RESEARCH BULLETIN 935 APRIL 1963

TILE AND SURFACE DRAINAGE OF CLAY SOILS

I. HYDROLOGIC PERFORMANCE WITH GRASS COVER

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ACKNOWLEDGMENT

The authors wish to acknowledge the helpful assistance of A. P. Leech, Robert Eby, J. P. Miller, N. R. Fausey, D. L. Van Doren, T. W. Edminster, N. H. Holowaychuk, and many others who assisted in the installation of the experiment and in the collection of data.

AGDEX 752

4-63-4M

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I. HYDROLOGIC PERFORMANCE WITH GRASS COVER

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INTRODUCTION

In Ohio over 3 million acres of land have been drained with tile and surface ditches, and an additional 75,000 acres are drained each year. The annual investment in drainage exceeds $6 million. Research to determine the economic feasibility of various drainage methods has been limited almost entirely to field observations where variation in soils, topography, drainage patterns, crops, year to year climate variables, and rainfall are not easily controlled.

In 1957 a field experiment was installed at the North Central substation near Sandusky, Ohio, to evaluate the relative effectiveness of tile and surface drainage systems. The experiment was designed to eliminate some of the above variables and to obtain reliable factual data. The drainage systems were confined to one-half acre plots to reduce soil and rainfall variability. The soil is fine-textured and typical of soils in the lakebed region. For the first three years a meadow crop was grown on all plots and a sprinkler irrigation system was provided to create wet conditions when desired.

This progress report includes soil and hydrologic measurements taken during the first four years of operation. Most of the data included in the report were taken during September 1960, June 1961, and August 1961. On these dates large amounts of water were applied with the irrigation system to simulate rainfall.

FIELD LAYOUT AND EQUIPMENT

Drainage and Irrigation Systems

The general layout of the experiment, including the location of plots and the irrigation system, is shown in Figure 1. The experiment consisted of four replicates each of four levels (treatments) of drainage or a total of sixteen plots. Each plot was 120 by 200 feet or 0.55 acre. The treatments included level plots with no drainage (A plots), surface drainage alone (B plots), level plots with tile drainage only (C plots), and a combination of tile and surface drainage (D plots). The plots were arranged in a Latin square for statistical analysis. The tile and surface drainage systems are shown in Figure 2. The tile depth and

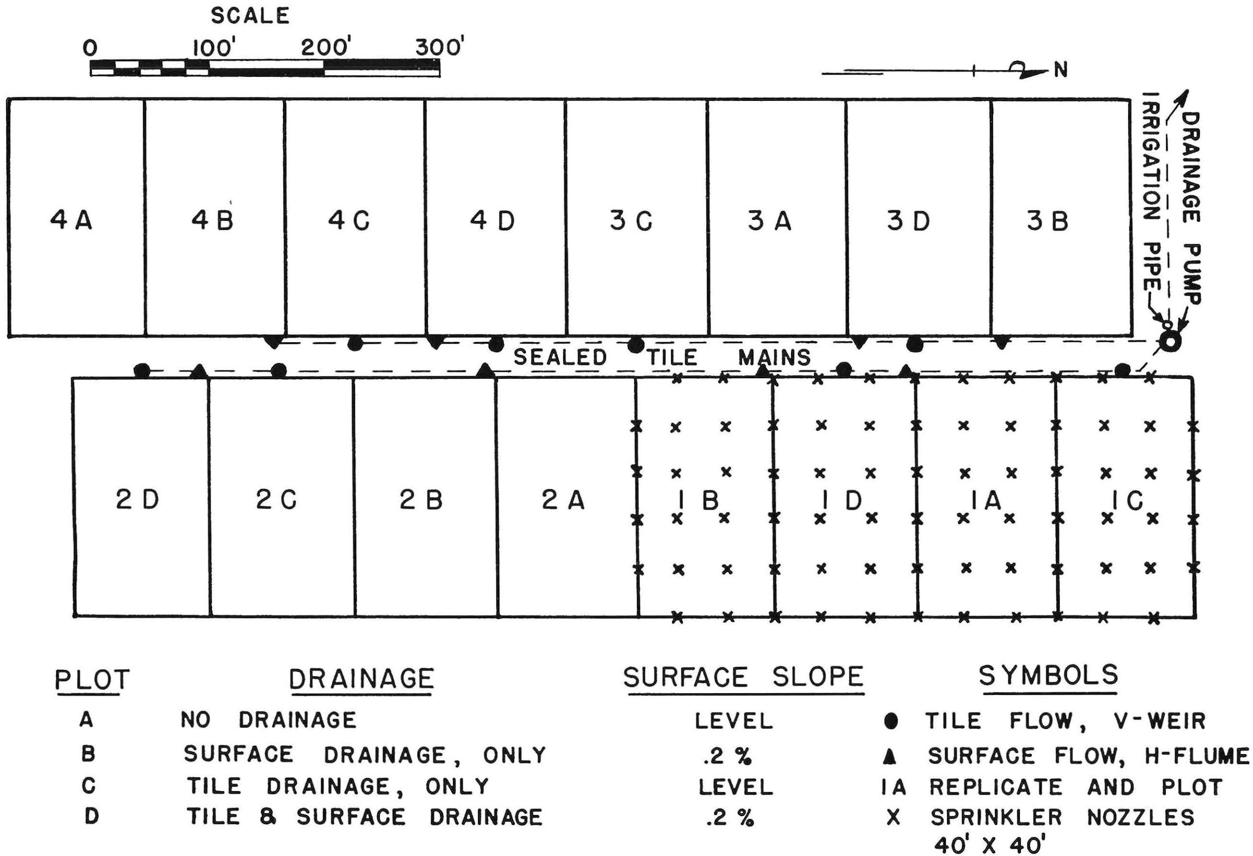

Fig. 1.—Tile-surface drainage experiment showing plot layout and irrigation sprinkler location.

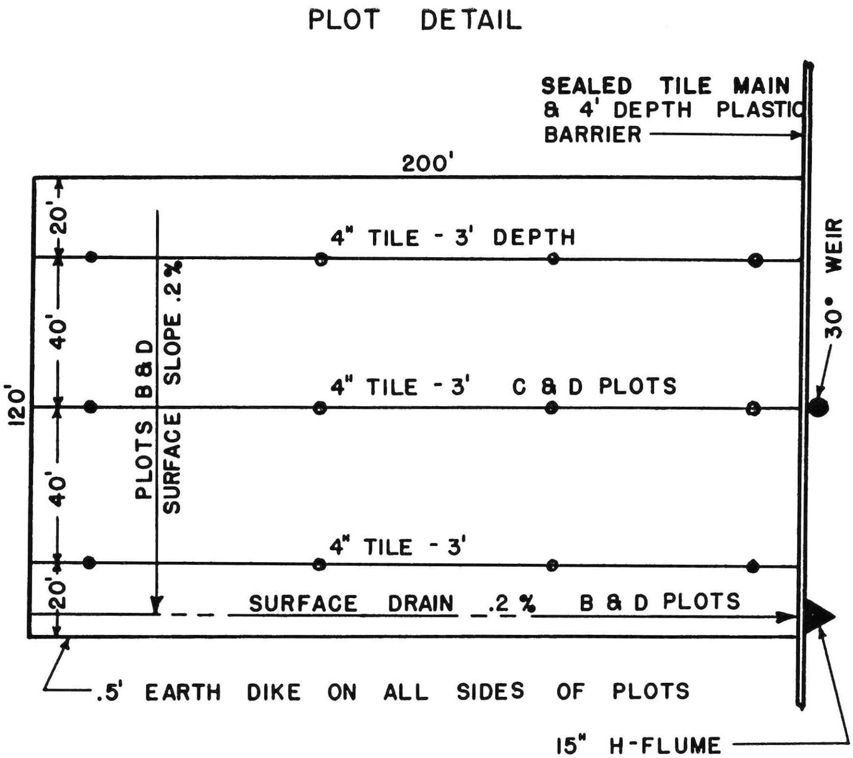

Fig. 2.—Tile and surface drainage systems in the plots.

spacing were 3 and 40 feet, respectively, which is a somewhat more narrow spacing than recommended in the Ohio Drainage Guide (1958). The general view of the experiment looking south, and showing the irrigation system in operation on replicate 2, is shown on the front cover. All plots were surrounded with an earth-dike border about 0.5 foot high to prevent surface flow into or from the plot. Tile flow was measured from the center tile line only. Surface runoff was measured from the entire plot. To prevent movement of soil moisture between the plots and the grass roadways, the outside borders of the eight east and the eight west sets of plots were surrounded by an 8-mil polyethylene plastic barrier. This plastic sheet was installed 4 feet deep in a trench made by a ditching machine as shown in Figure 3. The procedure for blinding the tile is shown in Figure 4. The topsoil, which included alfalfa stems and roots, was placed about 6 inches above the top of the tile. The drains were 4-inch concrete tile with spacers on one end so as to give a uniform crack width of about 1/8 inch. A typical surface

Fig. 3.—Installation of plastic barrier.

drain in the B and D plots and an earth dike between the plots are shown in Figure 5.

The surface drains and other earthwork were completed in 1958, one year after the tiles were installed. The soil was plowed to a depth of 10 inches prior to earth-moving and land-smoothing operations. The maximum cut or fill in the plots was approximately 0.5 foot. The surface-drained plots were graded with a small tractor scraper. Most of the soil fill was obtained from or near the surface drain and moved to the opposite side of the plot. The surface channels were built with a motor grader.

The drainage pump was necessary in order to provide an adequate outlet for the surface and tile drains. Because of the extra depth needed for flow measurement, the nearest natural outlet was not suitable. The tile mains which collected the plot runoff were concrete bell and spigot tile sealed with rubber gaskets. These sealed mains which were about 1 foot deeper than the laterals prevented drainage along the inner sides of the plots.

The irrigation sprinklers shown in Figures 1 and 6 were placed at a spacing of 40 by 40 feet. The irrigation water was obtained from a surface reservoir which was fed by artesian wells and tile drains, and was pumped underground through an 8-inch asbestos cement pipe to the experimental area. The sprinkler irrigation system consisted of 74 sprinklers which applied water to one replicate (4 plots) at a time. All outside sprinkler heads were adjustable part-circle sprinklers so as to minimize the irrigation of adjoining plots and roadways. These were adjusted to give about 30 degrees coverage outside the plot border in both directions.

Soil and Soil Management

The predominant soil type at the experimental site is Toledo silty clay, a fine-textured Humic Gley. The remaining 20 percent is clas-

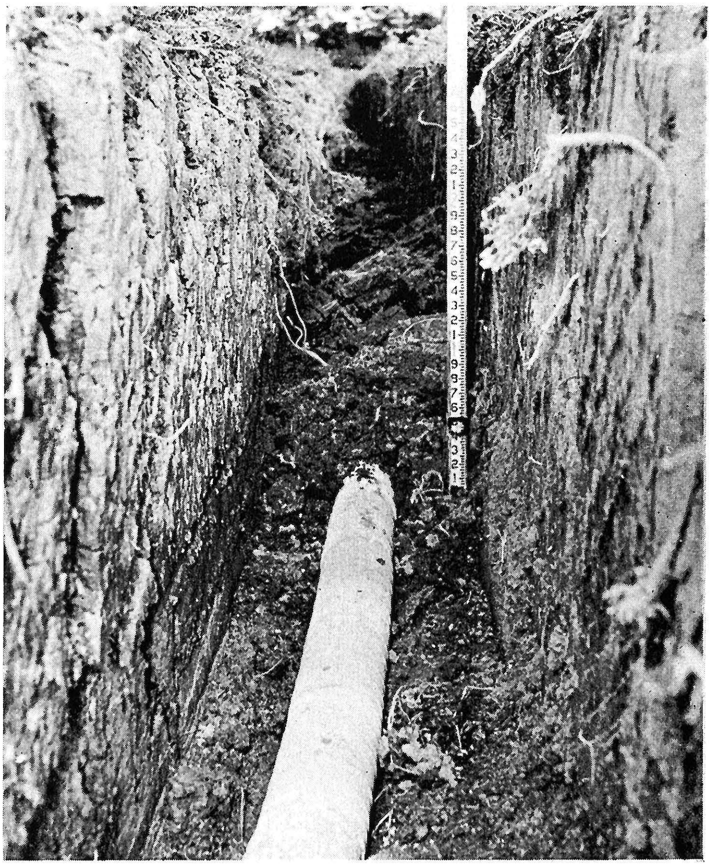

Fig. 4.—Binding the tile with topsoil.

Fig. 5.—Typical surface drain in the B and D plots and earth dike between plots on the left.

sified as Fulton silty clay, an "imperfectly drained" Gray Brown Podzolic soil which occurs at elevations 6 to 8 inches higher than the Todelo (see Figure 7). These soils are typical of the fine-textured soils that occur in the lake region of North Central United States. They are on flat or nearly level topography, are high in clay, require drainage, and are difficult to manage.

The Toledo soil contains approximately 45 to 50 percent clay in the plow layer. The clay contents approach 60 percent in the lower B horizon at about the 20- to 40-inch depths (see Appendix A). This soil is classified as being "very slowly permeable". Its hydraulic conductivity is greatly influenced by the large number of cracks that form upon drying and the rate at which they are closed by subsequent wetting. Root channels also appear to greatly influence the conductivity. The saturated hydraulic conductivity of the A and B horizons as evaluated from soil monoliths is shown in Table A1. These cores were taken in the spring months before cracking occurred, and the conduc-

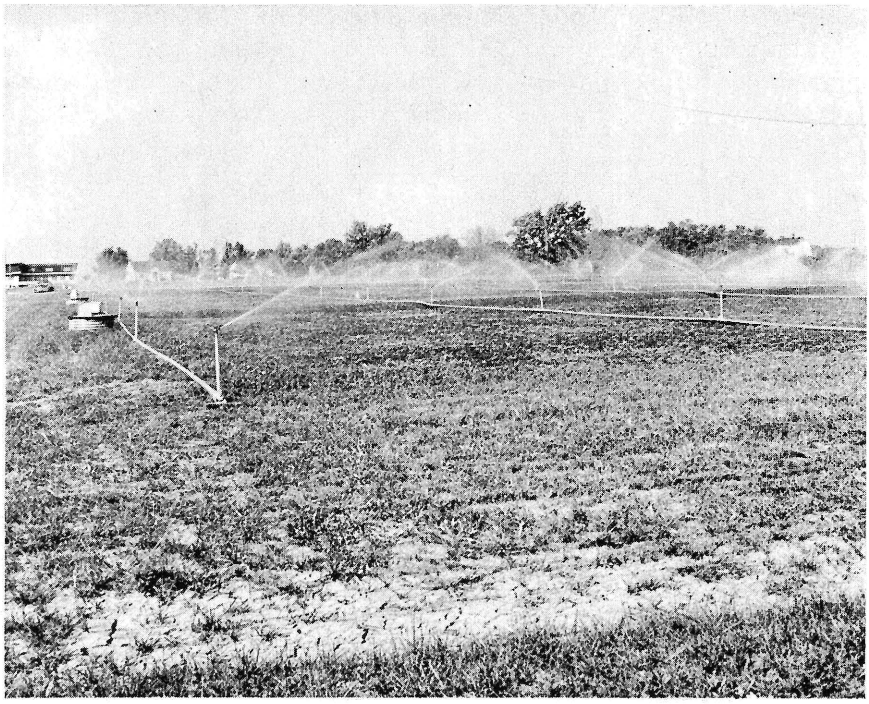

Fig. 6.—Sprinkler irrigation system.

tivity values should be indicative of those existing during periods of extended soil wetness. Because of the inherent difficulties in evaluating conductivity, the values reported herein should only be used as a guide to the relative permeability of the various horizons. The conductivity of the A horizon is quite high, ranging from 10 to 20 inches per day. These values in no way represent the conductivity of the upper inch since surface sealing is often encountered, sometimes before the subsurface soil is saturated. The conductivity of the B horizon varies between 0.9 to 2.8 inches per day. An additional description of the Toledo soil is reported by Taylor, *et. al.* (1961).

The Fulton soil has a slightly higher clay bulge than the Toledo, the former having clay contents of 62 percent in the lower B horizon (see Table A2). It is classified as being less permeable than the Toledo, particularly in the upper B horizon. As with the Toledo, cracking and root channels also greatly influence its hydraulic conductivity. Its hydraulic conductivity as evaluated from monoliths varied from 0.4

inch per day in the upper B horizon to 0.7 in the lower B. The saturated moisture content in the B_1 horizon is 30 percent by weight. For comparable densities in the A_p horizon, saturated moisture contents approximate those in the Toledo soil.

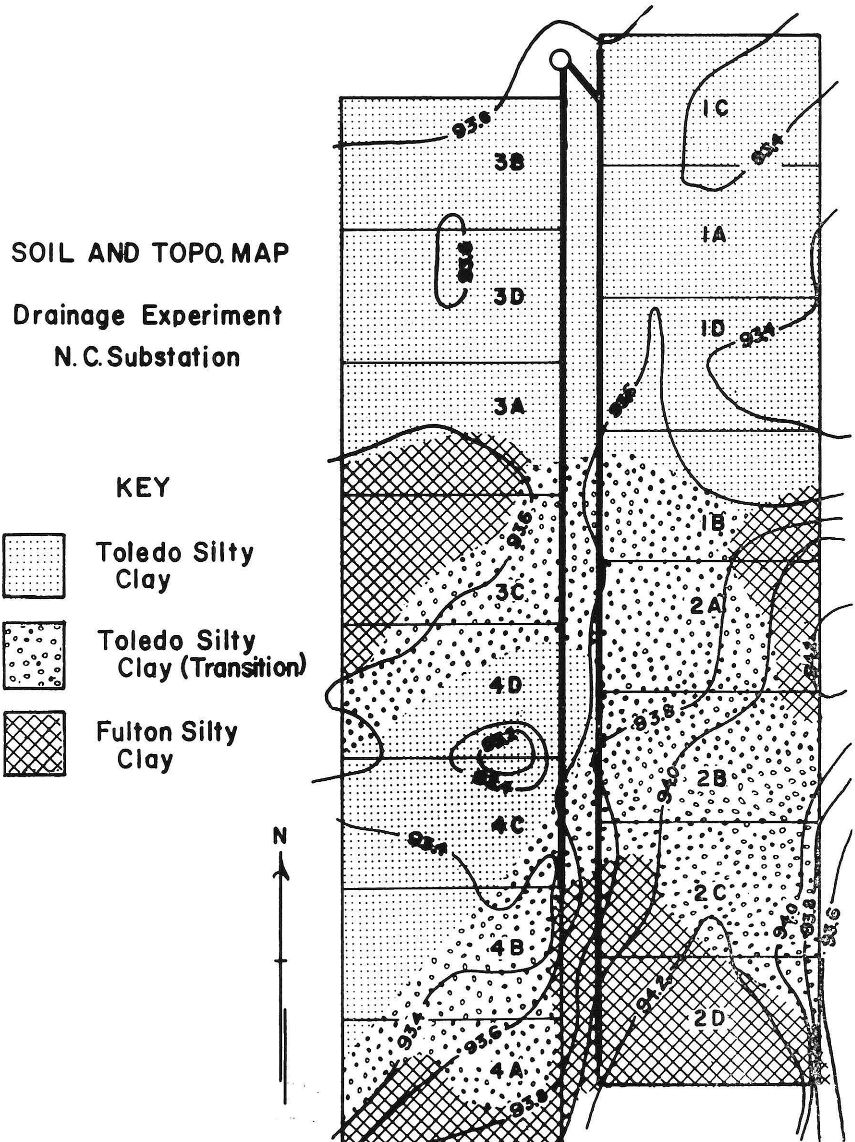

Fig. 7.—Soil and Topographic map prior to shaping the plots.

The plots were seeded to alfalfa in 1958 and reseeded in May 1959 because of poor stand. The stand was again very erratic and growth meager during 1959. Since a uniform plant cover was desirable for these studies, the area was reseeded to Kentucky 31 fescue in early autumn of 1959. A good stand was established and maintained on all plots throughout the 1960-61 period. Fertilizer applications were made as follows: 125 lbs. per acre (4-16-16) in May 1959; 325 lbs. per acre (10-10-10) September 1959; and 100 lbs. per acre of nitrogen in April 1960, 50 lbs. in March 1961, and 35 lbs. in May 1961. Fescue was also seeded in the roadways and in a surface channel just outside the plot area whose banks largely consisted of exposed subsoil. The fescue provided uniform, durable cover on all plots, roadways, and surface channels (see cover). The fescue was mowed to a height of 6 inches several times during the growing season.

Measuring Equipment

Tile and surface flow were measured continuously throughout the year. The surface flow was measured with a 1.25-foot H-flume as shown in Figure 8 and an FW-1 water level recorder as shown in

Fig. 8.—Surface flow measuring flume (H-type).

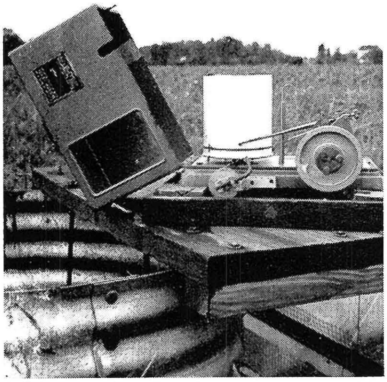

Fig. 9.—FW-1 tile and surface flow recorder.

Figure 9. The screen in Figure 8 prevented grass clippings from plugging the drainage pump. Tile flow was measured with a 30° V-weir shown in Figure 10 and an FW-1 recorder. The weir was placed below the tile line in a 42-inch corrugated metal manhole.

Water table height, soil moisture content, soil moisture tension, and oxygen diffusion rates were measured before and after irrigation. Water table height was obtained from three 3/4-inch pipes in each plot. In the tiled plots one pipe was placed 3 feet from the tile, and the other two were placed midway between the drains. The depth to the water table was taken as the average from these three pipes. Soil moisture content was obtained with the *Nuclear-Chicago Corporation Model 2800 scaler and P-19 probe shown in Figure 11. The number and relative location of the access tubes for the probe were the same as the water table pipe. Although not included in this report, gravimetric soil moisture contents were measured in the plow layer. Soil moisture tensions (plot 1C only) were measured with a porous cup tensiometer. Oxygen diffusion rates were obtained using equipment and procedures described by Lemon and Erickson (1952).

OPERATING PROCEDURE

The plots were irrigated in July 1960 with 2.8 inches of water and in September 1960, June 1961, and August 1961 with 3.9 inches. One replication (4 plots) was irrigated at one setting of the irrigation system. Water was applied during the night and early morning so that most of the measurements could be taken during the daylight hours. The rate and amout of irrigation and the range in the antecedent moisture

*Trade names and company names are included for the benefit of the reader and do not infer any endorsement or preferential treatment of the product.

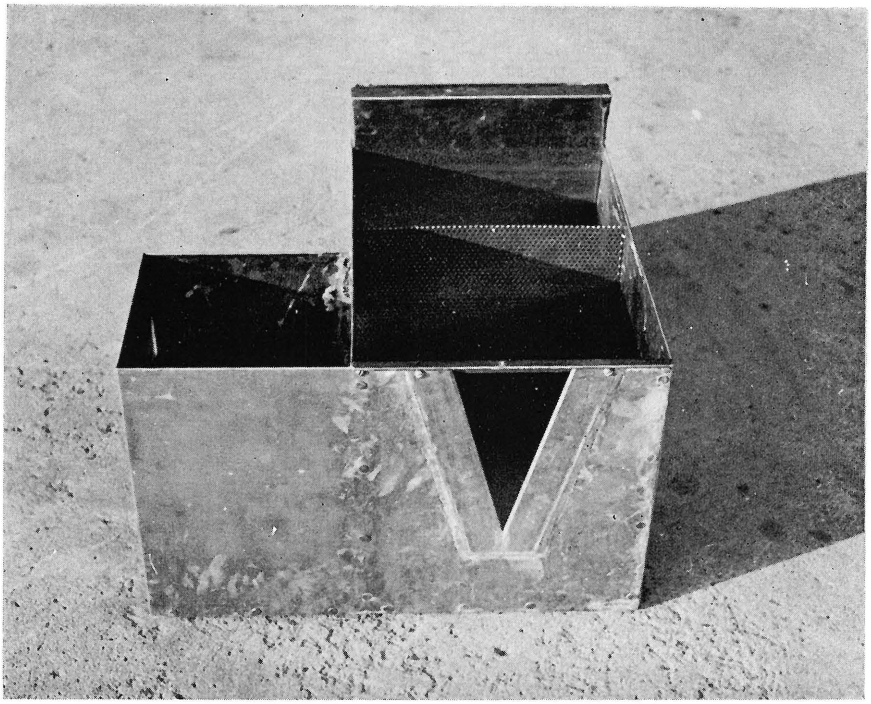

Fig. 10.—Tile flow measuring weir.

Fig. 11.—Neutron soil moisture meter.

TABLE 1.—Irrigation and Initial Moisture Conditions

Date	Irrigation: Amount Applied Inches	Irrigation: Rate, Inches Per Hour	***Antecedent Soil Moisture Content—6-Inch Depth Percent by Volume
July 1960*	2.8	0.23	24.3 to 26.5
September 1960	3.9	0.23	27.7 to 29.2
June 1961	3.9**	0.23	35.2 to 37.4
August 1961*	3.9	0.51	25.8 to 27.6

*Undrained A plots not irrigated.

**Does not include water applied to provide a high antecedent moisture condition.

***Values for B, C, and D plots only. See Table B1 for more detail.

content in percent by volume are shown in Table 1 and Appendix B, Table B1. The lowest moisture contents range from slightly above the permanent wilting percentage to near field capacity.

Prior to irrigation in July 1960, September 1960, and August 1961 the soil was fairly dry and many cracks were evident in the drained plots (B, C, and D). In June 1961 high antecedent moisture was obtained by irrigating two successive days just prior to the 3.9-inch application. This initial irrigation was discontinued when the tile drains started to flow. The amount required to start flow varied for the different replications.

The plots were irrigated only at the above times, except for a 1-inch application to establish the grass in September 1959. Precipitation and irrigation data by months are summarized in Table B2.

RESULTS

Tile and Surface Flow

The evaluation of the various methods of drainage is based primarily on hydrologic effects, including tile and surface flow, water table height, and soil moisture content. Although some of the grass died in the level (A) plots, variations in growth were not considered a major variable. Grass yields were not taken because of the generally poor response of such a crop to drainage. For three irrigation periods a summary of tile and surface flow volume is given in Table 2.

Figure 12 shows the effect of irrigation rate on tile flow for the tile-drained treatment (C plots) and for the combination tile- and surface-drained treatment (D plots). In both groups of plots the higher irrigation rate more than doubled the peak tile flow rate, but the volume of tile flow was not materially affected. In all cases the peak flow occurred at the end of the irrigation period. This time is

TABLE 2.—Average Volume of Tile and Surface Flow

Date	Antecedent Moisture Content (See Table 1)	Irrigation Rate (Total amount 3.9 inches)	Drainage Treatment	*Tile Flow Volume (inches)	*Surface Flow Volume (inches)	Total Flow Volume (inches)
			B	———	1.26±.31	1.26
September 1960	Low	Low	C	1.22±.18	———	1.22
			D	0.65±.12	0.82±.06	1.47
			B	———	3.17±.53	3.17
June 1961	High	Low	C	2.53±.70	———	2.53
			D	1.31±.45	2.17±.29	3.48
			B	———	1.20±.18	1.20
August 1961	Low	High	C	1.13±.14	———	1.13
			D	0.74±.16	0.56±.18	1.30

*Fiducial limits were computed at the 95 percent level.

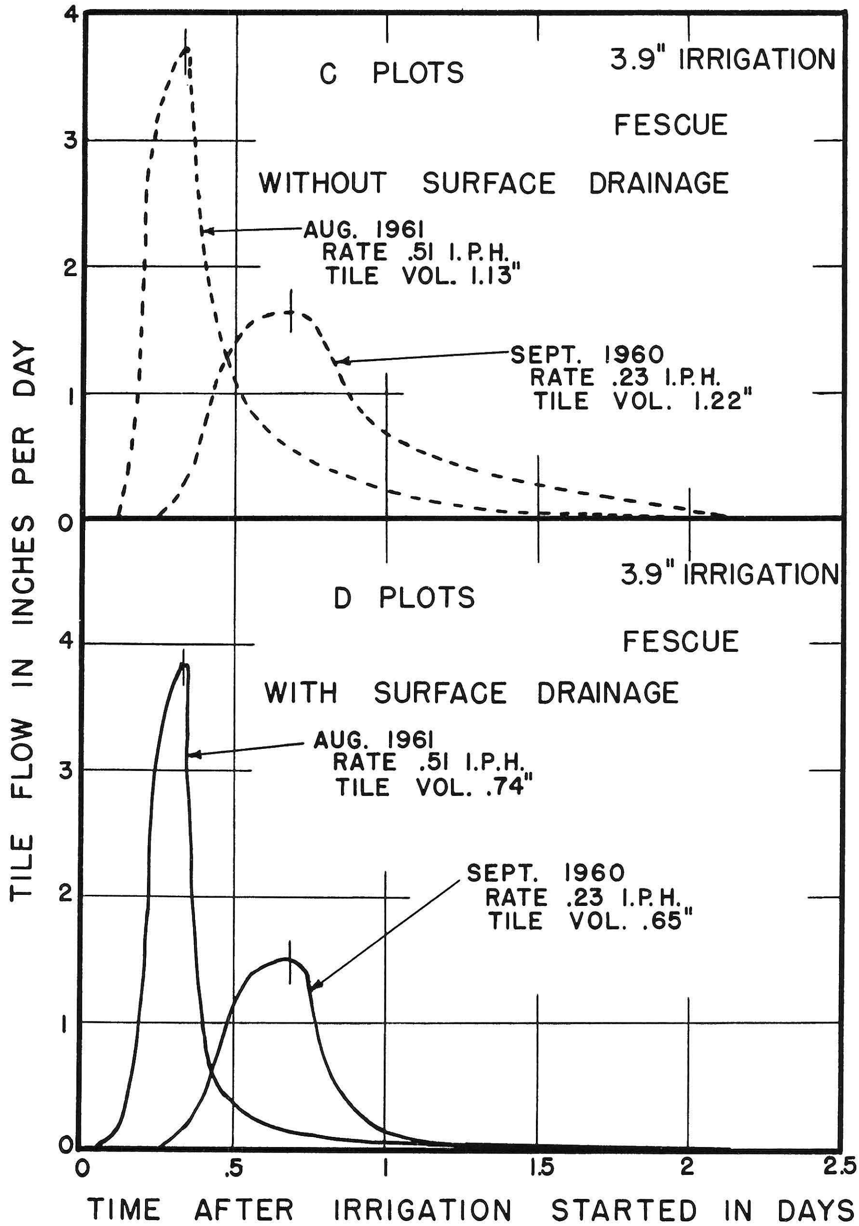

Fig. 12.—Effect of water application rate on tile flow from plots with and without surface drainage. (The following notation applies to all subsequent hydrographs: rate of water application is in inches per hour, iph, and volume of flow is in inches of water over the area drained. The short vertical line at the peak of each hydrograph is the time irrigation stopped. Each hydrograph is the average of four replications taking zero time at the start of irrigation).

PLOT IDENTIFICATION

B (long dashed line) 0.2 percent slope; surface drained
C (short dashed line) level; tile drained
D (solid line) 0.2 percent slope; tile and surface drained

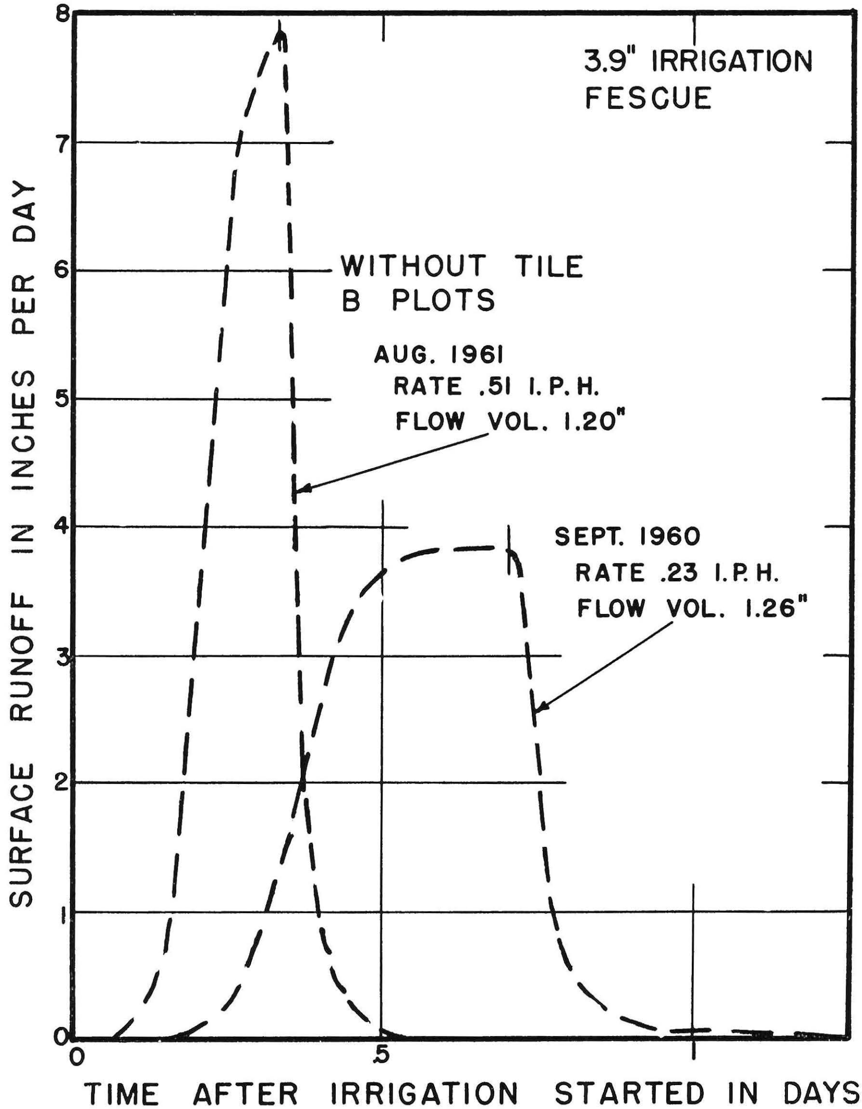

Fig. 13.—Effect of water application rate on surface runoff from nontiled plots.

shown on this hydrograph and others to follow by a vertical line drawn through the peak of each hydrograph. With the high rate of application the flow began several hours sooner, but the amount applied prior to the start of flow was nearly the same.

The effect of irrigation rate on surface runoff is shown for the surface-drained treatments (B plots) in Figure 13 and for the combination tile- and surface-drained treatment (D plots) in Figure 14. For the surface-drained (B) plots the peak runoff was nearly directly proportional to the irrigation rate, but the volume of flow at the two application rates was nearly the same. In Figure 14 the high rate of application increased the peak runoff only about one-third for the combination tile- and surface-drained (D) plots, but the volume of surface runoff was decreased by 0.26 inch (0.82-0.56), of which only

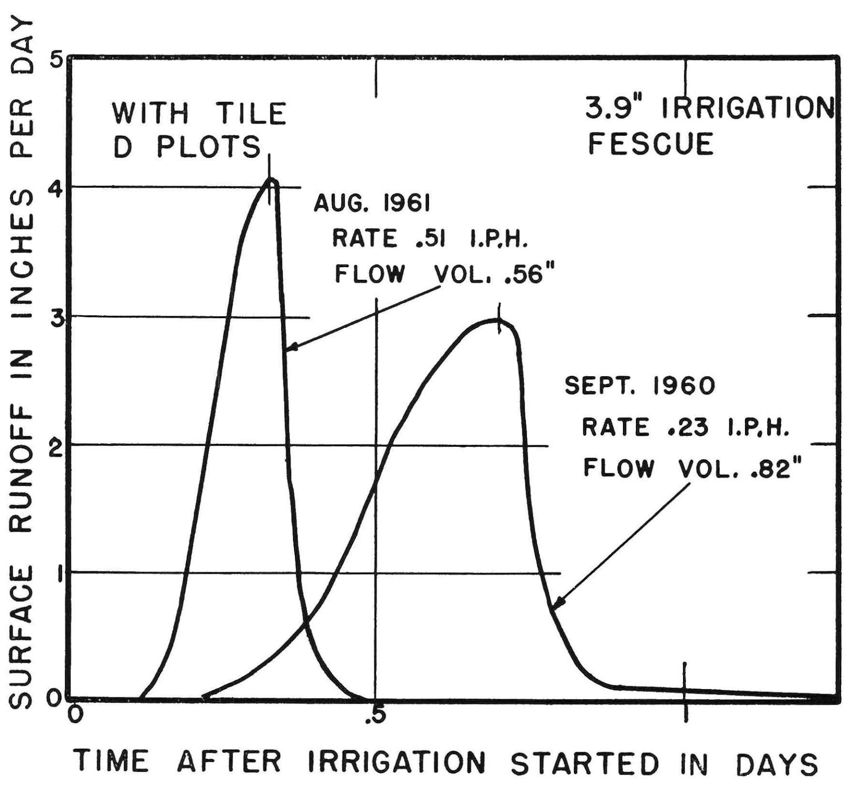

Fig. 14.—Effect of water application rate on surface runoff from tile-drained plots.

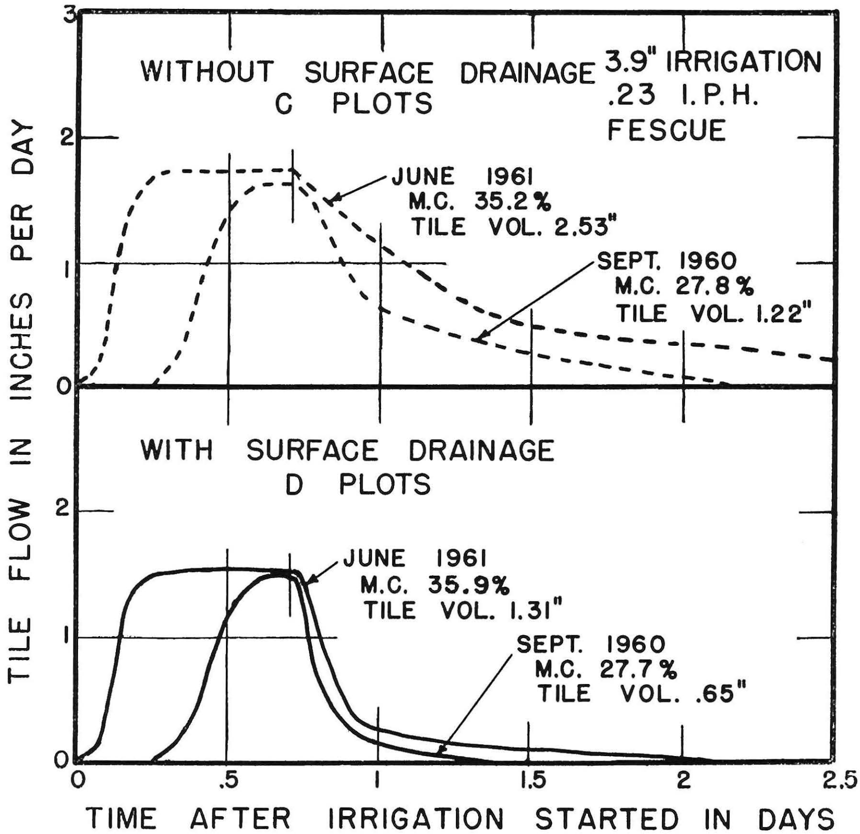

Fig. 15.—Effect of antecedent moisture on tile flow from plots with and without surface drainage. (M.C. is the soil moisture content in percent by volume at the 6-inch depth).

0.09 inch (0.74-0.65) was due to a difference in tile flow (Figure 12). This decrease of (0.26-0.09) 0.17 inch in surface runoff volume at the higher irrigation rate indicates that surface sealing due to higher application rates was probably not a factor. In comparing Figures 13 and 14 one might expect that the better drained (D) plots could provide more effective drainage from higher intensity storms.

The effect of antecedent moisture on tile flow is shown in Figure 15, and its effect on surface runoff is shown in Figures 16 and 17. Comparisons of plots were made only at the lower irrigation rate (0.23 inches per hour) which was applied in September 1960 and in June

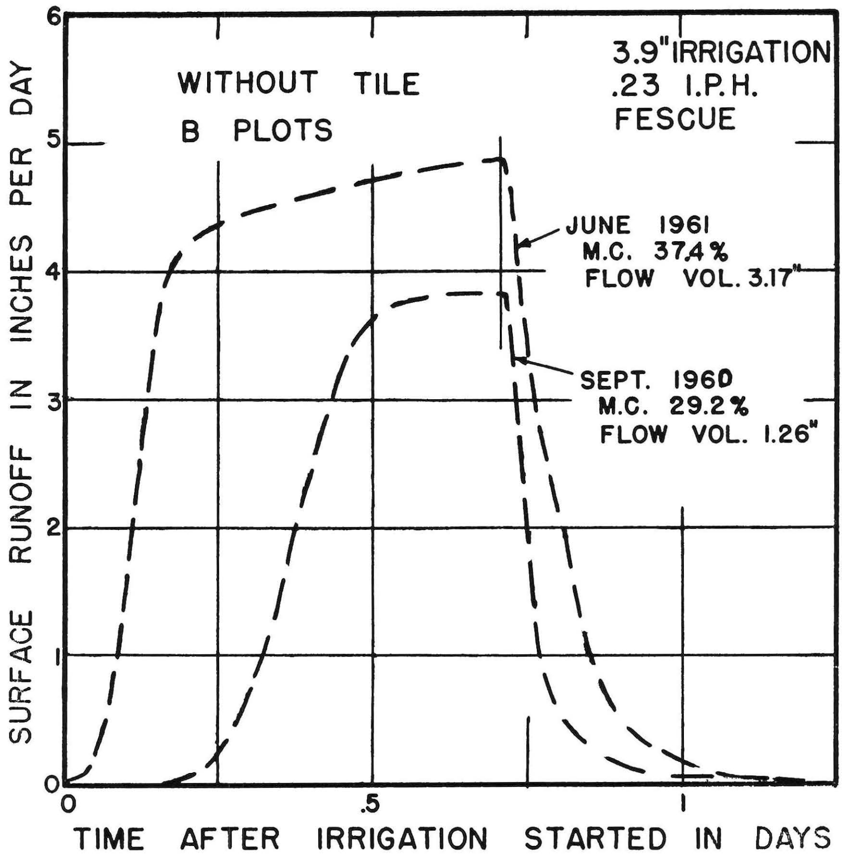

Fig. 16.—Effect of antecedent moisture on surface runoff from non-tiled plots.

1961. Since high antecedent moisture (about field capacity in June 1961) was obtained by irrigating until the tile began to flow on the first day prior to measurement, tile and surface flow began almost immediately after water was applied. The soil at low antecedent moisture (arbitrarily selected) showed considerable cracking on the surface, but at a depth of 12 to 18 inches it was quite moist.

As shown in Figure 15, the high antecedent moisture condition increased the peak tile flow only about 10 percent, but it increased the volume of flow by more than 100 percent as compared with the low antecedent measurements. At the high moisture level the tile flow rate increased more rapidly at first than at the low level. After reaching the peak, the flow remained nearly constant until irrigation

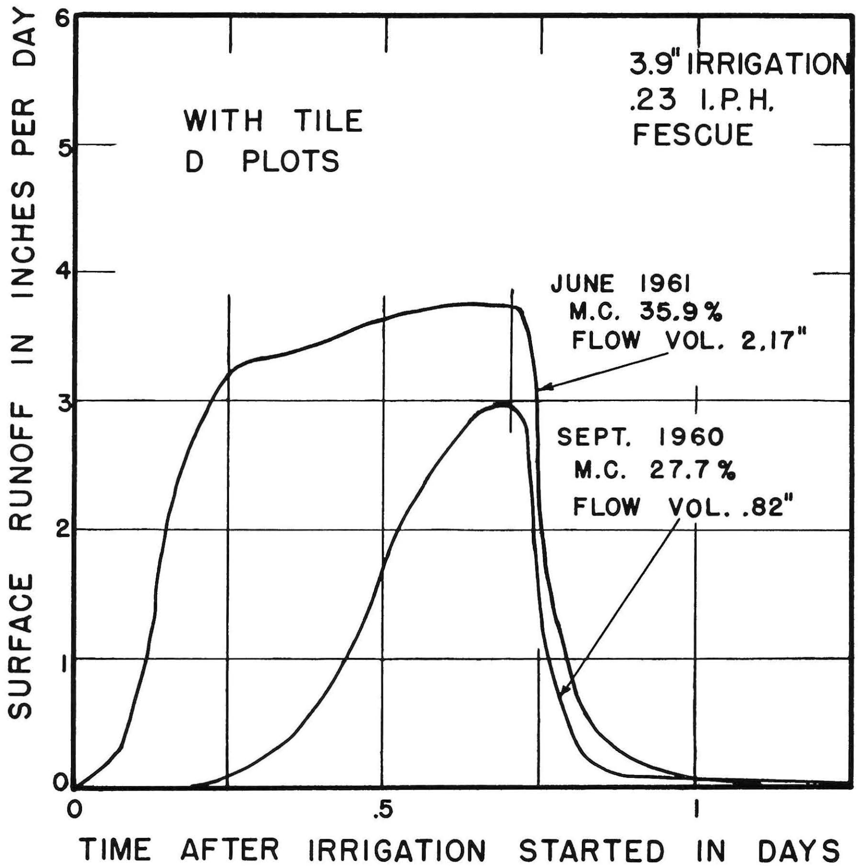

Fig. 17.—Effect of antecedent moisture on surface runoff from tile-drained plots.

stopped. The highest average peak tile flow recorded at the low irrigation rate (1.89 inches per day) was only about one-third of the application rate of 0.23 inches per hour.

As shown in Figures 16 and 17 high antecedent moisture caused about a 20 percent increase in peak surface runoff and over 150 percent increase in runoff volume. These increases in runoff peaks and volume were greater for the nontiled (B) plots (Figure 16) than for the tiled (D) plots.

The effect of surface drainage on tile flow for the three irrigation periods is shown in Figure 18. The area between the C and D curves represents the decrease in volume of tile flow due to surface drainage. The greatest reduction in volume (48 percent) was 1.22 inches (2.53-1.31 or 31 percent of the water applied) in June 1961 under high antecedent moisture conditions. In all cases surface drainage reduced the peak tile flow only slightly, but the average volume of flow was reduced 43 percent. The greatest reduction occurred on the receding portion ot the hydrographs, which indicates that surface drainage can in effect speed up the removal of water from the soil after rainfall stops.

The effect of tile drainage on surface runoff for the three irrigation periods is shown in Figures 19, 20, and 21. The area between the B and D curves represents the decrease in surface runoff volume caused by tile drainage. As in the case of tile flow, the greatest reduction in surface runoff volume was in June 1961 under high antecedent moisture conditions. This reduction in flow was 1.00 inch (26 percent of the water applied). The average reduction in surface runoff was 40 percent for the three periods or only slightly less than the effect of surface drainage on tile flow.

For the three irrigation periods tile drainage reduced the average peak surface runoff rates about 30 percent, but this reduction was nearly 50 percent with the high irrigation rate (Figure 21) in August 1961. In all cases the greatest reduction in peak runoff occurred from the beginning of flow to the end of the irrigation period. After the end of irrigation, the period of flow was only a few hours for both hydrographs, showing that the tile could have little effect during this period.

Water Table and Soil Moisture

The water table height and rate of drop for the three irrigation periods are shown in Table 3 and Figure 22. In the undrained (A) plots water ponded on the surface and remained for as long as 10 days in some plots. The rate of drop of the water may have been due mostly to evaporation, especially in June 1961 when antecedent moisture was high prior to irrigation. In the surface-drained (B) plots the highest water table was within 0.1 foot of the surface. The rate of drop was 0.40 feet per day in June 1961 compared to 0.49 and 0.68 feet per day when the antecedent moisture content was low. The rate of drop in the tiled (C) plots averaged nearly the same as the surface-drained (B) plots for the three irrigation periods. The initial water table height in the tiled (C) plots was 0.1 foot above the surface in June 1961 because of the high antecedent moisture conditions which caused ponding on the surface.

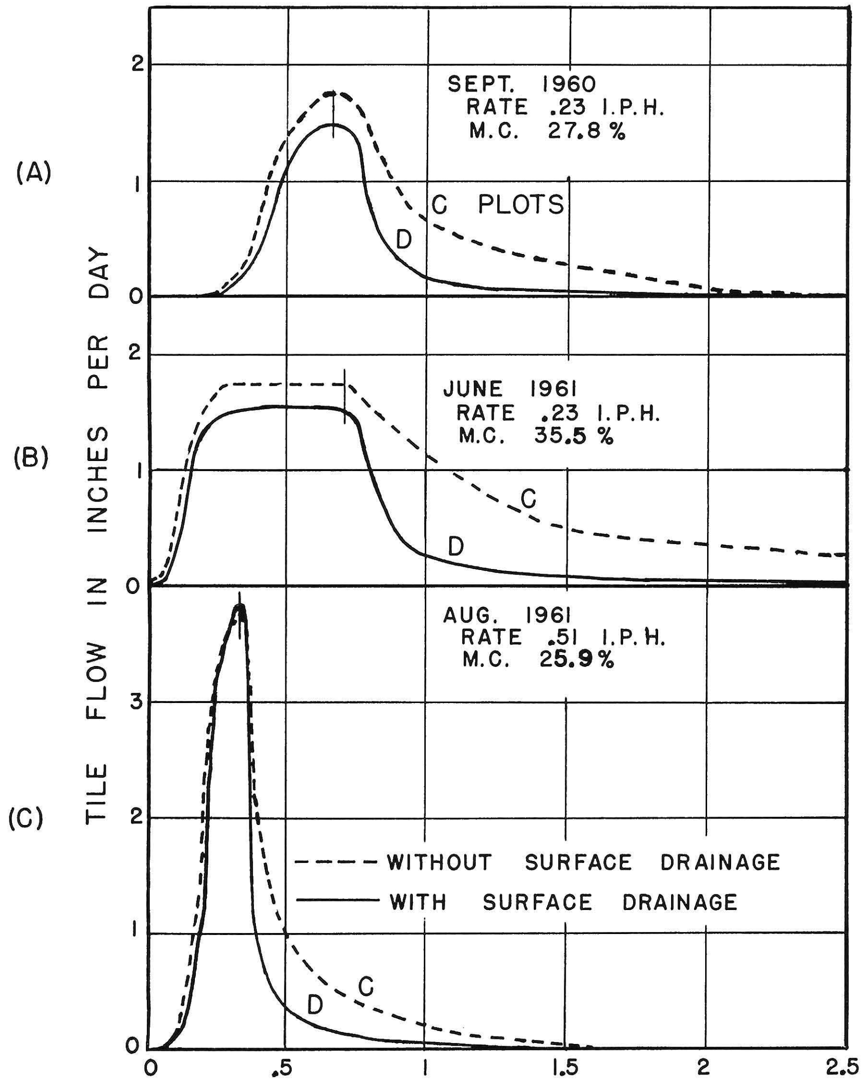

Fig. 18.—Effect of surface drainage on tile flow. (A) Low antecedent moisture and low water application rate, (B) high antecedent moisture and low water application rate, and (C) Low antecedent moisture and high water application rate.

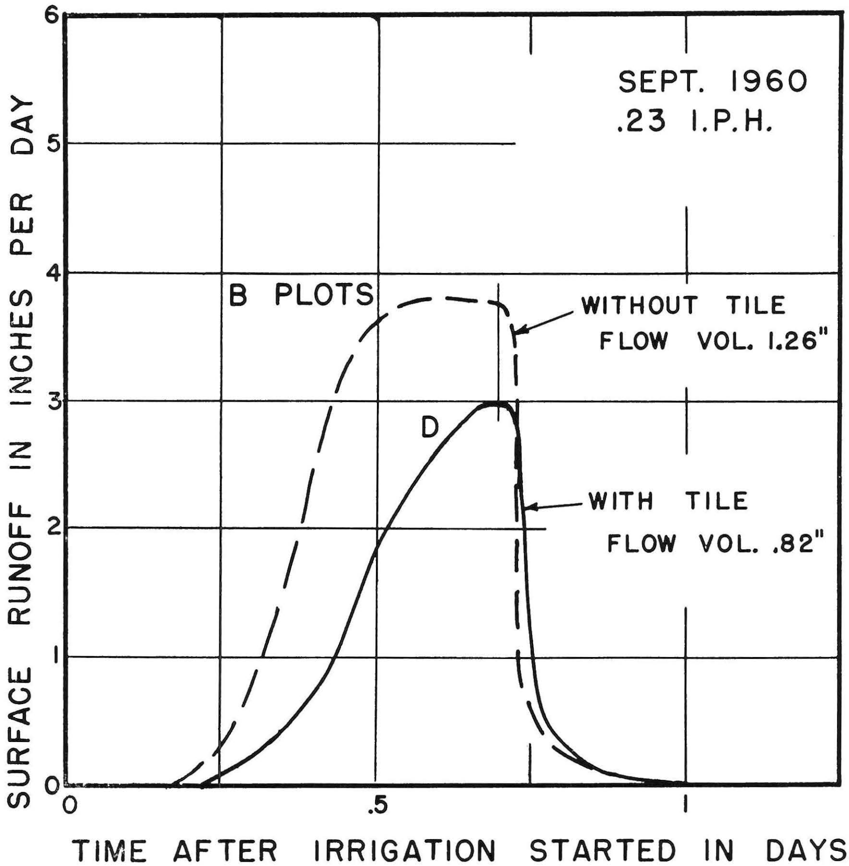

Fig. 19.—Effect of tile drainage on surface runoff for low antecedent moisture and low water application rate.

The rate of drop of the water table for all plots at the high rate of irrigation in August 1961 was about 50 percent faster than at the low rate. This difference may be partly explained by the slightly lower antecedent moisture and higher evapotranspiration rates in August 1961.

The relative changes in soil moisture content at the 6-inch depth corresponded roughly to changes in the water table. However, because fewer measurements were taken and because the range in moisture from saturation to field capacity is small, the regression of soil moisture content and time were in most cases not significant at the

90 percent level. Even with the neutron meter, soil moisture measurements are very time consuming, and its usefulness for this purpose seemed questionable.

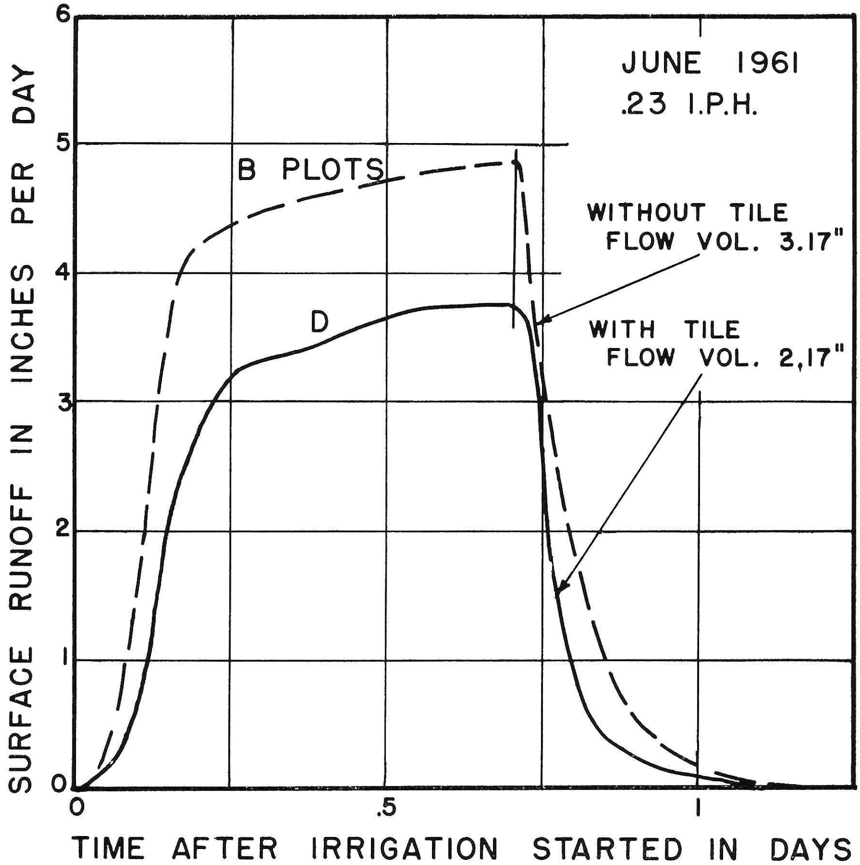

Fig. 20.—Effect of tile drainage on surface runoff for high antecedent moisture and low water application rate.

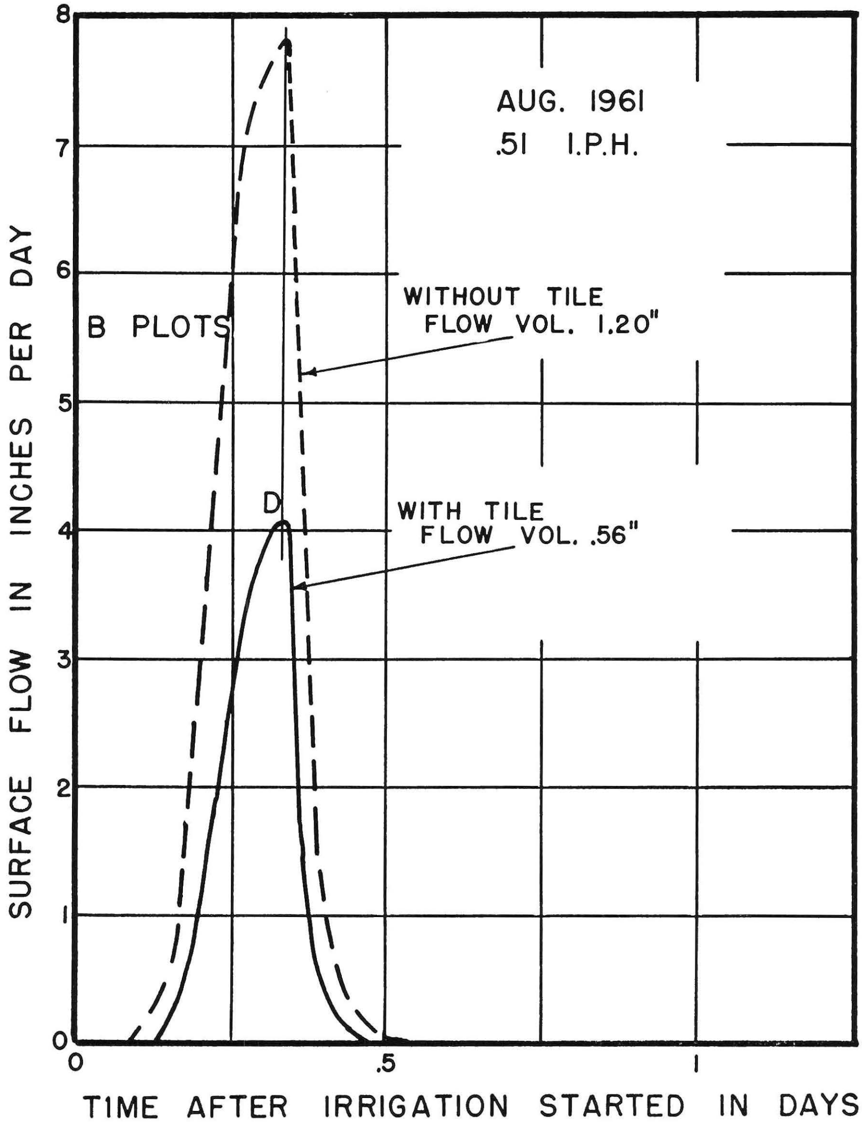

Fig. 21.—Effect of tile drainage on surface runoff for low antecedent moisture and high water application rate.

TABLE 3.—Water Table and Soil Moisture Data (first 3 days after irrigation)

Date	Antecedent Moisture Content	Irrigation Rate Inches per Hour (Total amount 3.9 inches)	Drainage Treatment	Water Table		***Soil Moisture at 6-Inch Depth	
				*Initial Height	**Drop Feet per Day	Initial Percent	Change Percent per Day
September 1960	Low	Low (0.23 iph)	A	3.1	0.05	32.0	+0.09
			B	2.9	.49	29.2	— .31
			C	2.9	.44	27.8	— .26
			D	2.8	.63	27.7	— .68
June 1961	High	Low (0.23 iph)	A	3.1	0.03	37.9	+0.02
			B	2.9	.40	37.4	— .30
			C	3.1	.43	35.3	— .40
			D	2.8	.48	35.9	— .59
August 1961	Low	High (0.51 iph)	A	not irrigated			
			B	2.9	0.68	27.6	
			C	2.9	.78	26.1	
			D	2.8	.91	25.8	

*Height above center of tile (3.0 feet is at soil surface).

**Rate of drop for first 3 days following end of irrigation. Data for B, C, and D plots significant at 99 percent level.

***Measured with neutron probe (most values of percent change per day were not significant at 90 percent level). See Table B1 for averages in each replication.

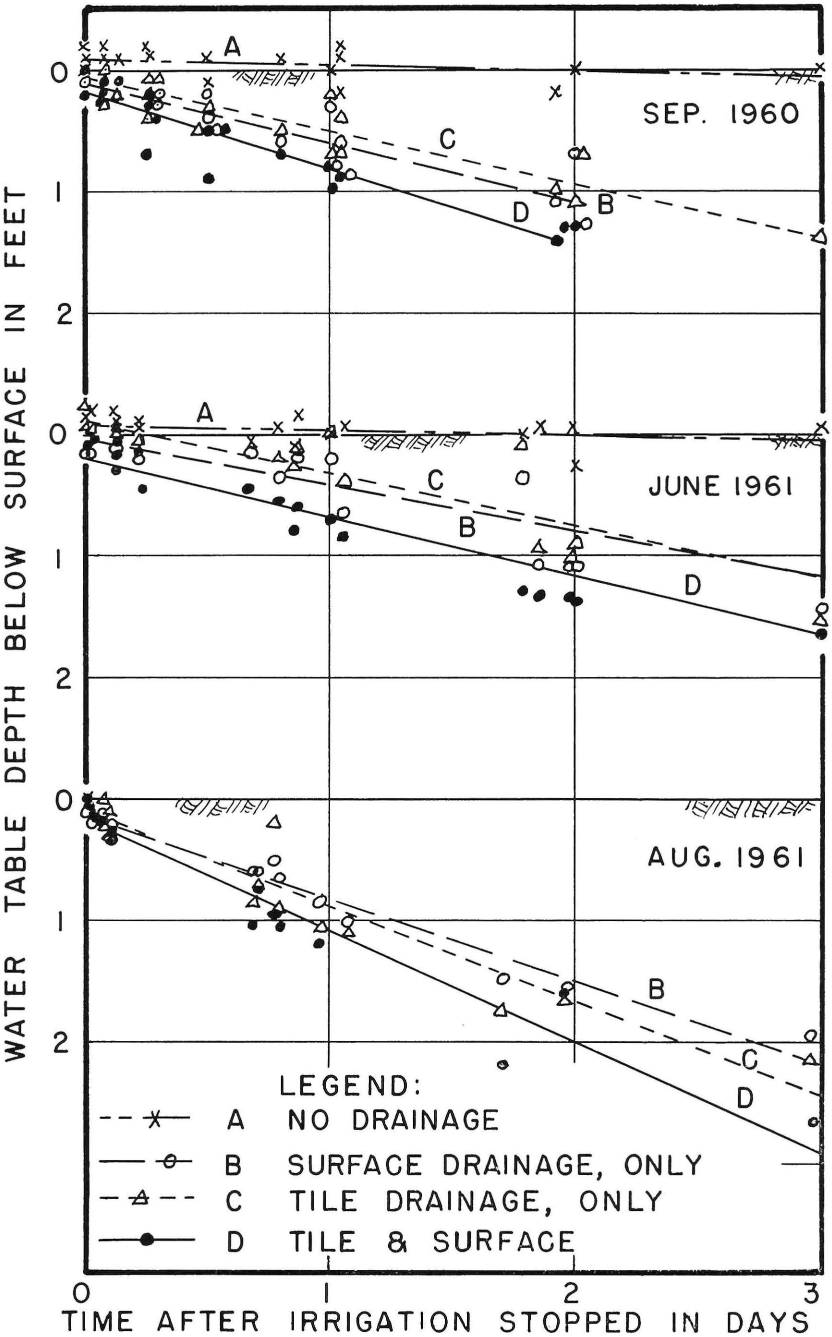

Fig. 22—Average height of the water table following irrigation. (Each point is the average of three observations, one 3 feet from the tile and two midway between the tile in the C and D plots. In the B plots the wells were located in the same relative position as those midway between the tile in the C and D plots).

SUMMARY

Replicated drainage systems were established on a heavy clay lakebed soil near Sandusky, Ohio. The systems included no drainage (level), surface drainage, tile drainage (level), and a combination of tile and surface drainage. A uniform stand of grass was established over the entire experiment. The plots were irrigated twice in 1960 and twice in 1961 to simulate heavy rainfall that would normally occur once in 10-15 years. Tile and surface flow, water table height, and soil moisture content were collected for these irrigation periods. Antecedent soil moisture was near field capacity prior to one irrigation and low (dry surface) on the other three. Water was applied by sprinklers at two rates (0.23 and 0.51 inches per hour). The results show that surface drainage greatly reduced tile flow, and tile drainage reduced surface flow volume about the same amount. Evaluation of the drainage systems is based entirely on hydrologic measurements rather than on crop response.

CONCLUSIONS

1. Based on flow data, the combination tile and surface drainage system gave the best drainage. Tile plus surface flow volume varied from 0.10 to 0.95 inches greater than the amount of water removed by either the tile system or surface drainage system alone. Although these data indicate that a good drainage system may increase the peak and volume of streamflow following heavy rainfall, the differences indicated above were not significant.

2. Except for high antecedent moisture conditions, tile-drained (level) plots gave about the same degree of drainage as the surface-drained (no tile) plots.

3. Surface drainage reduced the amount of water removed by the tile by 43 percent and tile drainage reduced the amount of surface runoff about 40 percent.

4. High antecedent moisture increased tile flow volume 100 percent and the surface runoff volume more than 150 percent, but peak tile flow rates were increased only slightly and peak surface runoff rates were increased about 20 percent on the average.

5. Doubling the rate of water application increased the peak tile and surface flow rates, but had little effect on the volume of flow.

6. The average rate of drop of the water table for the first three days following irrigation was 0.52 foot per day for the surface drainage only, 0.55 foot per day for tile drainage only, and 0.67 foot per day for the combination tile and surface drainage. In the undrained plots the ponded water receded about 0.04 foot per day or roughly double the evapotranspiration rate.

7. The rate of decrease of soil moisture content at the 6-inch depth following irrigation corresponded generally to the water table levels, but rate of change (on the order of 0.3 to 0.6 percent per day) was too small to measure accurately drainage differences with the neutron soil moisture meter.

8. Tall fescue can withstand rather severe drainage conditions. Some reduction in growth and loss of stand occurred in the undrained plots, which were flooded several times for periods up to 10 days.

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APPENDIX A

Table A1. Physical properties of Toledo Silty Clay. Drainage experimental site, North Central Substation, 1957

Horizon	Depth	Sand	Silt	Clay	pH	Bulk Density	Hydraulic Conductivity[1]	Moisture Retention[1] 60 cm.	Moisture Retention[1] 15 atmos.
	(in.)	(%)	(%)	(%)		(g./cc.)	(in./day)	(% by volume)	
A_p	0-8	3	46	51	5.8	1.22	24.0	41	21
$B_{1}g$	8-13	3	43	54	6.4	1.39	2.8	42	25
$B_{21}g$	13-20	4	41	55	6.7	1.43	1.3	46	27
$B_{22}g$	20-30	3	38	59	7.0	1.45	0.9	46	28
$B_{23}g$	30-38	2	40	58	7.0	1.48	1.6	44	30
C_{11}	38-50	5	48	47	7.2	1.49	--	43	28
C_{12}	50-64	3	45	52	7.5	1.40	--	--	25
C_{2}	64-70+	3	44	53	7.5	--	--	--	--

[1] Saturated conductivities and moisture contents at 60 cm. suction were determined from 3-inch diameter soil cores. Each value reported is the average from 6 cores. The 15 atmosphere moisture determinations were made on disturbed soil samples.

Table A2. Physical properties of Fulton Silty Clay. Drainage experimental site, North Central Substation. 1957

Horizon	Depth	Sand	Silt	Clay	pH	Bulk Density	Hydraulic Conductivity[1]	Moisture Retention[1] 60 cm.	Moisture Retention[1] 15 atmos.
	(in.)	(%)	(%)	(%)		(g./cc.)	(in./day)	(% by volume)	
A_p	0-8	5	50	45	6.1	1.29	---[2]	41	22
B_1	8-11	5	47	48	6.4	1.48	0.4	43	24
B_{21}	11-14	4	42	54	6.7	1.47	0.4	44	26
B_{22}	14-21	4	34	62	7.1	1.47	0.5	46	28
B_{23}	21-34	3	35	62	7.4	1.50	0.7	43	28
C_{11}	34-48	2	55	43	7.6	1.50	---	39	24
C_{12}	48-58	3	55	42	7.8	1.40	---	36	20
C_2	58-64+	4	43	53	7.8	----	---	--	--

[1] Saturated conductivities and moisture contents at 60 cm. suction were determined from 3-inch diameter soil cores. Each value reported is the average from 6 cores. The 15 atmosphere moisture determinations were made on disturbed soil samples.

[2] The hydraulic condutivity of the A_p horizon would be approximately that shown for the Toledo soil.

APPENDIX B

TABLE B 1. -IRRIGATION SCHEDULING, SOIL TEMPERATURE, AND ANTECEDENT MOISTURE

Test No.	Replicate	Date Irrigation Started	Soil Temp. °F. 8" depth min.-max.	Irrigation Rate iph	Irrigation Amount inches	Antecedent Moisture Content-6"depth in % by volume for plots A	B	C	D
1	1	7/13/60	63-71	0.23	2.7	*	27.8	26.3	26.5
	2	7/20/60	"	"	2.8	*	24.3	24.1	23.2
	3	7/13/60	"	"	2.9	*	28.2	25.5	25.6
	4	7/19/60	"	"	2.8	*	25.8	22.7	22.0
					Avg.		26.5	24.6	24.3
2	1	9/13/60	69-73	0.23	3.9	31.9	26.7	25.1	26.1
	2	9/16/60	"	"	"	35.7	27.7	28.3	27.4
	3	9/14/60	"	"	"	29.3	30.7	25.9	29.1
	4	9/15/60	"	"	"	31.2	31.5	31.8	28.3
					Avg.	32.0	29.2	27.8	27.7
3	1	6/13/61	68-75	0.23	3.9	--	37.7	35.9	36.8
	2	6/7/61	"	"	"	38.4	36.6	34.1	33.9
	3	6/16/61	"	"	"	37.5	37.6	34.9	36.1
	4	6/21/61	"	"	"	37.7	37.5	36.1	36.9
					Avg.	37.9	37.4	35.2	35.9
4	1	8/29/61	62-74	0.51	3.9	*	28.3	28.0	27.1
	2	8/28/61	"	"	"	*	28.4	26.9	25.7
	3	8/30/61	"	"	"	*	27.0	22.8	25.6
	4	8/31/61	"	"	"	*	26.8	26.5	24.7
					Avg.	--	27.6	26.1	25.8

* Treatment not irrigated.

Note: Tall fescue mowed to 4" to 6" height prior to irrigation on all tests.

TABLE B 2. -PRECIPITATION AND IRRIGATION DATA

Month	Rainfall, Sandusky City 60-yr. avg. in inches 1896-1955	Rainfall and Irrigation on Plots in Inches 1959	1960	1961
January	2.39	5.11	2.68	0.19
February	1.88	2.90	1.67	2.51
March	2.91	2.08	1.13	3.38
April	2.85	3.79	1.99	6.09
May	3.14	2.98	3.87	2.01
June	3.65	2.07	4.82	8.44*
July	3.50	4.43	6.42*	6.11
August	3.13	3.76	4.47	6.65*
September	2.89	2.33*	5.08*	4.80
October	2.32	3.11	1.02	1.39
November	2.26	2.53	1.58	2.05
December	2.14	2.20	0.80	2.21
Total Rainfall & Irrigation		37.29	35.53	45.83
Total Irrigation		1.00	6.70	9.30
Total Rainfall	33.06	36.29	28.83	36.53

* Amount includes rainfall and irrigation.

APPENDIX C

TABLE C 1. -AVERAGE MONTHY TILE FLOW IN INCHES

Month	No Surface Drainage C Plots			With Surface Drainage D Plots		
	1959	1960	1961	1959	1960	1961
Jan	2.430	2.098	--	1.234	1.798	--
Feb	0.325	1.5888	0.835	0.050	1.445	0.545
Mar	2.072	0.653	1.738	0.813	0.304	2.075
Apr	1.712	0.253	4.628	1.481	0.373	3.888
May	0.615	0.034	0.139	0.512	0.039	0.131
Jun	0.110	0.280	*2.772	0.081	0.367	*1.471
Jul	0.127	*1.056	0.106	0.123	*0.770	0.070
Aug	0.186	0.012	*1.068	0.217	0.006	*0.749
Sep	--	*1.307	*1.089	--	*0.767	*0.562
Oct	0.156	--	--	0.302	--	--
Nov	0.646	--	--	0.974	--	--
Dec	1.692	--	--	1.686	--	--
Total	10.071	7.281	12.375	7.473	5.849	9.491
Total from Natural Rainfall	10.071	4.172	8.720	7.473	4.676	7.437
Total Tile Flow from Natural Rainfall as a Per Cent of Annual Rainfall	27.8	14.5	23.9	20.6	16.2	20.4

* Includes flow from irrigation water applied.

TABLE C 2. -TILE FLOW FROM C PLOTS, SEPTEMBER 1960

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd*				
	Replicate				
	1	2	3	4	Avg.
4	0	0	0	0	0
6	0	.08	0	.04	.03
8	.08	.55	.23	.19	.26
10	.60	1.30	.60	1.13	.91
12	1.68	2.07	.77	1.13	1.41
14	2.59	1.94	.89	1.13	1.64
16	3.11	1.81	.89	1.13	1.74
18	2.85	1.68	.77	1.13	1.61
20	1.50	1.64	.71	1.13	1.25
22	.83	.96	.71	1.04	.89
24	.37	.71	.65	.96	.67
30	.10	.46	.55	.71	.46
36	.05	.26	.42	.46	.30
42	.04	.12	.29	.26	.18
48	.02	.06	.14	.06	.07
54	.02	.02	.14	.05	.06
60	.02	.02	.12	.02	.04
66	.02	.01	.10	.02	.04
72	.02	.01	.06	.02	.03
78	0	0	0	0	0
Volume of Flow, in.	1.19	1.36	1.10	1.21	1.22
Peak Flow, ipd	3.11	2.20	0.89	1.13	1.83

* ipd is inches per day.

TABLE C 3. -TILE FLOW FROM C PLOTS, JUNE 1961

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1*	2*	3*	4	Avg.
0	.06	.12	.02	.02	.06
1	.19	.10	.04	.02	.09
2	.60	.55	.19	.37	.43
3	1.50	1.04	.51	.60	.91
4	2.98	1.13	.60	.65	1.34
5	3.63	1.13	.65	.71	1.53
6	4.41	1.13	.71	.71	1.74
8	4.41	1.13	.71	.71	1.74
10	4.41	1.13	.71	.71	1.74
12	4.41	1.04	.71	.71	1.72
18	3.83	.96	.89	.83	1.63
24	1.94	.89	.89	.83	1.14
30	.83	.65	.77	.71	.74
36	.26	.46	.60	.65	.49
42	.14	.46	.55	.65	.45
48	.12	.37	.46	.60	.39
54	.10	.23	.29	.55	.29
60	.06	.23	.26	.46	.25
66	.06	.14	.23	.42	.21
72	.04	.10	.17	.29	.15
78	.03	.06	.14	.23	.12
84	.02	.05	.14	.14	.09
90	.02	.04	.14	.06	.06
96	.01	.03	.14	.04	.06
102	0	.02	.08	.03	.03
108	0	.02	.07	.03	.03
114	0	.02	.06	.02	.02
120	0	.01	.06	.02	.02
132	0	0	.02	0	0
144			.02		
168			.01		
182			0		
Volume of Flow, in.	3.84	2.18	2.10	1.99	2.53
Peak Rate, ipd	4.60	1.17	0.96	0.83	1.89

* Flow estimated because of irrigation stoppage and rainfall during runoff period.

TABLE C 4.—TILE FLOW FROM C PLOTS, AUGUST 1961

Water Application: 3.9", 12.24 ipd (0.51 iph)

Time After Irrigation Started	Runoff in ipd				
	Replicate				
Hours	1	2	3	4	Avg.
2	0	0	0	0	0
3	.04	0	.14	.07	.06
4	.42	.96	.83	.55	.69
5	1.94	2.98	1.40	1.45	1.94
6	5.57	4.41	1.69	1.50	3.29
7	6.48	4.51	1.88	1.55	3.60
8	7.00	4.51	1.94	1.55	3.75
9	1.94	4.02	1.50	1.50	2.24
10	.83	3.24	1.30	1.45	1.70
11	.60	1.94	1.13	1.40	1.27
12	.33	1.50	1.04	1.21	1.02
13	.26	1.13	.96	1.04	.85
14	.19	.83	.89	.96	.72
15	.17	.42	.83	.89	.58
16	.14	.26	.80	.83	.51
18	.12	.17	.71	.77	.44
20	.10	.14	.60	.65	.37
22	.08	.10	.42	.60	.30
24	.07	.08	.29	.51	.24
28	.05	.07	.14	.42	.17
32	.03	.04	.07	.26	.10
36	.01	.02	.04	.10	.04
40	0	.02	.03	.07	.03
48		0	.01	.04	.01
56			0	0	0
Volume of Flow, in.	1.16	1.35	0.94	1.07	1.13
Peak Rate, ipd	7.00	4.51	1.94	1.55	3.75

TABLE C 5. -TILE FLOW FROM D PLOTS, SEPTEMBER 1960

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1	2	3	4	Avg.
4	0	0	0	0	0
6	0	.01	.01	.02	.01
8	.08	.14	.19	.26	.16
10	.60	.55	.50	.83	.51
12	1.50	.83	.96	1.04	1.08
14	1.94	1.04	1.59	1.13	1.42
16	2.20	.96	1.68	1.13	1.49
18	1.94	.71	.83	.71	1.05
20	.55	.42	.42	.33	.43
22	.26	.23	.23	.19	.23
24	.19	.14	.17	.14	.16
30	.12	.10	.10	.08	.10
36	.06	.05	.06	.06	.06
42	.05	.04	.04	.04	.04
48	.02	.02	.02	.02	.02
54	.02	.02	.02	.02	.02
60	.02	.02	.01	.02	.02
66	0	.01	0	.02	.01
72	0	0	0	0	0
Volume of Flow, in.	0.85	0.49	0.65	0.59	0.65
Peak Rate, ipd	2.20	0.96	1.82	1.13	1.53

TABLE C 6. -TILE FLOW FROM D PLOTS, JUNE 1961

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1*	2*	3*	4	Avg.
0	.06	.08	.01	.05	.05
1	.10	.07	.02	.05	.06
2	.26	.33	.17	.26	.26
3	.83	.60	.83	.60	.72
4	2.46	.71	1.21	.77	1.29
5	2.72	.77	1.40	.83	1.43
6	2.72	.77	1.50	.83	1.46
8	2.98	.77	1.50	.89	1.54
10	2.98	.77	1.50	.89	1.54
12	2.98	.77	1.50	.89	1.54
14	2.98	.77	1.50	.89	1.54
16	2.98	.77	1.50	.89	1.54
18	2.30	.71	1.68	.96	1.41
20	0.71	.51	.89	.89	.75
22	.42	.33	.42	.33	.38
24	.26	.23	.26	.14	.22
30	.19	.14	.14	.12	.15
36	.14	.10	.10	.10	.11
42	.10	.08	.06	.06	.08
48	.06	.06	.02	.06	.05
54	.06	.05	.02	.06	.05
60	.03	.04	0	.05	.03
66	.02	.03		.04	.02
72	.02	.02		.02	.02
84	.01	.02		.02	.01
96	0	0		0	0
Volume of Flow, in.	2.12	1.00	1.23	0.89	1.31
Peak Rate, ipd	3.24	0.77	1.68	0.96	1.66

* Flow estimated because of irrigation stoppage and rainfall during runoff period.

TABLE C 7. -TILE FLOW FROM D PLOTS, AUGUST 1961

Water Application: 3.9", 12.24 ipd (0.51 iph)

Time After Irrigation Started	Runoff in ipd				
	Replicate				
Hours	1	2	3	4	Avg.
2	0	.07	0	.04	.03
3	0	.42	0	.14	.14
4	.83	.89	.08	.60	.60
5	1.94	1.30	1.30	1.50	1.51
6	5.18	1.94	3.82	1.94	3.22
7	5.57	2.59	4.41	2.01	3.65
8	5.77	2.59	4.99	2.07	3.86
9	1.13	1.30	2.46	1.50	1.60
10	.46	.60	.96	.60	.65
11	.33	.40	.60	.37	.42
12	.27	.26	.42	.19	.28
13	.25	.23	.37	.17	.25
14	.19	.17	.26	.14	.19
15	.17	.12	.23	.12	.16
16	.17	.10	.19	.10	.14
18	.14	.07	.17	.07	.11
20	.12	.05	.13	.07	.09
22	.10	.04	.10	.05	.07
24	.08	.03	.08	.05	.06
28	.07	.02	.04	.04	.04
32	.04	0	.01	.03	.02
36	.02		0	.03	.01
40	.01			.03	.01
48	0			.02	.01
56				0	0
Volume of Flow, in.	0.92	0.64	0.89	0.52	0.74
Peak Rate, ipd	5.77	2.60	4.99	2.07	3.86

APPENDIX D

TABLE D 1. -AVERAGE MONTHLY SURFACE FLOW IN INCHES

	No Tile Drainage B Plots			With Tile Drainage D Plots		
Month	1959	1960	1961	1959	1960	1961
Jan	NR	2.22	--	NR	1.31	--
Feb	NR	2.27	0.86	NR	2.09	0.39
Mar	NR	0.52	1.25	NR	0.08	0.14
Apr	NR	0.52	3.80	NR	0.02	1.28
May	0.13	--	--	0.02	--	--
Jun	0.02	0.28	*3.43	--	0.04	*2.26
Jul	0.16	*1.44	0.06	0.01	*0.76	0.02
Aug	0.56	--	*1.22	0.15	--	*0.56
Sep	--	*1.36	*1.02	--	*0.85	*0.55
Oct	0.29	--	--	0.05	--	--
Nov	0.93	--	--	0.21	--	--
Dec	1.37	--	0.01	0.46	--	0.01
Annual Total	3.46	8.61	11.65	0.90	5.15	5.21
Total from Natural Rainfall	3.46	6.17	7.28	0.90	3.74	2.48
Total Surface Flow from Natural Rainfall as a PerCent of Annual Rainfall	--	21.4	20.0	--	13.0	6.8

* Includes flow from irrigation water applied.
NR - No record as flumes were not yet installed.

TABLE D 2. -SURFACE RUNOFF FROM B PLOTS, SEPTEMBER 1960

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1	2	3	4	Avg.
2	0	0	0	0	0
4	0	0	0	.09	.02
6	.35	.09	.16	.46	.26
8	1.81	.86	.35	1.81	1.21
10	3.33	2.55	1.60	3.63	2.78
12	3.97	3.33	3.33	3.97	3.65
14	3.97	3.63	3.63	3.97	3.80
16	3.07	4.32	3.63	3.97	3.75
18	.35	.72	.72	.72	.63
20	.16	.25	.16	.16	.18
22	.16	.09	.16	.09	.12
24	.09	.03	.09	.09	.08
30	.09	.03	.09	0	.05
36	.09	.03	.09	0	.05
42	0	0	0	0	0
Volume of Flow, in.	1.47	1.34	0.69	1.56	1.26
Peak Rate, ipd	3.97	4.32	3.63	4.67	4.15

TABLE D 3. -SURFACE RUNOFF FROM B PLOTS, JUNE 1961

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1*	2	3*	4*	Avg.
1	.25	.16	0	.03	.11
2	1.38	1.60	.09	1.02	1.02
3	3.33	3.20	1.38	3.07	2.74
4	4.67	3.97	3.33	3.97	3.98
6	5.01	4.67	3.60	4.32	4.40
8	5.01	4.67	3.63	4.67	4.50
10	5.01	4.82	3.63	5.01	4.62
12	5.01	5.01	3.63	5.01	4.67
14	5.22	5.23	3.63	5.01	4.77
16	5.44	5.44	3.63	5.01	4.88
17	5.44	5.44	3.63	5.01	4.88
18	3.97	2.55	1.38	5.01	3.23
19	2.16	1.02	.46	5.01	2.16
20	1.19	.51	.20	2.81	1.18
22	.46	.25	.09	1.00	.45
24	.25	.05	.09	.35	.18
26	.09	.03	.09	.12	.08
28	.08	0	.09	.09	.06
30	.07		.05	.05	.04
36	0		.03	0	.01
42			0		0
Volume of Flow, in.	3.81	3.05	2.29	3.53	3.17
Peak Rate, ipd	5.44	5.44	3.80	5.01	4.92

* Flow estimated because of irrigation stoppage and overflow of dikes.

TABLE D 4. -SURFACE RUNOFF FROM B PLOTS, AUGUST 1961

Water Application: 3.9", 12.24 ipd (0.51 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1	2	3	4	Avg.
1	0	0	0	0	0
2	0	.25	0	0	.06
3	0	1.02	0	.16	.29
4	.16	2.81	.25	1.38	1.15
5	3.63	5.44	1.81	3.63	3.63
6	7.21	7.21	4.67	5.88	6.24
7	8.46	7.95	6.31	6.98	7.42
8	8.73	8.21	6.98	7.21	7.78
8½	5.88	4.32	3.63	3.97	4.45
9	3.07	2.03	2.03	2.29	2.35
10	.72	.72	.35	.72	.63
11	.25	.09	.05	.16	.14
12	.09	0	.03	.05	.04
14	.03	0	0	0	.01
16	0	0	0	0	0
Volume of Flow, in.	1.29	1.45	0.93	1.14	1.20
Peak Rate, ipd	8.73	8.21	6.98	7.21	7.78

TABLE D 5. -SURFACE RUNOFF FROM D PLOTS, SEPTEMBER 1960

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started	Runoff in ipd				
	Replicate				
Hours	1	2	3	4	Avg.
4	0	0	0	0	0
6	.09	.03	.16	.09	.09
8	.35	.16	.46	.35	.33
10	.46	.35	1.19	1.19	.80
12	.86	1.60	2.29	2.29	1.76
14	1.60	2.81	2.55	2.81	2.44
16	2.55	3.33	2.68	3.33	2.97
18	3.07	.46	.72	.46	1.18
20	.35	.16	.09	.16	.19
22	.16	.03	.03	.09	.08
24	.09	.03	0	.06	.04
30	.09	0	0	0	.02
36	.09	0	0	0	.02
42	.09	0	0	0	.02
48	0	0	0	0	0
Volume of Flow, in.	0.84	0.71	0.84	0.88	0.82
Peak Rate, ipd	3.33	3.33	2.68	3.33	3.17

TABLE D 6. -SURFACE RUNOFF FROM D PLOTS, JUNE 1961

Water Application: 3.9", 5.52 ipd (0.23 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1*	2	3*	4*	Avg.
1	0	.03	0	0	.01
2	.16	.72	.09	.35	.33
3	.86	1.60	.86	1.81	1.28
4	1.81	2.55	1.81	3.07	2.31
6	2.55	3.63	2.81	3.97	3.24
8	2.81	3.63	3.07	3.97	3.37
10	3.33	3.63	3.07	3.97	3.50
12	3.33	3.97	3.07	4.32	3.67
14	3.80	3.97	3.10	4.32	3.80
16	3.80	4.10	3.20	3.97	3.77
17	3.80	4.10	3.20	3.97	3.77
18	1.81	2.29	1.60	3.97	2.42
19	.72	.86	.46	2.29	1.08
20	.46	.35	.09	1.19	.52
22	.25	.09	.02	.16	.13
24	.09	.09	0	.09	.07
26	.03	0		.03	.02
28	0			0	0
Volume of Flow, in.	1.81	2.45	1.85	2.57	2.17
Peak Rate, ipd	3.80	4.32	3.20	4.49	3.95

* Flow estimated because of irrigation stoppage and overflow of dikes.

TABLE D 7. -SURFACE RUNOFF FROM D PLOTS, AUGUST 1961

Water Application: 3.9", 12.24 ipd (0.51 iph)

Time After Irrigation Started Hours	Runoff in ipd				
	Replicate				
	1	2	3	4	Avg.
2	0	0	0	0	0
3	0	.09	0	.03	.03
4	0	1.38	.09	.09	.39
5	1.02	2.43	.72	1.39	1.39
6	2.03	3.63	1.81	3.63	2.78
7	2.55	4.67	2.81	5.01	3.76
8	2.55	5.01	3.33	5.44	4.08
8½	1.81	3.07	1.81	2.81	2.38
9	.86	1.19	.72	1.81	1.15
10	.25	.25	.09	.58	.29
11	.03	.06	0	.16	.06
12	0	0		.09	.02
14				0	0
Volume of Flow, in.	0.34	0.77	0.38	0.74	0.56
Peak Rate, ipd	2.55	5.01	3.33	5.44	4.08