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ABSTRACT

THE BEHAVIOR OF SOLUBLE SALT IN SHARKEY CLAY - II

Soluble salts have been shown to accumulate in Arkansas soils in sufficient quantities to impair crop plant growth. The major objective of this study was to describe the behavior of soluble chloride salt over long time periods in Sharkey clay - a major Mississippi Delta soil. Prior to flooding rice, leaching of chloride in response to rainfall was observed. The inclusion of a sandy subsoil layer reduced this effect presumably by limiting downward movement of water under unsaturated conditions. No lateral movement of the chloride salt was found during the period prior to flooding. Removal of soluble chloride salts from the top 100 cm of Sharkey soil was complete in a 1-2 year period depending on weather conditions. In a year where the rice cropping season was followed by a wet winter, losses were smaller than in a year where the rice cropping season was followed by a drier winter. These results suggested that removal of soluble salts via leaching in this soil was more efficient under less saturated soil conditions.

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INTRODUCTION

Waters used for irrigation of agronomic crops such as rice and soybean are currently assessed as to suitability through the University of Arkansas (Gilmour, 1983). Extensive research has been conducted to support the recommendations 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of the sodium hazard has been made, few waters with sodium hazards are expected to occur in Arkansas (L.H. Hileman, unpublished data). The Arkansas River, often thought as being a source of excessive sodium, has been shown to have little sodium hazard (Gilmour et al., 1983).

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. 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 behavior of soluble salts can be made for the range of soils common to Arkansas and surrounding states.

A. Purpose and Objectives

The major objective of this study was to quantify the behavior of soluble salt in Sharkey clay. The salt amended plots established in 1984 were continued in order to assess the downward redistribution of salt over a 2 year time period. And, the 1984 field study was expanded to include Sharkey soil with and without sand blow inclusions which were formed during the New Madrid earthquake of 1811 (Ferguson and Gray, 1971). The sandy areas are generally small with a diameter of 2 to 3 meters. Where sand blows occur, layers of sand 15 to 30 cm thick may be found in the soil profile between 15 and 100 cm deep.

The results obtained in this study in combination with previous research will allow a more precise evaluation of the salinity component of irrigation water in climatic areas similar to Arkansas. Guidelines can then be established to determine the feasibility of using a water of known salinity in an irrigation program such that soil productivity is maintained.

B. Related Research and 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 (US 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 salts. 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. Recently, Gilmour and Scott (unpublished data, 1984) demonstrated the downward redistribution of salt in Crowley silt loam. The use of tile drains to remove soluble salts from a McGehee silt loam has been shown to offer limited potential as a reclamation procedure due to small soil conductivities (Keisling et al., 1984).

Water balance data have been collected on Crowley silt loam soil and a model developed by Ferguson and Gilmour (1981). McCauley (1983) has initiated work on the water balance of rice fields on Houston clay.

In 1984, a project entitled "The Behavior of Soluble Salt in Sharkey Clay" (Gilmour et al., 1985) was initiated. Soluble salts were added to the Sharkey soil prior to cropping to rice. More than 50% of the salt was removed from the top 100 cm of soil by the end of the rice season. Salt which remained in the profile was concentrated near the surface. Salinity sensors were not sufficiently sensitive to record a progressive downward redistribution of salt as was the case for Crowley silt loam soil in previous studies. Runoff was identified as a potential loss pathway.

METHODS AND PROCEDURES

Field Experiment One

This study was a continuation of the experiment begun on the Northeast Research and Extension Center near Keiser, Arkansas in 1984 (Gilmour et al., 1985). At that time, 1052 kg/ha of chloride was applied to three plots to simulate a saline soil. Muriate of potash fertilizer (KCl) was the source of chloride. Bedford soybeans (*Glycine max*) were planted for the 1985 cropping season.

A chronological sequence of cultural and management events beginning with the 1984 rice study may be found in Table 1. Four sets of soil cores were collected over the two year period. Two of the core samplings were taken after the 1984 rice study. Each core was separated into segments by depth. The top segment was measured from the surface to 7.6 cm and all other segments were separated into 15.2 cm increments to a depth of 98.8 cm. The cores were placed in plastic bags, sealed and stored for laboratory analysis.

Table 1. The chronological sequence of events for field experiment one.

Date	Days from treatment	Event
		1984
05/15	0	Salt addition
05/15	0	Seeded Lebonnet Rice
05/15	0	Took initial soil cores
06/20	36	Flooded plots
09/11	119	Drained plots
09/27	135	Harvested rice
10/02	140	Took fall soil cores
		1985
04/09	329	Took spring soil cores
05/07	357	Tilled plot area
05/16	366	Seeded Bedford soybeans
05/16	366	Lexone hericide preplant
06/20	401	Weeded plot area with hoe
07/09	420	Mechanical cultivation
11/10	543	Harvested soybeans
		1986
03/05	659	Took spring soil cores

Field Experiment Two

Six plots were located in a field which contained a sand blow. Three of the plots were established over a sand layer about 15.2 cm thick located about 38 cm below the soil surface. The other three plots were located adjacent to but where no sand layer was found between the soil surface and the 98.8 cm depth. Lebonnet rice (*Oryza sativa* L.) was drill seeded on May 7, 1985. Due to rainfall, salt additions and levee establishment were delayed until May 16, 1985 (9 days). A chronological list of cultural and management practices may be found in Table 2. Once the 3.0 by 6.7 meter plots had been established with levees, 480 kg Cl/ha was broadcast into each plot. The chloride source was muriate of potash.

Soil cores were taken periodically to monitor salt movement within the profile. The first segment was measured from the surface to 7.6 cm. The remainder of the cores were separated into 15.2 cm segments to a depth of 98.8 cm. As before, the cores were placed in plastic bags and stored for later analysis.

Laboratory Analyses

Soil samples were analyzed for moisture and chloride content as soon after they were collected as possible. Analyses of soil samples were generally completed within three days and never required more than five days. A 1.0 M solution of $Ca(NO_3)_2$ was used as an extractant (1:2 soil:water ratio) to prevent interference caused by the volume of exclusion noted previously (Gilmour et al., 1985). The chloride content was determined by the coulometric method with a

Table 2. The chronological sequence of events for field experiment two.

Date	Days from Seeding	days from treatment	days from flooding	Event
		1985		
05/07	0	-9	-43	Seeded rice
05/16	9	0	-34	Pulled levees
05/16	9	0	-34	Salt additions
05/18	11	2	-32	Rice emerged
05/22	15	6	-27	First soil cores
05/31	24	15	-19	Second set cores
06/06	30	21	-13	Third set cores
06/06	30	21	-13	Herbicide treat
06/18	42	33	-1	Fourth set cores
06/19	43	34	0	Preflood fert
06/19	43	34	0	Flood plots
07/16	70	61	27	Midseason N
07/26	80	71	37	Midseason N
08/01	86	77	43	Heading
08/31	117	108	74	Drained plots
09/28	144	135	101	Harvested rice
09/29	145	136	102	Fifth set cores
		1986		
03/05	302	293	259	Sixth set cores.

Buchler chloridometer. Gravimetric water contents were determined from a subsample of each soil core segment, so that chloride contents could be calculated for the segment on a dry weight basis.

Statistical Analysis

Because the variability in chloride concentrations was related to the magnitude of the chloride concentrations, the chloride data were transformed by taking the natural logarithm of the concentration plus one. The differences noted below are based on these transformed data.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Field Experiment One

Rainfall data for the 1985-86 period are given in Table 3. During the prior winter over 75 cm of rainfall occurred (Gilmour et al., 1985). This was followed by nearly 44 cm of rainfall during the 1985 soybean growing season, and only 26 cm of rainfall the next winter.

Soil chloride concentrations for the 659 d period are presented in Table 4, while the statistical analysis is given in Table 5. Soil chloride concentrations at day 0 were small as the KCl likely had not dissolved. The next sample time (day 140) was five days after rice harvest. Significant movement of the chloride to the 91 cm depth in response to the flood was found. The following spring (day 329), large amounts of chloride were still in the soil profile and, at most depths, chloride concentrations had not changed significantly from the 140 d sample even though over 75 cm of rainfall had been recorded for the period. By 659 d, surface chloride concentrations had returned to

Table 3. Rainfall data from 05/16/85 to 03/05/86 as reported by NEREC.

Year	Month	Seeding to Harvest	Post-harvest
		---------- cm -----------	
1985	May	8.53	---
	June	11.15	---
	July	4.55	---
	August	2.84	---
	Sept.	5.44	---
	Oct.	10.57	---
	Nov.	0.74	12.16
	Dec.	---	4.60
1986	Jan.	---	2.74
	Feb.	---	6.20
	March	---	---
TOTAL		43.82	25.70

GRAND TOTAL=69.52 cm.

Table 4. Mean soil chloride concentrations in field experiment one as a function of time.

Days after salt added	Mean soil depth (cm)						
	3.8	15	30	46	61	76	91
	ug chloride/g soil						
0	19	25	18	16	14	6	2
140	33	75	56	17	18	12	28
329	77	80	69	44	33	40	36
659	3	6	17	23	25	22	18

Table 5. Natural logarithm of mean soil chloride plus one as a function of time for field experiment one.

Days after salt added	Mean soil depth (cm)						
	3.8	15	30	46	61	76	91
	ln (Cl + 1)						
0	2.94	3.22	2.90	2.79	2.65	1.79	0.73
140	3.49	4.31	4.03	2.85	2.92	2.52	3.33
329	4.34	4.39	4.23	3.79	3.59	3.68	3.58
659	1.08	1.83	2.85	3.14	3.23	3.09	2.86

LSD within the 0 and 659 day time periods = 0.69

LSD within the 140 and 329 day time periods = 0.78

LSD between the different time periods = 3.19

background levels, while concentrations at lower depths remained above initial values. Interestingly, the removal of chloride was much more noticeable the second year (between 329 and 659 d) when soybean was the crop and winter rainfall was small (about 26 cm) as compared to the first year when rice was the crop and a wet winter occurred (nearly 76 cm rainfall).

Mass balances of chloride in the soil profile for individual cores were unreliable because of the variability in soil bulk density and the inability to obtain the bulk density of single soil cores. However, using an average bulk density of 1.5 g/cm^3 (unpublished data) and mean profile chloride concentrations, it was possible to estimate the amount of chloride in the 99 cm soil depth. For these calculations, the mean chloride concentration below the first depth increment at time 0 (14 ug/g) was assumed to represent background levels. At 140, 329 and 659 d, mean profile chloride amounts were 300, 570, and 45 kg chloride/ha, respectively. These masses corresponded to losses from the profile of 71, 46, and 96 percent, respectively.

Field Experiment Two

Rainfall data for the duration of this experiment are given in Table 6. The preflood rainfall of 13 cm occurred during the collection of the first four samples (6 to 33 d after salt added). The 136 d soil sample was collected after the flooded rice season plus 5 cm of rainfall between plot drainage and sampling. The final soil samples were collected the next spring after 37 cm of rainfall had

Table 6. Rainfall data from 05/07/85 to 03/05/86 as reported by NEREC.

Year	Month	Pre-flood	Flood	Pre-harvest	Post-harvest
		----------------	cm	----------------	
1985	May	10.03	---	---	---
	June	3.25	7.90	---	---
	July	---	4.55	---	---
	August	---	2.84	---	---
	Sept.	---	---	5.00	0.43
	Oct.	---	---	---	10.57
	Nov.	---	---	---	12.90
	Dec.	---	---	---	4.60
1986	Jan.	---	---	---	2.74
	Feb.	---	---	---	6.20
	March	---	---	---	---
Total		13.28	15.29	5.00	37.44

GRAND TOTAL=71.01 cm.

occurred over the winter.

Soil chloride concentrations for the 293 d period are given in Table 7, while the statistical analysis is presented in Table 8. During the period prior to flooding, the presence of the sand layer affected the movement of chloride. Where the sand layer was present, the surface chloride concentrations were consistently higher than those where the sand layer was absent. These differences were significant at 15 d. At 15 and 21 d, the soil chlorides followed a similar trend for the 15, 30, and 46 cm soil depths. Using the mass balance logic described above in field experiment one and a background chloride concentration of 8 ug/g (obtained from 293 d means), little chloride was lost from the 99 cm profile during the first 33 d where the sand layer was present. Where the sand layer was absent, from 31 to 69 percent of the chloride was estimated to have been lost from the soil profile. Apparently, the sand layer prevented downward redistribution of chloride during unsaturated soil conditions.

During the period prior to flooding, lateral movement of chloride to the borrow ditch area between the plot and the levee was determined. Chloride concentrations were typical of background levels in the borrow ditch to a depth of 75 cm (data not given). Thus, lateral losses of chloride did not appear to be a factor in this study as plots had no outlets and runoff.

The chloride concentrations in the 136 d sample illustrated that substantial decreases in soil chloride over the entire soil profile occurred in response to flooding. The effect was larger in the

Table 7. Mean soil chloride concentrations in field experiment two as a function of time.

Days afer salt added	Mean soil depth (cm)						
	3.8	15	30	46	61	76	91
	------------ ug chloride/g soil -------------						
	SAND LAYER PRESENT						
6	247	27	20	17	10	7	5
15	255	30	48	48	21	12	9
21	200	40	33	46	18	14	5
33	308	42	18	18	18	15	3
136	61	35	11	11	14	14	12
293	6	9	12	14	12	9	9
	SAND LAYER ABSENT						
6	230	11	11	12	5	8	6
15	119	16	9	10	11	7	7
21	122	19	15	17	13	10	2
33	196	26	14	22	16	17	1
136	36	6	6	10	6	4	4
293	4	4	9	12	11	7	3

Table 8. Natural logarithm of mean soil chloride plus one as a function of time for field experiment two.

Days after salt added	Mean soil depth (cm)						
	3.8	15	30	46	61	75	91
	ln (Cl + 1)						
	SAND LAYER PRESENT						
6	5.51	3.30	2.98	2.86	2.32	1.91	1.68
15	5.54	3.41	3.87	3.88	3.06	2.51	2.16
21	5.30	3.68	3.49	3.82	2.90	2.65	1.68
33	5.73	3.74	2.90	2.90	2.88	2.72	1.13
136	4.11	3.55	2.43	2.40	2.62	2.61	2.51
293	1.79	2.25	2.45	2.61	2.50	2.21	2.18
	SAND LAYER ABSENT						
6	5.44	2.42	2.41	2.50	1.70	2.04	1.75
15	4.78	2.75	2.23	2.33	2.40	1.95	1.92
21	4.80	2.94	2.74	2.84	2.60	2.32	0.41
33	5.28	3.28	2.62	3.09	2.76	2.86	0.27
136	3.59	1.75	1.77	2.27	1.78	1.48	1.45
293	1.28	1.30	2.24	2.48	2.37	1.91	1.06

LSD within a row=0.60

LSD within a column=1.18

LSD between blocks=0.76

absence of the sand layer. The only decreases which were statistically significant were in the surface of both areas and the second soil depth where the sand layer was absent. Estimates of chloride masses in the soil profile at 136 d were 180 and 0 kg/ha for the sand layer present and absent plots, respectively. These chloride masses corresponded to leaching losses of 62 and 100 percent, respectively. In comparison to field experiment one, much higher chloride losses in response to flooding were found in field experiment two.

At 293 d after salt addition, soil chloride concentrations had returned to background levels. Essentially all the added chloride had been leached from the soil and the impact of the sand layer on the process disappeared.

CONCLUSIONS

Prior to flooding rice, leaching of chloride in response to rainfall was observed. Estimates of chloride losses ranged from 0 (sandy subsoil) to 31 percent of the added salt. The inclusion of a sandy subsoil layer reduced this effect presumably by limiting downward movement of water under unsaturated conditions. No lateral movement of the chloride salt was found during the period prior to flooding. After one flooded rice cropping season, redistribution of chloride to the 100 cm soil depth was observed in both field experiments. Total profile losses of chloride as a result of flooding rice were estimated to range from 62 to 100 percent of the added salt.

Removal of soluble chloride salts from the top 100 cm of Sharkey soil was complete in a 1-2 year period depending on weather conditions. In a year where the rice cropping season was followed by a wet winter (1st year of field experiment one), chloride salt was moved from the surface soil to the subsoil with profile losses of about 50 percent of the added salt. The remainderof this salt was leached from the soil profile during the second year of field experiment one. In a year where the rice cropping season was followed by a drier winter (field experiment two), total profile chloride losses neared 100 percent. These results suggested that removal of soluble salts via leaching in this soil was more efficient under less saturated soil conditions.

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