TR- 115
1981

Feasibility Study of the Effects of Water Quality on Soil Properties in the Red River Valley

C.J. Gerard
B.W. Hipp
J.R. Runkles
D.J. Bordovsky
W.G. McCully

Texas Water Resources Institute

Texas A&M University

TECHNICAL COMPLETION REPORT

FEASIBILITY STUDY OF THE EFFECTS OF WATER QUALITY ON SOIL PROPERTIES IN THE RED RIVER VALLEY

C. J. Gerard
B. W. Hipp
J. R. Runkles
D. G. Bordovsky
W. G. McCully

Contributions of Texas A&M Research and Extension Center at Chillicothe-Vernon, Dallas, Munday and Texas Water Resources Institute; College Station and supported in part by the Tulsa District, U.S. Corps of Engineers.

TECHNICAL REPORT NO. 115
Texas Water Resources Institute
Texas A&M University

August 1981

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

LIST OF FIGURES

Feasibility Study of the Effects of Water Quality on Soil Properties in the Red River Valley 1/

C.J. Gerard, B.W. Hipp, J.R. Runkles, D.G. Bordovsky
and W.G. McCully 2/

INTRODUCTION

The suitability of water for irrigation depends upon many factors, of primary concern is the quantity and quality of salts present in the water Ayers and Wescot (1) . If total dissolved solids in the irrigation water are too high, salts accumulate in the crop root zone to the extent that yields are reduced. Excessive soil salinity means the crops have difficulty extracting water from the soil solution.

The other problems with respect to salinity are concerned with the effects of water quality on permeability of soil to water. The effects of specific ions such as Na^+ or lack of salts in the water can reduce permeability to the extent that crops are not adequately supplied with water and yields are reduced. As pointed out by Rhoades and Ingvalson (7) and Frenkel, Goertzen and Rhoades (2) one of the major factors affecting the suitability of water for irrigation is its sodicity hazard usually expressed as SAR. According to these investigators, our greatest limitation in assessing the sodium hazard is our inability to predict how the water will affect soil structure and permeability. This may be because soil structural stability or instability is a function of many factors. The effect of Na^+ on soil structure can be

1/ Contributions of Texas A&M Research and Extension Center at Chillicothe-Vernon, Dallas, Munday and Texas A&M Water Resources Institute; College Station and supported in part by the Tulsa District, U.S. Corps of Engineers.

2/ Professor, Chillicothe-Vernon; Associate Professor, Dallas; Director, Water Resources Institute, College Station; Research Engineer, Munday; and formerly Professor, Chillicothe-Vernon.

modified by other soil properties such as texture, organic matter, etc.

In Texas, Naghshineh-Pour, Kunze and Carson (6) stated that sodium absorption ratio (SAR), exchangeable Na^+ percentage (ESP), electrolyte concentration, clay content, free iron oxides and clay mineral species are important factors involved in permeability of selected soils. Saffaf (9) noted the decrease of unsaturated hydraulic conductivity with decreasing electrolyte concentrations and increasing the SAR (sodium absorption ratio) of the soil solution was especially pronounced for swelling clay soils.

Water in the Red River Basin is often high in salinity and in sodium concentrations (high SAR). Studies evaluated the influences of present and "predicted after reclamation" dissolved solids (TDS) and SAR on permeability of different soils in the Red River Basin. These studies should give some insight as to the effect of present levels of SAR on soil structure and permeability. It was also the purpose of this investigation to evaluate the effects of reduced SAR and total dissolved solids(TDS) on soil permeability. The permeability to rainfall (low TDS) of soils leached with different levels of SAR and salinity was simulated and determined in the laboratory.

Description of Area

The study area shown in Figure 1 extended 1.5 miles on each side of the Red River and its major tributaries which include the North and South Forks of the Wichita River, Pease River, Elm Fork, North Fork and Prairie Dog Town Fork. The land area extends on the east from Bowie County, Texas to the west boundaries of Harmon County, Oklahoma and Hardeman County, Texas. The names of rivers and streams and Texas and Oklahoma counties in the various reaches are shown in Table 1.

Figure 1. Map of study area in Oklahoma and Texas

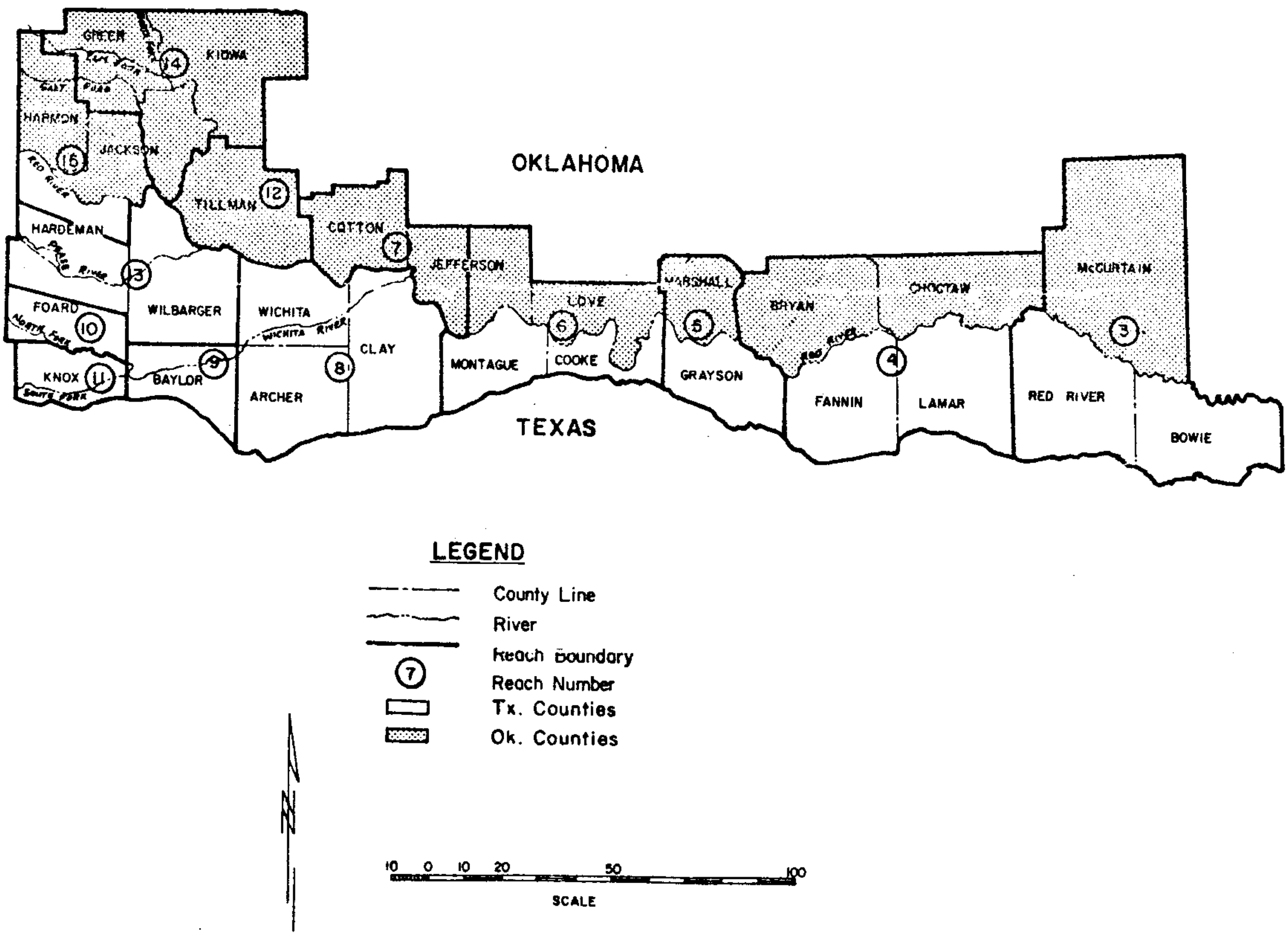


Table 1. Names of rivers and streams and the Texas and Oklahoma counties in the various reaches.

Reach	River	Texas Counties	Oklahoma Counties
3	Red River	Bowie & Red River	McCurtain
4	Red River	Lamar & Fannin	Choctaw & Bryan
5	Red River	Grayson	Marshall
6	Red River	Montague & Cooke	Love & ½ Jefferson
7	Red River	--	½ Jefferson & Cotton
8	Wichita River	Clay, Wichita & Archer	--
9	Wichita River	Baylor	--
10	North Fork Wichita River	½ Foard	--
11	South Fork Wichita River	Knox	--
12	Red River	--	Tillman
13	Pease River Elm Fork	½ Foard, Wilbarger & Hardeman	--
14	North Fork Red River	--	½ Jackson, Kiowa & Greer
15	Prairie Dog Town Fork	½ Hardeman	½ Jackson & Harmon

As shown in Table 2 the salinity and SAR of the Red River and its tributaties are relatively low in Reaches 3, 4 and 5. The salinity contents of the waters in Reach 6 (Red River), Reach 7 (Red River), Reach 8 (Wichita River) and Reach 9 (Wichita River) are similiar and moderate to moderately high with ECw of 3.9 to 5.5 mmhos/cm (Table 2). The SAR of the waters in Reaches 6 through 9 is moderate, ranging from 9-11 according to data in Table 2. Salinity levels of ECw in Reaches 10 through 15 are high to very high, ranging from 7.4 to 23.7 mmhos/cm. The SAR values of the water in these reaches are high to very high ranging in value from 15 to 33.

The reclamation program designed to remove significant total salts and Na^+ from the Red River and its tributaries as shown in Table 2 would significantly improve the water quality in Reaches 3 through 15. However, the greatest benefit in water quality due to the reductions in salt and Na^+ in the Red River and its tributaries would be in Reaches 6 through 15 (Table 2). As will be pointed out later, the investigation of the effects of water quality on soil properties will be concentrated in Reaches 6 through 15.

Soils

A General Soil Map of Texas (5) indicates that the major land resource areas west of Reach 6 are the North Central Prairies and Rolling Plains. The land areas in Clay, Archer, and a small part of Wichita counties in Texas and Jefferson County in Oklahoma are in the North Central Prairies. The remainder and most of the land area under investigation is in the Rolling Plains. Most of the soils in the area within 1.5 miles of Red River and its tributaries are coarse to medium-textured soils. Godfrey et al (5) indicate the soils in this area are mostly loamy throughout but some have sandy surface layers and some have clayey subsoils.

Table 2. Salinity and SAR of alluvium waters for various reaches of Red River under natural condition (nat) and with upstream treatment (mod.) (Time equalled or exceeded = 50%)

Reach	Status	ECw mmhos/cm	SAR 1/
3	Nat	1.13	3.5
	Mod	0.79	2.1
4	Nat	1.42	4.6
	Mod	0.97	2.8
5	Nat	1.56	5.3
	Mod	1.05	3.2
6	Nat	3.86	9.3
	Mod	1.94	3.2
7	Nat	5.00	10.8
	Mod	2.47	3.5
8	Nat	5.47	9.6
	Mod	1.50	0.9
9	Nat	4.27	10.7
	Mod	1.21	2.6
10	Nat	20.50	15.3
	Mod	5.39	3.9
11	Nat	21.69	29.6
	Mod	5.80	3.8
12	Nat	7.43	32.0
	Mod	3.33	3.9
13	Nat	21.44	22.5
	Mod	6.01	4.9
14	Nat	12.29	28.0
	Mod	2.86	3.1
15	Nat	23.70	33.2
	Mod	4.81	4.6

1/ S&R = Sodium absorption ratio (8).

Soil names like Yahola, Miles, Enterprise and Hardeman fine sandy loam and Tipton, Clairemont and Spur silt loam are most common. Abilene, Port, Mangum, Spur and Tillman clay loam soils comprise less of the soil area but are important soils along the Red River and its tributaries. Clay soils comprise a very small percentage of the soils along the various reaches of the Red River.

Soils in the Rolling Plains are low in organic matter, ranging from 0.50% on the fine sandy loam soils to about 1.0% on some clay loam soils. Bulk densities of many of these soils are high. Soils in the study area tend to puddle, crust and are susceptible to compaction. Some soils have clay type pans close to the soil surface. These properties probably play an important role in the response of these soils to water quality, specifically Na^+ or SAR.

METHODS AND MATERIALS

The salinity and SAR levels of the present or natural (nat) alluvium waters and modified (mod.) water quality of the various reaches of the Red River are given in Table 2. Natural water quality refers to the present level of total dissolved salt (TDS) and SAR in the Red River Alluvium. Modified water quality refers to the predicted levels of total dissolved salts and SAR along the reaches after reclamation or after a significant reduction of the TDS and sodium levels in the Red River and its tributaries. The natural and modified water qualities were determined or predicted by the U.S. Army Corps of Engineers of Tulsa, Oklahoma.

Soil Sampling

Three soils were sampled in each of five reaches along the Red River and its tributaries.

In order to evaluate their permeability to different water qualities, undisturbed soil cores were taken. Soil types which were selected for investigation typically are found 1 to 2 miles from the Red River and its tributaries.

A coarse-textured (fine sandy loam), medium-textured (silt loam) and fine-textured (clay loam) soil types were investigated on each reach (Table 3). The number of cores taken for each soil and reach used in saturated hydraulic conductivity evaluations for different natural and modified TDS and SAR water qualities are shown in Table 4.

Reaches which were sampled included (1) Reach 7 near Cache Creek in Okla., (2) Reach 8 on Tex. Agri. Expt. Sta. at Iowa Park, (3) Reach 13 near Vernon, Texas (4) Reach 14 near Mangum, Okla. and (5) Reach 15 near Elmer and Olustee, Okla.

Soil cores 3 inches long and 4 inches in diameter were taken in PVC tubes for depths of 0-3 and 6-9 inches. A Giddings soil sampler was used to push PVC columns to the desired depth, and a sharpshooter was used to lift the cores from the soil mass. The bottom of soil cores was trimmed and cores and soil columns were held in place with cheesecloth and rubber bands. Foam rubber was placed on top and bottom of cores during transport from field to laboratory. Cores were enclosed in plastic bags to minimize evaporation during transport and storage.

Soil Physical and Chemical Analyses

Soils were set in solutions of prescribed TDS and SAR overnight for saturation. The water qualities were fabricated in the laboratory by using different amounts of NaCl and $CaCl_2$ to achieve TDS and SAR values (Table 5) supplied by U.S. Army Corps of Engineers, Tulsa, Oklahoma. Natural concentrations equaled or exceeded 10 and 50% of the time refer to present levels of salinities in the Red River

Table 3 Soil types which were sampled and number of cores taken for reaches 7, 8, 13, 14 and 15 along the Red River.

REACH NO. 7

Soil Type	Depth Inches		No. of Cores
Yahola fine sandy loam	0-3		16
Yahola fine sandy loam	6-9		16
Tipton silt loam	0-3		16
Tipton silt loam	6-9		16
Port clay loam	0-3		16
Port clay loam	6-9		16
		Total	96

REACH NO. 8

Soil Type	Depth Inches		No. of Cores
Yahola fine sandy loam	0-3		16
Yahola fine sandy loam	6-9		16
Clairemont silt loam	0-3		16
Clairemont silt loam	6-9		16
Mangum clay loam	0-3		16
Mangum clay loam	6-9		16
		Total	96

REACH NO. 13

Soil Type	Depth Inches		No. of Cores
Yahola fine sandy loam	0-3		16
Yahola fine sandy loam	6-9		16
Tipton silt loam	0-3		16
Tipton silt loam	6-9		16
Abilene clay loam	0-3		16
Abilene clay loam	6-9		16
		Total	96

REACH NO. 14

Soil Type	Depth Inches		No. of Cores
Yahola fine sandy loam	0-3		16
Yahola fine sandy loam	6-9		16
Spur silt loam	0-3		16
Spur silt loam	6-9		16
Spur clay loam	0-3		16
Spur clay loam	6-9		16
		Total	96

REACH NO. 15

Soil Type	Depth Inches		No. of Cores
Yahola fine sandy loam	0-3		16
Yahola fine sandy loam	6-9		16
Tipton silt loam	0-3		16
Tipton silt loam	6-9		16
Tillman clay loam	0-3		16
Tillman clay loam	6-9		16
		Total	96

Table 4. The number of cores for each soil per reach used in determining hydraulic conductivity for different natural and modified TDS and SAR water qualities.

Soil depths inches	NATURAL 50% TDS SAR	NATURAL 10% TDS SAR	MODIFIED 50% TDS SAR	MODIFIED 10% TDS SAR
	Number of Cores			
0-3	4*	4*	4*	4*
6-9	4*	4*	4*	4*

* After above analyses 2 cores were placed under a 2" head of distilled water and K_s evaluated. The other 2 cores were used to determine bulk density, calcium, sodium and magnesium concentration of soil solution.

Table 5. Qualities of water used to evaluate conductivities of soils along different reaches in the Red River Basin.

Water Qualities Used in K_s Determinations

Water Quality	Percent of Time Equalled or Exceeded	Total Salt (TDS) ppm	Sodium Adsorption Ratio[1/] SAR
		REACH NO. 7	
Natural	10%	4700	10.8
Natural	50%	3315	10.8
Modified	10%	2850	3.5
Modified	50%	1635	3.5
		REACH NO. 8	
Natural	10%	4700	9.6
Natural	50%	3380	9.6
Modified	10%	3000	0.9
Modified	50%	1235	0.9
		REACH NO. 13	
Natural	10%	24000	22.5
Natural	50%	14364	22.5
Modified	10%	7800	4.9
Modified	50%	3528	4.9
		REACH NO. 14	
Natural	10%	8525	27.95
Natural	50%	7866	27.95
Modified	10%	4269	3.11
Modified	50%	1831	3.11
		REACH NO. 15	
Natural	10%	15497	33.24
Natural	50%	15169	33.24
Modified	10%	11252	4.57
Modified	50%	3078	4.57

1/

$$SAR = \frac{Na+\ meq/l}{\sqrt{\frac{Ca{+}{+}\ meq/l\ +\ Mg{+}{+}\ meq/l}{2}}}$$

Basin. Modified concentrations at 10 and 50% refer to levels of salinities in the Red River Basin predicted after deletion of selected pollution sources in and along the Red River and its tributaries.

After saturation in described solutions, 2-inch heads of the same solutions were maintained above the cores for several hours. The flow rates of 10% natural, 50% natural, 10% modified and 50% modified solutions through the cores were evaluated for several hours.

Two of the four cores leached with each saline solution described in Table 5 were placed under a 2 inch head of distilled water. The latter simulated rain water. Structural stability of the surface 3 inches of Yahola and Clairemont soils from Reach 8 (Iowa Park) after treatment with different rates of concentrated H_sSO_4 was evaluated. The relative change in saturated hydraulic conductivity (K_s) of these cores with time to distilled water was compared with cores which were not treated with concentrated H_2SO_4. Flow rates of distilled water through cores as a function of time were determined. The saturated conductivity of soils of different water qualities and distilled water was determined using the following formula: $K_s = \frac{Q\Delta L}{At\Delta H}$ (8) where Q is volume of water passing through the core per unit time (t), A is the cross sectional area of the core, ΔL is the soil depth and ΔH is the hydraulic head. K_s is in cm/hr if t is expressed in hours, Q is cm^3, and ΔH and ΔL are in cm.

The two other cores leached with saline solution were dried under a heat lamp. Cores were dried, ground and analyzed for salinity and soluble Ca^{++}, Mg^{++} and Na^{++} concentrations using an atomic absorption technique. Bulk densities and saturated moisture contents of different soils and depths were evaluated.

Attempts to measure crust strength by using a force transducer were not satisfactory. Strength was unrealistically high and core conditions did not simulate a surface crust. However, previous studies and results on soil strength or crusting by Gerard (3) evaluating the roles of moisture, drying conditions, texture and Na^+ will be included in this report. A procedure for evaluating modulus of rupture, an index of crusting is given in U.S. Salinity Handbook No. 60 (8).

In these studies effects of Na^+ and drying at 27°C and 55°C on different mixtures of sand and silt and clay on modulus of rupture were evaluated. The silt-clay fractions were mixed to fabricate soils containing (A) 20% silt-clay and 80% sand (B) 40% silt-clay and 60% sand, and (C) 60% silt-clay and 40% sand. The silt-clay fraction of mixture A had the following percentage of exchangeable cations: 1.2% Na^+, 60.2% Ca^{++} and 28.9% Mg^{++}. The silt-clay fraction of mixture B had the following percentages of exchangeable cations: 13.5% Na^+, 48.9% Ca^{++} and 17.4% Mg^{++}. More detailed procedures are outlined elsewhere (3).

RESULTS AND DISCUSSIONS

The hydraulic conductivity data for 3 soils in Reaches No. 7, 8, 13, 14, and 15 as influenced by natural and modified water qualities are reported in Tables 6-10. As expected considerable variability was experienced. The average hydraulic conductivities of these soils, especially coarse and medium-textured soils, are somewhat lower than expected ranging from about 0.5 to 2.5 cm/hr. The lower organic matter content, low amount of soil aggregation and moderate to high bulk densities probably contributed to the low to moderate permeability of Yahola, Tipton and Clairemont soils.

Water quality caused small but significant effects on hydraulic conductivities of soils in all reaches. In the case of Reach 7, soils were more

Table 6. Hydraulic conductivity (K_s-cm/hr) of 3 soils in Reach No. 7 (Cache Creek, Okla) as influenced by different water qualities.

			Water Qualities					
			Natural Total salt-ppm			Modified Total salt-ppm		
			4700 a/	3315 b/		2850 c/	1635 d/	
			SAR			SAR		
Soil Type	Depth Inches	Bulk density gm/cm^3	10.8	10.8		3.5	3.5	
			$-K_s$-cm/hr-		Ave	$-K_s$-cm/hr-		Ave
Yahola fine sandy loam	0-3	1.34	0.49	1.17	0.83	0.97	1.34	1.16
Yahola fine sandy loam	6-9	1.59	1.10	1.17	1.14	0.85	0.95	0.90
Tipton silt loam	0-3	1.33	0.86	1.33	1.10	0.97	1.47	1.22
Tipton silt loam	6-9	1.46	0.52	1.60	1.06	1.15	2.02	1.59
Port clay loam	0-3	1.35	1.53	0.36	0.95	0.40	0.43	0.42
Port clay loam	6-9	1.49	0.12	0.40	0.29	0.03	0.10	0.07
		Ave	0.77	1.01		0.73	1.05	

a/ Electrical conductivity = 7.3 mmhos/cm

b/ Electrical conductivity = 5.2 mmhos/cm

c/ Electrical conductivity = 4.5 mmhos/cm

d/ Electrical conductivity = 2.6 mmhos/cm

Sign (0.01): Soil, water quality and soil x depth and soil x water interactions

Table 7. Hydraulic conductivity (K_s-cm/hr) of 3 soils in Reach No. 8 (Iowa Park, Texas) as influenced by different water qualities.

			Water Qualities					
			Natural Total salt-ppm			Modified Total salt-ppm		
			4700 a/	3380 b/		3000 c/	1235 d/	
			SAR			SAR		
Soil Type	Depth Inches	Bulk density gm/cm^3	9.6	9.6	Ave	0.9	0.9	Ave
			K_s-cm/hr			K_s-cm/hr		
Yahola Fine sandy loam	0-3	1.49	0.45	0.45	0.45	1.08	0.94	1.01
	6-9	1.47	1.85	2.06	1.96	2.18	1.30	1.74
Clairemont silt loam	0-3	1.36	0.93	1.22	1.08	1.27	1.49	1.38
	6-9	1.47	1.97	2.34	2.16	0.38	0.66	0.52
Mangum clay loam	0-3	1.31	0.91	0.06	0.49	0.23	0.06	0.15
	6-9	1.49	0.28	0.20	0.24	0.12	0.25	0.19
		Ave	1.07	1.06		0.88	0.78	

a/ Electrical conductivity = 7.3 mmhos/cm

b/ Electrical conductivity = 5.3 mmhos/cm

c/ Electrical conductivity = 4.7 mmhos/cm

d/ Electrical conductivity = 1.9 mmhos/cm

Sign (0.01): Soil, depth and soil x depth interactions

Sign (0.05): Soil x water quality and depth x water quality interactions

Table 8. Hydraulic conductivity (K_s-cm/hr) of 3 soils in Reach No. 13 (Vernon, Texas) as influenced by different water qualities.

			Water Qualities					
			Natural Total salt-ppm			Modified Total salt-ppm		
			24000 a/	14364 b/		7800 c/	3528 d/	
			SAR			SAR		
Soil Type	Depth Inches	Bulk density gm/cm^3	22.5	22.5		4.9	4.9	
			$-K_s$-cm/hr-		Ave	$-K_s$-cm/hr-		Ave
Yahola fine sandy loam	0-3	1.37	2.64	2.52	2.57	2.17	2.65	2.41
Yahola fine sandy loam	6-9	1.59	1.44	1.06	1.25	0.99	1.16	1.08
Tipton silt loam	0-3	1.38	0.63	0.23	0.43	0.54	1.28	0.91
Tipton silt loam	6-9	1.52	0.50	0.19	0.35	1.47	0.25	0.86
Abilene clay loam	0-3	1.45	0.80	0.32	0.56	0.10	0.20	0.15
Abilene clay loam	6-9	1.57	0.04	0.14	0.09	0.03	0.14	0.09
		Ave	1.01	0.74		0.88	0.95	

a/ Electrical conductivity = 37.5 mmhos/cm

b/ Electrical conductivity = 22.4 mmhos/cm

c/ Electrical conductivity = 12.2 mmhos/cm

d/ Electrical conductivity = 5.5 mmhos/cm

Sign (0.01): Soil, depth and soil x depth interaction

Table 9. Hydraulic conductivity (K_s-cm/hr) of 3 soils in Reach No. 14 near Mangum, OK as influenced by different water qualities.

			Water Qualities					
			Natural Total salt-ppm			Modified Total salt-ppm		
			8525[b/]	7865[c/]		4630[d/]	1830[e/]	
			SAR			SAR		
			28.0	28.0		3.1	3.1	
Soil Type	Depth Inches	Bulk density gm/cm^3	K_s-cm/hr		Ave.	K_s-cm/hr		Ave.
Yahola fine sandy loam	0-3	1.63	5.35	5.38	5.37	8.13	7.81	7.94
Yahola fine sandy loam	6-9	1.63	4.89	4.71	4.80	4.83	1.33	3.06
Spur silt loam	0-3	1.41	0.06	0.66	0.36	2.39	0.50	1.45
Spur silt loam	6-9	1.57	0.86	0.99	0.93	0.58	0.48	0.53
Spur clay loam	0-3[a/]	1.20	2.11	2.64	2.38	6.40	3.72	5.06
Spur clay loam	6-9[a/]	1.22	4.03	7.93	5.98	6.30	6.09	6.20
		Ave.[f/]	2.79	2.94		3.98	2.53	

[a/] K_s data for Spur clay loam are not considered reliable. Soil was dry when sampled and severely cracked. Variability between duplicate core was too high to be analyzed.

[b/] Electrical conductivity = 13.3 mmhos/cm

[c/] Electrical conductivity = 12.3 mmhos/cm

[d/] Electrical conductivity = 7.2 mmhos/cm

[e/] Electrical conductivity = 2.9 mmhos/cm

[f/] Average of Yahola and Spur silt loam and not Spur clay loam.

Sign (0.01): Soil, depth, soil x depth and depth x water. Sign (0.05): Water

Table 10. Hydraulic conductivity (K_s-cm/hr) of 3 soils in Reach No. 15 near Elmer and Olustee, Okla. as influenced by different water qualitites.

			Water Qualities					
			Natural Total salt-ppm			Modified Total salt-ppm		
			15500 1/	15170 2/		11240 3/	3080 4/	
			SAR			SAR		
			33.2	33.2		4.6	4.6	
Soil Type	Depth Inches	Bulk density gm/cm^3	K_s-cm/hr		Ave	K_s-cm/hr		Ave
Yahola fine sandy loam	0 - 3	1.33	0.46	0.74	0.60	1.04	0.87	0.96
	6 - 9	1.57	0.33	0.18	0.26	0.34	0.20	0.27
Tipton silt loam	0 - 3	1.29	3.34	2.83	3.09	2.65	3.19	2.92
	6 - 9	1.48	0.17	0.31	0.24	0.10	0.24	0.17
Tillman clay loam	0 - 3	1.23	2.21	0.69	1.45	1.34	1.74	1.54
	6 - 9	1.40	0.06	0.03	0.05	0.06	0.03	0.05

1/ Electrical conductivity = 24.2 mmhos/cm

2/ Electrical conductivity = 23.7 mmhos/cm

3/ Electrical conductivity = 17.6 mmhos/cm

4/ Electrical conductivity = 4.8 mmhos/cm

Sign (0.01) Soil, depth and soil x depth interaction.

permeable to the waters with 3315 and 1635 ppm than to waters with 4700 and 2850 ppm. As shown in Table 6 hydraulic conductivity of soils in Reach 7 also showed significant soil x depth and soil x water interactions.

Hydraulic conductivities of soils in Reach 8 as shown in Table 7 were influenced by soils, depth and interactions of soil x depth, soil x water quality and depth x water quality. Hydraulic conductivities of soil in Reach 13 (Table 8) were influenced by soils, depth and soil x water interaction.

Hydraulic conductivities of soils in Reach 14 leached with 4630 ppm and an SAR of 3.1 were slightly higher than hydraulic conductivities of soils leached with other water qualities (Table 9). As shown in Table 9 hydraulic conductivities of soils in Reach 14 were significantly influenced by soils, depth, water, soil x depth and depth x water interactions. As shown in Table 10, hydraulic conductivities of soils in Reach 15 were influenced by soils, depth and soil x depth interaction.

A number of factors, as shown in Tables 6-10, significantly influenced hydraulic conductivity of soils. However, the only common and significant factor which consistently influenced hydraulic conductivity was soil texture. Saturated moisture content for different soils, an index of soil texture, is shown in Table 11. Saturated moisture content is related to clay content, and as shown in Figure 2, saturated hydraulic conductivity of soils is inversely related to saturated moisture content of soil or to clay content. Other effects and factors caused relatively small and inconsistent differences in saturated hydraulic conductivity of soils.

However, as shown in Figures 3-9 the residual effects from leaching a soil with water with a relatively high SAR on permeability of soils subsequently leached with distilled water gives an excellent testimonial to the

Table 11. Saturated soil moisture content of different soils in different reaches along the Red River.

Soils Type	Depth Inches	Saturated Soil Moisture Content %
	Reach No. 7	
Yahola fine sandy loam	0-3	32.8
Yahola fine sandy loam	6-9	33.0
Tipton silt loam	0-3	29.4
Tipton silt loam	6-9	30.8
Port clay loam	0-3	36.3
Port clay loam	6-9	37.1
	Reach No. 8	
Yahola fine sandy loam	0-3	30.9
Yahola fine sandy loam	6-9	32.2
Clairemont silt loam	0-3	36.5
Clairemont silt loam	6-9	37.9
Mangum clay loam	0-3	41.1
Mangum clay loam	6-9	44.4
	Reach No. 13	
Yahola fine sandy loam	0-3	31.6
Yahola fine sandy loam	6-9	31.2
Tipton silt loam	0-3	35.1
Tipton silt loam	6-9	35.8
Abilene clay loam	0-3	40.1
Abilene clay loam	6-9	39.7
	Reach No. 14	
Yahola fine sandy loam	0-3	21.9
Yahola fine sandy loam	6-9	25.2
Spur silt loam	0-3	35.5
Spur silt loam	6-0	32.9
Spur clay loam*	0-3	58.9
Spur clay loam*	6-9	60.9
	Reach No. 15	
Yahola fine sandy loam	0-3	30.4
Yahola fine sandy loam	6-9	31.6
Tipton silt loam	0-3	30.2
Tipton silt loam	6-9	34.3
Tillman clay loam	0-3	44.3
Tillman clay loam	6-9	47.3

*Could be classified as clay soil.

Figure 2. Relationship between saturated soil moisture and saturated hydraulic conductivity of soils in the Red River Basin.

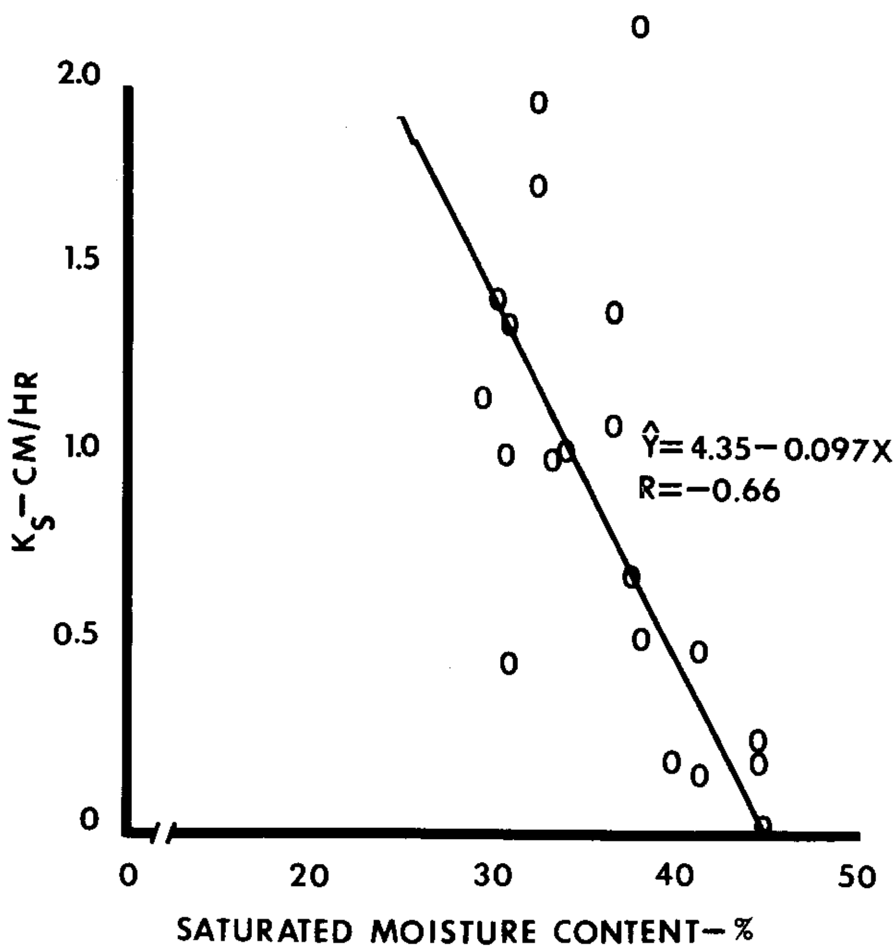


Figure 3. Saturated hydraulic conductivities (K_s) in cm/hr as a function of time of cores of Yahola fine sandy loam (Reach 8) to distilled water after being leached with waters of indicated qualities for several hours.

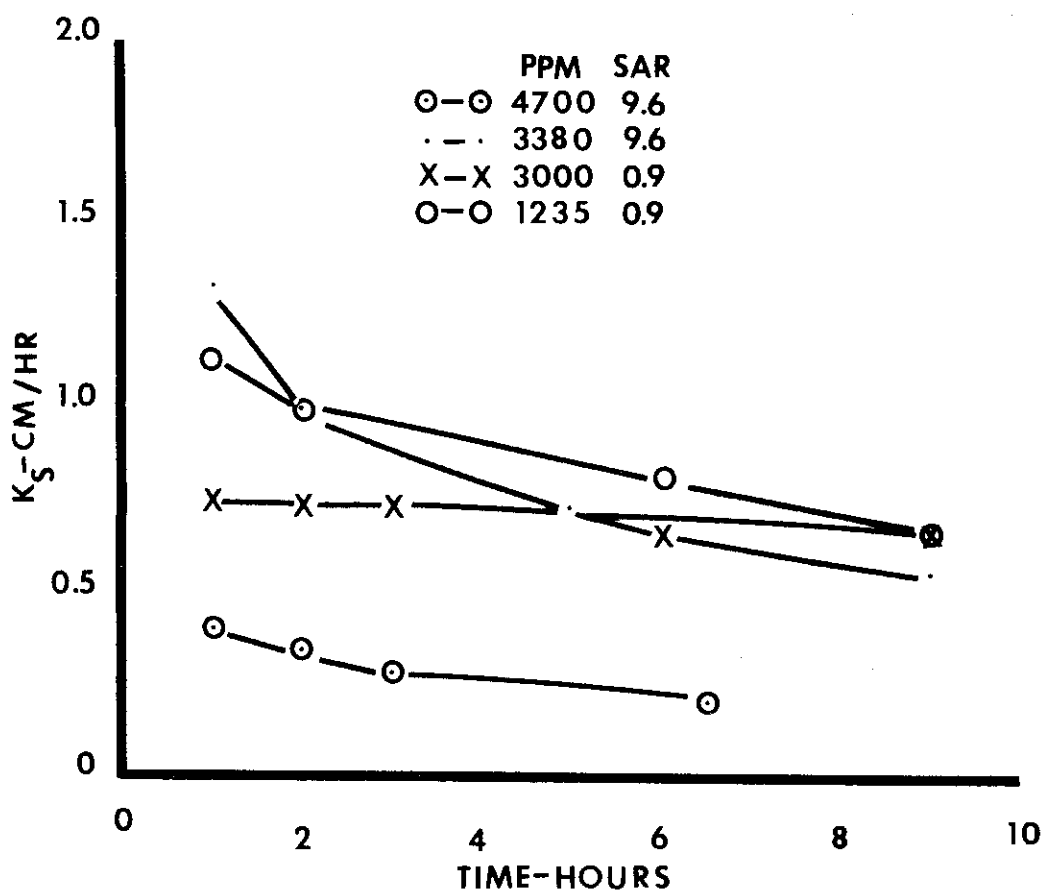


Figure 4. Saturated hydraulic conductivities (K_s) in cm/hr as a function of time of cores of Clairemont silt loam (Reach 8) to distilled water after being leached with waters of indicated qualities for several hours.

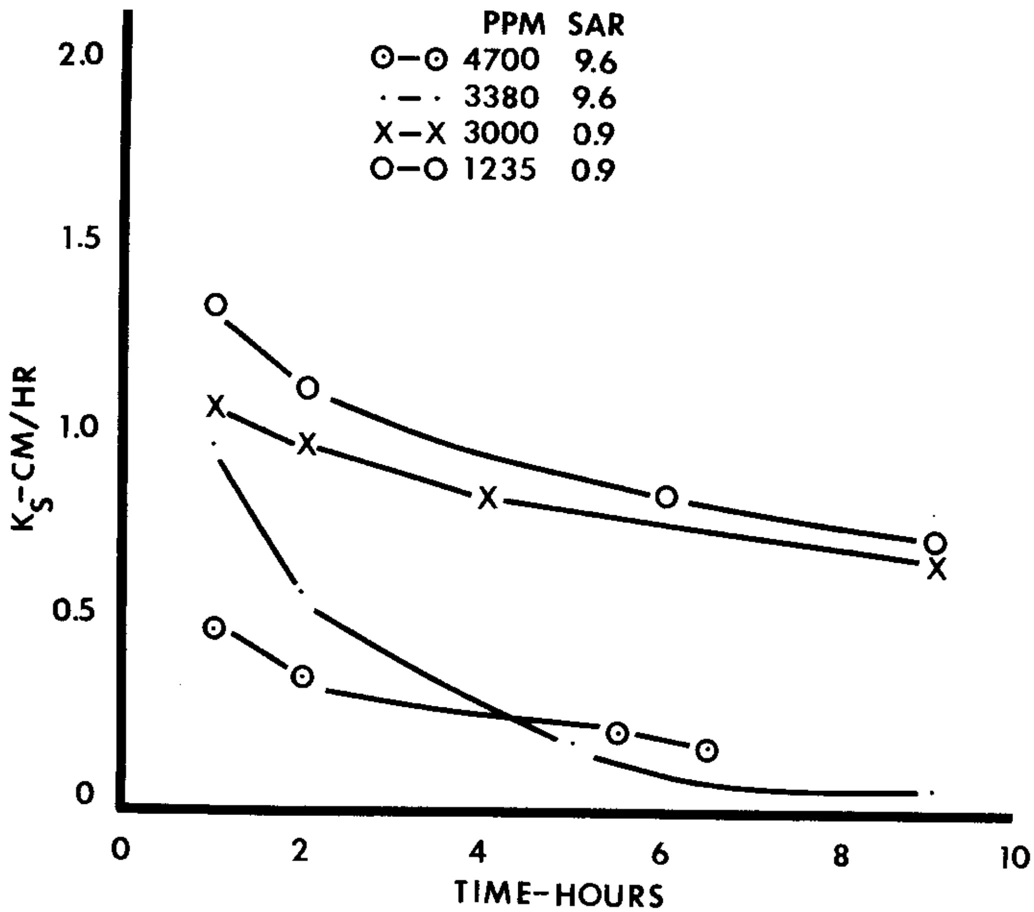


Figure 5. Saturated hydraulic conductivities (K_s) in cm/hr as a function of time of Yahola fine sandy loam (Reach 13) to distilled water after being leached with waters of indicated qualities for several hours.

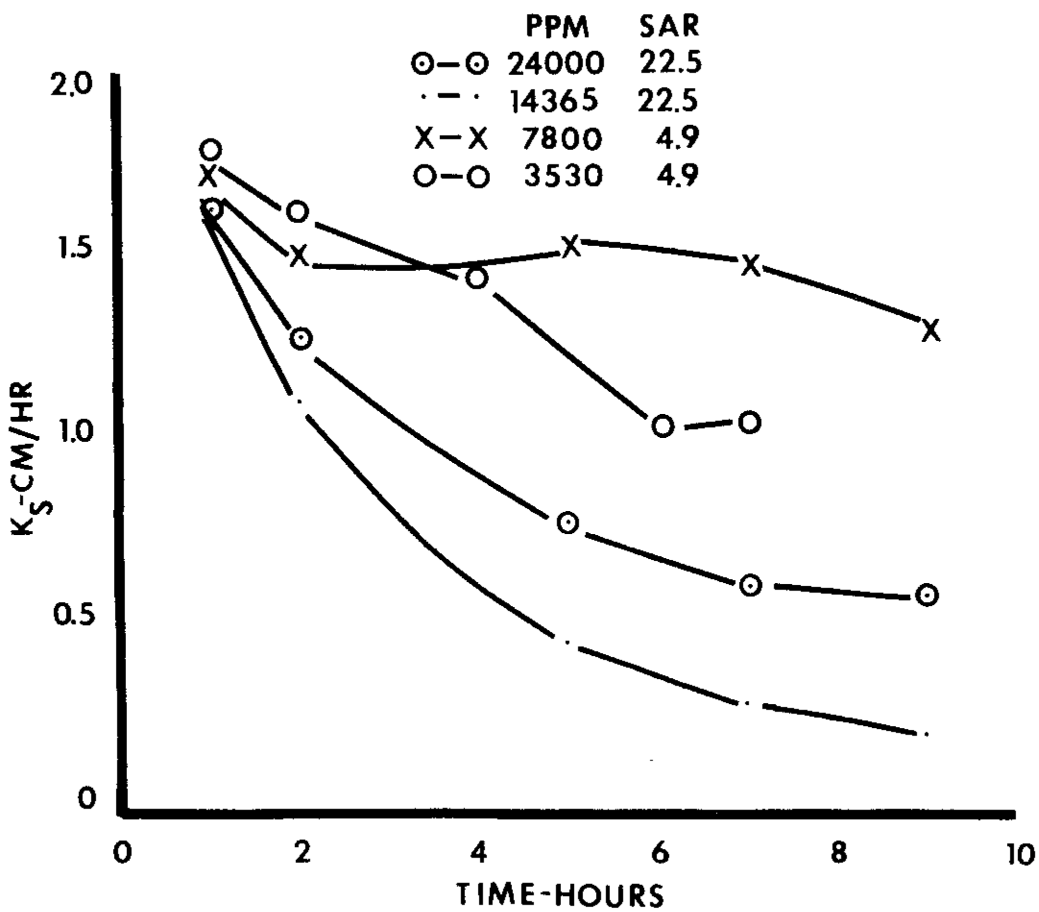


Figure 6. Saturated hydraulic conductivities (K_s) in cm/hr as a function of time of Tipton silt loam (Reach 13) to distilled water after being leached with waters of indicated qualities for several hours.

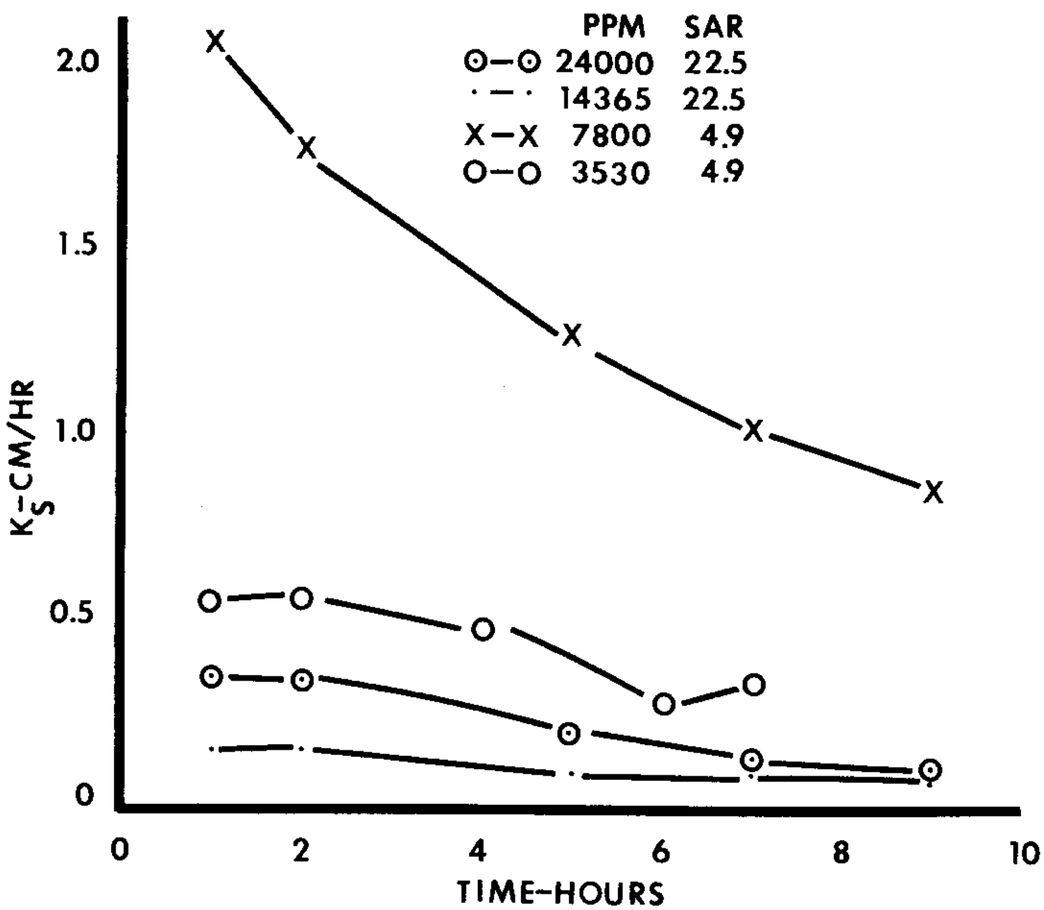


Figure 7. Saturated hydraulic conductivities (K_s) in cm/hr as a function of time of Yahola fine sandy loam and Tipton silt loam (Reach 7) to distilled water after being leached with waters of indicated qualities for several hours.

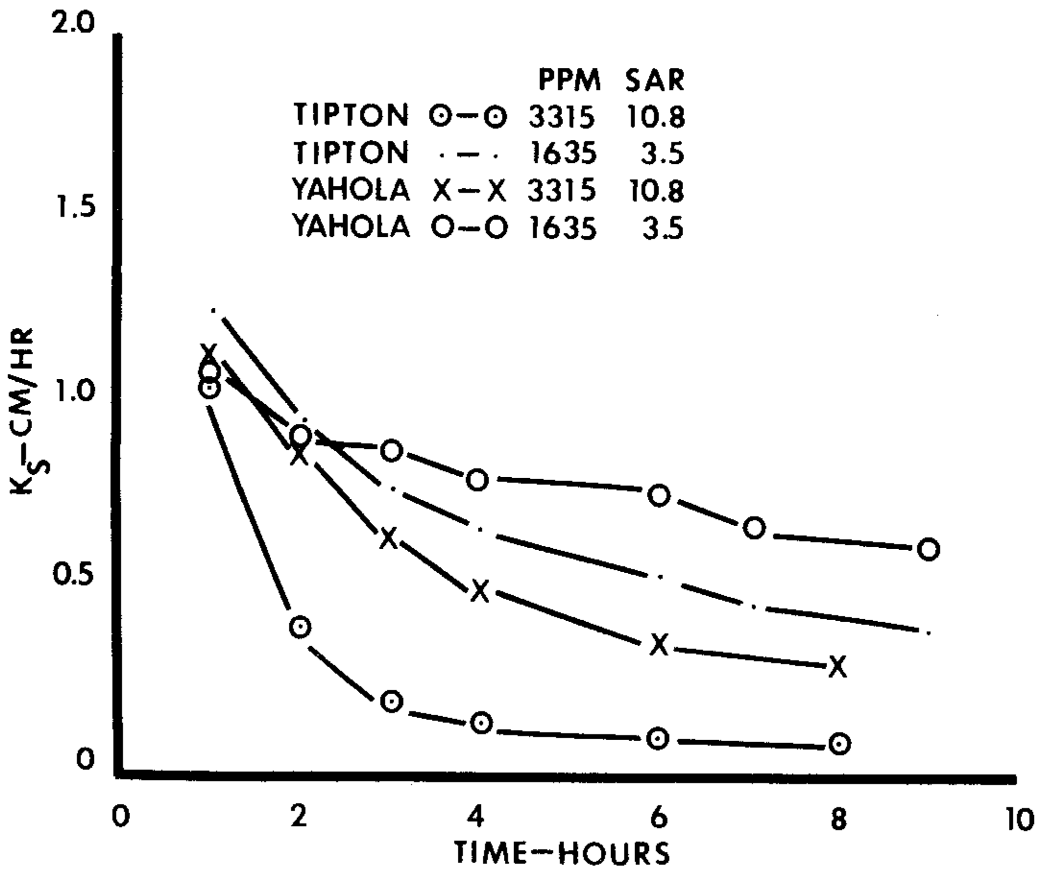


Figure 8. Saturated hydraulic conductivities in cm/hr as a function of time of Yahola fine sandy loam (Reach 14) to distilled water after being leached with water of indicated qualities for several hours.

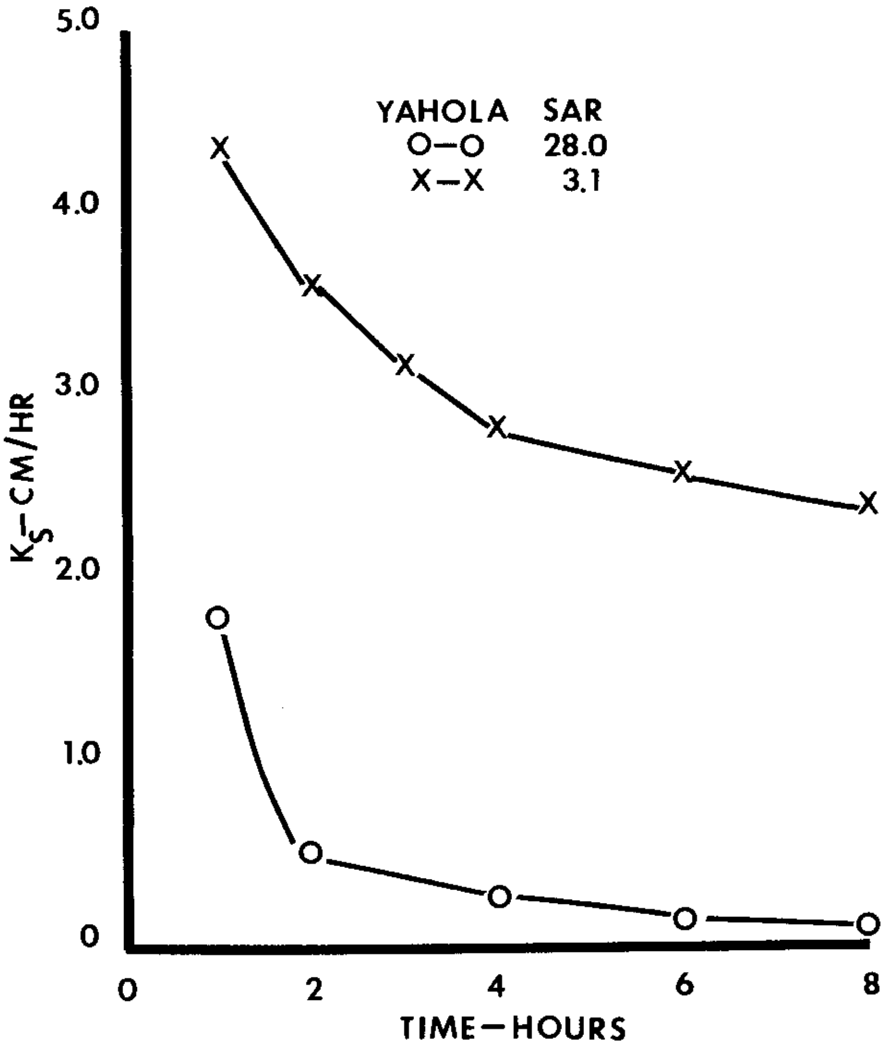
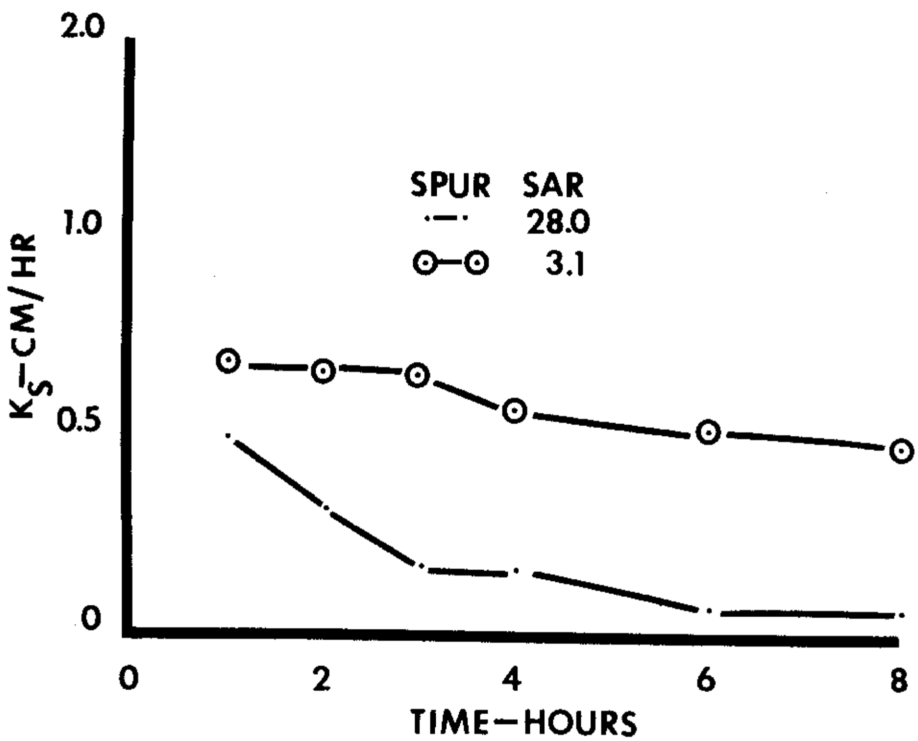


Figure 9. Saturated hydraulic conductivities in cm/hr as a function of time of Spur silt loam (Reach 14) to distilled water after being leached with water of indicated qualities for several hours.



adverse effect of Na^+ on soil structure and permeability. The permeability of the coarse and medium-textured Yahola, Tipton, Clairemont and Spur soils to distilled water decreases with time (Figures 3-9). This was particularly true of soils leached with saline waters having SAR values greater than 5 (Figure 10). After reclamation of present water supplies in the Red River, as shown in Table 2, the SAR of water on all reaches would be less than 5. After 1 to 2 hours of leaching with distilled water the Yahola, Clairemont, Tipton and Spur soils in Reaches 8, 13 and 14 initially leached with moderate to high SAR levels were highly puddled. The amount of clay in the leachate of Yahola fine sandy loam (Reach 14) as a function of time is shown in Figure 11. The leachates contained high concentrations of clay. The latter would clog up or reduce the size of the macropores in soils; thereby significantly reducing the permeability of the soil to water, especially permeability to water with low levels of electrolyte such as rain water.

The distilled water leachate of Yahola and Tipton soils in Reach 7 contained considerable clay regardless of the quality of the prior leachate. However, the Yahola and Tipton soils leached with water with an SAR of 10.8 puddled quicker and lost their ability to conduct distilled water faster than when they were leached with waters having an SAR of 3.5 (Figure 7). The meaning of the response differences between reaches is not clear; however, research (4) has shown that antecedent soil moisture suction and management can influence the ability of soil to conduct water.

As pointed out previously many soils in the Rolling Plains, such as the Yahola, Clairemont and Tipton soils, are low in organic matter with weak or poor structure. Because of their weak structure, these soils quickly puddle and

Figure 10. Saturated hydraulic conductivities (K_s) in cm/hr after 8 hours to distilled water of medium-textured soils leached with different SAR waters.

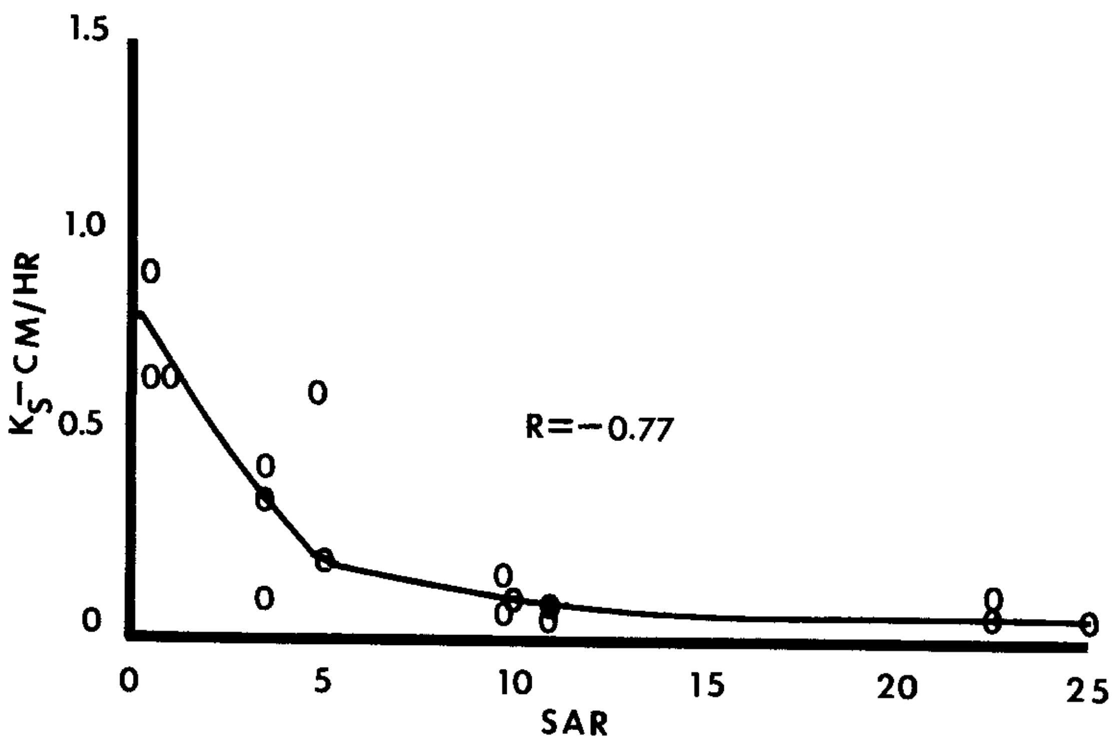
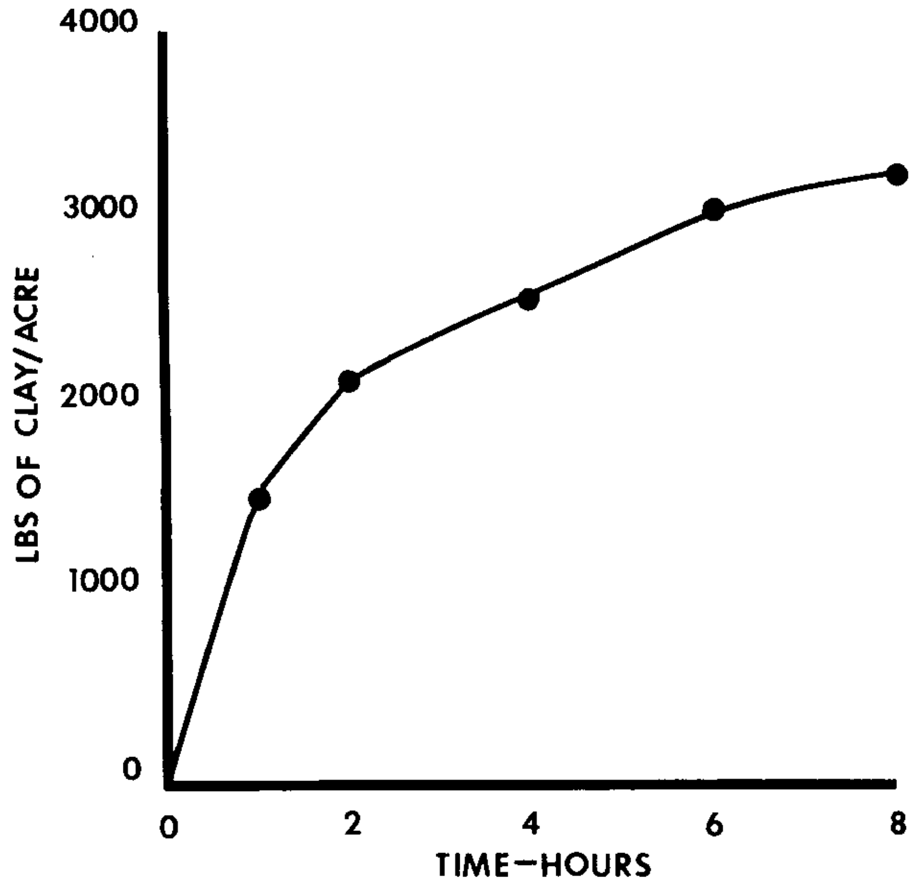


Figure 11. Accumulative amounts of clay in pounds/acre (percolating through soils during leaching with distilled water) as a function of time of Yahola fine sandy loam (Reach 14) which was initially leached with water with SAR of 28.0.



lose their ability to conduct rain water and therefore are subject to runoff, wind and water erosion. The loss of conductivity to distilled water which simulates rain water of Yahola and Clairemont soils is shown in Figures 12 and 13. As shown in Figures 12 and 13, soil surface conditions can be modified by additions of amendments such as H_2SO_4 (8). Amendments are used to replace exchangeable Na^+ and therefore decrease its deleterious effects. The Yahola and Clairemont soils have SAR's of 10 to 14, which correspond to the SAR of the water from Lake Kemp used to irrigate these soils. The choice of a chemical amendment may be influenced by the time required for its reaction (8). Sulfuric acid is a quick acting amendment. However, additions of amendments to modify soil permeability are often expensive, and also their effectiveness is often temporary.

In the Rolling Plains, structural maintenance or improvement on soils such as the Yahola and Clairment, is probably a continual process which depends upon periodic additions of plant residues. Management practices such as minimum tillage or cropping systems are needed which maintain or increase the residue and organic matter levels of most Rolling Plains soils.

The salinities of soil solutions from soils in Reaches 7, 8, 13, 14 and 15 are shown in Tables 12-16. Obviously, the cores did not attain chemical equilibrium. This was particularly true of soils having low hydraulic conductivities. However, it is assumed that part of the soil columns, especially those of the more permeable Yahola, Tipton and Clairemont soils, attained some level of equilibrium with the saline leaching solutions. The responses obtained are believed indicative of the permeability characteristics of these soils after irrigation with different quality waters.

Figure 12. The relative change with time in saturated hydraulic conductivity (K_s) to distilled water of the 0-3 inch depth of a Yahola fine sandy loam in Reach 8 not treated and surface treated with 5.5 meq/100 gms of concentrated H_2SO_4.

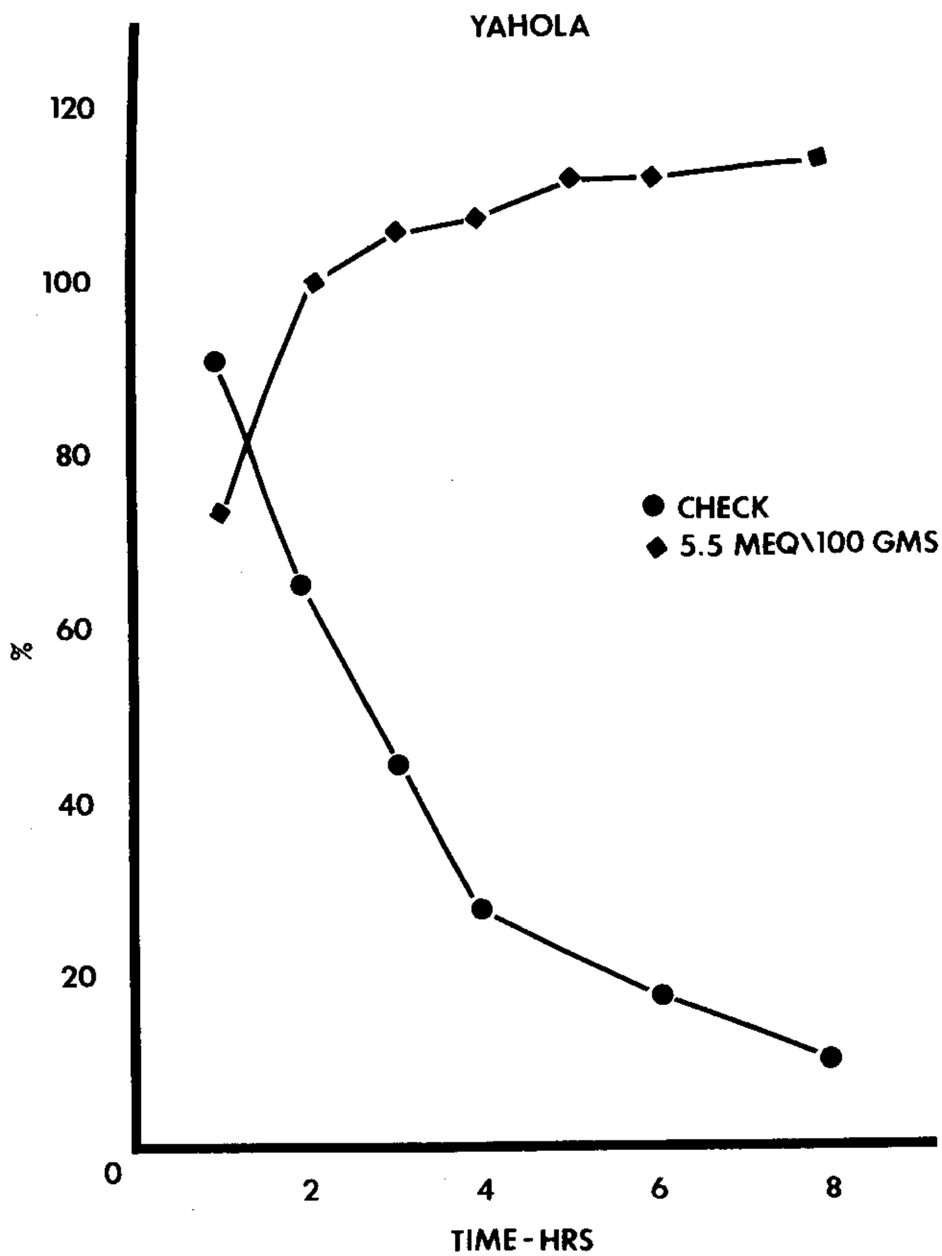


Figure 13. The relative change with time in saturated hydraulic conductivity (K_s) to distilled water of the 0-3 inch depth of a Clairemont silt loam in Reach 8 not treated and surface treated with 11 meq/100 gms of concentrated H_2SO_4.

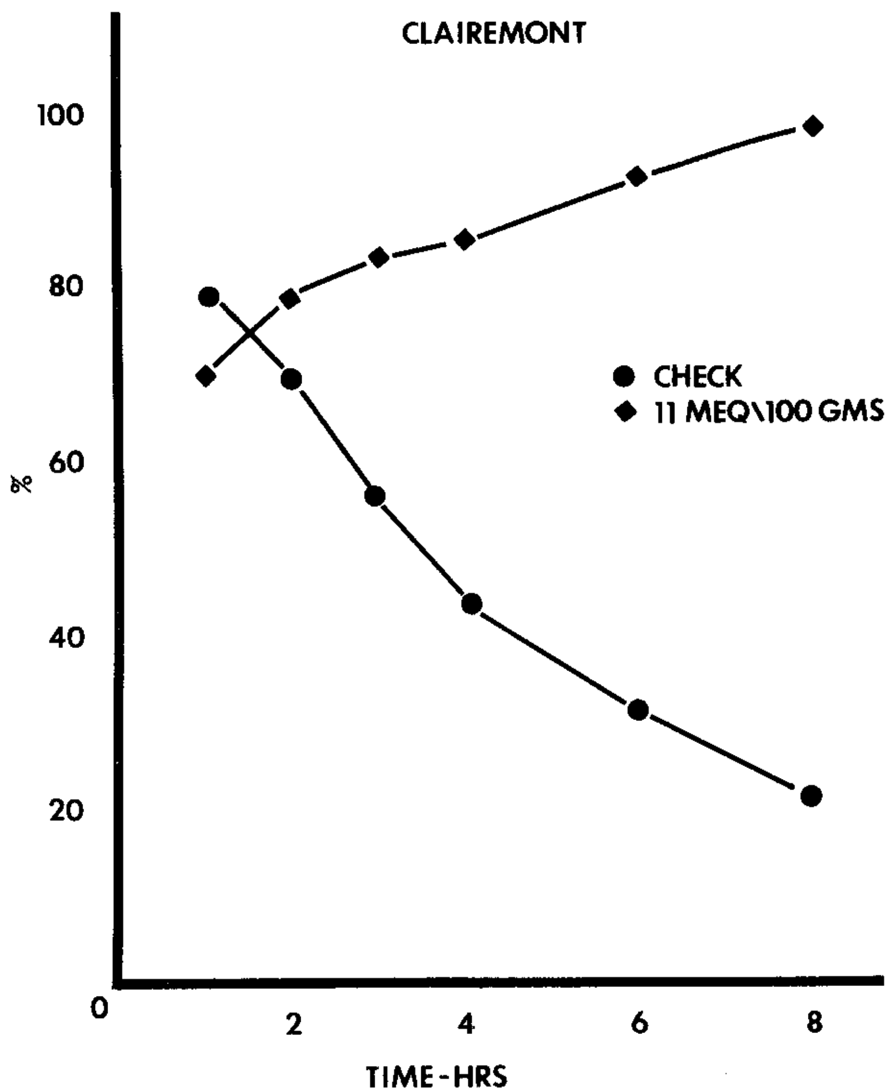


Table 12 Salinity of soils in Reach 7 after leaching with waters of different qualities.

		Water Qualities			
		Natural Total salt-ppm		Modified Total salt-ppm	
		4700	3315	2850	1635
		SAR		SAR	
Soil Type	Depth Inches	10.8	10.8	3.5	3.5
		mmhos/cm		mmhos/cm	
Yahola fine sandy loam	0-3	5.0	4.0	3.8	2.5
Yahola fine sandy loam	6-9	4.7	3.6	3.0	2.0
Tipton silt loam	0-3	5.7	4.0	3.6	2.4
Tipton silt loam	6-9	4.8	3.6	3.4	2.0
Port clay loam	0-3	5.1	3.0	2.6	2.3
Port clay loam	6-9	2.0	3.4	1.8	1.8

Table 13. Salinity of soils after leaching with waters of different qualities (Reach 8).

		Water Qualities			
		Natural Total salt-ppm		Modified Total salt-ppm	
		4700	3380	3000	1235
		SAR		SAR	
		9.6	9.6	0.9	0.9
Soil Type	Depth Inches	Soil Salinity mmhos/cm		Soil Salinity mmhos/cm	
Yahola fine sandy loam	0-3	4.6	4.1	3.4	2.3
Yahola fine sandy loam	6-9	5.1	3.9	3.9	2.3
Clairemont silt loam	0-3	5.1	4.6	3.9	2.2
Clairemont silt loam	6-9	4.8	3.6	3.4	2.0
Mangum clay loam	0-3	5.8	4.7	4.5	3.7
Mangum clay loam	6-9	6.0	5.3	4.4	5.6

Table 14. Soil salinity of soils in Reach 13 after leaching soil core with different quality waters.

		Natural Total salt-ppm		Modified Total salt-ppm	
		24000	14364	7800	3528
		SAR		SAR	
Soil Type	Depth Inches	22.5	22.5	4.9	4.9
		mmhos/cm		mmhos/cm	
Yahola fine sandy loam	0-3	27.9	17.0	9.0	4.8
Yahola fine sandy loam	6-9	31.5	16.6	9.3	4.3
Tipton silt loam	0-3	24.0	12.0	7.1	3.7
Tipton silt loam	6-9	14.3	12.2	7.5	2.6
Abilene clay loam	0-3	17.6	6.2	4.5	1.8
Abilene clay loam	6-9	10.7	5.5	3.0	1.9

Table 15. Salinity of soils in Reach 14 after leaching with water of different qualities.

		Natural Total salt-ppm		Modified Total salt-ppm	
		8525	7865	4630	1830
		SAR		SAR	
	Depth	28.0	28.0	3.1	3.1
Soil Type	Inches	mmhos/cm		mmhos/cm	
Yahola fine sandy loam	0-3	9.8	6.4	5.1	3.1
Yahola fine sandy loam	6-9	9.0	7.1	4.8	2.7
Spur silt loam	0-3	5.9	7.8	5.0	3.1
Spur silt loam	6-9	8.9	8.5	4.5	3.0
Spur clay loam	0-3	4.0	6.7	3.8	2.2
Spur clay loam	6-9	4.7	6.7	3.9	2.2

Table 16. Salinity of soils in Reach 15 after leaching with waters of different qualities.

Soil type	Soil depth inches	Natural Total salt-ppm 15500 SAR 33.2 mmhos/cm	Natural Total salt-ppm 15170 SAR 33.2 mmhos/cm	Modified Total salt-ppm 11240 SAR 4.6 mmhos/cm	Modified Total salt-ppm 3080 SAR 4.6 mmhos/cm
Yahola fine sandy loam	0 - 3	23.8	22.4	14.8	8.6
Yahola fine sandy loam	6 - 9	23.4	24.4	14.5	12.3
Tipton silt loam	0 - 3	14.0	20.4	9.6	3.2
Tipton silt loam	6 - 9	9.9	13.8	6.4	3.2
Tillman clay loam	0 - 3	16.5	16.4	10.7	4.3
Tillman clay loam	6 - 9	7.9	7.3	6.8	2.7

The Na^+, Ca^{++}, and Mg^{++} concentrations of variously treated soils in Reaches 7, 8, 13, 14 and 15 are shown in Tables 17-21. Soils in Reach 8 are irrigated with water from Lake Kemp and Lake Diversion. Quality of this water averages about 3000 to 4000 ppm (4.7 to 6.2 mmhos/cm) with an SAR of 10 to 14. The Yahola in Reach 15 was from a saline seep. As expected the SAR of the soil solutions, at these locations, expecially the Mangum soils and Yahola fine sandy loam, are relatively high. Salinities of soils at time of sampling are reported in Table 22.

Soil strength as influenced by soil texture, drying rate, moisture, and low (Mixture A) and moderate to high exchangeable Na^{++} (Mixture B) is reported in Figures 14, 15, and 16 and Figures 17, 18 and 19, respectively. These data indicate that strength of the surface crust of soil or crusting is increased by clay, slow drying, low soil moisture and Na^+. Sodium increased maximum crust strength by better than 50%, as shown in Figures 14-19. Typically, slow drying and the dispersing action of Na^+ increased close-packing of soil particles and therefore soil strength.

CONCLUSIONS

Hydraulic conductivity of soil varying in salinity was inversely related to saturated soil moisture or clay content. As expected, soils with increased clay would tend to accumulate salt faster under irrigation than the more permeable soils. This would mean that soils with increased clay would need greater care in management. Occasional monitoring of soil salinity of soils which tend to accumulate salts is a desirable management practice. However, it should be emphasized that all the soils investigated had physical properties which would make them suitable for irrigation.

Table 17 Calcium (Ca++) Mg++ and Na+ and calculated SAR concentrations of soil solutions of different soils and depths after leaching with waters of different qualities in Reach 7.

		Natural Total Salt-ppm								Modified Total Salt-ppm							
		4700				3315				2850				1635			
		SAR 10.8				SAR 10.8				SAR 3.5				SAR 3.5			
		Ca++	Mg++	Na+		Ca++	Mg++	Na+		Ca++	Mg++	Na+		Ca++	Mg++	Na+	
Soil Types	Depth Inches	PPM			SAR	PPM			SAR	PPM			SAR	PPM			SAR
Yahola fine Sl	0 - 3	525	37	548	6.2	300	20	508	7.7	531	21	249	2.9	341	19	162	2.3
Yahola fine Sl	6 - 9	466	24	548	6.7	278	24	408	6.3	406	21	319	4.2	219	17	125	2.2
Tipton Sl	0 - 3	372	44	654	8.5	234	26	438	7.2	405	28	248	3.2	212	25	162	2.8
Tipton Sl	6 - 9	462	61	469	5.4	266	41	385	5.8	344	42	218	2.9	188	32	188	3.3
Port Cl	0 - 3	500	62	550	6.2	256	42	249	3.8	249	43	169	2.6	225	39	191	3.1
Port Cl	6 - 9	272	32	162	3.0	225	42	344	5.5	256	30	131	2.1	155	28	116	2.2

Table 18. Calcium (Ca^{++}) Mg^{++} and Na^{+} and calculated SAR concentrations of soil solutions of different soils and depths after leaching with waters of different qualities in Reach 8.

		Natural Total Salt-ppm								Modified Total Salt-ppm							
		4700				3380				3000				1235			
		SAR 9.6				SAR 9.6				SAR 0.9				SAR 0.9			
Soil Type	Depth Inches	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR
Yahola Sl	0-3	327	37	538	7.5	263	25	495	7.9	462	40	158	1.9	176	17	233	4.5
	6-9	352	26	574	8.0	266	18	438	7.0	566	20	118	1.3	176	15	242	4.8
Clairemont Sl	0-3	387	45	500	6.4	322	33	567	8.1	443	59	214	2.6	229	25	128	2.2
	6-9	338	41	603	8.3	185	18	441	8.3	170	40	771	13.9	110	10	326	8.0
Mangum CL	0-3	281	59	825	11.7	217	45	760	12.4	222	57	710	11.0	282	45	995	14.6
	6-9	298	60	849	11.8	218	30	798	13.4	250	38	770	12.0	236	29	394	6.5

Table 19. Calcium (Ca++), Mg++ and Na+ and calculated SAR concentrations of soil solutions of different soils and depths after leaching with waters of different qualities in Reach 13.

		Natural Total salt-ppm								Modified Total salt-ppm							
		24000				14365				7800				3530			
		SAR 22.5				SAR 22.5				SAR 4.9				SAR 4.9			
Soil Type	Depth inches	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR	Ca++ PPM	Mg++ PPM	Na+ PPM	SAR
Yahola fine Sl	0 - 3	2656	33	3525	18.6	1600	26	2791	19.0	1338	21	602	4.5	616	34	436	4.6
Yahola fine Sl	6 - 9	2738	38	3556	18.5	1372	46	2493	18.0	1466	53	619	4.3	402	40	557	4.5
Tipton Sl	0 - 3	2241	161	2663	14.7	1004	175	1338	10.3	875	125	339	2.8	422	64	314	3.8
Tipton Sl	6 - 9	1514	169	1644	10.1	1084	157	1299	9.8	1047	126	427	3.4	332	86	89	1.2
Abilene Cl	0 - 3	1762	131	3147	22.1	680	104	432	4.1	600	92	225	2.2	211	37	190	3.1
Abilene Cl	6 - 9	1172	144	755	5.5	649	96	405	3.9	350	54	94	1.3	225	35	103	1.7

Table 20. Calcium, Mg++ and Na+ and calculated SAR concentrations of soil solutions of different soils and depths after leaching with waters of different qualities in Reach 14.

		Natural Total Salt-ppm								Modified Total Salt-ppm							
		4700				3315				2850				1635			
		SAR 27.9				SAR 27.9				SAR 3.1				SAR 3.1			
		PPM				PPM				PPM				PPM			
Soil Types	Depth Inches	Ca++	Mg++	Na+	SAR	Ca++	Mg++	Na+	SAR	Ca++	Mg++	Na+	SAR	Ca++	Mg++	Na+	SAR
Yahola fine sandy loam	0 - 3	454	17	1819	21.0	264	16	1125	18.9	685	24	262	2.7	357	25	203	2.8
Yahola fine sandy loam	6 - 9	466	19	1637	20.3	265	14	1174	19.4	656	20	249	2.6	313	21	163	2.4
Spur silt loam	0 - 3	581	35	660	7.1	445	25	1096	13.7	701	25	258	2.6	372	35	152	2.0
Spur silt loam	6 - 9	499	22	1600	19.1	394	20	1344	18.0	577	25	206	2.3	347	23	163	2.3
Spur clay loam	0 - 3	348	76	570	7.2	278	49	940	13.6	429	78	184	2.2	200	40	146	2.2
Spur clay loam	6 - 9	329	65	665	8.8	275	50	938	13.6	444	84	214	2.4	195	42	143	2.4

Table 21. Calcium Mg^{++} and Na^{+} and calculated SAR concentrations of soil solutions of different soils and depths after leaching with waters of different qualities in Reach 15.

Soil Types	Depth Inches	Natural Total Salt-ppm 15500, SAR 33.2 Ca++ (PPM)	Mg++ (PPM)	Na+ (PPM)	SAR	Natural Total Salt-ppm 15170, SAR 33.2 Ca++ (PPM)	Mg++ (PPM)	Na+ (PPM)	SAR	Modified Total Salt-ppm 11240, SAR 4.6 Ca++ (PPM)	Mg++ (PPM)	Na+ (PPM)	SAR	Modified Total Salt-ppm 3080, SAR 4.6 Ca++ (PPM)	Mg++ (PPM)	Na+ (PPM)	SAR
Yanola fine sandy loam	0 - 3	1180	230	3227	22.6	1249	112	3200	23.3	2624	135	698	3.6	953	223	445	3.4
Yanola fine sandy loam	6 - 9	1171	245	2740	19.0	1169	412	2998	19.2	2132	330	879	4.7	969	496	967	6.1
Tipton silt loam	0 - 3	918	29	2971	26.3	962	22	3199	27.9	1600	26	537	3.7	292	25	173	2.7
Tipton silt loam	6 - 9	664	139	1313	12.1	763	109	1986	17.9	799	145	240	2.0	270	41	177	2.7
Tillman clay loam	0 - 3	975	27	2763	23.8	920	39	2144	18.8	1823	44	547	3.5	505	26	258	3.1
Tillman clay loam	6 - 9	902	52	792	6.9	738	49	529	5.1	1073	50	225	1.8	338	25	72	1.1

Table 22. Salinity of soil solution of surface 9 inches of different soils and reaches under field conditions.

Soils	mmhos/cm
	Reach No. 7
Yahola fine sandy loam	1.0
Tipton silt loam	1.4
Port clay loam	1.1
	Reach No. 8
Yahola fine sandy loam	3.3
Clairemont silt loam	3.7
Mangum clay loam	6.8
	Reach No. 13
Yahola fine sandy loam	5.1
Tipton silt loam	1.3
Abilene clay loam	0.8
	Reach No. 14
Yahola fine sandy loam	1.2
Spur silt loam	1.3
Spur clay loam	1.6
	Reach No. 15
Yahola fine sandy loam[a/]	21.0
Tipton silt loam	1.5
Tillman clay loam	1.3

a/ Saline seep

Figure 14. Relationship between percent soil moisture and strength of briquets containing different amounts of silt-clay (Mixture A) and sand. Percent of sand is 80%.

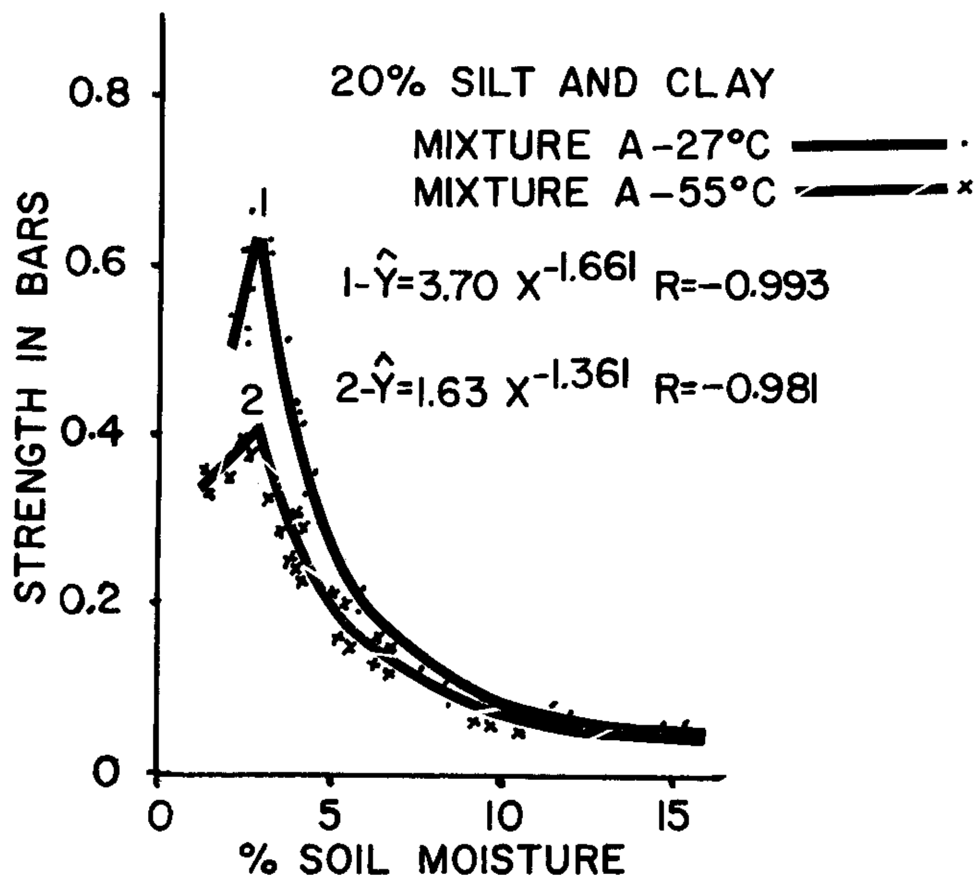


Figure 15. Relationship between percent soil moisture and strength of briquets containing different amounts of silt-clay (Mixture A) and sand. Percent of sand is 60%.

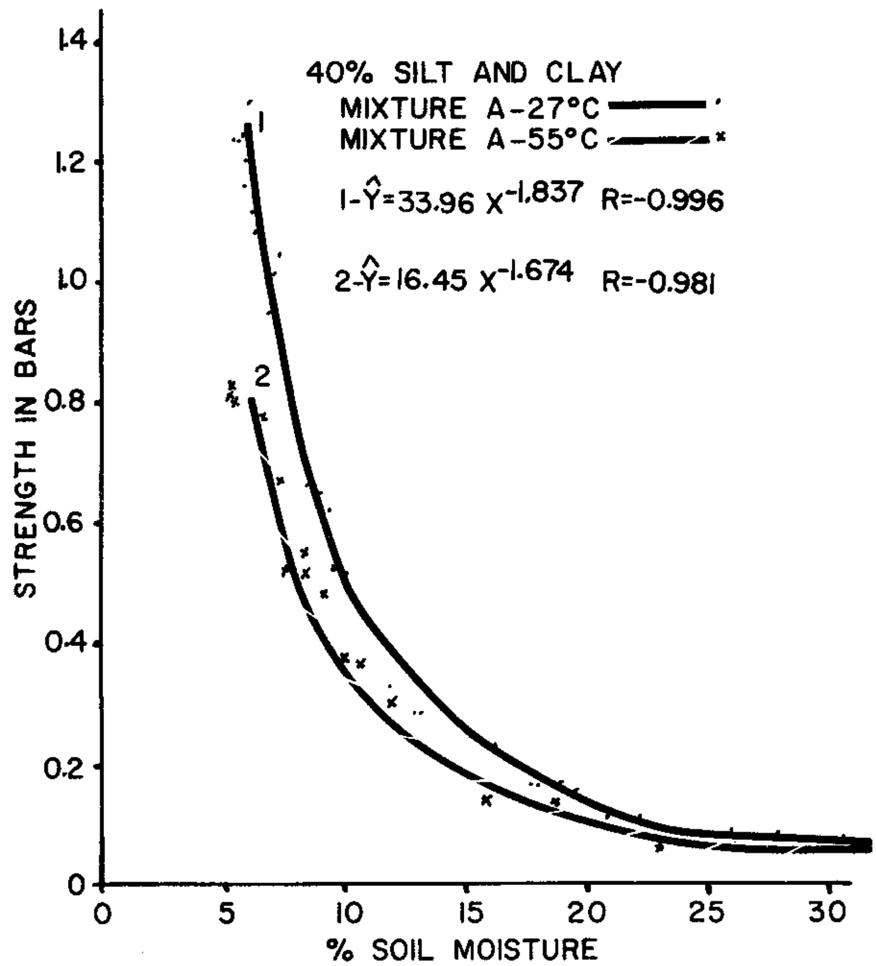


Figure 16. Relationship between percent soil moisture and strength of briquets containing different amounts of silt-clay (Mixture A) and sand. Percent of sand is 40%.

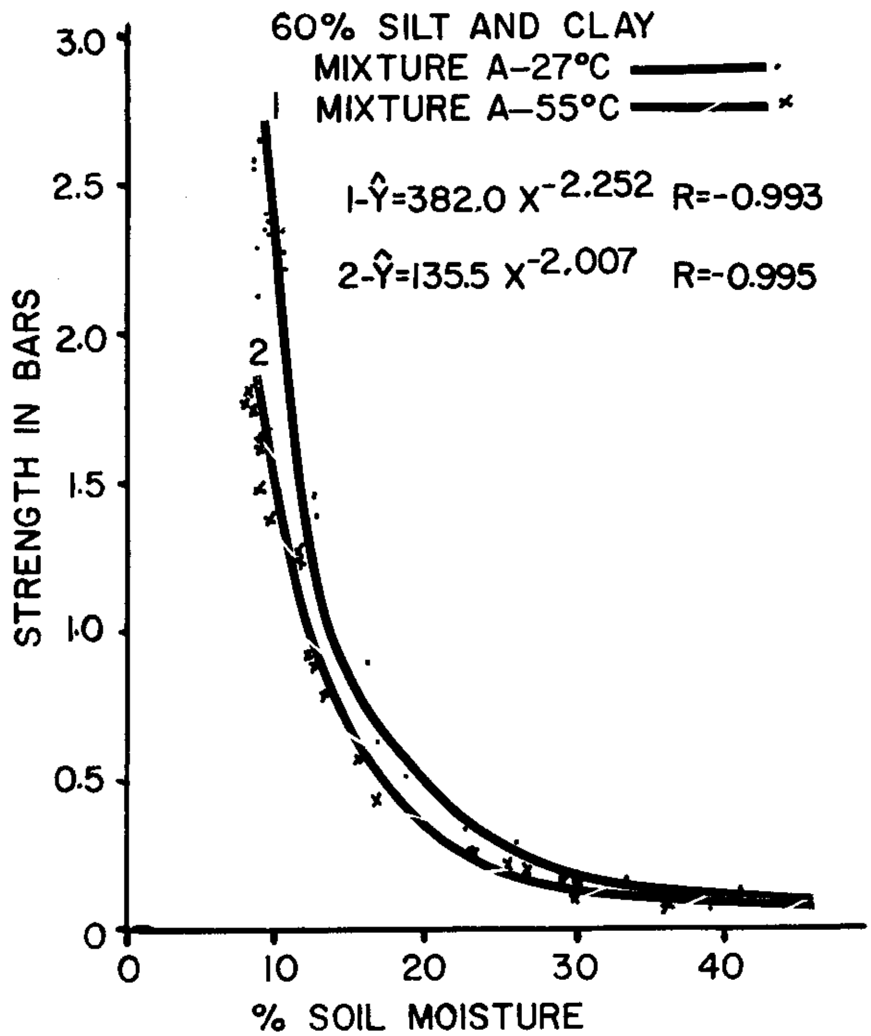


Figure 17. Relationship between percent soil moisture and strength of briquets containing different amounts of silt-clay (Mixture B) and sand. Percent of sand is 80%.

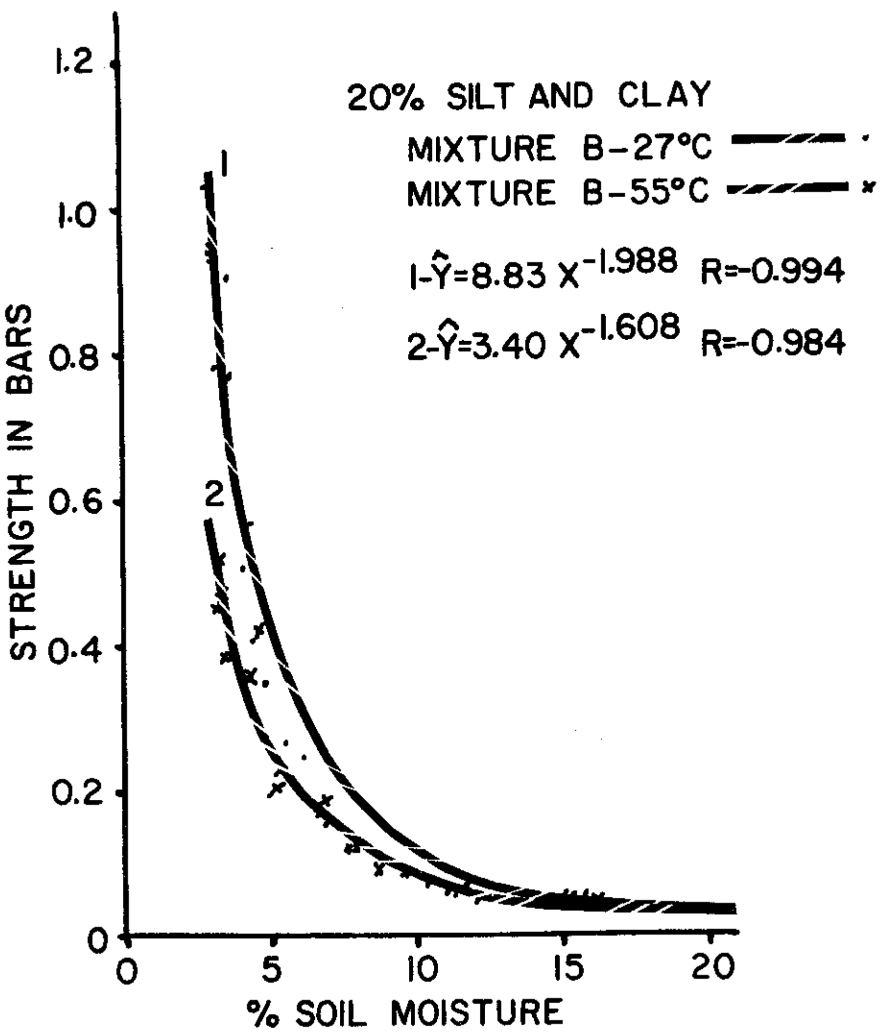


Figure 18. Relationship between percent soil moisture and strength of briquets containing different amounts of silt-clay (Mixture B) and sand. Percent of sand is 60%.

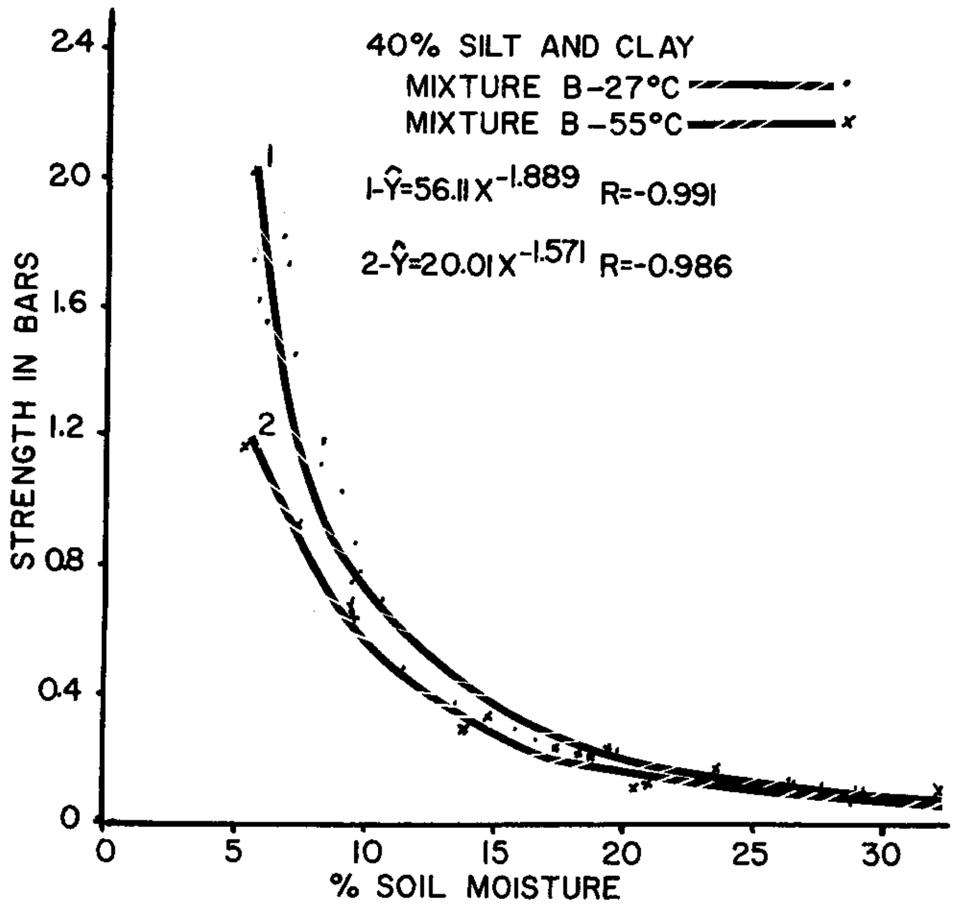
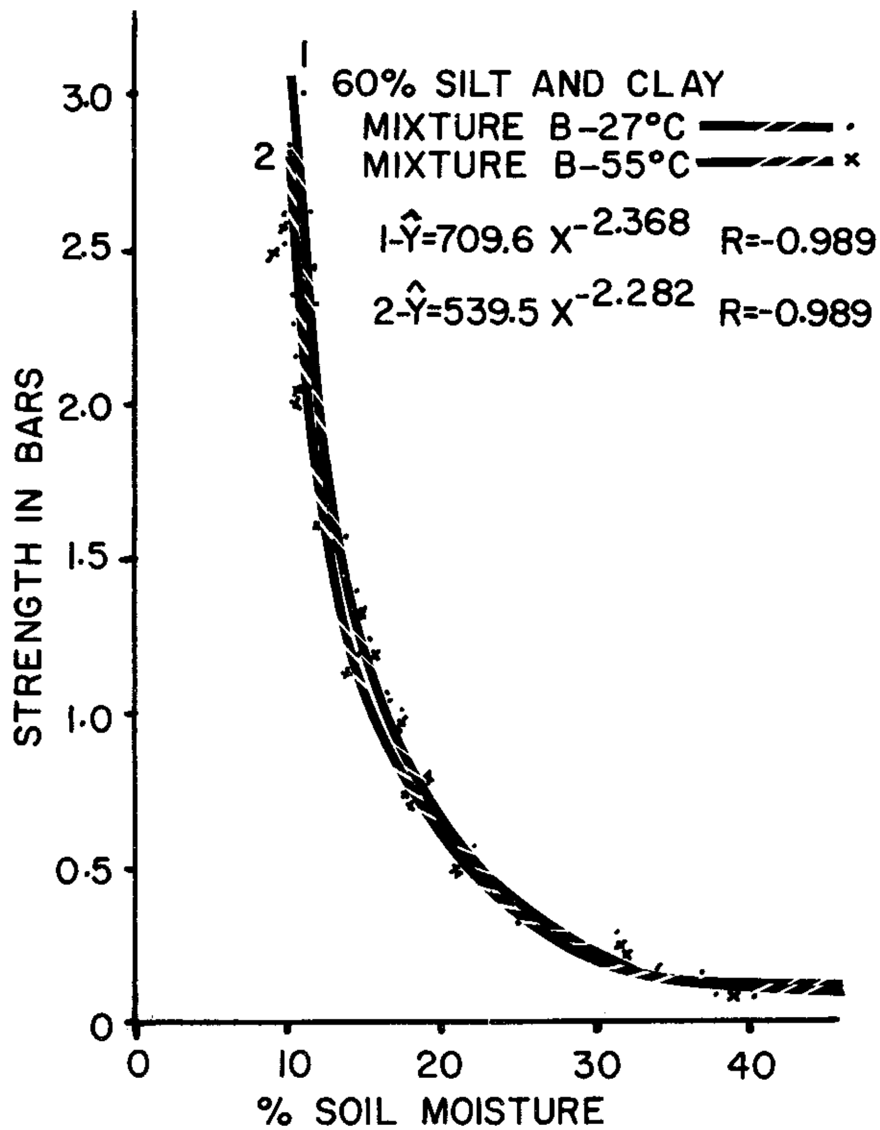


Figure 19. Relationship between percent of soil moisture and strength of briquets containing different amounts of silt-clay (Mixture B) and sand. Percent of sand is 40%.



SAR of the leaching saline solutions caused only small if any differences in the conductivity of the soil to the natural and modified water qualities. However, soils leached with moderate or high SAR solutions were markedly less permeable to low electrolyte water. Soils leached or irrigated with waters with SAR of about 5 or higher would be puddled during and after rainfall. Presently, waters in the Red River Basin west of Reach 6 have SAR higher than 9.6. After reclamation, water in all reaches on the Red River would have SAR less than 5. Clay movement through the profile after rainfall on soils with SAR of 10-14 would be significant. This occurrence would mean reduction in the soil macrovoids which are responsible for water movement through soils. The effectiveness of rains in supplying necessary leaching and needed water would be considerably reduced. Runoff and pollution from soils irrigated with SAR of about 10 or higher would be considerable. Crusting, which is influenced by puddling, would be increased and seedling emergence and stands would suffer.

Reclamation of waters would reduce the Na^+ concentration in the Red River. Reduced levels of Na^+ would mean that crusting would be less of a problem. Reducing the Na^+ concentration of water in the Red River would benefit present and future users of its waters for agricultural production.

In summary the effects of Na^+ (SAR) on soil productivity are subtle, often ignored and little understood. Soil structural stability is essential for water movement in soils--especially rainwater. The presence of moderate to high Na^+ concentrations on the clay particles contribute to structural instability, puddling and close-packing of soil particles. Results suggest that the SAR of irrigation water is of considerable importance for soils which have low organic matter contents, low levels of aggregation or structure, moderate to high soil densities and which are susceptible to compaction. The above describes many of the soils in the Rolling Plains and in The Red River Basin. Moderate to high Na^+ content (SAR) of irrigation waters further complicates and degrades soil productivity by accelerating crusting, compaction, runoff and erosion. Waters with moderate to high SAR reduce the permeability of the soil to rainfall and plant roots thereby reducing water use efficiency by crops. Reduction of Na^+ concentrations of the Red River and its tributaries should make these waters more suitable for irrigation.

LIST OF DEFINITIONS AND SYMBOLS

SAR = Sodium Absorption ratio $= \dfrac{Na + meq/l}{\sqrt{\dfrac{Ca{+}{+}\ meq/l + Mg{+}{+}\ meq/l}{2}}}$

Ca++ = Calcium

Mg++ = Magnesium

Na+ = Sodium

K_s = Saturated hydraulic conductivity = $K_s = \dfrac{Q\ \Delta\ L}{At\ \Delta H}$

Q = volume of water through core in time (t)

A = cross sectional area of core

ΔL - soil depth

ΔH = hydraulic head

K_s will be in cm/hr if t is expressed in hours, Q in cm^3, and ΔH and ΔL are in cm.

TDS = Total dissolved solid (ppm)

mmhos/cm = electrical conductivity of water or soil solutions.

mmhos/cm x 640 = ppm.

LITERATURE CITED

(1) Ayers, R.S. and D.W. Westcot. 1976. Irrigation and Drainage Paper No. 29: Water Quality for Agriculture. 97 pp.

(2) Frenkel, H., J.O. Goertzen and J.D. Rhoades. 1978. Effect of clay type and content, exchangeable sodium percentages and electrolyte concentration on clay dispersion and soil hydraulic conductivity. Soil Sci. Soc. Amer. Proc. 42:32-39

(3) Gerard, C.J. 1965. The influence of soil moisture, soil texture, drying conditions and exchangeable cations on soils. Soil Sci. Soc. Amer. Proc. 29:641-645.

(4) Gerard, C.J. 1974. Influence of antecedent soil moisture suction on saturated hydraulic conductivity of soils. Soil Sci. Soc. of Amer. Proc. 38:506-509.

(5) Godfrey, C.L., G.S. McKee, H. Oakes 1973. General Soil Map of Texas. Tex. Agri Expt. Sta. Mp 1034.

(6) Naghshineh-Pour, B., G.W. Kunze and C.D. Carson. 1970. The effect of electrolyte composition on hydraulic conductivity of certain Texas soils. Soil Sci. 104:125-127.

(7) Rhoades, J.D. and R.D. Ingvalson. 1969. Macroscopic swelling and hydraulic conductivity properties of four vermiculitic soils. Soil Sci. Soc. Amer. Proc. 33: 364-369.

(8) Richards, L.A., Editor. Diagnosis and Improvement of Saline and Alkali Soil. U.S.D.A. Handbook No. 60. 1954.

(9) Saffaf, A.Y. 1969. The effect of solution composition on unsaturated hydraulic conductivity of some Texas Soils. Texas A&M University. Ph.D. Dissertation.