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Percolation of Water Through Pullman Soils

Texas High Plains

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Summary

Nine locations including both irrigated and nonirrigated lands were explored for moisture penetration beneath the Pullman clay loam. It was concluded that, except for those irrigated areas with an extended intake opportunity time, little or no measurable deep percolation occurs. The Pleistocene sediments transmit water readily when saturated or near field capacity, but the transmissibility is negligible with lower moisture contents. Continued productivity of the irrigated soil profile without the buildup of salinity is primarily due to the excellent quality of the Ogallala water with a favorable calcium: sodium ratio and low total dissolved salts. It should be emphasized that this study was confined to the hardland soils, and findings may not apply to areas where the soil profile is more permeable.

EVALUATION OF DEEP PERCOLATION by rainfall and irrigation water through the slowly permeable subsoil of the Pullman clay loam and related soils is important to water management planning on the Southern Great Plains. These soils occupy more than 5 million acres on the Texas High Plains of which nearly 3 million acres are irrigated with water derived from the Ogallala aquifer. Approximately 90 percent of the irrigated land is cropped to sorghum, wheat and some cotton with an average annual water application of about 18 inches. Deep percolation may influence the accumulation of salts and loss of nitrate with implied aquifer pollution; it also might provide a source of recharge to the rapidly diminishing ground water reserve.

Theis (9) estimated that annual recharge to the Ogallala is less than 0.5 inch. He suggests, however, that recharge occurs only in areas where the Ogallala is either exposed or overlain by porous sediments. Cronin and Myers (2) point out that in the areas of slowly permeable soils underlain by relatively impermeable caliche strata, little, if any, deep percolation will occur. Irrigated land as a contributor to deep percolation is not mentioned.

The evapotranspiration potential for the area far exceeds the average annual or monthly precipitation. Taylor et al. (8) show that pan evaporation exceeds precipitation in every month by three times or more and on an annual basis by approximately five times. Occasionally rainfall exceeds evapotranspiration when storms extend over a period of several days or are separated by short intervals. Evapotranspiration is substantially reduced by cloud cover between intermittent storms. Antecedent irrigations or rainfall may fill the soil water reservoir so that the addition of water from a storm or irrigation will result in runoff and possible deep percolation.

Taylor et al. (8) measured infiltration rates into the Pullman clay loam. An initial rate of 0.62 inch per hour was obtained following the filling of a level border but rapidly dropped, as the soil reservoir filled, to a final rate of 0.05 inch per hour. In a 15-hour period 1.9 inches of water entered the profile. Thus, only after prolonged irrigation applications or substantial and continuing rainfall will the soil water storage capacity be exceeded and deep percolation possibly occur at a rate of 0.05 inch per hour.

Since only limited measurements of soil moisture below the 6-foot depth have been made in the area, deep percolation that may have occurred has not been investigated adequately. The objective of this study was to determine the magnitude of deep percolation occurring under several cultural practices in irrigated and nonirrigated lands.

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PROCEDURE

Description of Study Area

Study sites were located on or immediately adjacent to the USDA Southwestern Great Plains Research Center at Bushland. All sites were on the Pullman clay loam profile described by Taylor et al. (8). This soil is underlain by a thin porous caliche layer which grades into buff to reddish colored pluvial sediments of Pleistocene age. These sediments vary in thickness, depending upon site elevation, from less than 25 to more than 150 feet. A sometimes-indurated caprock of caliche separates the Pleistocene from the underlying dewatered upper strata of the Ogallala formation. The Pleistocene sediments form a protective blanket over the Ogallala, and it is in this material that the present surface relief of plain and playa has been sculptured.

The Pleistocene in the High Plains area has been ignored by most hydrologists because the formation is usually nonwater bearing. A limited amount of work was done by Frye and Leonard (5) on the physical and hydrologic properties of these sediments and their mode of formation. Because they are the parent material for a great expanse of Pullman soils and form the major mantle overlying the Ogallala in this region, they take on added significance from the standpoint of aquifer recharge of both potable and polluted water.

TABLE 1. HTSTORY OF LAND USE AT BORING SITES, PULLMAN CLAY LOAM

Boring No.	Depth of hole	Period	Land use and water management
	Feet		
1	23	-1917	Grassland, native
		1917-1937	Wheat, dryland
		1937-1969	Grassland, revegetated
2	51	-1917	Grassland, native
		1917-1949	Wheat, dryland
		1949-1955	Limited irrigation of wheat
		1955-1963	Continuous basin irrigation
		1963-1969	Continuous basin irrigation with no nitrogen fertilizer
3	46	-1917	Grassland, native
		1917-1949	Wheat, dryland
		1949-1955	Limited irrigation of wheat
		1955-1969	Continuous basin irrigation
4	30	-1917	Grassland, native
		1917-1943	Wheat, dryland
		1943-1969	Wheat-sorghum-fallow, terraced
5	21	1927-1958	Wheat, dryland
		1958-1969	Wheat-sorghum-fallow, furrow irrigated 0.15 % slope
6	20	-1950	Wheat, dryland
		1950-1970	Wheat-sorghum-fallow, furrow irrigated 0.15 % slope
7	44	-1950	Grassland
		1950-1968	Wheat-sorghum-fallow, furrow irrigation
		1968	Sugar beets, furrow irrigation, 0.2 % slope
		1969	Fallow
B-1[1]	49		Grassland, native
F-1[1]	41		Grassland, native

[1] Neutron access tube; no soil or substratum samples obtained.

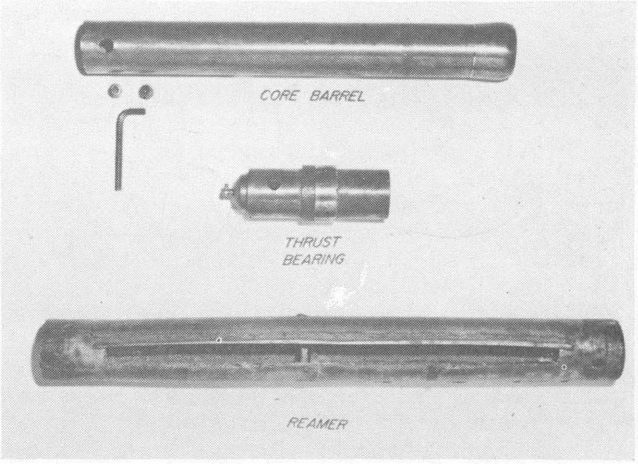

Figure 1. Breakdown of soil and substrata coring equipment.

Seven representative sites within a radius of 1 mile were selected for this study. Table 1 summarizes the land use and water management of these sites. The only differences lie in the land management history and slope. Two additional moisture profiles were obtained for native grassland using the neutron meter in access tubes established for other studies.

Sampling Equipment

It was necessary to design special coring equipment capable of taking 1-foot increments to depths in excess of 50 feet with minimum core disturbance or contamination. Since no water could be used in the sampling, conventional, hydraulic-rotary well-drilling equipment was unsuitable. Equipment was constructed to work on a small Damco AR 500 drilling rig. The sampling unit consists of three parts—the core barrel, a thrust bearing and a reamer (Figure 1). The core barrel is 18 inches long and has a 2.7-inch inside diameter with a bit silver soldered to one end. The core barrel is attached to the thrust bearing by large set screws, which, when in place, are flush with the outside of the core barrel. The reamer is attached to the upper portion of the thrust bearing with set screws. The reamer consists of a cylinder slotted on three sides and fitted with cutting blades to ream the hole to approximately 3.2 inches in diameter. The cuttings are collected in the reamer cylinder. An adapter fitted with standard drill pipe threads is attached to the upper end of the reamer with set screws. This adapter connects directly to the drill pipe.

Samples are obtained by applying hydraulic thrust up to 6 tons as the drill pipe is rotated. As the reamer rotates above the core barrel enlarging the bore hole, the core barrel is pressed into the sediment without rotation so that an undisturbed core is obtained. Cores are taken in 1-foot increments. After the sample is taken, the assembly is pulled from the bore hole, the core barrel removed and the reamer cleaned of cuttings. A second core barrel is attached to the thrust bearing and the process repeated.

The material in the core barrel is carefully removed by sliding the sample out the upper end. The few thousandths of an inch difference between the inside diameter of the bit and the barrel allows the sample to slide freely out of the core barrel. After the sample is placed in a tray and the loose material is removed, the core length is measured and the core weighed. An aliquot sample is removed for gravimetric soil moisture determination and a second subsample taken for ion analyses at a later date. Moisture content in milliliters per cubic centimeter (ml/cm^3) is later calculated using the dry bulk density values and gravimetric moisture determinations. Sampling continues until it is no longer possible to press the sampler using the full 6 ton thrust. Sampling of the Pleistocene alluvium with this unit became impractical when the moisture content dropped to less than 0.18 ml/cm^3. As this moisture level is at or below wilting point, there seemed to be no need to continue, as a wetting front had not extended below this point within the time of modern agricultural history.

Establishment of Water Holding Characteristics of Pleistocene

Without predetermination of the moisture holding characteristics of the Pleistocene, moisture profiles would have little significance relative to deep percolation. Data from an earlier study of ground-water recharge through the Pleistocene suggested these values (1). This study used recharge basins excavated through the Pullman soil on grassland which had never been irrigated. A set of neutron access tubes was installed in the basins before they were filled with water. These access tubes extended to the caprock 50 feet below the original ground surface.

The moisture content was measured in foot increments from the surface to the caprock before water was applied to the basin. Moisture contents were recorded during recharge at or near saturation in a zone above the caprock and below a perched water table. Thirty-eight days after water additions were stopped, moisture was again measured. The perched water table disappeared within 24 hours after the basin was empty indicating that free drainage took place. These three observations suggested values for specific retention or field capacity, saturation and, possibly, wilting point. These observations were further supported by groups of undisturbed cores taken at the 6-foot depth near neutron access tube B-1[1] and between 6 and 12 feet at another location. One-third and 15-Bar suction moisture determinations were made on these samples[2].

Results, compared in Table 2, suggest that the wilting point or 15-bar suction is about 0.20 ml/cm^3, field capacity or $\frac{1}{3}$-bar suction is about 0.32 ml/cm^3 and saturation will approach or exceed 0.40 ml/cm^3. These volumetric moisture contents may also be expressed as feet of water per foot of soil. With this basic information, it is possible to determine, at least within recent historical time, the depth and amount of deep percolation.

The diffusivity of the undisturbed cores collected near neutron access tube B-1 was measured using the E. J. Doering one-step technique (3)[1]. These values were then used to calculate the unsaturated hydraulic conductivity. At $\frac{1}{3}$-bar suction with a moisture content of 0.3 ml/cm^3, the flow was 18.9 feet per year, but at 1-bar suction with a moisture content of 0.25 ml/cm^3 hydraulic conductivity was reduced to 0.14 feet per year. The sharp drop in hydraulic conductivity when the water content decreases below $\frac{1}{3}$-bar suction suggests that deep percolation into dry sediments would produce a well-defined wetting front.

RESULTS

Characterization of Pleistocene Sediments

Field observation of the several hundred cores taken from the seven borings revealed the Pleistocene to be a porous material containing many root and worm hole casts ranging in size from 5 millimeters (mm) to less than 1 mm. These

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[1] Unpublished data, Paul Unger, Southwestern Great Plains Research Center at Bushland.

[2] Unpublished data, Harold Eck, Southwestern Great Plains Research Center at Bushland.

TABLE 2. WATER HOLDING CHARACTERISTICS AND BULK DENSITY OF PLEISTOCENE SEDIMENTS

	Water content of sediment					
Source of data	Saturation	$\frac{1}{3}$ bar	72 days drainage	15 bar	Calculated pore space	Bulk density
			ml/cm^3			g/cm^3
Deep percolation sampling stations[1]				0.19 to 0.20	0.40	1.59
Neutron access tubes in recharge basins[2]	0.40		0.33	0.19	.40	1.57
Undisturbed cores 6-foot depth[3]	.42	.32				
Undisturbed cores 6-12-foot depth[4]				.20	.42	1.53

[1] Summary of cores taken between 5 and 50 feet.

[2] See Aronovici et al. (1).

[3] Unpublished data collected by Paul Unger, SWGPRC.

[4] Unpublished data collected by Harold Eck, SWGPRC.

casts were found to the maximum depth of sampling. The color ranges from almost white to brick red. The light color is dependent upon the calcium carbonate content, and the brick-red zones suggest fossil soil profiles or weathered surfaces. Unconsolidated caliche stringers are common. With a material so highly structured, a conventional mechanical analysis is of little significance. The pluvial sediments are composed of very fine, well-rounded silica sand, probably of Ogallala origin, suspended in a matrix of silt and clay. The material is quite stable when confined in a core, but a clod placed in water disintegrates rapidly.

Although bulk density and degree of cementation vary considerably from foot to foot, a comparison of the average of all samples taken at each station shows the material to be quite uniform. The average bulk density of all cores taken was 1.59 g/cm^3, and the average bulk density for the individual borings ranged from 1.52 to 1.63 g/cm^3. Thus, comparisons of cumulative soil moisture between stations are reasonably valid.

Moisture Profiles

The differences in moisture contents of the Pleistocene sediments underlying the several land treatments are best shown in a comparison of cumulative moisture values with depth. These data for all sampled profiles and the two neutron access holes drilled in grassland are summarized in Figure 2. By utilizing the data presented in Table 2, it is possible to draw a cumulative moisture curve for a saturated profile and a profile at ⅓-bar suction. A point at the 50-foot depth for the 15-bar suction shows a cumulative moisture content of 9.5 feet of water. The B-1 cumulative moisture underlying grassland terminates at the same point, suggesting that the profile underlying the grassland averages 15-bar suction moisture content. Two other grassland samplings, F-1 and Boring 1, in part, have less than 15-bar moisture. It can be assumed that under present ecological conditions no deep percolation has occurred in grassland.

The grassland moisture profiles will be used as a base for comparison. If the moisture content in the profile, particularly beneath the root zone, exceeds the 15-bar moisture content, deep percolation is assumed to have occurred during recent times. Where the moisture content is at or below the 15-bar value, no deep percolation is assumed.

Boring 4 underlies land that has been terraced since 1943 and cropped to a dryland wheat-sorghum-fallow rotation. The boring was made

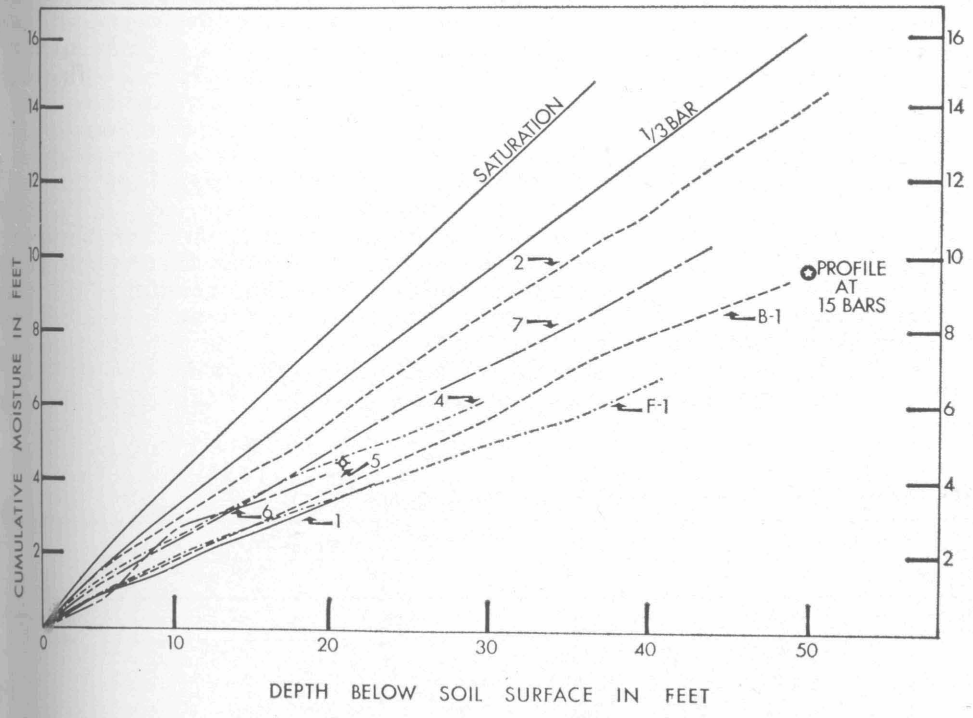

Figure 2. Cumulative soil moisture in Pullman clay loam and underlying Pleistocene sediments.

LEGEND

Boring 1	Native grassland
Boring 2	Level border, irrigated
Boring 4	Dryland, wheat-sorghum-fallow, terraced
Boring 5	Irrigated wheat-sorghum-fallow, infrequent applications
Boring 6	Irrigated wheat-sorghum-fallow, frequent applications 1.2 percent slope
Boring 7	Irrigated wheat-sorghum-fallow, frequent applications 0.2 percent slope
Boring F-1	Native grassland
Boring B-1	Native grassland

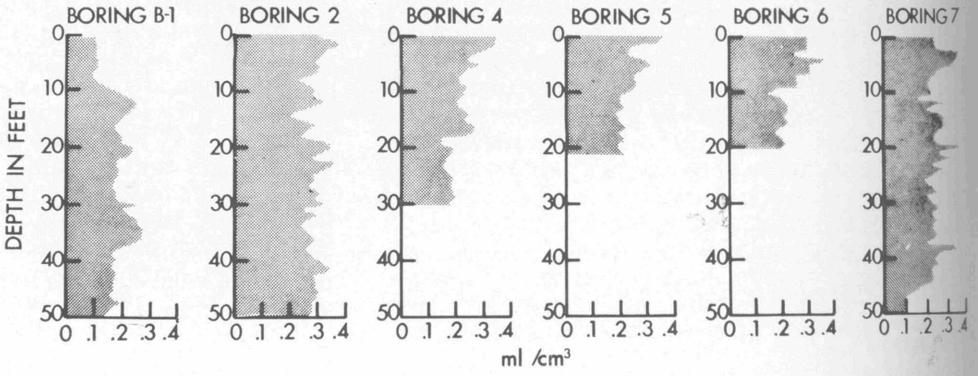

Figure 3. Moisture distribution in Pullman clay loam and underlying Pleistocene sediments.

on the natural land slope on the normal terrace interval. This cultivated dryland has accumulated some water to 17 feet as compared with grassland. Boring 5, shown only as a point on Figure 2, is in a field that was dry farmed to wheat-fallow from 1927 to 1958 and sparingly irrigated in a wheat-sorghum-fallow sequence since 1958. Surprisingly, deep percolation is less than for Boring 4. Boring 6 is in a furrow-irrigated field with 1.2 percent slope. It has been frequently irrigated in a more intensive cropping system than the Boring 5 site. No evidence of deep percolation at Boring 6 was observed beyond 8 feet. In contrast to Boring 6, Boring 7 is in a field with 0.2 percent slope that has been furrow irrigated and intensively cropped for the same period of time and by the same operator. Here deep percolation extends to more than 40 feet. Borings 2 and 3 (number 3, not shown on graph, is identical to number 2) are located in a closed, level basin where irrigation and rainfall since 1955 have provided some intake opportunity times extending from 24 to 48 hours. Here deep percolation reaches 50 feet, and the moisture content throughout the profile approaches $1/3$-bar suction or field capacity.

A group of representative moisture profiles is presented in Figure 3. For all practical purposes, 0.2 ml/cm^3 is equivalent to wilting point, 0.3 ml/cm^3 is approximately $1/3$-bar suction or field capacity and 0.4 ml/cm^3 approaches saturation. Only in the case of Boring 2, which underlies a heavily irrigated level-basin, does the entire profile approach field capacity. B-1, underlying grassland, shows three distinct zones of moisture above 0.2 ml/cm^3. A possible explanation is that these zones represent historic very wet seasons when downward percolation occurred. However, the downward progress of these moisture waves would have been extremely slow. It is doubtful that these zones are associated with recorded exceptional rainfall seasons—probably they are zones of finer textured material having a higher moisture content at wilting point.

Salinity Distribution

A reliable indicator of downward percolation is the salinity concentration and distribution in the profile and substrata (7). A soil saturation extract analysis of Pullman clay loam that has never been irrigated is summarized in Table 3. Some difficulty was experienced in securing good anion-cation balances; however, the analyses show that under normal grassland conditions there is a natural concentration of ions in the profile between the 3- and 7-foot depth. The distribution of total soluble salts as shown by the EC (electrical conductivity) x 10^3 @ 25° C of the soil

TABLE 3. SOLUBLE ION ANALYSES BY DEPTH INCREMENTS TO 11 FEET, GRASSLAND SITE, BORING 1

		Cations					Anions				
Depth	EC	Ca	Mg	Na	K	Total	Cl	HCO$_3$	SO$_4$	Total	SAR
Inches	mmhos	meq/l									
3- 17	.69	3.2	1.9	2.9	.4	8.4	.4	4.3			1.8
17- 24	.57	1.9	1.0	3.9	.2	5.2	1.9	3.4	.1	5.5	3.2
24- 36	.86	2.6	1.2	5.4	.2	9.4	2.0	2.4	2.8	7.2	4.0
36- 48	3.90	24.5	5.8	8.0	.4	38.8	8.8	1.2	28.7	38.7	2.1
48- 60	2.8	14.4	4.3	7.7	2.7	29.1	10.9	1.0	13.8	25.7	2.5
60- 72	3.6	24.1	5.3	7.8	.5	37.8	12.0	1.1	24.7	37.8	2.0
72- 84	2.0	8.7	2.7	7.2	.4	19.1	10.9	1.2	5.1	17.2	3.0
84- 96	1.7	8.5	2.6	7.0	.4	18.5	13.4	1.1	3.5	18.0	2.9
96-108	1.5	6.3	2.0	5.8	.2	14.8	10.9	1.0	3.9	15.8	2.8
108-120	1.4	6.8	1.9	5.8	.2	12.4	10.6	1.2	2.2	14.0	2.7
120-132	1.4	5.5	2.0	5.1	.2	11.8	11.3	1.3	5.0	17.6	2.7

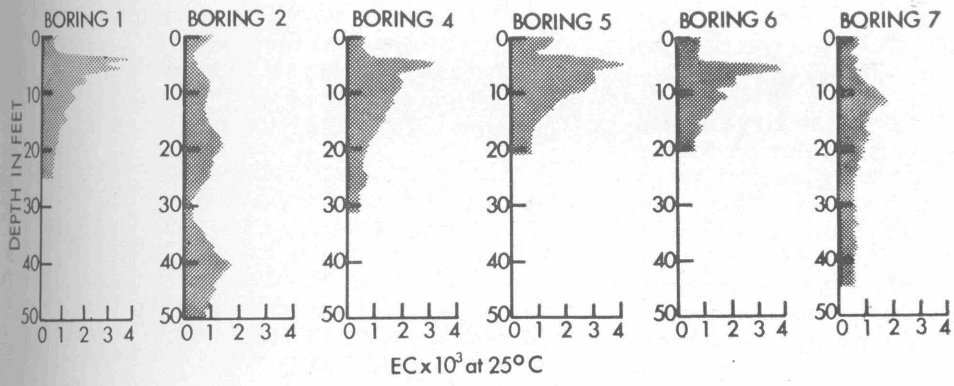

Figure 4. Electrical conductivity of Pullman clay loam and underlying Pleistocene sediments.

saturation extract is presented in Figure 4. At all borings where deep percolation is not indicated by the moisture profile—Borings 1, 4, 5 and 6—a distinct concentration of total salts is present in the profile between 3 and 7 feet. That this zone has been leached in Borings 2 and 7 again reflects that deep percolation has occurred.

Chloride distribution in the soil and substrata may provide a more reliable means of tracing moisture movement as the chloride ion moves freely with relatively slow moisture flow. Dyer (4) used this technique in tracing moisture movement in Central California. Figure 5 presents chloride concentration profiles of five representative profiles. The chloride concentration has been deflected slightly deeper than the total salts. That both Boring 4 (dryland terrace) and Boring 6 (furrow irrigated on 1.2-percent slope) show only a slight downward deflection of the chloride concentration supports the moisture profile evidence that little or no deep percolation has occurred.

Of special interest is the concentration of chlorides between 38 and 47 feet in Boring 2 (heavily irrigated level basin). It is not clear why the large concentration of chlorides is found at this depth while Boring 7 (furrow irrigated on 0.2 percent slope) does not show this concentration.

DISCUSSION

The seven borings and two neutron tube observations of soil and substrata moisture distribution are believed to be fairly representative of the conditions found in the Pullman clay loam and related soils of the Southern High Plains. Data from these observations support some reasonably sound conclusions. The sharp drop in diffusivity when the moisture content of the Pleistocene sediments falls below $1/3$-bar suction suggests that there would be a relatively sharp demarcation of a wetting front had there been deep percolation within recent time. This is shown clearly in Boring 7 at 44 feet and by the impossibility of sampling beyond 30, 21 and 20 feet at Borings 4, 5 and 6, respectively. Soluble salt profiles, as shown by the EC and chloride concentration of the saturation extracts, support the conclusion that only under very special conditions does deep percolation occur.

There has been little or no deep percolation on native or revegetated grassland within historic time where natural surface drainage occurs. Plains grasses have deep rooting systems that are able to deplete soil moisture when it becomes available during the growing season. Since the soil profile underlying the grass is depleted much of the time, rainfall is insufficient to rewet the entire profile and initiate deep percolation. When

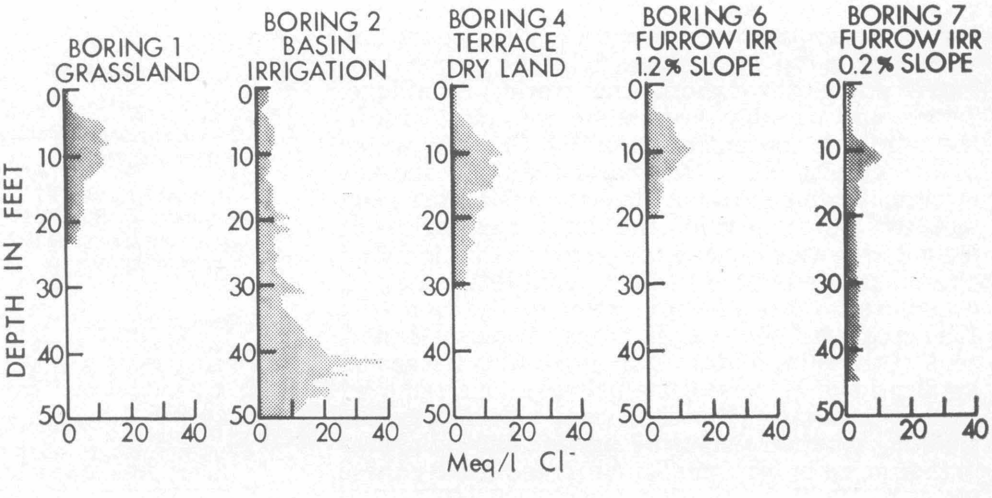

Figure 5. Distribution of chlorides in Pullman clay loam and underlying Pleistocene sediments.

intense rains occur, excess rainfall runs off. The tightly matted and consolidated upper root zone may reduce the infiltration rate.

The conditions are different on dry-farmed cropland. Here there are periods during fallow or the early part of the growing season when the relatively high soil moisture and a sequence of moderate storms might contribute to deep percolation. The surface roughness of cultivated land may provide a longer surface detention period and, consequently, a longer period for downward percolation. Cultivated land also may be subject to more extensive cracking of the slowly permeable subsoil which may contribute to deep percolation when the profile is quite dry. The moisture profile on the terraced land suggests that this may occur, but in no significant quantities.

Deep percolation on irrigated land does not occur to any significant extent under most conditions as shown by Borings 5 and 6. However, under the following combinations of conditions, deep percolation can occur:

1. Frequent irrigations with prolonged application time.
2. Irrigation followed by rainfall.
3. Gentle slopes with resulting slow irrigation and rainfall drainage which provides for a prolonged intake opportunity time.

That these conditions are conducive to deep percolation is supported by a comparison of Borings 5 and 6 with Borings 2 and 7. Deep percolation at Boring 2 is roughly 5 feet of water for 50-foot depth while Boring 7 shows an accumulation of 2.2 feet of water in 43-foot depth. At the time Boring 7 was sampled, soil profile moisture was very low compared with that in Boring 2. Boring 5 and Boring 6 show less than a foot percolation in 20-foot depth, and in both cases most of the percolated water is in the upper 10 feet.

The Pullman clay loam has an inherent salinity. Surprisingly, there appears to be no major buildup of salinity in the areas either sparingly or frequently irrigated. This condition, when compared with those in other major irrigated areas throughout the world, is unique. There are possibly two main reasons: First, the total salt concentration of the Ogallala water is low with an EC x 10^3 of less than 0.5, and the calcium: sodium ratio is ideal for sustaining good soil structure; second, the total application of irrigation water is small compared to that in many other irrigated areas. Other possibilities may be considered. Crops remove some of the ions (6). It is estimated that sorghum may remove 10 percent of the salts contained in an 18-inch irrigation application. However, the primary ions removed include calcium, potassium and chlorides while sodium, magnesium, bicarbonates and sulphates are removed in very small quantities. Under these circumstances it might be assumed that the soil Sodium-Adsorption Ratio (SAR) would gradually increase. However, this was not observed as both irrigated and nonirrigated fields are about the same with an SAR of 3.0 or less.

Under present land management and irrigation practices, the possibility is remote that there are any measurable quantities of deep percolation through the Pullman clay loam profile and underlying blanket of Pleistocene sediment into the Ogallala aquifer; if deep percolation occurs, it will not be a significant source of recharge or pollution except where water is held on the land for sustained periods.

ACKNOWLEDGMENT

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