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The Behavior of Soluble Salt in Sharkey Clay

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Technical Completion Report Research Project G-893-03

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ABSTRACT

THE BEHAVIOR OF SOLUBLE SALT IN SHARKEY CLAY

Soluble salt problems do exist and are significant in Arkansas. Studies have been conducted on Crowley silt loam (Typic Albaqualfs) which have established the behavior of soluble salt in that soil. The major objective of this study was to quantify the behavior of soluble salt in a second important Mississippi River Delta soil - the Sharkey (Vertic Haplaquepts). To this end, estimation of the downward redistribution of salt and the estimation of various components of the water balance for this soil served as specific objectives. Field studies were designed to monitor the movement of salt in the Sharkey soil and to characterize selected components of the water balance. In total, three tentative conclusions may be drawn from the data. First, the infiltration for the Sharkey soil was approximately three times that of the Crowley silt loam. The average value was 29 cm for the rice season. Second, levee seepage, while significant for small plots, was shown to be small for production-sized fields. Levee seepage remained relatively constant throughout the season and averaged 0.025 $m^3/m/d$. And third, downward redistribution of salt was large and appeared to follow a pattern where a peak occurred at the surface and, possibly, at the lower soil depths.

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Keywords -- Soil Salinity/Irrigation/Rice

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INTRODUCTION

Waters used for irrigation of agronomic crops in Arkansas such as rice and soybean are currently assessed as to suitability through the University of Arkansas. This evaluation considers mineral water quality, pumpage rate, field size, crop rotation and soil texture (Gilmour, 1983). The extent of calcium carbonate, soluble salt and sodium hazard are estimated from input data.

Extensive research has been conducted to support the recommendations of the University in regard to calcium carbonate deposition from irrigation water which causes zinc deficiency in rice (Ferguson et al., 1975; Gilmour et al., 1978; Gilmour and Ferguson, 1981; Ferguson and Gilmour, 1981). While little study of the sodium hazard has been made, few waters with sodium hazards are expected to occur in Arkansas (L. H. Hileman, unpublished data). In fact, the Arkansas River, often thought as being a source of excessive sodium, has recently been shown to have little sodium hazard (Gilmour et al., 1983).

Unlike the sodium case, soluble salt problems do exist and are significant in Arkansas. Surveys of available water quality data (Gilmour et al., 1983) as well as those conducted on suspect fields (Gilmour et al., 1977; Gilmour, 1981) offer ample evidence that soluble salts can exist in Arkansas' soils and that irrigation water is often the source of those salts.

Little information exists on the downward movement and loss of these harmful, soluble salts for all of Arkansas' important agricultural soils except the Crowley silt loam. Thus, for all soils except the latter the overall impact of a given amount of salt added via irrigation water is based on what we affectionately term the "educated guess". We have chosen the Sharkey clay for this study because it represents a very different soil series which could be thought of as being on the opposite end of the spectrum from the Crowley silt loam. With our previous information on the Crowley silt loam (e.g. Gilmour et al., 1981) and parallel data on the Sharkey clay, a much better estimate of the behaviour of soluble salts can be made for the range of soils common to Arkansas and surrounding states. Such data should allow a more precise evalution of the soluble salt component of irrigation water quality.

A. Purpose and Objectives

The major objective of this study was to quantify the behavior of soluble salt in Sharkey clay. To this end, estimation of the downward redistribution of salt and the estimation of various components of the water balance for this soil served as specific objectives.

B. Related Research or Activities

The vast majority of research on the fate of soluble salts in irrigated agriculture has been conducted in arid rather than humid climates. The most recent treatise on the subject (Bresler et al., 1982) provides an informative update on the information first presented by USDA Handbook 60 (U.S. Salinity Laboratory Staff, 1954). In regard to soluble salt movement, these references and others (e.g. Wilcox and Durem, 1967) usually assume that all leaching is from irrigation in excess of atmospheric demands. Where sufficient rainfall exists to effect leaching, little, if any, research on the relationships established for arid areas has been conducted.

In Arkansas, Place and Keith (1971) were among the first researchers to present data which suggested movement of soluble salt. They interpreted decreases in surface salinity as due to lateral movement of the soluble species in the soil, Freeland silt loam. Gilmour et al. (1983) recorded profile salinity data for several soils along the Arkansas River which had been irrigated with salt-bearing river water. They found smaller electrical conductivity readings (a measure of soluble salt) in the surface of these soils than in the subsoil which suggested leaching of salt had occurred. Baser and Gilmour (1982) reported that salt leached from the surface of a Crowley silt loam during the rice season. Salt peaks were recorded near the surface and at the 90-120 cm depth. Recently, Gilmour and Scott (unpublished data, 1984) quantified the rate of downward redistribution of salt in Crowley silt loam. The use of tile drains to remove soluble salts from a McGehee silt loam was studied by Keisling et al. (1984) who found that the low hydraulic conductivity of this soil during rice production precluded use of tile drains as a management alternative. To our knowledge, no research on the downward redistribution of salt has been conducted on Sharkey clay. The Sharkey series and similar soil associations occupy as much as 50 percent of the soils in the lower Mississippi Delta.

Water balance data have been collected on Crowley silt loam and a model developed by Ferguson and Gilmour (1981) and Gilmour et al. (1981). McCauley (1983) has initiated work in Texas on the water balance of rice fields on Houston clay, a soil somewhat similar to the Sharkey.

METHODS AND PROCEDURES

Field Studies

The first field study was designed to monitor the movement of salt and water in the Sharkey soil (Vertic Haplaquepts). To simulate a saline Sharkey soil, 1052 kg/ha chloride were applied to three plots located on the Northeast Research and Extension Center near Keiser, Arkansas. Potassium chloride (KCl), more commonly termed muriate of potash fertilizer, was the source of chloride. The salt was incorporated into the soil surface to about 5 cm prior to seeding. Lebonnet rice (*Oryza sative* L.) was drill seeded in the 12.3 by 18.3 meter plots. The rows were spaced 15.2 cm apart. The seeding rate was 123 kg/ha.

Immediately after the rice was seeded, three initial soil cores were taken from each plot with a probe tractor. The dimensions of a typical soil core was 4.0 cm in diameter and 91 cm in length. Each core was separated into 15.2 cm segments starting from the soil surface. Each soil sample was put into a plastic bag and stored until water content, electrical conductivity (EC) and chloride analyses could be made.

Salinity sensors, tensiometers, and water stage recorders were installed in each plot at seeding. Two banks of 5 salinity sensors

(Rhoades probes by Martek) were installed in each plot at depths where the center of the probe was located at 4, 32, 46, 61 or 91 cm. Two banks of 6 tensiometers were also installed in each plot at depths where the center of the porous cup was located at 4, 32, 46, 61, 76 or 91 cm. A water stage recorder was installed in each plot to help determine the amount of water applied either by irrigation or rainfall. Rainfall was recorded by Northeast Research and Extension Center personnel.

After the instruments were installed, levees were pulled with a levee plow. From this time forward, cultural management practices were made as recommended by the Arkansas Cooperative Extension Service and the DD-50 program. Specific information on cultural practices may be found in Table 1.

Salinity sensors were calibrated for the surface soil using methods similar to those reported by Sryotai and Gilmour (1976).

Soil cores were also taken with the probe tractor after harvest (140 days after the salt was added) and the following spring (339 days after the salt was added). This set of soil cores was separated by depth where the top segment was from 0 to 7.6 cm and all other segments were in 15.2 cm increments to 98.8 cm. Each segment or sample was packaged and stored for laboratory analysis.

Laboratory analysis of soil samples were made as quickly as possible after they were collected. The chloride content was determined by the coulometric method with a Buchler chloridometer. The EC 1:2 was determined by measuring the EC of a 1:2 soil:water extract with

Table 1 - The chronological sequence of cultural events from date of salt addition and flooding.

Date	Days after treatment	Days from flooding	Event
05-15/84	0	-36	Salt addition
05-15	0	-36	Seeded Lebonnet rice
05-15	0	-36	Initial soil cores
05-16	1	-35	Install instruments
05-17	2	-34	Install rain gage
05-30	15	-21	Flush
05-31	16	-20	Seedling emergence
06-12	28	-8	Flush
06-15	31	-5	Herbicide application
06-20	36	0	Preflood nitrogen
06-20	36	0	Flood
07-06	52	16	Herbicide application
07-16	62	26	Mid-season Nitrogen application
07-30	76	40	Mid-season Nitrogen application
08-21	98	62	Heading
09-11	119	83	Flood drained
09-27	135	99	Harvest
10-02	140	104	Fall soil cores
4/85	339	303	Spring soil cores

a YSI model 31 conductivity bridge before harvest. A YSI model 32 conductivity bridge was used to measure EC soil samples collected after harvest and the next spring.

The second field study was designed to obtain components of the water balance for the Sharkey soil. Circular plots were constructed and rice planted within the plots. The plots were constructed with a conventional levee plow. Each replication consisted of three plots, one of each of the following diameters: 13.4 m, 26.8 m and 40.3 m. There were four replications. Lebonnet rice was grown in the plots with normal cultural practices as outlined above.

All water applied to each individual plot was measured with a 50 mm inline flowmeter. Water was added to each plot roughly twice a week in amounts sufficient to bring the water level up to a predetermined level (generally about a 50 mm deep flood). The irrigation was initiated on May 30, 1984 and a flood was established on June 20 and sustained through September 6.

Appendix I gives the development of the relationship for determining the amount of levee leakage as a function of volume of water applied and plot diameter. The flooded season was broken into time intervals of approximately 14 days for analysis purposes.

Laboratory Experiments

Potassium nitrate (2000 ppm NO_3) was used to determine the volume of exclusion (Vex) of a Sharkey clay soil. The volume of exclusion is the volume of extractant solution from which chloride is excluded due to repulsion from the negatively charged soil colliods. To determine the Vex over depth, samples from the soil cores obtained after harvest were used. Chlorides were determined for both a 1:2 soil:water extract and a 1:2 soil:KNO_3 extract. From these data the Vex for each depth was calculated by assuming that Vex was zero for the KNO_3 case. These calculations are described in the Appendix.

A second laboratory experiment was designed to show the relationship between the electrical conductivity of the saturation extract (ECe) and the electrical conductivity of the 1:2 extract (EC1:2) for the surface horizon (Ap) of the Sharkey soil. To obtain a wide range of ECs, 10 g samples of dry soil were saturated with 6 concentrations of two salts (KCl and $CaCl_2$). The EC of the solution used to saturate a sample was assumed to be the ECe of that soil. Once the soil was brought to saturation, enough deionized water was added to make a 1:2 soil:water extract. Electrical conductivity was determined for each sample. Then the soil:water slurry was filtered through Whatman #1 filter paper and EC measured. These date are presented in the Appendix.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Water Balances

An understanding of the water balance and its components is prerequisite to a discussion of the behavior of soluble salt in the Sharkey soil. Table 2 presents the water balances for the circles. Several features emerged which are different from previous data for the Crowley soil (Gilmour et al., 1981). The total amount of water added by rainfall and irrigation ranged from 116 to 177 cm as compared to 76 cm for the Crowley soil. This increased water requirement was largely due to increased infiltration. Infiltration values of 24 to 34 cm were measured in the Sharkey soil as compared to the Crowley which has an infiltration component of about 10 cm. The levee seepage depths for the Sharkey soil were 27 to 82 cm for total losses of 116 to 176 cm. The levee seepage was inversely related to ratio of the area of the circle to its circumference. These ratios were 3.3, 5.5 and 10 m for the 13.3, 26.7 and 40.3 m diameter circles, respectively. Extrapolating these results to a 16 ha square field, levee seepage would be about 2.7 cm. These data suggest that levee seepage is a minor water loss pathway as compared to evapotranspiration (see below) and infiltration. The rainfall (20 cm) and evapotranspiration (60 cm) were similar to averages of 31 and 53 cm, respectively, for the Crowley soil. Runoff was zero as the circular plots had no outlets.

Water balances were also constructed for the salt plots as given in Table 3. Large total losses were calculated (100 to 201 cm). Using the results from the circular plots to estimate losses in the salt plots, levee seepage was estimated to be about 45 cm and infiltration about 29 cm for a total of 74 cm. This total plus about 20 cm as an estimate for surface runoff (94 cm) is near the reported values for plots 1 and 2. The exceptionally high value for plot 3 coincided with the visual observation that leakage immediately below the levee in one area of the plot wet a large area of soil outside the plot boundary. No leaks in the aboveground portion of the levees of these plots were observed. The losses (infiltration, levee seepage and runoff) were 5 to 10 times larger than that found for the Crowley soil (Gilmour

Table 2 - Water balances for circles. The data for each circle diameter are averaged over four replications.

Circle	Rain	Irrig.	Total Added	ET	Levee Seepage	Infil.	Total Lost
m	----------------------cm----------------------						
40.3	20	96	116	60	27	29	116
26.7	20	105	125	60	41	24	125
13.3	20	157	177	60	82	34	176

Table 3 - Average water balances for salt plots.

Plot	Rainfall	Irrig.	Total	ET	Drainage*	Total
	----------------------cm----------------------					
1	20	140	160	60	100	160
2	20	162	182	60	122	182
3	20	241	261	60	201	261

*infiltration, levee seepage and runoff

et al., 1981).

The temporal variation of selected components of the water balance is shown in Table 4. While ET and levee seepage remained relatively constant, infiltration decreased markedly with time. The large values of infiltration prior to flooding were thought to be due to storage in the soil profile. The decreases in infiltration with time are attributed to either the swelling of the soil colloids or the slow clogging of large pores. The small infiltration rates after flooding were similar to those reported by Keisling et al. (1984) for a McGehee silt loam.

Rainfall data are presented in Table 5. The depth during the flooded rice season was equal to that for the Crowley soil reported by Gilmour et al. (1981), while the depth after the flood was removed to the next spring (84 cm) was much larger than the typical depth for the Crowley soil (55 cm). The grand total was 120 cm as compared to 121 cm for the Crowley soil (Gilmour et al., 1981). Thus, rainfall amounts were typical, but monthly distribution was atypical for Arkansas' conditions.

Soluble Salt

The most general measure of soluble salt in this soil was electrical conductivity of the 1:2 soil:water extract presented in Figs. 1 and 2. The distribution of EC was uniform with depth prior to salt addition. In the fall sample, EC showed a bimodal distribution with peaks at 15 and 91 cm. None of these increases were significantly different from the initial sample.

Table 4 - Average rates of evapotranspiration (ET), infiltration and levee seepage for circles.

Days after Flooding*	ET	Infil.	Levee Seepage#
	------cm/d-------		m^3/m/d
-19 to -7	0.46	1.65	-----
-7 to 6	0.65	0.66	0.013
6 to 21	0.67	0.22	0.061
21 to 34	0.66	0.01	0.037
34 to 43	0.62	<0.01	0.034
43 to 80	0.60	0.02	0.023

*plots flooded 6/20/84
#levee seepage rate per unit length

Table 5 - Rainfall data from 5/15/84 to 4/20/85 as reported by the NEREC.

Year	Month	Pre-flood	flood	Pre-harvest	Post-harvest
		----------------	cm	-------------------	
1984	May	3.55	----	----	----
	June	0.88	2.14	----	----
	July	----	8.24	----	----
	August	----	9.02	----	----
	Sept.	----	12.24	8.73	----
	Oct.	----	----	----	19.33
	Nov.	----	----	----	16.10
	Dec.	----	----	----	9.17
1985	Jan.	----	----	----	7.77
	Feb.	----	----	----	9.52
	March	----	----	----	9.30
	April	----	----	----	4.37
Total		4.43	31.64	8.73	75.56
Grand Total					120.36

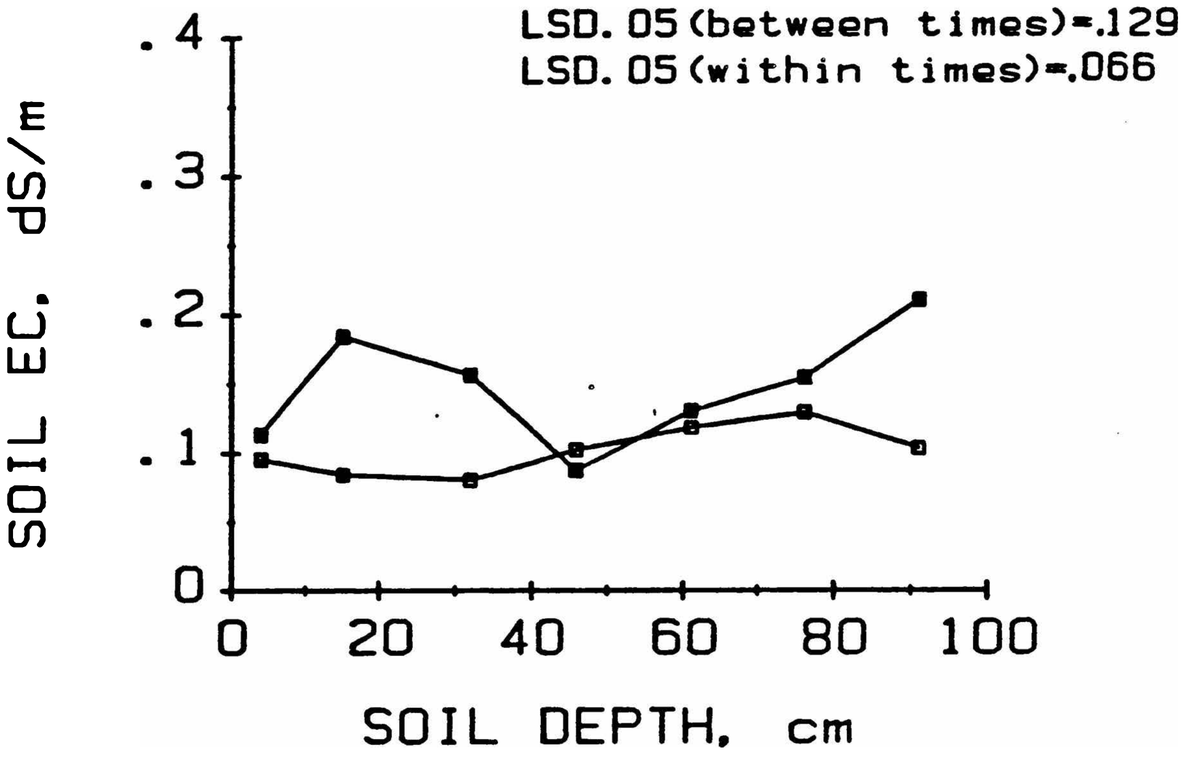


Fig. 1 - Mean soil electrical conductivities as a function of depth for preflood (open squares) and fall (closed squares) samples.

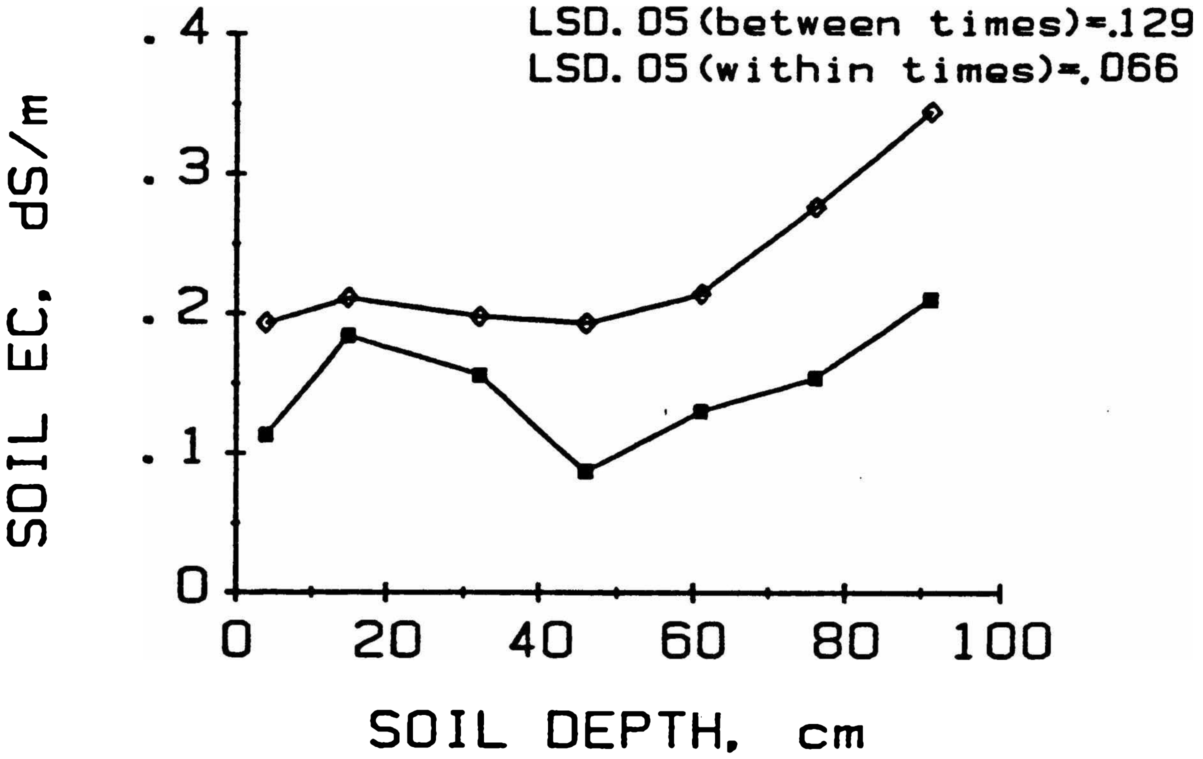


Fig. 2 - Mean soil electrical conductivities as a function of depth for fall (closed squares) and spring (open diamonds) samples.

A comparison of the fall and spring ECs (Fig. 2) showed a smoothing of the EC peak near the surface and an increase at the lower depths. Differences in EC between fall and spring samples were only significant at the lowest depth. The increases in EC at the two lowest depths were significant when compared to the top four depths. The overall distribution of EC with depth over time suggested that a portion of the salt was leached below the 99 cm depth and that another portion remained near the soil surface.

Soil chloride data which parallel the soil EC data are presented in Figs. 3 and 4. Initially, the chloride concentration uniformly decreased with depth. In the fall, a peak was found at 15 cm which was significantly different from the initial value. The small increases in chloride in the fall sampling at the lower depths were not significant.

In the spring, the peak concentration near the surface was more diffuse than in the previous fall and was significantly greater than the chloride concentrations at the lower depths. Chloride concentration in the topmost depth was significantly larger in the spring than in the fall. The increases in chloride concentration in the four lower depths in the spring as compared to the fall were significant at the 7 percent level. In general, the soil chloride data followed the pattern found with the soil EC data, but high variability in chloride concentration precluded a conclusion as to the extent of downward movement. The increase in EC at the lower depths (Fig. 2) was not reflected in a statistically significant increase in chloride (Fig. 4). Whether

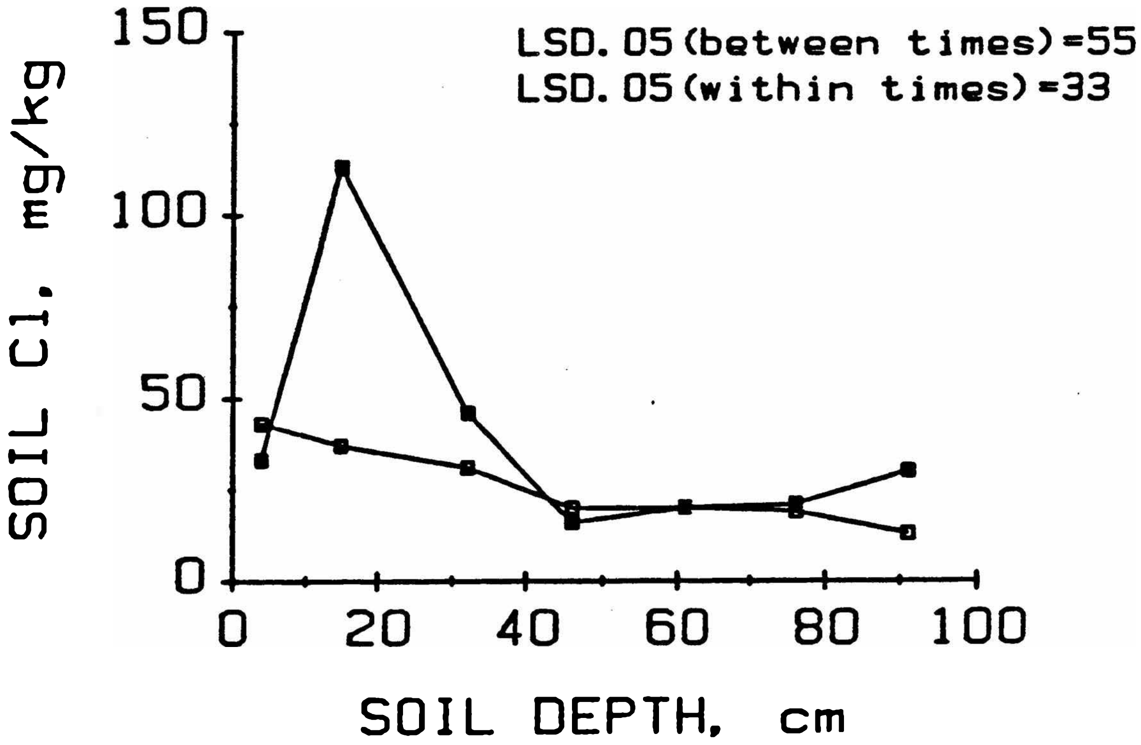


Fig. 3 - Mean soil chlorides as a function of depth for preflood (open squares) and fall (closed squares) samples.

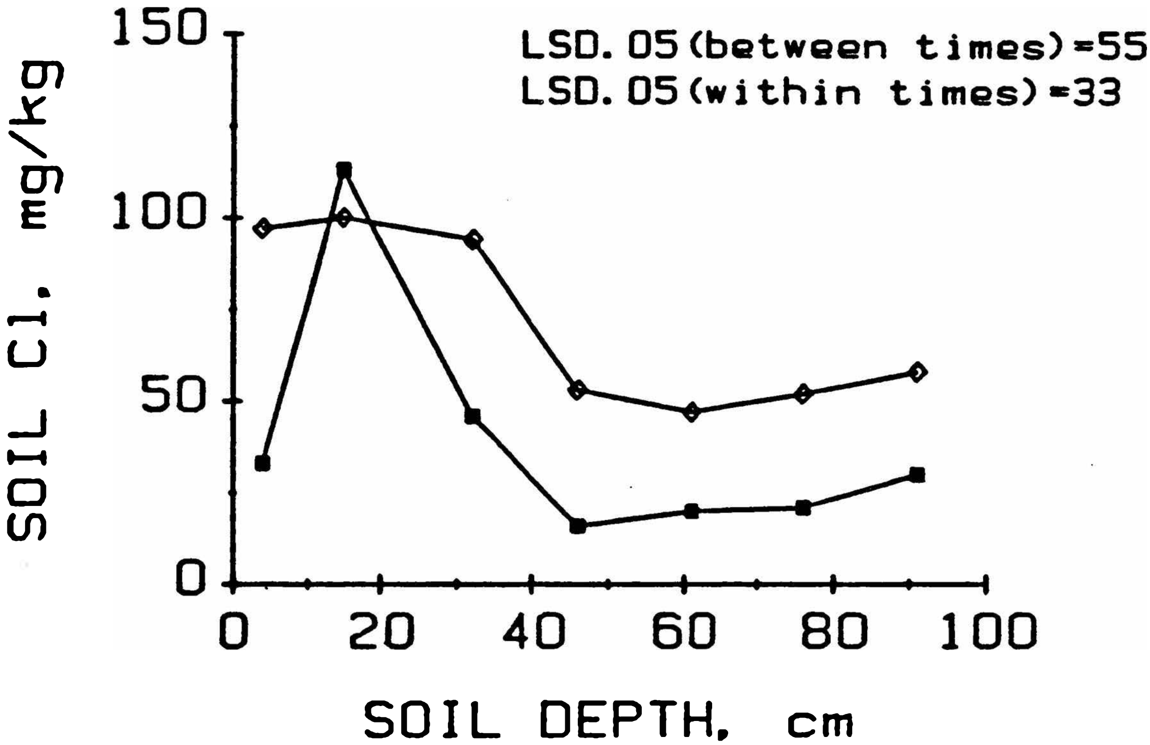


Fig. 4 - Mean soil chlorides as a function of depth for fall (closed squares) and spring (open diamonds) samples.

this observation was a result of the variable nature of the chloride data or the introduction of salt from the subsoil could not be determined.

The general pattern of EC and chloride concentration versus depth in the Sharkey soil is similar to that reported by Baser and Gilmour (1982) for a Crowley silt loam. In the Crowley, a peak in fall EC samples was from 15-30 cm as compared to 15 cm found for the Sharkey soil. Soil chlorides followed a similar pattern in the Crowley soil with an additional peak at 90-120 cm. Gilmour and Scott (unpublished data, 1984) reaffirmed these concentration distribution patterns with time using Rhoades probes to monitor EC in the Crowley soil.

During the rice season, tensiometers showed that the soil was saturated and Rhoades probes provided rather invariant readings for the Sharkey soil (data not shown). The Rhoades probe technique which worked well on the Crowley silt loam was apparently not sensitive enough for the Sharkey soil.

CONCLUSIONS

In total, three tentative conclusions may be drawn from these data. First, the infiltration for the Sharkey soil was approximately three times that of the Crowley silt loam. The average value was 29 cm for the rice season. Second, levee seepage, while significant for small plots, was shown to be small for production-sized fields. Levee leakage remained relatively constant throughout the season and averaged 0.025 m^3/m/d. And third, downward redistribution of salt was large and appeared to follow a pattern where a peak occurred at the surface and, possibly, at the lower soil depths.

LITERATURE CITED

Baser, R.E. and Gilmour, J.T. 1982. Tolerance of rice seedlings to potassium salts. Ark. Agri. Exp. Sta. Bull. 860.

Bresler, E., McNeal, B.L. and Carter, D.L. 1982. Saline and sodic soils. Springer-Verlag, New York.

Ferguson, J.A., Gilmour, J.T. and Griffis, C.L. 1975. A water management model for predicting carbonate accumulation in rice soils. Ark. Farm Res. 24:5.

Ferguson, J.A. and Gilmour, J.T. 1981. A hydrologic carbonate chemistry model of flooded rice fields. Ark. Water Resources Res. Center Pub. No. 78.

Gilmour, J.T., Sriyotai, K. and Correa, L. 1977. Soil salinity and rice seedling survival. Ark. Farm Res. 26:4.

Gilmour, J.T., Shirk, K.S., Ferguson, J.A. and Griffis, C.L. 1978. A kinetic study of the $CaCO_3$ precipitation reaction. Agr. Water Manag. 1:253-262.

Gilmour, J.T., Ferguson, J.A. and Wells, B.R. 1981. A salt and water balance model for a silt loam soil cropped to rice and soybean. Ark. Water Resources Res. Center Pub. No. 82.

Gilmour, J.T. and Ferguson, J.A. 1981. Liming silt loam and soils cropped to rice and soybean. Ark. Farm Res. 30:7.

Gilmour, J.T. 1981. Salinity damage to rice seedlings. Better Crops with Plant Food. Winter 1980-81:3-15.

Gilmour, J.T. 1983. Water quality in rice production. Proceeding of the National Rice Culture Workshop. USDA-SCS (held October 1983 in Little Rock, Ark.).

Gilmour, J.T., King, D. and Hileman, L.H. 1983. Salinity of irrigation water assessed. Ark. Farm. Res. 32:9.

Gilmour, J.T., Scott, H.D. and Baser, R.E. 1983. A survey of soils irrigated with the Arkansas River. Ark. Water Resources Res. Center Pub. No. 96.

Keisling, T.C., Gilmour, J.T., Scott, H.D., Sadeghi, A.M. and Baser, R.E. 1984. Evaluation of drainage tile to alleviate salt building in heavy soils irrigated with brackish water and cropped to rice and soybeans. Ark. Water Resources Res. Center Pub. No. 111.

McCauley, G.N., Bettge, R., Crenwelge, G. and Wiederhold, R. 1983. Technical report on cooperative rice irrigation study - 1982 crop season. Texas A&M Univ. Beaumont Center Tech. Rpt. 83-10.

Place, G.A. and Keith, H.R. 1971. Effects of potassium fertilizers on Arkansas' alkaline, saline and sodic rice soils. Ark. Agr. Exp. Sta. Bul. 768.

Sposito, G. 1984. The surface chemistry of soils. Oxford University Press, New York.

Sriyotai, K. and Gilmour, J.T. 1976. Soil salinity measurement by the four-electrode probe technique. Proc. Ark. Acad. Sci. 30:84-85.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S.D.A. Handbook 60.

Wilcox, L.V. and Durem, W.H. 1967. Quality of irrigation water. In R.M. Hagan et al. (ed.) Irrigation of agricultural lands. Agronomy 9:104-122.

APPENDIX

Correction of Chloride Data

The equation which describes the relationship among Vex (l/kg), volume of solution containing chloride (V, l), total volume of solution (Vt, l) and mass of dry soil (DS, kg) is given below.

$$V=Vt-(Vex)(DS) \qquad [1]$$

Since the mass of chloride must be the same for both extractants, Eq. 2 shown below holds,

$$(Cl1)(V1)/DS1=(Cl2)(Vt2)/DS2 \qquad [2]$$

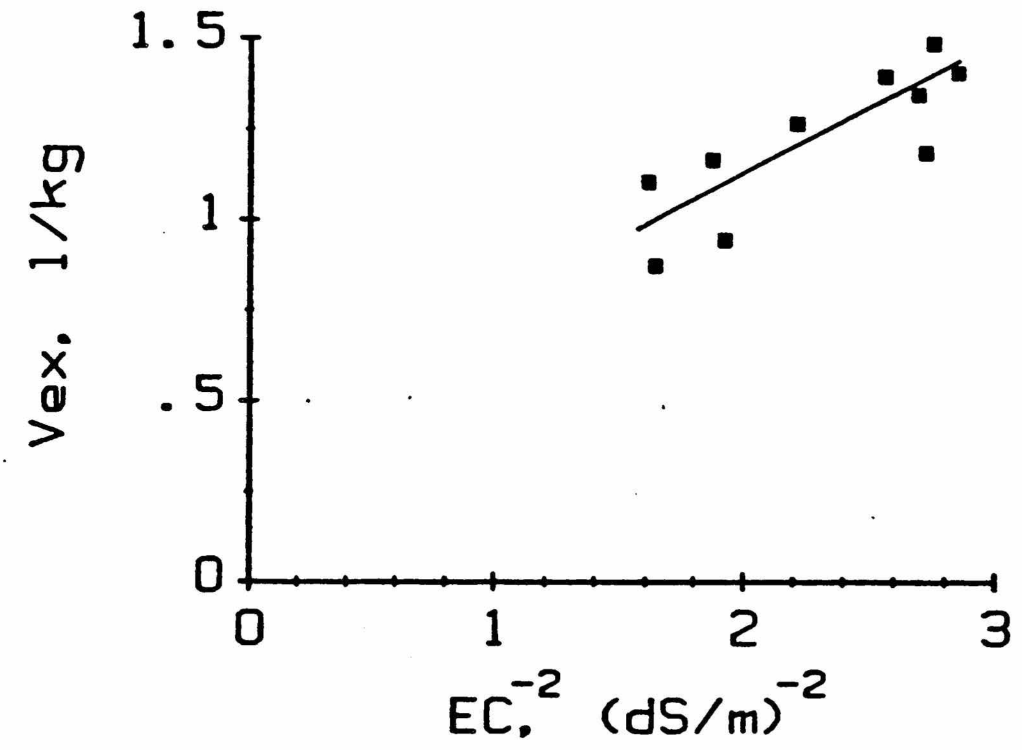
where the 1 refers to the water extract and the 2 refers to the KNO_3 extract. Combining Eqs. 1 and 2, and solving for Vex gives Eq. 3 which was used to estimate volumes of exclusion by depth.

$$Vex=[(Cl1)(Vt1)-(Cl2)(Vt2)(DS1/DS2)]/[(Cl1)(DS1)] \qquad [3]$$

These volumes of exclusion where then regressed against the inverse of the square root of the soil EC as shown in the equation below.

$$Vex=A/(EC^{-2}) + B \qquad [4]$$

Eq. 4 is a modification of an equation given by Sposito (1984) which suggested that the volume of exclusion was proportional to the inverse square root of the salt concentration. Appendix Fig. 1 shown below give this relationship for the four lowest depths. The values of A and B were 0.36 and 0.40, respectively, while the square of the correlation coefficient was 0.708. A similar relationship was not found for the surface (0-38 cm) soil depths so an average volume of exclusion of 0.48 l/kg was used.



Appendix Fig. 1 - Relationship between volume of exclusion and the inverse of the square root of electrical conductivity.

Once the slope and intercept were known for various depths of the Sharkey soil, the Cl concentrations of the field samples could be corrected for Vex and the effect of water content in the soil at the time of extraction. Equation 5 was used to correct for Vex, while Eq. 6 was used to correct for water content (M) where: C1 is original solution Cl, C2 is Cl corrected for Vex and C is the estimate of actual Cl in a 1:2 soil:water extract.

$$C2 = (C1)[Vt-(Vex)(DS)]/Vt \qquad [5]$$

$$C = (C2)(Vt)(15)/[(30)(DS)] \qquad [6]$$

EC1:2 versus ECe

There were no statistical differences due to filtering or salt type on this relationship. Appendix Fig. 2 had a slope of 0.167 and an intercept of 154. The square of the correlation coefficient was 0.991.

Derivation of volume-seepage relationship

Over any time period, dT, in a circular plot of diameter D, where the depth of water stored at the start of the period is the same as that at the end of the period, the following mass balance is valid:

$$VI = ETV + VSV + LSV - PPTV \qquad [7]$$

where: VI is input volume into the plot, ETV is evapotranspiration volume from the plot, VSV is vertical seepage volume from the plot, LSV is lateral seepage volume from the plot, and PPTV is rainfall volume into the plot.

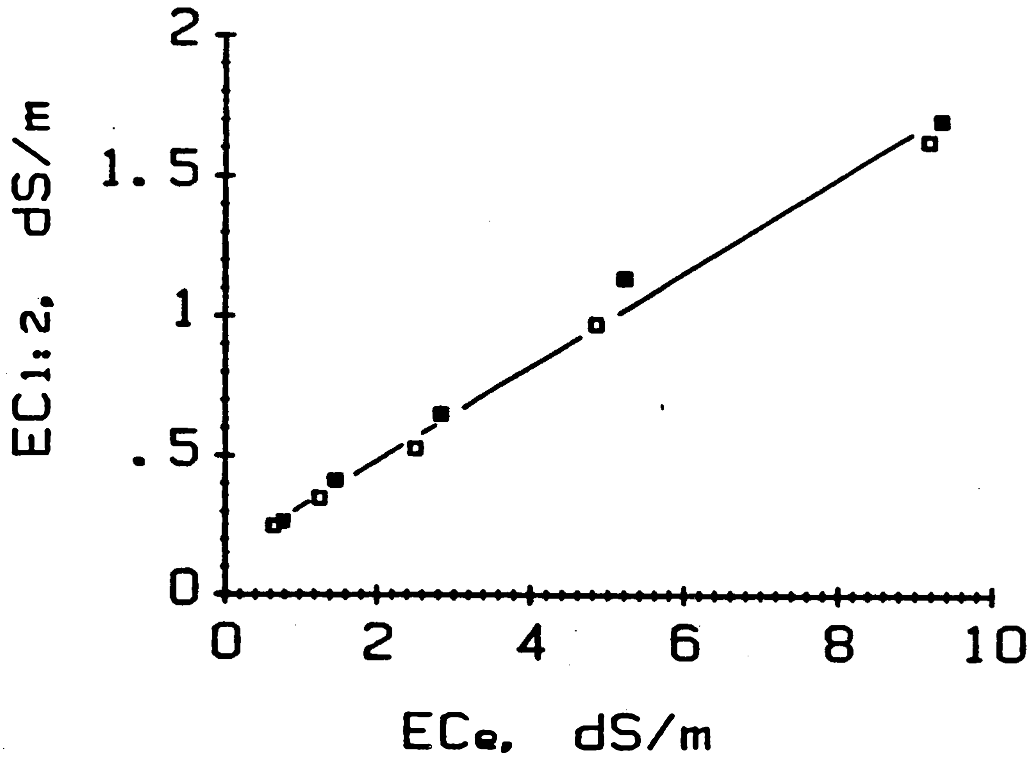
Let:

$$ETV = (K1)(dT)(Pi/4)(D^2) \qquad [8]$$

$$VSV = (K2)(dT)(Pi/4)(D^2) \qquad [0]$$

$$LSV = (KS)(dT)(Pi*D) \qquad [10]$$

$$PPTV = (k3)(dT)(Pi/4)(D^2) \qquad [11]$$



Appendix Fig. 2 - EC in a 1:2 extract versus EC in a saturation extract.

where: K1 is average evapotranspiration rate over dT, K2 is average vertical seepage rate over dT, K3 is average rainfall rate over dT, and KS is average lateral seepage rate over dT.

It can be shown:

$$VI=(Pi)(dT)[(C)(D^2)+(KS)(D)] \qquad [12]$$

where: $C = (K1 + K2 + K3) / 4$.

Considering two circles, then, of differing diameter, D_1 and D_2 with differing input volumes, VI_1 and VI_2, it can be shown:

$$KS=[1/(Pi*dT)][VI_1*D_2^2-VI_2*D_1^2]/(D_1*D_2^2-D_2*D_1^2) \qquad [13]$$

Thus, lateral seepage rate over time dT can be calculated if the input volume and diameter of the two circular plots are known. This is subject to the assumption that K1, K2, and K3 are equal for both plots.