-, and 45- to 60-cm depths. These measurements were made after a rainfall had wetted the soil. In July, additional measurements were made after an irrigation and rainfall. These measurements were made with four electrodes 1.6 cm in diameter provided with the R-40C meter. In May of 1982 measurements were again made at 0- to 30-, 30- to 60-, 60- to 90-, and 90- to 120-cm depths. In this case, the electrodes were permanently mounted on a board and were wired to a switch so that all depths could be measured in rapid succession without moving any electrodes. These electrodes were .8 cm in diameter. This probe system made the measurements much easier and more rapid. Each time resistivity measurements were taken, soil samples were also taken from each depth. The electrical conductivity of the 1:1 extract, EC_e, was determined in the laboratory.

Figures 8 and 9 show results for 1981 and 1982 respectively. Each year, the relationship between EC_e and EC_a appears to be linear. There is a considerable scatter around the least-squares line. The r^2 values were .75 and .73 in 1981 and 1982 respectively. One surprising and disturbing fact is that the regression lines have very different slopes. The cause of this is not known. Only the electrodes were different in the two years.

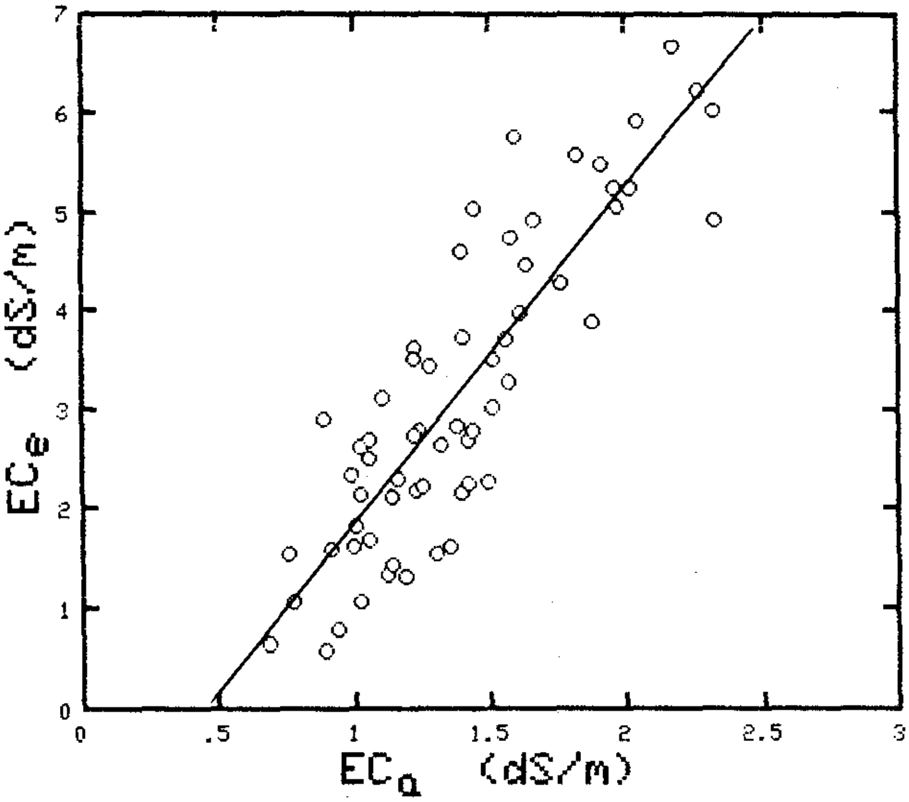

Figure 8. Electrical conductivity of 1:1 extract, EC_e, versus bulk soil electrical conductivity, EC_a, determined by field probe in 1981 ($EC_e = 3.42\ EC_a - 1.60$).

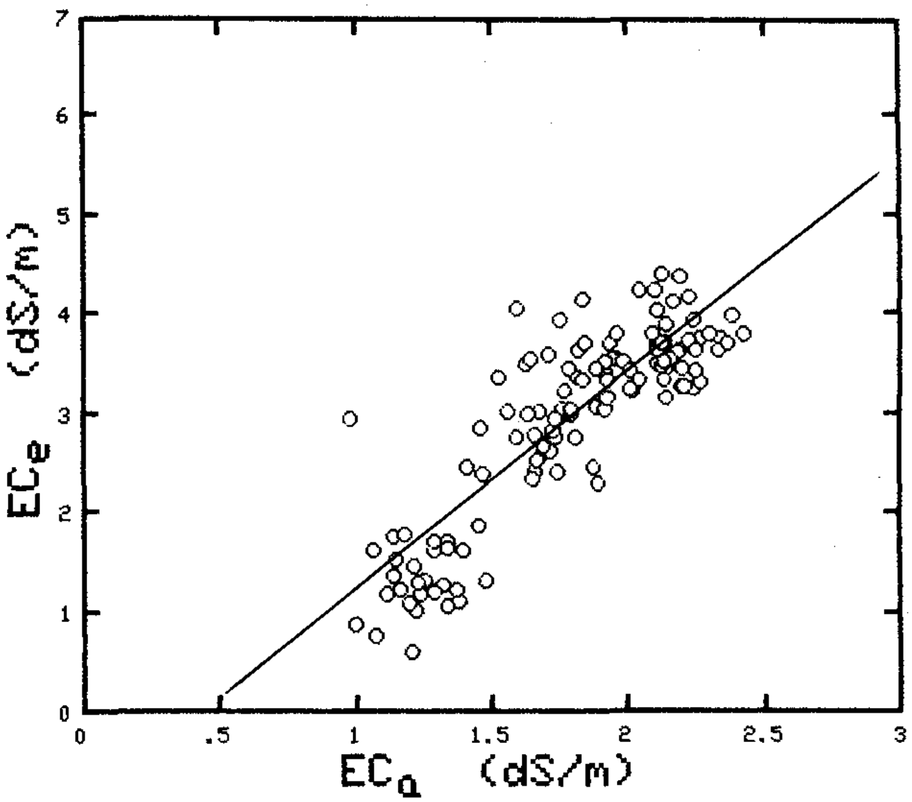

Figure 9. Electrical conductivity of 1:1 extract, EC_e, versus bulk soil electrical conductivity, EC_a, determined by field probe in 1982 ($EC_e = 2.21\ EC_a - 1.05$).

Although the scatter around the regression lines is greater than one would prefer, this probe appears to be useful in the characterization of field salinity. It is much more rapid than soil sampling techniques. It also samples a larger volume of soil which is desirable. This instrument should prove useful in the on-going salinity monitoring process.

Appendix B

In Situ Measurement of Unsaturated Hydraulic Conductivity

Darcy's equation is commonly used to estimate water movement in soils. The equation can be written as

$$q = - K(\theta) \quad \partial H/\partial z$$

where q is the flux density of water at depth z, $K(\theta)$ is the hydraulic conductivity of the soil at a water content θ, and $\partial H/\partial z$ is the gradient in the total potential. If the gradient is measured by means of tensiometers and the hydraulic conductivity is known, the flux density can be calculated. However, Darcy's equation is of little value if the conductivity is not known.

In 1981, five sites were instrumental for the determination of $K(\theta)$. The sites were separated by less than 2 km. Each 3-m by 3-m site was instrumented with duplicate tensiometers at 15-, 30-, 60-, 90-, 120-, and 150-cm depths. The tensiometers were located in a circle with a diameter of 1 m. A neutron access tube was located at the center of the circle (and the center of the 3-m by 3-m site). Water was ponded on the site for 2 to 3 days to thoroughly wet the soil profile. Between 30 and 45 cm of water were applied. When the soil was thoroughly wetted the surface water was drained and the bare soil was covered with plastic to prevent evaporation and with R-11 insulation to minimize temperature changes. The entire plot was covered with a removable roof to protect the plot from rainfall.

Water potentials and water contents were measured for at least 60 days of drainage in these soils. The measurements were made at four hour intervals initially. As water movement decreased, the interval increased to 3 or 4 days. A Troxler Model 3223 neutron probe was used for the water-content measurements.

The water-potential measurements were used to determine the gradient in total potential. Water-content values were used to determine the flux. Darcy's equation was rearranged and these values were used to determine the conductivity. Methods of calculation were identical to those used for the Bethany soil reported by Nofziger et al. (1983).

Figures 10 and 11 show the hydraulic conductivity as a function of volumetric water content and suction, respectively, for different depths and sites. The hydraulic conductivity is highly dependent upon the water content (and suction). Agreement between sites is quite good. The change in water content is generally less than .02 cm^3/cm^3 in the entire 60 day drainage period except at the 15- and 30-cm depths. This is further evidence of very slow water movement in these soils.

These results provide conductivity data for these soils. They will be useful for modeling water and salt transport in this soil.

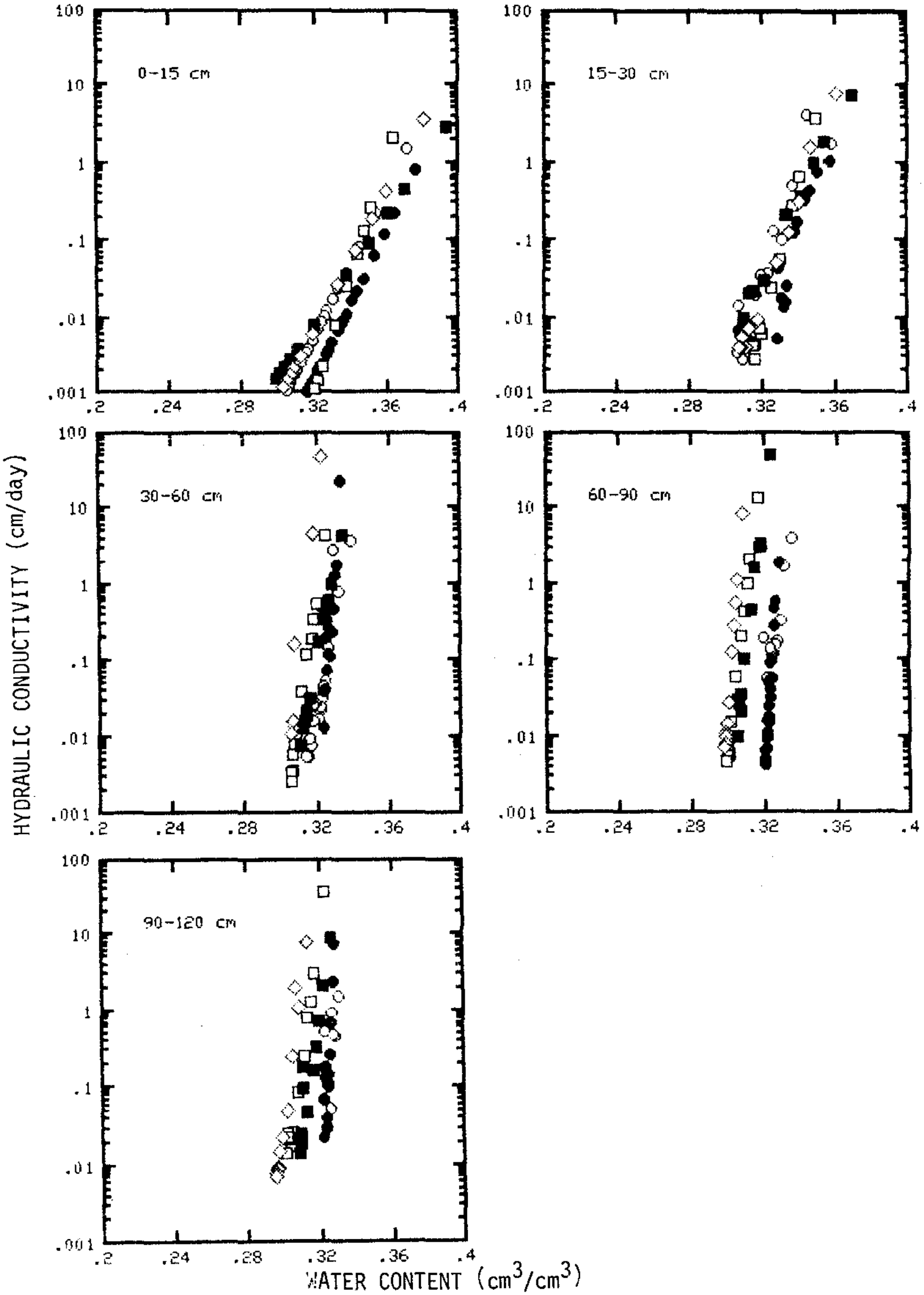

Figure 10. Hydraulic conductivity as a function of volumetric water content for different depths. Different symbols represent different sites.

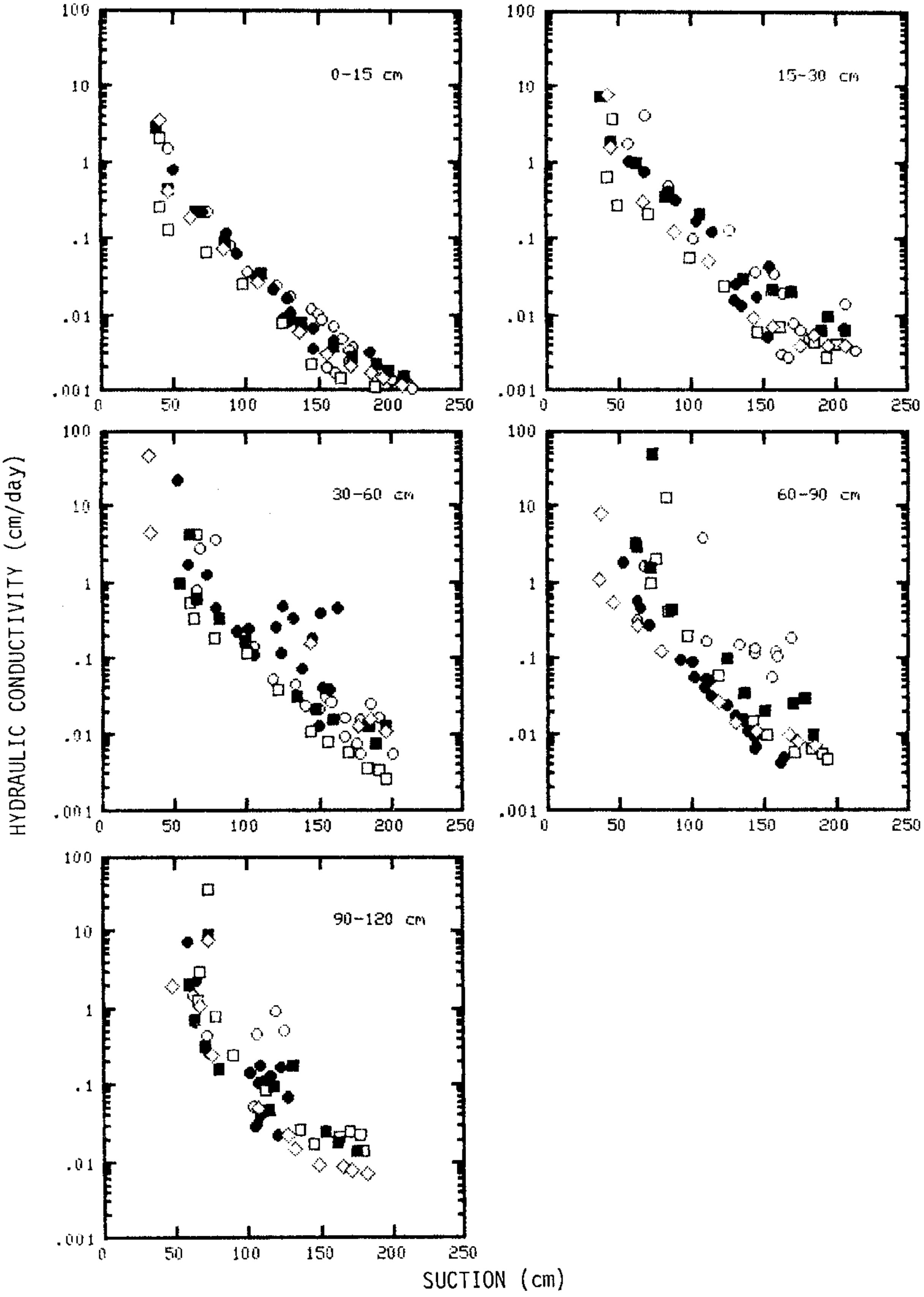

Figure 11. Hydraulic conductivity as a function of suction for different depths. Different symbols represent different sites.