EFFECTS of
ALFALFA, CROP SEQUENCE, and TILLAGE PRACTICE

On intake rates of Pullman silty clay loam and grain yields

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CONTENTS

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Effects of Alfalfa, Crop Sequence, and Tillage Practice on Intake Rates of Pullman Silty Clay Loam and Grain Yields

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INTRODUCTION

The High Plains of Texas is one of the largest irrigated areas in the United States. Most of the 5.7 million acres irrigated in Texas (1959 census) is concentrated in the High Plains. The area is unique because most of the irrigated land is of one soil series—Pullman. Pullman soils represent over 5 million acres of the "hardlands" in the Southern High Plains of Texas, New Mexico, and Oklahoma.[1]

The term "hardlands" is used extensively when referring to the High Plains because of the soil characteristics of the area. The soils are mostly clay loams and silty clay loams.[2] They have low intake rates, are dense, and become very hard and difficult to till when dry. The differences between the clay loams and silty clay loams are minor. The physical characteristics of a given layer of these Pullman soils are very uniform over large areas, some as extensive as several counties.

Pullman soils have characteristically low intake rates—0.1 inch or less per hour 4 to 6 hours after water is applied. Ten hours after an irrigation, intake rates of 0.05 to 0.08 inch per hour are common. Intake rates this low have both advantanges and disadvantages. They allow the farmer to use irrigation furrows up to one-half mile long and still obtain reasonably uniform distribution of water. Loss of water by deep percolation during irrigation is usually insignificant. However, low intake rates limit the penetration of irrigation water during the growing season, when evapotranspiration rates are high and heavy irrigations are needed. Runoff from this soil frequently occurs during high-intensity rains even on gently sloping land. Runoff also occurs during irrigation when sets of 12 to 24 hours are used to obtain adequate penetration. Many farmers use pump-back systems to recirculate runoff irrigation water from the lower end of fields. If not recirculated, runoff accumulates in the numerous shallow playa lakes, where 90 percent of it may be lost through evaporation.

[1] TAYLOR, H. M., VAN DOREN, C. E., GODFREY, C. L., and COOVER, J. R. SOILS OF THE SOUTHWESTERN GREAT PLAINS FIELD STATION. Tex. Agr. Expt. Sta. MP-669, 14 pp. 1963.

[2] LOTSPEICH, F. B., and COOVER, J. R. SOIL FORMING FACTORS ON THE LLANO ESTACADO: PARENT MATERIAL, TIME, AND TOPOGRAPHY. Tex. Jour. Sci. 14: 7-17. 1962.

Development of irrigation from wells in the High Plains expanded rapidly after 1945, bringing increased attention to the problems involved in farming Pullman soils. Recommendations were needed on crop and tillage practices to modify the intake characteristics of these soils. This report summarizes the result of an experiment (1955–62) designed to evaluate the effects of alfalfa, crop sequence, and tillage practice on intake rates of Pullman silty clay loam and grain yields.

STUDY AREA

Location

The experiment was conducted on the U.S. Department of Agriculture Southwestern Great Plains Research Center, Bushland, Tex. (lat. 35°15′ N., elevation 3,825 feet). The station is near the northern edge of the major irrigated portion of the High Plains area. The soil on the station is representative of this irrigated area and is also representative of that in the area north of Bushland in which irrigation has recently been developed.

Soil

The soil on the site of the experiment is Pullman silty clay loam.[3] [4] Organic matter in the 0- to 6-inch surface layer ranges from 1.6 to 2.1 percent after several years of tillage as compared with 2.6 percent for soil in native grass. Caliche ($CaCO_3$) accumulation extends downward starting at depths of approximately 3.5 to 4 feet.

Bulk density determinations were made on 1.85- by 4-inch cores on September 18, 1956, at four sites in the experimental area. The averages of these measurements are shown in figure 1. The coefficient of variability of the mean of four cores per increment of depth was 3.8 percent. An abrupt decrease in bulk density occurs where $CaCO_3$ has accumulated.

Moisture-holding characteristics are summarized in table 1. Field capacity values are the mean of high values measured 5 to 10 days after preplanting irrigations. Wilting point values are the mean of low values measured near harvesttime. These data were obtained on an adjacent sorghum-experiment site. The field capacity values were determined after normal irrigations. They would be less than the values obtained 2 to 3 days after excessive irrigation, but should represent effective available water-holding capacities when evapotranspiration rates are low.

Pullman soil cracks extensively 2 to 4 days after surface irrigation (fig. 2). Cracks in the surface crust increase in width and depth as drying continues. Similar cracks develop when a crop is grown. Cracks materially affect the intake during the first hour of irrigation because they initially increase the surface area for intake. However, their effectiveness diminishes as the soil swells.

[3] See footnote 1, p. 1.

[4] COOVER, J. A., VAN DOREN, C. E., and WHITFIELD, C. J. SOME CHARACTERISTICS OF THE PULLMAN SOILS ON THE AMARILLO EXPERIMENT STATION. Tex. Agri. Expt. Sta. MP–97, 11 pp. 1953.

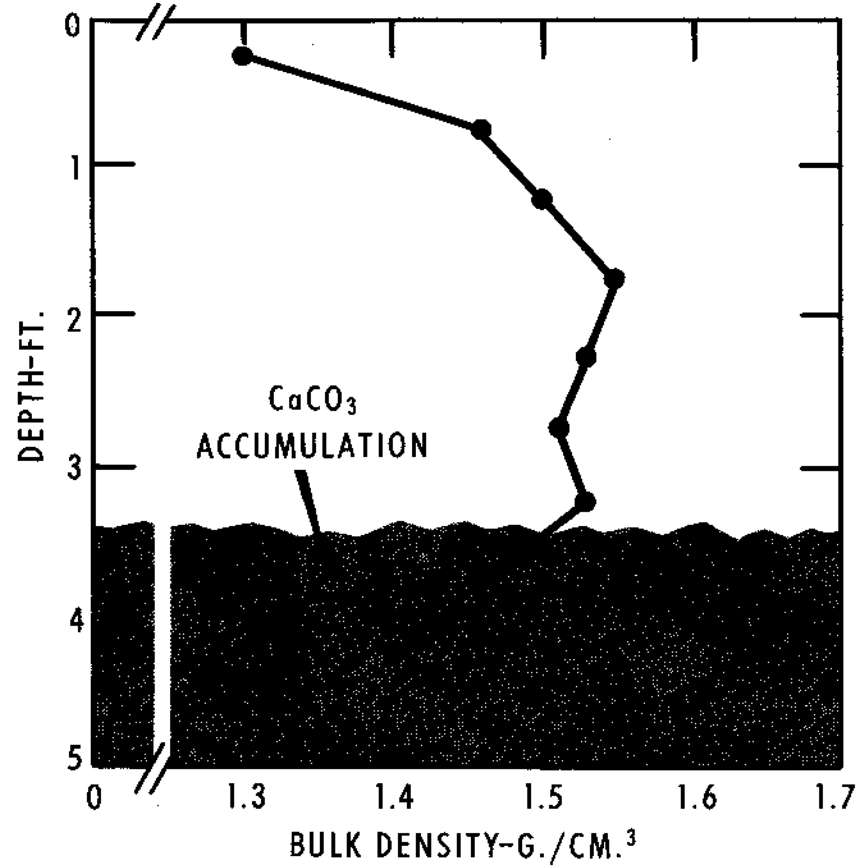

FIGURE 1.—Bulk density of Pullman silty clay loam at various depths.

TABLE 1.—*Moisture-holding characteristics of Pullman silty clay loam*

Depth from surface	Field [1] capacity	Wilting [1] point	Available water
Inches	*Percent*	*Percent*	*Inches*
0 to 12	24. 6	12. 6	1. 99
12 to 24	22. 7	13. 5	1. 67
24 to 36	21. 0	13. 0	1. 46
36 to 48	20. 4	13. 5	1. 24
48 to 60 [2]	21. 9	[3] 13. 5	1. 41

[1] Dry weight basis.
[2] Contains as much as 45 percent $CaCO_3$ by weight.
[3] Estimated.

FIGURE 2.—Cracks in Pullman silty clay loam after surface irrigation.

EXPERIMENTAL PROCEDURE

Experimental Design

The experiment consisted of two parts, designated series, one with winter wheat and the other with grain sorghum as the major crop. Each series was designed as a randomized complete block. Three replications of three crop sequence treatments with three tillage treatments were used in each series. Each plot of a crop-tillage combination was a level basin, 30 by 105 feet, diked on all sides. The same plots were used throughout the study.

Crop Sequence Treatments

Three crop sequence treatments were used in each series. The continuous crop treatment in each series was used as the check to evaluate intake rates.

Crop Sequence Treatments for Wheat Series

The crop sequence treatments for the wheat series experiment (1955–56 to 1961–62, inclusive) consisted of (1) continuous wheat, (2) 2 years of alfalfa followed by 5 years of wheat, and (3) 2 years of grain sorghum followed by 5 years of wheat.

Crop Sequence Treatments for Sorghum Series

The crop sequence treatments for the sorghum series experiment (1956 to 1962, inclusive) consisted of (1) continuous grain sorghum, (2) 2 years of alfalfa followed by 5 years of grain sorghum, and (3) continuous grain sorghum with interplanted cowpeas. Treatment 3 was a current practice in the area.

Tillage Treatments

Three tillage treatments were used on each crop sequence treatment. Other shallow tillage operations were carried out as needed to control volunteer growth and weeds. The sweep-and-chisel treatment was used as a check on each series to evaluate intake rates. A summary of all tillage operations is presented in table 2.

Sweep-and-Chisel

Shallow sweep-plowing (2 to 4 inches) with 30-inch cultivator sweeps and shallow chiseling (3 to 6 inches) were the major operations of the sweep-and-chisel treatment; disking and harrowing were performed as needed to control weeds and prepare a seedbed.

Moldboard

A moldboard plow was used as the major tillage implement for the moldboard treatment—plowing to a depth of 6 to 7 inches. Additional tillage with sweep plows, disk harrows, and spike-tooth harrows was carried out to prepare a seedbed and control weeds.

Rough

A moldboard plow was used in the rough treatment as in the moldboard treatment except that additional surface tillage to control weeds was kept to a minimum for the first three seasons. After the third crop season this treatment was changed to deep-chiseling to a depth of 13 to 15 inches, 20 to 24 inches apart, since the rough treatment and the moldboard treatment produced no significant difference in intake or yield during the first three seasons. The wheat series was deep-chiseled in the fall of 1958 and 1959. The sorghum series was deep-chiseled once, in the spring of 1959.

TABLE 2.—*Summary of tillage operations from 1955 to 1962 for the wheat and sorghum series experiments*

WHEAT SERIES

Year	Date and tillage operation[1]					
	Sweep-chisel treatment		Moldboard treatment		Rough treatment	
1955	10/12	Sweep-plowed, 3 in.	10/12	Plowed, 6–7 in.	10/12	Plowed, 6–7 in.
			10/13	Harrowed twice		
1956	7/3	Chiseled, 5–6 in.	7/12	Plowed, 4–5 in.	7/12	Plowed, 4–5 in.
	7/5	Sweep-plowed, 4–5 in.				
	7/26	Sweep-plowed, 3 in.	7/26	Sweep-plowed, 3 in.	7/26	Sweep-plowed, 3 in.
	9/4	Sweep-plowed, 3–4 in.	9/4	Sweep-plowed, 3–4 in.	9/4	Sweep-plowed, 3–4 in.
	9/4	Floated	9/4	Floated		
	9/14	Harrowed	9/14	Harrowed	9/14	Harrowed.
1957	7/6	Sweep-plowed, 4 in.	7/6	Plowed, 7 in.	7/6	Plowed, 7 in.
	8/14	Sweep-plowed, 3–4 in.	8/14	Sweep-plowed, 3–4 in.	8/14	Sweep-plowed, 3–4 in.
	8/23	Sweep-plowed	9/30	Sweep-plowed, 2–3 in.		
1958	8/1	Sweep-plowed, 4 in.	7/19	Plowed	7/9	Plowed.
	8/1	Chiseled, 5 in.	8/20	Sweep-plowed	8/20	Sweep-plowed.
					9/20	Chiseled, 13–15 in.
	9/22	Floated	9/22	Floated	9/22	Floated.
	9/22	Chiseled, 4 in.	9/22	Chiseled, 4 in.	9/22	Chiseled, 4 in.
	10/10	Sweep-plowed	10/10	Sweep-plowed	10/10	Sweep-plowed.
	10/10	Harrowed	10/10	Harrowed	10/10	Harrowed.
1959	7/10	Disked	7/10	Disked	7/10	Disked.
	8/1	Sweep-plowed	8/1	Plowed, 7 in.	8/1	Sweep-plowed.
					8/5	Chiseled, 15 in.
	9/3	Disked	9/4	Disked	9/3	Disked.
	10/10	Disked	10/10	Disked	10/10	Disked.
	10/16	Sweep-plowed	10/16	Sweep-plowed	10/16	Sweep-plowed.
	10/16	Harrowed	10/16	Harrowed	10/16	Harrowed.
1960	8/2	Disked, 5–6 in.	8/2	Disked, 5–6 in.	8/2	Disked, 5–6 in.
	8/25	Sweep-plowed	8/25	Sweep-plowed	8/25	Sweep-plowed.
	8/26	Disked	8/26	Disked	8/26	Disked.
	9/19	Disked	9/19	Disked	9/19	Disked.
	9/19	Harrowed	9/19	Harrowed	9/19	Harrowed.
1961	6/28	Sweep-plowed, 3–4 in.	6/28	Sweep-plowed, 3–4 in.	6/28	Sweep-plowed, 3–4 in.
	7/30	Disked	7/30	Disked	7/30	Disked.
	9/11	Disk and harrowed	9/11	Disked and harrowed	9/11	Disked and harrowed.

SORGHUM SERIES

Year	Date and tillage operation[1]					
	Sweep-chisel treatment		Moldboard treatment		Rough treatment	
1956	3/28	Sweep-plowed, 3 in.	3/27	Plowed, 6–7 in.	3/27	Plowed, 6–7 in.
			3/30	Disked		
	4/2	Floated	4/2	Floated		
	4/2	Chiseled, 3–4 in.	4/2	Chiseled, 3–4 in.		
	4/27	Disked	4/27	Disked		
	5/4	Harrowed	5/4	Harrowed	5/23	Sweep-plowed, 2–3 in.
	6/22	Sweep-plowed, 2.5 in.	6/22	Sweep-plowed, 2.5 in.	6/22	Sweep-plowed, 2.5 in.
	7/12	Cultivated	7/12	Cultivated	7/12	Cultivated.
	Oct.	Sweep-plowed, 4–5 in.				
1957	3/19	Disked, 3–4 in.	3/19	Disked	3/9	Disked.
	6/7	Sweep-plowed, 3 in.	6/8	Plowed, 6–7 in.	6/8	Plowed, 6–7 in.
	6/7	Chiseled, 5–6 in.	6/10	Disked		
	6/20	Sweep-plowed, 2.5 in.	6/10	Harrowed		
	6/20	Harrowed	6/20	Harrowed	6/20	Harrowed.
	7/26	Cultivated	7/26	Cultivated	7/26	Cultivated.
	12/17	Sweep-plowed, 5 in.	Nov.	Plowed	Nov.	Plowed.
1958	4/25	Disked	4/12	Disked	4/12	Disked.
	6/6	Sweep-plowed, 2 in.	6/6	Sweep-plowed, 2 in.	6/6	Sweep-plowed, 2 in.
	6/11	Disked	6/11	Disked		
	6/11	Harrowed	6/11	Harrowed	6/11	Sweep-plowed.
	7/18	Cultivated	7/18	Cultivated	7/18	Cultivated.
	11/12	Disked	11/12	Disked	11/12	Disked.
1959			3/10	Plowed, 7 in.	3/10	Chiseled, 15 in.
	4/31	Sweep-plowed	4/31	Disked	4/31	Sweep-plowed.
	5/30	Disked	5/30	Disked	5/30	Disked.
	6/16	Sweep-plowed, 2 in.	6/16	Sweep-plowed, 2 in.	6/16	Sweep-plowed, 2 in.
	6/16	Harrowed	6/16	Harrowed	6/16	Harrowed.
	7/14–21	Cultivated	7/14–21	Cultivated	7/14–21	Cultivated.
	12/1	Disked	12/1	Disked	12/1	Disked.

See footnote at end of table, p. 8.

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TABLE 2.—*Summary of tillage operations from 1955 to 1962 for the wheat and sorghum series experiments*—Cont.

SORGHUM SERIES—Continued

Year	Date and tillage operation[1]					
	Sweep-chisel treatment		Moldboard treatment		Rough treatment	
1960	4/4	Disked	4/4	Disked	4/4	Disked.
	5/16	Disked, 4 in.	5/16	Disked, 4 in.	5/16	Disked, 4 in.
	6/17	Sweep-plowed	6/17	Sweep-plowed	6/17	Sweep-plowed.
	6/18	Harrowed	6/18	Harrowed	6/18	Harrowed.
	7/26	Cultivated	7/26	Cultivated	7/26	Cultivated.
	11/21	Disked	11/21	Disked	11/21	Disked.
1961			2/15	Plowed, 8–9 in.		
	4/24	Disked	4/24	Disked	4/24	Disked.
	5/16	Disked			5/16	Disked.
	6/7	Disked	6/7	Disked	6/7	Disked.
	7/5	Cultivated	7/5	Cultivated	7/5	Cultivated.
1962	3/8	Disked	3/8	Disked	3/8	Disked.
	5/1	Plowed	5/1	Plowed	5/1	Plowed.
	5/8	Disked	5/8	Disked	5/8	Disked.
	6/28	Sweep-plowed	6/28	Sweep-plowed	6/28	Sweep-plowed.
	6/28	Harrowed	6/28	Harrowed	6/28	Harrowed.

[1] A spike-tooth harrow was used for harrowing, a moldboard plow was used for plowing, and 30-inch sweeps were used for sweep-plowing.

Other Tillage Operations

Light surface smoothing (floating) was used on the moldboard and on the sweep-and-chisel treatments to remove minor surface variations. Deviations from the planned tillage operations were necessary on some plots after the 2 years of alfalfa and sorghum. All alfalfa plots in the wheat series were moldboard-plowed 5 inches deep on August 28, 1957, sweep-plowed on October 9, and disked on December 4. On December 2, 1957, the moldboard and rough tillage plots previously in sorghum were moldboard-plowed 6 inches deep. The sweep-and-chisel plots previously in sorghum were chiseled to a depth of 4 inches and then disked on December 4. On December 4, the moldboard plots were disked twice, the rough tillage plots were disked once, and both the moldboard and rough tillage plots were then spike-tooth-harrowed. The sorghum plots in the wheat series in 1956 and 1957 were treated the same as corresponding sorghum plots in the sorghum series. The alfalfa plots in the sorghum series were plowed in November 1957.

All plots in the wheat series were tilled in the same manner, beginning in 1960, to evaluate the residual effects of tillage. In 1961, the moldboard plots in the sorghum series were plowed to a depth of 8 to 9 inches, which was deeper than usual.

In general, all stubble residue was left on the plots and incorporated into the surface soil. A shredder was used to facilitate incorporation of the residue. An exception occurred on the wheat series in 1957. The combine used discharged the threshed sorghum stalks to the side of the plots. All remaining threshed stalks were removed from the plot area to avoid mixing the residue from several plots.

Cultural Practices

Seeding and harvest dates, rate of seeding, and rate of nitrogen application are presented in table 3. A uniform application of 200 pounds of P_2O_5 per acre was applied to all plots at the beginning of the experiment. Alfalfa (Buffalo) plots were seeded in the fall of 1955 and reseeded on April 18, 1956. A winter wheat variety (Concho) was seeded in 10-inch rows. Hybrid grain sorghum (RS–610) was seeded in 20-inch rows. Inoculated hybrid cowpeas (No. 8) were interplanted with the grain sorghum on one crop sequence treatment at the following rates, in pounds per acre: 6 in 1956, 6 in 1957, 1.8 in 1958, 19.7 in 1959, 15 in 1960, 17 in 1961, and 8 in 1962.

Irrigations

Irrigation water was delivered to each plot by aluminum gated pipe. The water applied was measured with a flowmeter in the pipeline. Only one replication could be irrigated during 1 day because of the time required to apply the water, the time required to move the pipeline to the next replication, and the availability of only nine water stage recorders. About 20 minutes were required to apply 4 inches of irrigation water to each plot.

TABLE 3.—*Summary of cultural practices*[1] *used in experiments on intake rate and yield*

Year	Date seeded	Seeding rate	Nitrogen applied	Date harvested
Wheat Series Experiment				
		Lb./acre	*Lb./acre*	
1955–56	10/12	75	0	6/23
1956–57	9/26	100	180	7/2
1957–58	12/6	60	120	7/2
1958–59	10/21	109	126	7/6
1959–60	10/19	129	126	7/1
1960–61	9/21	100	140	6/21
1961–62	9/15		120	7/2
Sorghum Series Experiment				
1956	6/22	11	0	10/30
1957	6/21	11	120	11/1
1958	6/12	16	172	11/4
1959	6/19	11	186	10/21–22
1960	6/20	14	180	11/8–11
1961	6/9	12	180	10/11–12
1962	6/28	13	220	10/29–30

[1] All plots received a uniform application of 200 pounds of P_2O_5 per acre.

Intake Measurements

The rapid initial rates and rates slower than 0.1 inch per hour (after 4 to 6 hours) were difficult to measure. Attempts to use a stilling basin and a staff gage were not satisfactory. Water stage recorders were used for intake measurements (fig. 3) beginning in September 1956. This method measures the recession of the water surface relative to the recorder stand.

The legs of the tripod stand were driven about 12 inches into the soil. The soil swelled upon wetting, causing a rise of the soil surface relative to the recorder stand. Most of the relative rise appeared to occur during the first hour.

This rise was measured on June 1, 1959, in one of the alfalfa sweep-and-chisel plots of the wheat series. The float line was attached to a perforated metal plate resting on the soil surface. A perforated plate was used so as not to restrict infiltration under the plate. The rate of rise of the metal plate relative to the elevation of the water stage recorder stand during the first 10 hours could be expressed by the equation $\Delta z = 0.95 - 0.71t^{-0.14}$ in., where Δz equals the difference in elevation between the plate and the stand, and t equals the number of hours after water was applied. From 0.33 to 1.33 hours, the plate and soil surface rose 0.15 inch more than the recorder stand (Δz at $t=1.33$ minus Δz at $t=0.33$). If the water surface rose with the soil surface, the measured decline of the water surface relative to the recorder stand would be about 0.1 inch too low during the first hour of measurement. The water stage recorders also began to rise, but usually not until 3 to 4 hours after water was applied. The water stage recorder and plate reached a maximum elevation about 4 days after the application of water; then both began to decline. The maximum difference in elevation between the plate and recorder also occurred after 4 days, although the maximum difference was only slightly more than during the first 4 hours.

These effects make precise evaluation of mathematical intake functions for this soil difficult. However, since all intake measurements were made in the same manner, values for differences in mean intake rate due to difference in treatment should be reliable. A correction for evaporation was not made because the lower intake rates were generally measured at night, when evaporation was negligible.

Intake rates were computed by scaling the water stage recorder graphs (fig. 4). The scaled distances to some datum were punched on IBM cards and all the computations and statistical analyses were made on a computer. The intake data apply to soil flooded with water and to a period beginning 20 minutes after water is applied. Thus, they are not directly applicable to intake under rainfall conditions where surface characteristics may have more influence.

FIGURE 3.—Water stage recorder, float, and stand used to measure intake rates. A windshield stilling basin (see fig. 5) was used when necessary.

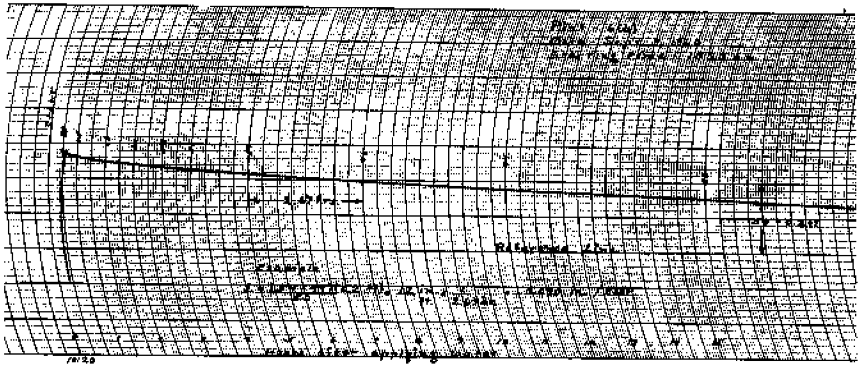

FIGURE 4.—Typical water stage recorder graph, illustrating decline in height of water surface and sample calculation of intake rate for one period.

Intake Rate Analysis

Several methods for analyzing the differences in intake rates resulting from various treatments have been proposed.[5] Equation parameters can be compared (1) directly for each irrigation or for an average of all irrigations, (2) as a difference between parameters before and after treatments, or (3) as a ratio of aftertreatment to pretreatment parameters. The simplest procedure is to compare average intake rates for a specified period or to compare the total times required to absorb a given amount of water.

A treatment must produce substantial differences in intake rates to warrant being adapted as a new farm practice. Therefore, complex analyses to verify the significance of small differences are not justified. Also, the use of the empirical equations $I=At^B$ for cumulative intake, where A and B are constants derived experimentally and t is time, or $i=ABt^{B-1}$ for intake rate, requires reliable evaluation of the constants A and B. Determination of these constants for the cumulative equation would require either an estimate of the intake during the first 20 minutes or of the total time to absorb the depth of irrigation with the measurement procedure used in this study. Estimating the cumulative intake for the first 20 minutes, when intake rates are high and when water is being applied, is subject to large errors. Likewise, estimating a total time accurately is difficult because of the minor variations in soil surface elevation and because the end time frequently occurs at night when personnel are not available to observe the disappearance of water from the soil surface. Evaluation of the intake data indicated that the empirical equation $i=ABt^{B-1}$ would fit only after the first 1 to 1.5 hours.

A calibration of individual plots before treatment for comparative analysis was not possible, although some later comparisons were made. The simplest and perhaps most reliable procedure for comparing intake rates for the measurement technique used was to evaluate mean intake rates for specified periods. The differences in intake rates for the period 0.33 to 1.33 hours were due primarily to differences in voids, cracks, and density of surface layers; the differences for the period 1.33 to 7.33 hours represented primarily the influence of physical characteristics deeper in the profile.

[5] SWARTZENDRUBER, D., and HUBERTY, M. R. USE OF INFILTRATION EQUATION PARAMETERS TO EVALUATE INFILTRATION DIFFERENCES IN THE FIELD. Amer. Geophys. Union Trans. 39: 84–93. 1958.

RESULTS AND DISCUSSION

General Intake Trends

A summary of the changes in intake rate of Pullman silty clay loam due to crop sequence and tillage treatments is presented in table 4. The mean intake rates measured 0.33 to 7.33 hours after irrigation, for all irrigations during the growing seasons, are compared in table 4, with the sweep-and-chisel or the continuous crop treatment used as a check. Mean intake rates are expressed as ratios with the rate on the check used as the denominator in the ratio.

In the wheat series experiment, the influence of 2 years of sorghum on mean intake rates from 1958 to 1962 was not significant when compared with the influence of continuous wheat. In contrast, the influence of 2 years of alfalfa on intake rates was materially significant for several years when compared with the influence of continuous wheat.

In the sorghum series experiment, continuous sorghum and sorghum with interplanted cowpeas had nearly the same intake

TABLE 4.—*Influence of crop sequence treatment and tillage treatment on mean relative intake rate*[1] *of Pullman silty clay loam, from 0.33 to 7.33 hours after beginning irrigation during the growing season—wheat and sorghum series experiments*

Series and treatment	Mean relative intake rate during—					
	1957	1958	1959	1960	1961	1962
Wheat:						
Continuous wheat [2]	1.00	1.00	1.00	1.00	1.00	1.00
Sorghum-wheat	------	1.01	.93	1.02	1.06	1.05
Alfalfa-wheat	------	.86	1.24	1.17	1.13	1.02
Sweep-chisel [2]	1.00	1.00	1.00	1.00	1.00	1.00
Moldboard	1.15	1.10	1.00	1.08	1.15	1.01
Rough	1.27	1.11	1.25	1.33	1.17	1.05
Sorghum:						
Continuous sorghum [2]	1.00	1.00	1.00	1.00	1.00	1.00
Sorghum-cowpeas	.95	1.01	1.00	.88	1.06	.95
Alfalfa-sorghum	------	1.00	1.43	1.37	1.25	1.11
Sweep-chisel [2]	1.00	1.00	1.00	1.00	1.00	1.00
Moldboard	1.12	1.08	1.47	1.07	1.41	1.10
Rough	1.10	1.09	2.06	1.53	1.31	1.20

[1] Mean intake rates are expressed as dimensionless ratios with the rate on the check used as the denominator of the ratio.
[2] Check treatment.

rates during the 6-year period. In this same sorghum series experiment, alfalfa increased intake rates for several years after it was plowed under.

Deep-chiseling (rough tillage in 1959) increased intake rates in both the wheat and sorghum series experiments. The effects of one deep-chiseling operation lasted for several years. The high intake rate resulting from the moldboard treatment on the sorghum series in 1961 was due to plowing deeper than normal that year. The reason for the high intake rate resulting from the moldboard treatment in 1959 (sorghum series) is not known.

Mean 0.33- to 7.33-hour intake rates for each irrigation and the mean intake rates for all irrigations for the crop season are presented in tables 5 and 6. Intake rates were highest for the preplanting irrigation, and generally decreased for irrigations during the crop season. The 6-year average seasonal intake rate from 0.33 to 7.33 hours on the sweep-and-chisel treatment was 0.13 inch per hour on the wheat and 0.14 inch per hour on the sorghum series. At these rates, only 0.9 to 1.0 inch of water is absorbed by the soil in 7 hours after the 20-minute water application period.

Influence of Alfalfa

One of the major objectives in this study was to determine whether growing alfalfa for 2 years would increase the intake rate and to determine the duration of the influence after the alfalfa was plowed under. While the plots were in alfalfa in 1957, the intake rates were as low as or lower than any other treatment (see tables 5 and 6).

After the alfalfa was plowed under in the fall of 1957 on the wheat series experiment and in the spring of 1958 on the sorghum series experiment, no increase in intake rate was detected during the first cropping season (1958, table 4). In the wheat series experiment, alfalfa increased the 0.33- to 7.33-hour intake rate 24, 17, 13, and 2 percent during the second, third, fourth, and fifth cropping seasons, respectively, after being plowed under. These results indicate that the increased intake rate after alfalfa grown for 2 years was plowed under persisted about 3 years on winter wheat, beginning with the second crop year.

Larger increases occurred in the sorghum series experiment. Intake rates were 43, 37, 25, and 11 percent higher during the second, third, fourth, and fifth cropping seasons, respectively, after the alfalfa was plowed under.

Influence of Deep-Chiseling

Deep-chiseling (13 to 15 inches, rough treatment) greatly increased the mean intake rates, compared to the rates obtained on the shallow sweep-and-chisel plots (table 4). Deep-chiseling the sorghum plots in the spring of 1959 doubled the 0.33- to 7.33-hour intake rate during the 1959 season. The intake rate on the deep-chiseled plots during the second, third, and fourth year after deep-chiseling was 53, 31 and 20 percent higher, respectively, than the rate on the shallow sweep-and-chisel plots. The intake rate on the rough plots before they

TABLE 5.—*Mean intake rate of wheat series plots by year, from 0.33 to 7.33 hours after beginning irrigation, related to time of irrigation, crop sequence treatment, and tillage treatment*

Irrigation or treatment	Year					
	1957	1958	1959	1960	1961	1962
	In./hr.	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*
Preplant			[1] 0.216	[2] 0.233		
1st spring	0.165	0.114	.186	.154	0.134	0.157
2nd spring	.134	.143	.128	.163	.105	
3rd spring			.135			
Continuous wheat	.149	.134	.142	.149	.112	.153
Sorghum-wheat		.136	.132	.152	.119	.161
Alfalfa-wheat	[3] .146	.115	.176	.175	.126	.156
Sweep-chisel	.131	.120	.138	.139	.108	.154
Moldboard	.151	.132	.138	.150	.124	.155
Rough	.166	.133	[4] .173	[4] .186	.126	.162

[1] Fall of 1958—1 year after alfalfa was plowed under and after plots were deep-chiseled in the summer of 1958. This value is not included in averages for crop sequence treatment or tillage treatment.
[2] Fall of 1959. This value is not included in averages for crop sequence treatment or tillage treatment.
[3] Average of four irrigations on all alfalfa plots in 1957.
[4] Deep-chiseled in summer of 1958 and 1959.

TABLE 6.—*Mean intake rate of sorghum series plots by year, from 0.33 to 7.33 hours after beginning irrigation, related to time of irrigation, crop sequence treatment, and tillage treatment*

Irrigation or treatment	Year					
	1957	1958	1959	1960	1961	1962
	In./hr.	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*	*In./hr.*
Preplanting	[1] 0.205		[1] 0.407			
First seasonal	.154	0.176	.252	0.200	0.204	0.135
Second seasonal	.165	.148	.195	.153	.139	
Continuous sorghum	.163	.161	.195	.163	.155	.133
Sorghum-cowpeas	.155	.163	.195	.144	.164	.126
Alfalfa-sorghum	[2] .146	.161	.280	.223	.194	.146
Sweep-chisel	.148	.153	.148	.147	.138	.123
Moldboard	.166	.165	.218	.157	[3] .194	.135
Rough	.163	.167	[4] .305	.226	.181	.147

[1] These values are not included in averages for crop sequence treatment or tillage treatment.
[2] Average of four irrigations on all alfalfa plots in 1957.
[3] Moldboard plowed 8–9 inches, Feb. 2, 1961 (deeper than usual).
[4] Deep-chiseled on Mar. 10, 1959.

were deep-chiseled was about 10 percent higher than on the sweep-and-chisel plots, due to the effects of previous tillage practices. The increase in intake rates with deep-chiseling on the wheat series plots was not as great as on the sorghum series plots even though the plots were deep-chiseled in September 1958 and in August 1959. However, in both 1958 and 1959, the soil, when deep-chiseled, was not as dry on the wheat series as on the sorghum series. Deep-chiseling is more effective when the soil is dry.

The combined effects of deep-chiseling and alfalfa on intake rate are illustrated in figure 5. About 21 hours after an irrigation, there was approximately 2 inches of water on the surface of a sweep-and-chisel, continuous wheat plot whereas there was no free water on the surface of the deep-chiseled alfalfa plot. Some water remained on the surface of the sweep-and-chisel plot 3 days after irrigation.

Influence of Soil Moisture

Detailed soil moisture evaluations were not made prior to each irrigation. After 1957, soil samples were taken from all plots, generally on the day before the first replication was irrigated. Approximately 60 to 70 percent of the available soil moisture in the 0- to 4-foot depth was depleted at this time. The soil moisture was approximately the same on all the plots except that the plots with higher intake rates were slightly higher in moisture.

Several heavy rains occurred between irrigations of some replications in the sorghum series. The dates of irrigation and of intervening rainfall, the depth of irrigation, the amount of rainfall, and the mean 0.33- to 7.33-hour intake rate for each replication in the sorghum series are given in table 7. In 1960, a 3.02-inch rain occurred

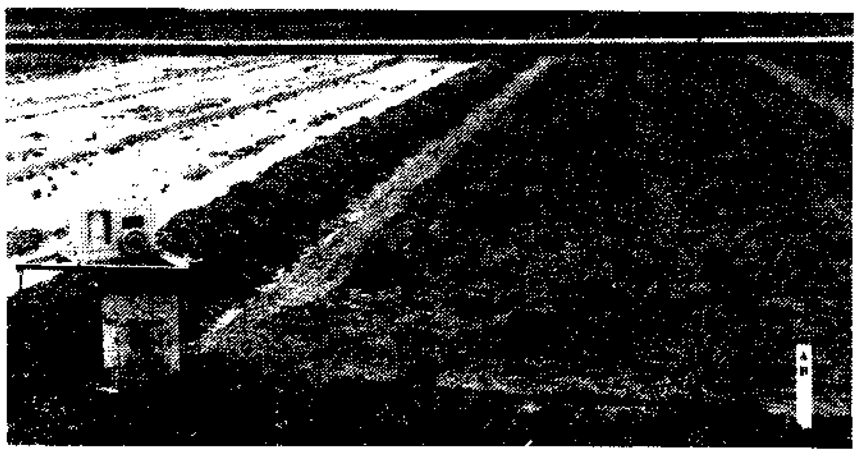

Figure 5.—Deep-chiseling and 2 years of alfalfa greatly increased intake rates. The plot on the left is a sweep-and-chisel, continuous wheat plot. The plot on the right is a wheat plot the second year after alfalfa was plowed under and the plot was deep-chiseled. Both plots received a 5-inch irrigation about 20 minutes apart. The photograph was taken about 21 hours after water was applied.

Table 7.—*Dates of irrigation and rainfall intervening between irrigations, amounts of rainfall, depths of irrigation, and mean intake rates* [1] *for replications in the sorghum series experiment*

Year	Replication	Preplanting irrigation				Irrigation No. 1				Irrigation No. 2			
		Date	Intervening rain	Irrigation depth	Mean intake rate	Date	Intervening rain	Irrigation depth	Mean intake rate	Date	Intervening rain	Irrigation depth	Mean intake rate
			In.	*In.*	*In./hr.*		*In.*	*In.*	*In./hr.*		*In.*	*In.*	*In./hr.*
1957	1	6/13	0	5	0.248	8/2	0	5	0.163	9/5	0	4	----
	2	6/12	0	5	.183	8/1	1.20	5	.140	9/5	0	4	0.176
	3	6/11	----	5	.184	7/29	----	5	----	9/4	----	4	.153
1958	1	----	----	----	----	8/14	----	5	.179	9/2	----	5	.153
	2	----	----	----	----	8/15	0	5	.169	9/3	0	5	.141
	3	----	----	----	----	8/16	0	5	.179	9/4	0	5	.149
1959	1	6/8	----	5	.321	7/29	----	5	.268	8/20	----	5	.200
	2	6/9	0	5	.343	7/30	0	5	.241	8/21	0	5	.196
	3	6/10	0	5	.268	7/31	0	5	.248	8/22	.08	5	.190
1960	1	----	----	----	----	8/9	----	5	.174	9/7	----	5	.145
	2	----	----	----	----	8/15	3.02	3	.224	9/8	0	5	.129
	3	----	----	----	----	8/16	0	3	.203	9/16	2.26	2.5	.184
1961	1	----	----	----	----	7/26	----	5	.203	8/15	----	6	.120
	2	----	----	----	----	7/27	0	5	.191	8/17	.97	5	.145
	3	----	----	----	----	7/28	0	5	.217	8/18	0	5	.152
1962	1	----	----	----	----	8/15	----	6	.138	----	----	----	----
	2	----	----	----	----	8/16	.33	6	.129	----	----	----	----
	3	----	----	----	----	8/17	0	6	.139	----	----	----	----

[1] Mean intake rates measured from 0.33 to 7.33 hours after irrigation.

between the irrigation of replication 1 and replications 2 and 3 (Aug. 9–16). Between September 8 and 16, 1960, a 2.26-inch rain occurred between the irrigation of the second and third replications. These rains increased the moisture level in the surface layers. In both cases, the mean 0.33- to 7.33-hour intake rate was higher after the rain than before, contrary to what would commonly be expected.

The influence of higher soil moisture in the surface layers on intake rates was also observed in May 1958, when a preplanting irrigation of the sorghum plots was given on the same day as an irrigation of the wheat plots. About 3.1 inches of rain had been received from April 14 to May 12. Therefore, the surface layers of the bare sorghum plots were moist. In contrast, wheat, in the early boot stage and actively using water, showed signs of wilting. Five inches of water was applied to the sorghum plots in the afternoon of May 13, and by the following morning (less than 15 hours afterward) no free water remained on the surface of any of the sorghum plots except those previously in alfalfa. Five inches of water was also applied to the wheat plots, but water remained on the surface of these plots for about 24 hours. These results are not unreasonable when one considers that after the cracks in the dry wheat plots were closed by soil swelling, the transmission of water was by flow through partially saturated soil. The hydraulic conductivity of the sorghum plot soil would be greater because of its higher degree of partial saturation.

Changes in Intake Rate With Time

The theory of intake rate received extensive study during the 1950's. Hansen presented a derivation of an approximate relationship of intake rate to time.[6] Approximate derivations are generally based on the assumption that from the water source to a short distance behind the wetting front, the degree of saturation and hydraulic conductivity are constant. The assumption implies a homogeneous material and no interaction between the fluid and porous material with time.

The results of approximate derivations indicate that if the soil were homogeneous and no interaction between the soil and water occurred, the intake rate would decrease initially at a rate equal to $C/\sqrt{t}$ where C is a constant determined experimentally and t is time. If the intake rate decreased more rapidly then $C/\sqrt{t}$, other factors such as the hydraulic conductivity must also be changing.

In their natural state, soils such as Pullman silty clay loam are not homogeneous. Shortly after the soil is plowed, the plow layer has large voids, some of which are open to the surface. After the first irrigation, surface cracks that extend below the plow layer will conduct water downward under pressures greater than atmospheric. As the voids in the plow layer become filled with water and the large cracks close because of soil swelling, the effective hydraulic conductivity also decreases. Thus, the intake rate on soils such as Pullman silty clay loam, which crack extensively and have large voids in

[6] HANSEN, V. E. INFILTRATION AND SOIL WATER MOVEMENT DURING IRRIGATION. Soil Sci. 79: 93–105. 1955.

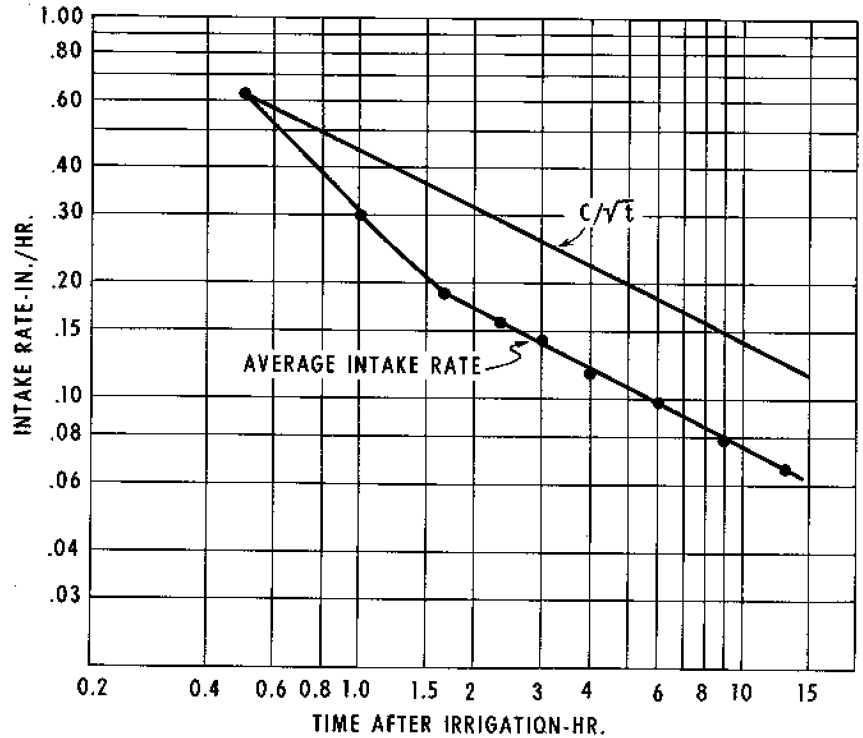

FIGURE 6.—Average intake rate of irrigations applied to soil in wheat and in grain sorghum compared to the empirical equation $i = C/\sqrt{t}$.

the plow layer, can be expected to decrease more rapidly than $C/\sqrt{t}$ during the first part of an irrigation. The intake rate should continue to decrease with time and approach a constant as t becomes very large.

The results obtained in this study followed the expected variation with time (see fig. 6). For three replications of two irrigations to soil in winter wheat, three irrigations to soil in grain sorghum, and three tillage treatments, in 1957, the average intake rate decreased more rapidly than $C/\sqrt{t}$ during the first 1.5 hours and then decreased proportionally to $C/\sqrt{t}$ for the next 12 hours. Actually, the intake rate for the first 1.5 hours decreased proportionally to $1/t$, rather than to $C/\sqrt{t}$.

Mean intake rates for the 0.33- to 1.33- and the 1.33- to 7.33-hour periods for two irrigations in 1959, 1960, and 1961 are presented in table 8.[7] Mean intake rates during the first hour of measurement were about 3 to 4 times greater than the average during the next 6 hours. Intake rates for both periods were increased by about the same magnitude by tillage treatments and alfalfa treatments. These

[7] Comprehensive intake rate tables and statistical analyses for all irrigations are available from the author upon request.

TABLE 8.—*Mean intake rates by periods for two irrigations in 1959, 1960, and 1961*

Crop sequence and tillage	Wheat series		Sorghum series	
	Period—hours after irrigation		Period—hours after irrigation	
	0.33 to 1.33	1.33 to 7.33	0.33 to 1.33	1.33 to 7.33
	In./hr.	*In./hr.*	*In./hr.*	*In./hr.*
Continuous:				
Sweep-chisel	0.280	0.087	0.301	0.105
Moldboard	.371	.099	.405	.122
Rough	.403	.115	.472	.177
Average	.351	.100	.392	.135
After alfalfa:				
Sweep-chisel	.365	.105	.368	.129
Moldboard	.424	.116	.568	.188
Rough	.525	.130	.568	.246
Average	.438	.117	.501	.188
All crop sequences: [1]				
Sweep-chisel	.314	.099	.328	.114
Moldboard	.365	.101	.462	.145
Rough	.450	.119	.500	.193
Average	.376	.106	.430	.151

[1] Including the sorghum-wheat treatment on the wheat series plots and the sorghum-cowpeas treatment on the sorghum series plots.

results indicate that tillage treatments were as effective as alfalfa in modifying intake rates and that the combination of deep-chiseling and alfalfa resulted in the largest increase in intake rates.

Yields

A summary of grain yields for 1956 through 1962 is presented in table 9 for winter wheat and in table 10 for sorghum. The sorghum yields on the wheat series were 7,097, 7,097, and 6,806 pounds per acre in 1956, and 5,992, 6,428, and 6,411 pounds per acre in 1957, on the sweep-and-chisel, moldboard, and rough plots, respectively. Yields on continuous wheat plots from 1958 to 1960 were lower than wheat yields following sorghum or alfalfa. Yields in 1961 and 1962 were affected by hail damage. Differences in wheat yield may be due to differences in the amount of residual nitrogen in the soil of the different plots. Over 120 pounds of N per acre was applied each year to all plots, including those formerly in alfalfa. Yields generally were less on sweep-and-chisel plots, possibly as a direct result of the lower intake rate, more compact surface layers, or the decomposition of the crop residue near the surface. Visual differences between the vegetation of the sweep-and-chisel treatment plots and of the other tillage treatment plots, and between the vegetation of the plots formerly in alfalfa and of the other crop sequence plots were apparent during the growing season.

There was essentially no difference between the yields of grain sorghum on the different tillage-treatment plots. Interplanting of cowpeas resulted in reduced yields from 1958 through 1962. The reduction is believed due primarily to competition between the cowpeas and sorghum for water and nutrients, when more than 10 pounds of cowpeas per acre was seeded.

SUMMARY AND CONCLUSIONS

Results of a 6-year study of the effect of crop sequence and tillage practice on water intake rates in large plots indicate that 2 years of alfalfa increased intake rates (measured 0.33 to 7.33 hours after irrigation) on Pullman silty clay loam beginning 1 year after the alfalfa was plowed under. Intake rates were increased for about 4 years. The intake rates were the highest the second year after the alfalfa was plowed under. The rates 3 to 4 years later approached those under continuous cropping.

Deep-chiseling to a depth of 13 to 15 inches at a spacing of 20 to 24 inches also increased intake rates over those obtained with shallow surface tillage. The effects of deep-chiseling also lasted about 4 years, decreasing each year after the tillage operation.

Intake rates generally decreased more rapidly during the first 1.5 hours of irrigation than theory would indicate for a homogeneous soil. The rapid initial intake is believed to be due to rapid filling of cracks and voids and the larger surface area available for intake. After the first 1.5 hours the decline in intake rate with time is similar to that predicted by theory for a homogeneous soil. Mean intake rates were 3 to 4 times greater from 0.33 to 1.33 hours after irrigation than from 1.33 to 7.33 hours after.

The use of cowpeas interplanted at high seeding rates in grain sorghum reduced sorghum yields and did not increase intake rates. Yields of wheat (1958–60) were higher from moldboard-plowed and deep-chiseled plots than from shallow sweep-and-chisel plots.

TABLE 9.—*Yield of winter wheat (Concho) as affected by crop sequence and tillage on the wheat series plots*

YIELD DATA

Crop sequence and tillage	1956	1957 [1]	1958 [2]	1959 [3]	1960	1961 [4]	1962 [5]	Average of 1958–61
	Bu./acre	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*	*Bu./acre*
Continuous wheat:								
Sweep-chisel	34.2	37.8	37.4	52.4	39.1	28.4	23.1	39.4
Moldboard	38.2	36.6	35.8	55.4	43.8	23.4	22.4	39.6
Rough	39.4	34.7	36.8	54.5	44.6	29.1	28.5	41.2
Average	37.3	36.3	36.7	54.1	42.5	27.0	24.7	40.1
Sorghum-wheat:								
Sweep-chisel			40.5	50.7	43.9	31.0	23.4	41.5
Moldboard			42.2	55.9	44.3	27.8	24.6	42.6
Rough			40.3	60.1	47.2	28.3	15.3	44.0
Average			41.0	55.6	45.1	29.0	21.1	42.7
Alfalfa-wheat:								
Sweep-chisel			35.8	56.8	42.4	31.2	24.0	41.6
Moldboard			38.2	58.3	47.0	27.3	17.5	42.7
Rough			40.6	56.1	48.9	33.6	23.9	44.8
Average			38.3	57.1	46.1	30.7	21.8	43.0
All crop sequences:								
Sweep-chisel			37.9	53.3	41.8	30.2	23.5	40.8
Moldboard			38.7	56.5	45.0	26.2	21.5	41.6
Rough			39.2	56.9	46.9	30.3	22.6	43.3
Average			38.7	55.6	44.6	28.9	22.5	41.9

SUMMARY OF ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [6]		
		1958	1959	1960
Crop sequence (C)	2	**86.34	39.74	**62.99
Tillage (T)	2	8.16	*71.32	**117.76
C x T	4	18.39	42.66	9.75
Error	16	12.36	18.54	8.36
Total	26			

[1] Hail damage in May.
[2] Low yields due to late seeding.
[3] Some loss due to high winds at maturity.
[4] Hail damage in May and June.
[5] Hail damage in June; some difficulty encountered with nitrogen application equipment.
[6] *—Significant at the 5-percent level; **—significant at the 1-percent level.

TABLE 10.—*Yield of hybrid grain sorghum (RS–610) as affected by crop sequence and tillage on the sorghum series plots*

YIELD DATA

Crop sequence and tillage	1956	1957	1958	1959	1960	1961	1962	Average of 1958–61
	Lb./acre	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*
Continuous sorghum:								
Sweep-chisel	7, 932	5, 923	6, 836	6, 988	6, 947	8, 173	7, 377	7, 264
Moldboard	6, 988	6, 158	6, 645	7, 306	6, 708	8, 372	7, 626	7, 331
Rough	7, 587	6, 402	6, 826	7, 158	6, 969	8, 176	7, 049	7, 236
Average	7, 502	6, 161	6, 769	7, 151	6, 874	8, 240	7, 350	7, 277
Sorghum-cowpeas:								
Sweep-chisel	7, 315	6, 280	6, 689	7, 110	6, 234	7, 572	6, 718	6, 865
Moldboard	7, 332	6, 262	6, 874	6, 496	6, 560	7, 156	7, 134	6, 844
Rough	7, 569	6, 080	7, 066	6, 456	6, 156	6, 993	6, 698	6, 674
Average	7, 405	6, 207	6, 876	6, 688	6, 317	7, 241	6, 850	6, 794
Alfalfa-sorghum:								
Sweep-chisel	----------	----------	6, 586	7, 197	6, 747	8, 534	7, 280	7, 269
Moldboard	----------	----------	6, 758	6, 792	6, 847	8, 948	7, 752	7, 419
Rough	----------	----------	7, 270	6, 366	7, 100	8, 712	7, 349	7, 359
Average	----------	----------	6, 871	6, 784	6, 898	8, 732	7, 460	7, 349
All crop sequences:								
Sweep-chisel	7, 623	6, 101	6, 704	7, 098	6, 643	8, 093	7, 125	7, 133
Moldboard	7, 160	6, 210	6, 759	6, 865	6, 705	8, 159	7, 504	7, 198
Rough	7, 578	6, 241	7, 054	6, 660	6, 742	7, 960	7, 032	7, 090
Average	7, 454	6, 184	6, 839	6, 874	6, 696	8, 071	7, 220	7, 140

SUMMARY OF ANALYSIS OF VARIANCE

Component	Degrees of freedom	Mean squares [1]				
		1958	1959	1960	1961	1962
Crop Sequence (C)	2	66, 370	**1, 074, 323	**1, 949, 927	**10, 391, 776	**1, 916, 362
Tillage (T)	2	636, 931	*866, 751	44, 715	183, 776	**1, 118, 108
C x T	4	201, 559	*564, 855	277, 399	343, 560	66, 838
Error	16	364, 136	168, 463	163, 622	254, 866	90, 053
Total	26					

[1] *—Significant at the 5-percent level; **—significant at the 1-percent level.

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