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QUALITY AND QUANTITY OF RETURN FLOW AS INFLUENCED BY TRICKLE AND SURFACE IRRIGATION

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QUALITY AND QUANTITY OF RETURN FLOW AS INFLUENCED BY TRICKLE AND SURFACE IRRIGATION

by

Peter J. Wierenga Ted C. Patterson	*Principal Investigators*
Eldon Hanson Arden A. Baltensperger	*Consultants*
Bill Hackett Susan Gomez Fran Hackett	*Research Associates*
Don McClanahan Ron van de Pol	*Research Assistants*
Sam Davis Bill Boyle Joel Mahill Jim Wood Pete Rios	*Research Aides*
John W. Clark	*Grant Director*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. Purpose and Project Description

Deterioration of the quality of the water in the Rio Grande is a major problem for the water users in Texas and New Mexico. The usual practice of irrigation in arid and semi-arid areas involves the use of heavy applications of water, in addition to the water used by the plants, for the purpose of removing accumulated salts or preventing an excessive increase of salts in the soil. The subsequent transport of this excess irrigation water to the groundwater causes pollution of the groundwater and of the irrigation return flow. The objectives of the present study, initiated in July of 1971, are to determine the quality and quantity of return flow as influenced by two irrigation systems: i.e., trickle and surface irrigation.

The effects of amount and frequency of water applications on water and solute movement within the soil are being studied for both irrigation systems. Twenty-seven field plots, each 20 x 20 feet, have been surrounded with plastic to a depth of three feet for the surface irrigation studies. The main treatment effects on these plots are frequency of irrigation and application efficiency. The plots are irrigated when 25, 50, or 75 percent of the available water is depleted. Field water application efficiencies of 50, 75, and 100 percent are used. The 100 percent efficiency treatment is irrigated to prevent any loss of moisture to the subsoil. Each treatment is block randomized with three replications per treatment. Six 20 x 60 feet plots were established to study the effects of trickle irrigation on return flow. The trickle plots are irrigated to maintain a soil water tension of or below .2 and .6 bars, respectively, for the two treatments measured at a depth of six inches.

To determine water loss by deep percolation, measurements are made of the water contents and the pressure gradients below the root zone of each plot. From the gradients and knowledge of the hydraulic conductivities and water contents below the root zone, the net fluxes in or out of the soil profiles are calculated, using Darcy's equation. The quality of the water percolating below the root zone is determined by collecting samples from suction cups located below the root zone.

B. Summary of Current Year's Work

This report presents results of the first cropping year of a three-year study on the quality and quantity of return flow as influenced by trickle and surface irrigation.

Cotton yields were not significantly affected by the efficiency of the surface irrigation system. The differences in yield due to percent depletion were small, although there appeared to be a trend toward higher yields with increasing percent depletion. Cotton yields from the trickle plots were considerably higher than from the surface irrigated plots, and less water was used per unit of cotton produced.

Measurements of soil salinity in the surface plots showed no significant effect as a result of irrigation efficiency. It appears that even the 100 percent efficiency treatment had adequate leaching of salts out of the soil profile. Movement of salts around the trickle system emitters was monitored.

Measurements of the hydraulic gradients below the root zone also showed a downward gradient in all surface irrigated plots during the growing season, indicating seepage losses from all treatments. The quality of the water percolating to the subsoil varied greatly from plot to plot. The average salt content of the deep percolation water was about 10X as high as in the applied irrigation water. Measurements were made of the hydraulic properties of the subsoil below the surface irrigated plots.

II. RESULTS AND DISCUSSION

A. Cotton Yield and Quality

Cotton was harvested by handpicking three center rows in each surface irrigated plot and four center rows in each trickle irrigated plot. The first harvest was on October 18, 1972 and the second, and last, harvest on November 1, 1972. After harvesting the cotton, the remaining stalks and the non-harvested plants were pulled out of the soil and removed from the plots. The plots were then raked and all plant material was removed to minimize the transfer of diseases to next year's crop. Samples of the cotton were analyzed for quality in the Cotton Fiber Laboratory at New Mexico State University.

Table 1 presents the effects of irrigation efficiency on the yield and quality of cotton from the surface irrigated plots. Irrigation efficiency did not significantly affect the yield from these plots. Although the average yield in the low efficiency plots (1.68 bales/acre) was somewhat higher than the average yield in the high efficiency plots (1.60 bales/acre), the difference was much too small to be significant. The average amounts of water, including an 8-inch preirrigation, added to the 50, 75, and 100 percent efficiency treatments were 36.0, 28.3, and 24.4 inches, respectively. Thus, irrigation with 36" of water gave about the same yield as irrigation with 24" of water. The amounts of water added to the 100 percent efficiency plots were based on U. S. Weather Bureau pan evaporation data. It is possible that the factor used for converting pan data to actual consumptive use data was overestimated, and that the 100 percent efficiency plots were irrigated at an efficiency less than 100 percent, causing relatively small differences in plant-water stress between the high and low efficiency treatments.

Table 1. Effects of irrigation efficiency on yield (treatment means for 1st and 2nd pick and total mean yields for 1st plus 2nd pick) and quality (treatment means) of cotton in surface plots.

Irrigation efficiency %	Yield bales/acre	Lint %	2.5% span	Uniformity ratio	MIC	Strength	Elongation
				1st pick			
50	.86	36.1*	1.21	47.3*	4.0*	24.8*	6.8
75	.87	35.3*	1.23	46.2*	4.0*	25.7*	6.6
100	.83	35.3*	1.22	44.6*	3.5*	26.0*	6.6
				2nd pick			
50	.82	37.8	1.17	43.6	3.8	20.2	6.7
75	.75	36.8	1.19	42.6	3.6	20.5	7.1
100	.77	36.9	1.17	42.6	3.7	20.4	6.5
				1st and 2nd pick combined			
50	1.68	37.0*	1.19	45.5*	3.9	22.5*	6.7
75	1.60	36.1*	1.21	44.4*	3.8	23.1*	6.8
100	1.60	36.1*	1.19	43.6*	3.6	23.2*	6.6

* Significant differences at the 5% level.

Irrigation efficiency treatments did not greatly affect fiber quality (Table 1). For the first harvest, the 50 percent efficiency treatment produced the highest lint percent and also the highest uniformity ratio. The 100 percent efficiency treatment resulted in the lowest micronaire (3.5) but the greatest strength (26.0). The cotton from the second harvest was of reduced quality, which is common, and does not imply effects from irrigation treatments.

The effects of water depletion on yield and quality are presented in Table 2.

Table 2. Effects of water depletion on yield (treatment means for 1st and 2nd pick and total mean yields for 1st plus 2nd pick) and quality (treatment means) of cotton in surface plots.

Depletion %	Yield bales/acre	Lint %	2.5% span	Uniformity ratio	MIC	Strength	Elongation
				1st pick			
25	.73	35.5*	1.23	46.3	3.7	25.6	6.7
50	.91	36.2*	1.21	46.3	4.0	25.1	6.5
75	.92	35.0*	1.22	45.5	3.8	25.9	6.7
				2nd pick			
25	.75	37.0	1.18	43.6	3.7	20.2	6.7
50	.76	37.7	1.17	43.3	3.8	20.6	6.7
75	.82	36.9	1.17	42.0	3.6	20.3	6.9
				1st and 2nd pick combined			
25	1.49	36.2*	1.21	44.9	3.7	22.9	6.7
50	1.67	37.0*	1.19	44.8	3.9	22.8	6.6
75	1.74	36.0*	1.19	43.7	3.7	23.1	6.8

* Significant differences at the 5% level.

There were no significant differences in yield due to percent depletion, although there appears to be a trend toward higher yields with increasing percent depletion. Apparently, frequent irrigation of cotton grown on the soil of this study had a negative effect on cotton yield. The 75 percent depletion treatment resulted in a lower lint percent than the other treatments: the difference may have been a result of the degree of seed development. Since the trickle plots were also irrigated very frequently but increased in yield, it appears the yield reduction due to frequent surface irrigation is caused by poor aeration.

There was significant interaction (at the 5% level) between water depletion and percent efficiency for span and strength of the first pick and for strength of the second pick (at the 1% level). When the 1st and 2nd pick were combined, significant interaction (at the 1% level) was found for strength for pick x depletion x efficiency.

Table 3 presents the effects of soil water tension measured at 15 cm in the soil below the trickle line on yield and quality of cotton.

Table 3. Effects of soil water tension on yield (treatment means for 1st and 2nd pick and total mean yields for 1st plus 2nd pick) and quality (treatment means) of cotton in trickle plots.

Tension bars	Yield bales/acre	Lint %	2.5% span	Uniformity ratio	MIC	Strength	Elongation
				1st pick			
0.2	.96	36.9	1.16*	45.2	4.1	25.4	5.9
0.6	1.61	34.7	1.26*	46.1	3.6	25.9	6.7
				2nd pick			
0.2	1.28*	38.3	1.14	42.9	4.1	22.4	8.0
0.6	.38*	37.6	1.18	43.4	3.4	20.3	7.5
				1st and 2nd pick combined			
0.2	2.24	37.6*	1.15*	44.1	4.1*	23.9	7.0
0.6	1.99	36.1*	1.22*	44.7	3.5*	23.1	7.1

* Significant differences at the 5% level.

The amounts of irrigation water applied to the trickle plots were 28 inches for the 0.2 bar treatment and 16.2 inches for the 0.6 bar treatments, including an 8-inch preirrigation.

Average cotton yields from the trickle plots (Table 3) were considerably higher than from the surface irrigated plots, while the amounts of water added were about the same, or less, than for the surface irrigated plots. Applying 28 inches of water, an average yield of 2.24 bales/acre was obtained from the wet (0.2 bars) trickle plots; and adding 16 inches of water, an average of 2.0 bales/acre was obtained from the dry (0.6 bars) trickle plots.

Due to the considerable variation in yield within treatments, the difference between the total yield of the dry and of the wet trickle treatments was not significant. However, in contrast to the surface plots, harvest x treatment was highly significant for the trickle plots. The cotton in the dry trickle plots matured earlier, with the first harvest having the highest yield, whereas in the wet trickle plots the second harvest yielded highest.

There were some significant differences in quality between the dry (0.6 bar) and the wet (0.2 bar) treatment. The dry treatment resulted in significantly lower fiber (% lint) than the wet treatment. When both harvests were considered, three significant differences in the fiber properties were noted: (1) the dry treatment produced lower lint percent; (2) the dry treatment resulted in longer fibers; and (3) the dry treatment produced a lower micronaire reading. Only the greater fiber length would be beneficial to a cotton producer, but the greater fiber length would have outweighed the reduction in micronaire and lint percent.

These results indicate that using soil moisture efficiently does not seriously reduce fiber quality. An excess of soil moisture is not necessary for production of good quality fiber.

B. Soil Salinity

1. Surface irrigated plots

Saturation extracts were prepared from soil samples taken from 20 cm depth intervals at two locations within each of the 27 plots. The samples were taken during the last two weeks of November and the first week of December. The electrical conductivity of the saturation extracts of each of these samples was measured in the laboratory. The soil sampling within the plots was repeated during the first two weeks of May, 1973. The plots had been irrigated with about 18 inches of water during the previous months and had been covered with polyethylene sheets in an effort to determine the hydraulic conductivity of the subsoil of each individual plot (see Section II-D). The samples are being oven dried, but saturation extracts have not yet been prepared.

The soil saturation extract data after the first cropping season (November, 1972) are presented in Table 4 for the surface irrigated plots. The data show no significant effect of irrigation efficiency on soil salinity at any depth. It is possible that all treatments, including the 100 percent efficiency treatment, received more water than planned. As a result, even the 100 percent efficiency treatment may have had adequate leaching.

There is some effect of percent depletion on soil salinity: The more frequently irrigated plots have the highest soil salinity. The less frequently irrigated plots received larger quantities of water per irrigation and may have had a larger effective leaching fraction than the plots more frequently irrigated.

It is interesting to compare the soil salinity data taken in the fall, after the first cropping season, with that from the previous spring (before preirrigation). Table 5 shows the average soil salinities of all 27 surface irrigated plots for the 0-80 cm soil depths before planting and after harvesting cotton. According to the data in Table 5, the soil salinity from 0 to 60 cm below the soil surface decreased while the salinity from 60-80 cm below the soil surface increased.

Table 4. Treatment means of the electrical conductivity of the saturation extracts (mmhos/cm) of the surface plots.

Efficiency percent	Depth (cm)								All
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	Depths
50	1.69	2.54	4.48	4.95	4.95	3.61	2.55	1.69	3.31
75	1.90	3.16	5.30	5.43	5.42	3.59	3.06	2.89	3.85
100	1.93	3.17	5.11	5.32	4.27	2.94	2.32	2.18	3.40
Depletion									
25	2.25*	3.32	5.61	6.14	6.32**	4.44	3.22	2.55	4.23*
50	1.68*	2.67	4.86	4.81	4.29**	3.08	2.47	1.86	3.22*
75	1.58*	2.87	4.42	4.75	4.03**	2.61	2.25	2.35	3.11*
All Treatments	1.84**	2.95**	4.96**	5.23**	4.88**	3.38**	2.65**	2.25**	

* Significant differences at the 5% level.
** Significant differences at the 1% level.

Table 5. Mean electrical conductivities of the saturation extracts (mmhos/cm) of 27 surface irrigated plots at four depths below the soil surface. (The numbers between brackets represent one standard deviation from the mean.)

Depth cm	Spring, 1972 mmhos/cm	Fall, 1972 mmhos/cm	Difference mmhos/cm
0-20	2.76(.94)	1.84(.60)	-0.92
20-40	3.95(1.82)	2.95(.83)	-1.00
40-60	5.39(1.97)	4.96(1.22)	-0.43
60-80	4.71(2.47)	5.24(1.45)	+0.53

During the spring, 1972, sampling, the majority of the soil samples obtained for determining soil salinity were taken from between the plots. This was done in order not to disturb the soil profiles within the plot areas. Using linear interpolation of the soil salinities between adjacent bore holes, the soil salinity inside each plot was calculated. The appropriate salinity values were then compared with the salinity values measured inside the 100 percent efficiency plots after the cotton harvest (Table 6).

Table 6. Mean electrical conductivities of the saturation extracts (mmhos/cm) of nine plots irrigated at 100% efficiency.

Depth cm	Spring, 1972* mmhos/cm	Fall, 1972 mmhos/cm	Difference mmhos/cm
0-20	2.87	1.93	- .94
20-40	4.25	3.16	-1.09
40-60	5.31	5.11	-0.20
60-80	4.91	5.32	+0.41

* Data partially obtained by interpolation between adjacent bore holes.

The data in Table 6 show the same trend as that in Table 5, indicating a decrease in soil salinity in the upper 60 cm of soil, even though the plots were irrigated at close to 100 percent efficiency. This decrease in soil salinity in the upper soil profile shown in Tables 5 and 6 strongly suggests that the true efficiency was less than 100 percent during the course of the experiment. Steps will be taken during the current year to approach more closely the 100 percent efficiency planned in the research outline (see Section H).

The numbers between brackets in Table 5 represent one standard deviation from the mean. Even though the whole field was irrigated before construction of the plots, the standard deviations are high, thus indicating much variation in soil salinity between individual plots.

2. Trickle irrigated plots

The electrical conductivities of the saturation extracts of the soil samples from the trickle irrigated plots are presented in Table 7. Except near the soil surface, the soil salinity in the trickle plots is considerably lower than the salinity in the surface irrigated plots. These differences existed before the start of treatments, however, and are not a result of irrigation treatments. Below a depth of 20 cm, the salt concentration in the plots irrigated at 0.6 atm soil-water tension is higher than the salt concentration in the plots irrigated at a tension of 0.2 atm. The differences were significant only at the 100-120 cm level.

It is somewhat surprising that in the trickle plots the differences between the salinity of the soil in the rows and between the rows were not larger (Table 7). The electrical conductivity of the saturation extracts of the samples taken from between the rows near the soil surface is higher than in the rows, as should be expected, but the difference is not significant (at the 5% level).

Soil salinity around the trickle lines was measured with salinity sensors. Fifteen sensors were installed in a grid pattern around a trickle line

Table 7. Treatment means of the electrical conductivity of the saturation extracts (mmhos/cm) of the trickle plots.

Tension atm	Depth (cm) 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	All Depths
0.2	2.71	2.03	2.07	2.06	2.19	1.72**	1.31*	1.31	.95	1.82
0.6	2.17	2.41	2.63	3.32	2.96	2.64**	2.00*	1.32	.91	2.26
Location										
Row	1.98	2.16	2.35	2.85	2.86	2.38	1.76	1.43	.99	2.08
Center	2.91	2.28	2.36	2.52	2.29	1.99	1.55	1.20	.87	2.00
All Treatments	2.44**	2.22**	2.35**	2.69**	2.58**	2.18**	1.66**	1.31**	.93**	

* Significant differences at the 5% level.
** Significant differences at the 1% level.

in Plot T2 (irrigated at a soil-water tension of 0.2 atm) and fifteen sensors were installed around a trickle line in Plot T6 (irrigated at a soil-water tension of 0.6 atm). The first readings were made on July 24, 1972, too late to cover the complete growing season, but the data from the salinity sensors show an increase in soil salinity between the trickle lines, especially close to the soil surface. One sensor in the dry treatment (irrigated at 0.6 atm), located at 10 cm below the soil surface and at 45 cm from the line, went off the scale (above 40 mmhos/cm) during August and September. However, the salinity rapidly decreased to about 1.7 mmhos/cm after rainfall in October, with a simultaneous increase in salinity at the 25 cm depth.

The salt distribution around a trickle line before and after leaching with 200 mm water (a normal preirrigation quantity in the Mesilla Valley) is shown in Figure 1. The upper part of the figure shows the salt distribution before leaching. This salt distribution was very similar to the salt distribution the previous fall. The lower part of the figure presents the salt distribution after leaching with 200 mm water applied through the trickle system. The data show that preirrigation with 200 mm water is very effective in moving the salts away from the trickle line. Since the storage capacity of the soil at the site is only about 100 mm, considerable leaching of the upper soil profile has occurred. In future years, the amount of preirrigation water will be reduced in order to minimize the deep percolation water losses.

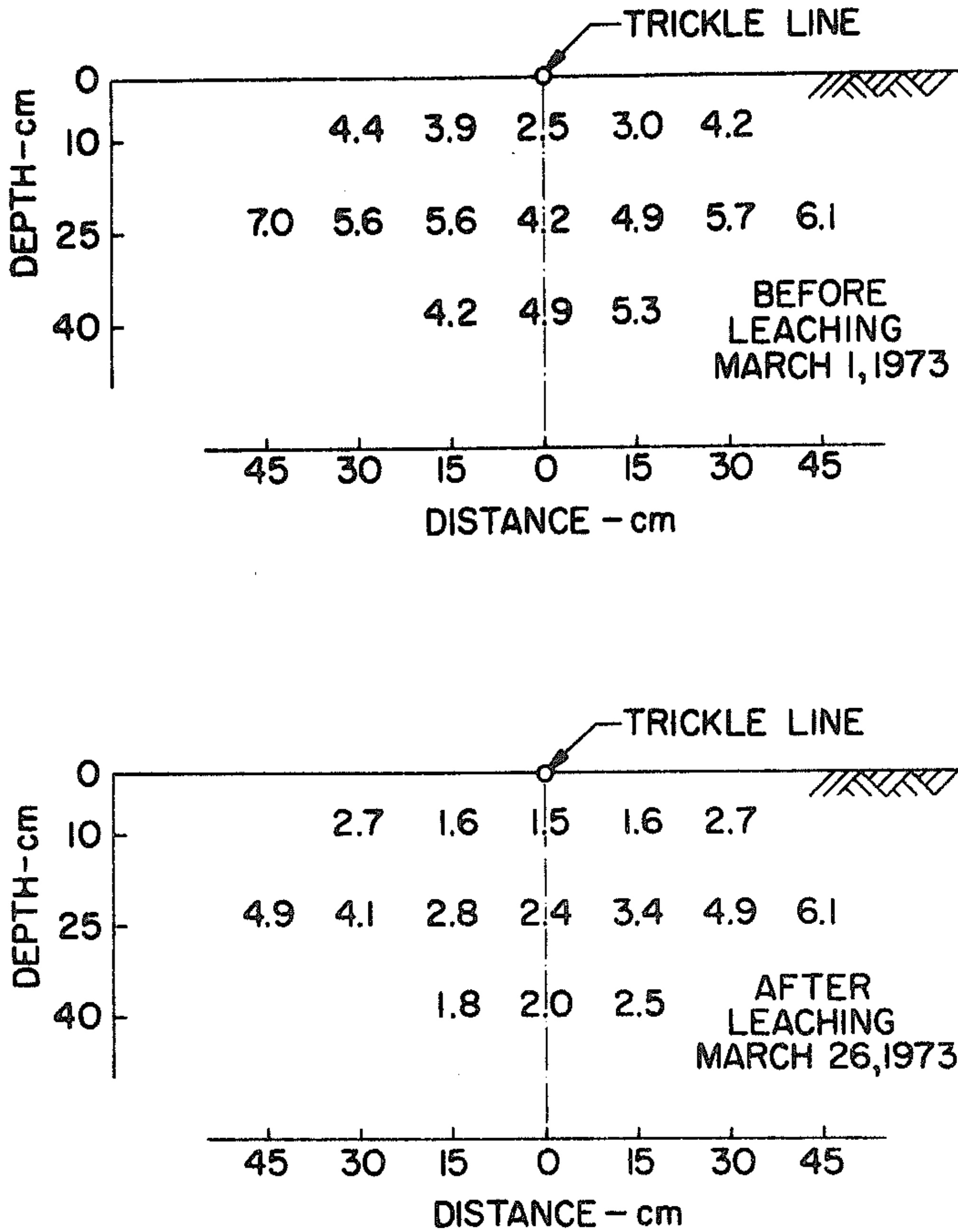

Figure 1. Soil salinity (mmhos/cm) around a trickle line measured with salinity sensors before and after preirrigation with 200 mm water (EC_{iw} = 1.4 mmhos/cm).

C. Return Flow Quality

Return flow quality was measured by withdrawing soil solution samples from the subsoil with suction cups. The suction cups were placed below the root zone at depths varying from 135 cm in the first row of plots, to 165 cm in the last row of plots and in the trickle plots. A suction of about 0.5 atm was applied through a central vacuum system. Because of the low water content of the sandy subsoil and the very low hydraulic conductivity of the soil around the cups, suction had to be applied for several days in order to get sufficient samples. Beginning August 23, a high-grade mineral oil was placed in the collection bottle to prevent evaporation from the free water-surface in the bottle.

The electrical conductivity of the samples was measured in the laboratory. Table 8 presents the electrical conductivities (mmhos/cm) of the soil solutions extracted through the cups at various sampling periods. The mean electrical conductivities and the standard deviations for all plots are also given. From a number of plots it was difficult to extract a soil solution sample because of the low water content of the sandy subsoil. For the last set of samples collected, the ionic composition was also determined.

The data from the January 10-May 14, 1973 sampling period are almost complete. During this period, all plots were irrigated with 18 inches of water and covered with plastic to determine the hydraulic conductivities of the subsoil of the plots. As a result, the subsoil below these plots was relatively wet, and a suction sample could be obtained from all plots except Plots T2 and T4.

The electrical conductivities of the saturation extracts of soil samples taken at approximately the same depths as the suction cups are presented in

Table 8. Electrical conductivity (mmhos/cm) of soil solution samples by sampling period and of saturation extracts.

Plot no.	Soil solution: July 5-9	July 25-Aug 1	Aug 23-29	Sept 21-28	Jan 10-May 14	Saturation extract: Nov 72
1	1.4	--	--	7.9	9.2	1.4
2	--	11.8	8.8	--	11.1	1.7
3	--	--	--	--	1.4*	2.7
5	4.0	14.3	7.4	8.0	6.9	1.7
6	2.3	6.4	6.6	6.9	6.6	2.1
7	3.2	8.1	4.0	4.0	7.5	1.5
8	6.3	--	--	--	4.7	2.1
9	--	--	--	--	9.9	2.7
10	9.9	14.5	11.4	12.7	13.5	5.8*
11	--	10.1	9.2	--	10.3	6.1*
12	--	--	9.1	13.9	11.8	1.8
13	--	--	--	--	10.1	3.1
14	5.6	6.9	6.3	6.5	5.4	1.5
15	--	--	9.0	13.4	7.5	2.1
16	--	--	6.2	8.1	9.6	1.2
17	4.2	11.1	5.9	6.6	9.8	1.3
18	8.4	--	8.7	11.1	9.2	2.1
20	9.8	15.5	9.7	11.1	8.7	2.6
21	--	3.0	2.9	2.9	5.5	.8
22	2.0	2.0	1.9	2.1	2.4	1.3
23	2.4	10.6	2.7	2.9	5.5	1.0
24	--	--	--	--	3.3	1.5
25	4.9	5.7	6.4	7.1	5.9	1.4
26	12.7	8.6	7.6	7.7	7.7	3.4
27	--	--	--	10.7	5.3	2.6
29	8.2	10.2	9.4	9.9	9.7	2.3
30	--	11.7	9.5	--	8.6	1.7
T1	3.5	3.7	3.9	4.4	4.9	1.3
T2	--	--	--	--	--	1.5
T3	--	--	--	--	5.8	1.0
T4	--	--	--	--	--	1.1
T5	--	--	--	4.2	4.7	1.9
T6	5.9	6.3	5.8	7.0	14.5*	1.3
Mean	5.57	8.92	6.93	7.69	7.62	1.79
St.Dev.	3.25	3.98	2.60	3.46	2.67	0.65

* Questionable data

the last column of Table 8. The average of the electrical conductivities of the saturation extracts is 1.79 mmhos/cm for all plots. The average electrical conductivity of the samples removed through the suction cups during the last sampling is 7.62 mmhos/cm. Thus the electrical conductivity of the soil solution is 4.2 times higher than the electrical conductivity of the saturation extracts. A multiplication factor of 4.2 is within the range of values given in the U. S. Salinity Handbook for medium to coarse textured soils.

The data in Table 8 show much variation in the electrical conductivity of the soil solution for different plots and sampling periods. The reason for the large variation in soil salinity between plots is not clear. It is probably a result of the variation in physical and chemical properties of the soil material within the plot area.

The chemical composition of the soil solutions extracted through the suction cups during the last sampling period was also determined. The average values for all plots are presented in Table 9, together with the composition of the irrigation water.

The data in Table 9 show that the salt concentration of the water percolating to the subsoil is almost ten times higher than the salt concentration of the irrigation water. The nitrate concentration of the deep percolation water is relatively high at 7.9 meq/1 or 490 ppm. High rates of fertilization and the lack of reducing conditions are the most probable reasons for these high nitrate concentrations since the nitrate concentrations in the Del Rio Drain are considerably lower (see Section E). The relatively high standard deviation from the mean for the various ions in the soil solution extracted through the suction cups is again due to the large variation in the physical and chemical properties of the soil material over the plot area.

Table 9. Average chemical composition of soil solution extracted through suction cups during the last sampling period, and chemical composition of irrigation water.

	Mean concentration of the solution at 120-150 cm	Standard deviation	Concentration irrigation water
EC x 10^3, mmhos/cm	7.89	3.01	1.45
pH	--	--	8.1
Ca, meq/l	28.6	8.5	3.6
Mg, meq/l	15.1	5.7	1.8
Na, meq/l	49.3	27.9	5.1
K, meq/l	.6	.3	.2
Cl, meq/l	35.5	21.5	2.8
CO_3, meq/l	--	--	.5
HCO_3, meq/l	5.9	1.0	3.0
SO_4	34.0	14.7	5.8
NO_3	7.7	3.3	0.0
PO_4, ppm	0.0	--	0.0
Sum cations	93.6		10.7
Sum anions	83.1		12.1

D. Return Flow Quantity

The return flow quantity, or the amount of water percolating to the subsoil, and the ground water table may be determined from knowledge of the hydraulic properties of the subsoil and the hydraulic gradients below the root zone in the plots.

In this experiment, the hydraulic gradients are determined from tensiometer readings at two depths below the root zone. In the first row of plots, triplicate tensiometers were installed with their tips at 120 and 150 cm below the surface of the soil; in the second row of plots, the tensiometers were installed at 135 and 165 cm; and in the third row of plots and in the trickle plots, tensiometers were installed at 150 and 180 cm, respectively. The tensiometers were connected to mercury manometers outside the plots. From the manometer readings, soil-water tensions were calculated for each depth below the soil surface. The soil-water tension data were then used to compute the hydraulic gradients.

An example of the variation in soil-water tension with time is presented in Figure 2 for Plot 22. The data in Plot 22 show a fairly constant soil-water tension at both depths until the end of August. There was no irrigation after September 1. However, the cotton was apparently still using water, which caused the soil-water tension at the 150 and 180 cm depths to increase gradually.

Figure 3 shows the average hydraulic gradient for plots 7, 13, and 22. There is considerable variation in the hydraulic gradient, due in part to malfunctioning of some of the tensiometers. However, during July and August the gradient was around minus one, with a slow increase in September due to the drying out of the soil above the tensiometers. A gradient of minus one means downward movement of soil-water at a rate equal to the hydraulic conductivity of the soil at the prevalent water content. Plots 7, 13, and 22, making up Treatment 9, were irrigated at a planned efficiency of 100 percent each time 75 percent of the available water was depleted. It is obvious from Figures 2 and 3 that water was lost from these plots by deep percolation and that a 100 percent irrigation efficiency (no loss to the subsoil) was never obtained. The data from the other surface treatments are similar to those in Figures 2 and 3. The hydraulic gradients tended to approximate unity in all plots, indicating downward movement of water. The hydraulic gradients in the trickle plots were near or above zero, possibly indicating some upward movement of water.

In calculating the actual amounts of water moving upward or downward below the root zone in the plots, the hydraulic conductivity of the subsoil

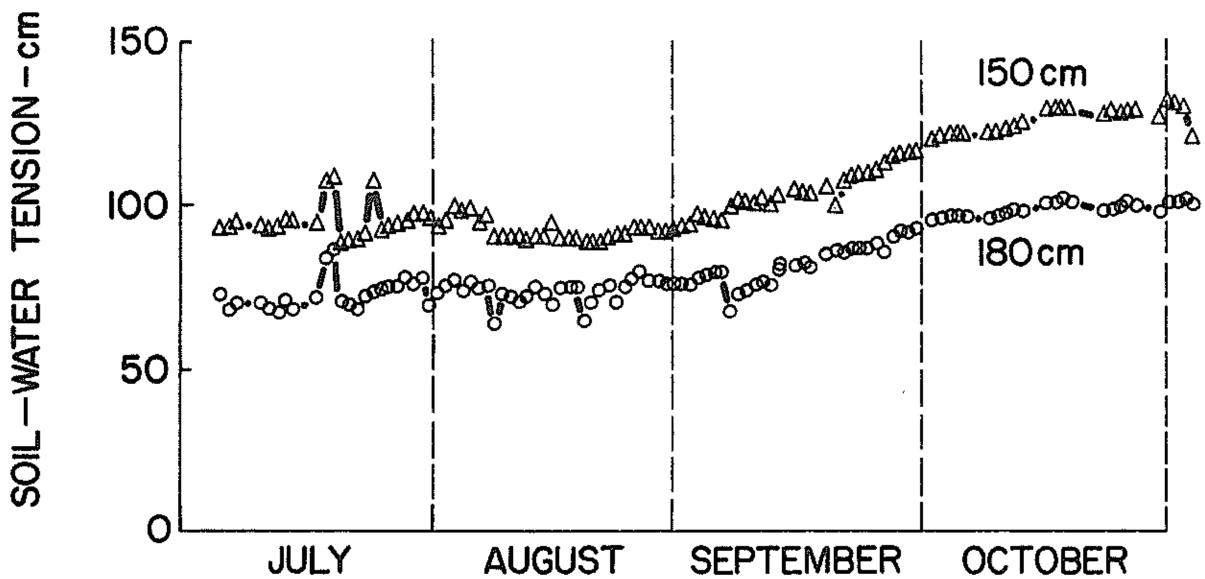

Figure 2. Variation of soil water tensions (cm of H_2O) at 150 and 180 cm depths with time.

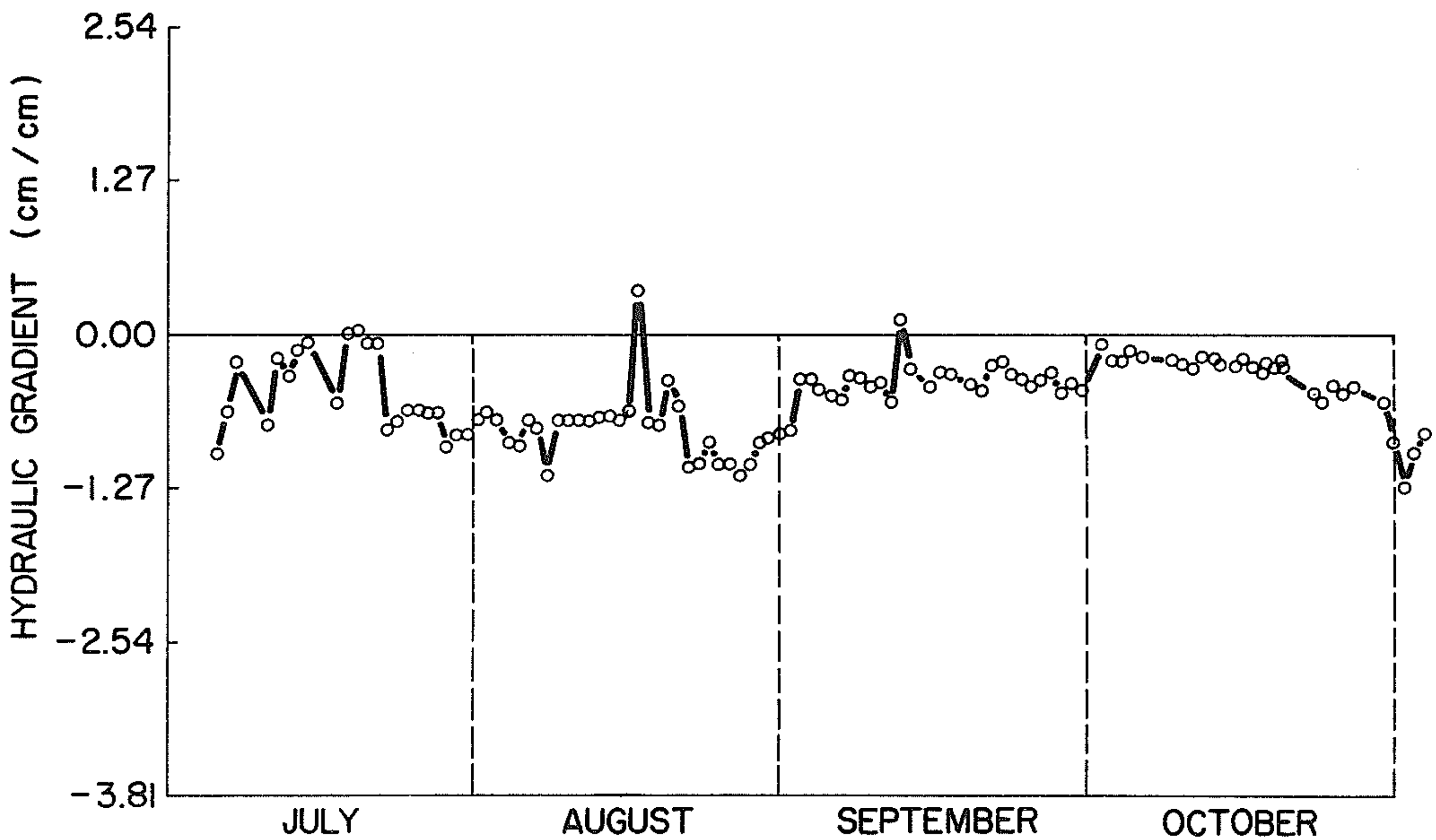

Figure 3. Variation of the mean hydraulic gradient between 150 and 180 cm depths for Treatment 9.

has to be known. Initially, three plots were set apart specifically for determination of the hydraulic conductivity of the subsoil. During the course of the experiment it became clear that the soil in the experimental area was too variable to assume uniform hydraulic properties. Therefore, efforts were made to determine hydraulic conductivity values for the subsoil of all surface irrigated plots. During the months of December, January, and February all surface irrigated plots were irrigated with 18 inches of water and covered with black polyethylene sheets. The water losses from each of these plots were measured with a neutron meter during time intervals varying from one to several days; simultaneously, the hydraulic gradients in the subsoil were obtained from tensiometer readings. From the water losses or fluxes out of the plots and the hydraulic gradients, values of the hydraulic conductivity could be calculated.

An example of the changes in the hydraulic conductivity with water content is presented in Figure 4 for the soil in Plot 4. Hydraulic conductivity versus water content relationships are presented for four depths below the soil surface. The data show that the hydraulic conductivity in the sandy subsoil (below 75 cm) changes very rapidly with water content. Therefore, for an estimate of the deep percolation losses, accurate measurements of the water content are required in addition to precise knowledge of the hydraulic conductivity water-content relationships of the subsoil of the various plots.

The results from the measurements of the hydraulic conductivities of the subsoils in the various plots taken during the past months are presently being analyzed and will be presented in future annual reports.

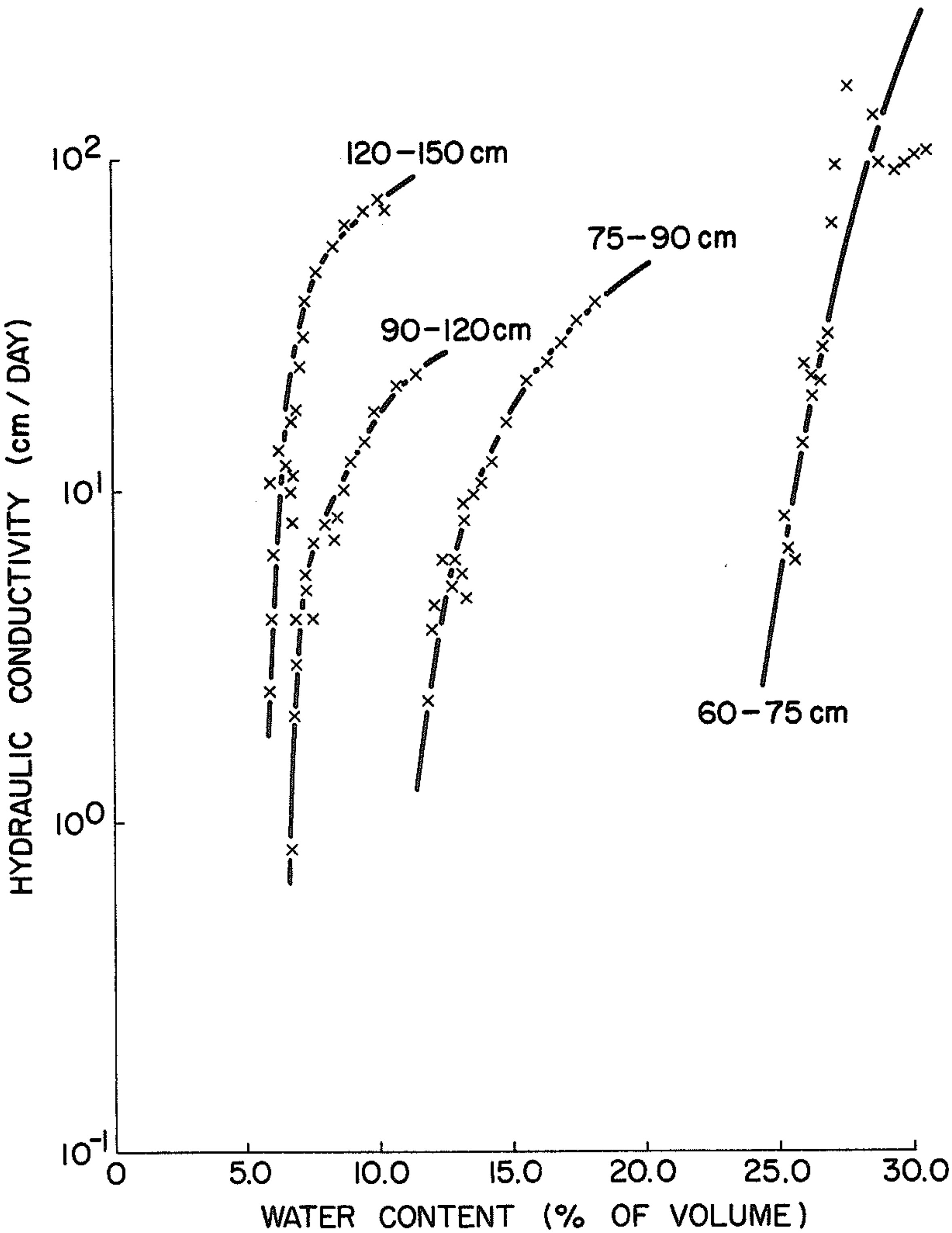

Figure 4. Relationship of hydraulic conductivity to the volumetric water content at four depths below the soil surface in Plot 4.

E. Observation on the Del Rio Drain

The two sampling stations on the Del Rio Drain have been maintained and monitored. Station A is located 2.8 miles upstream from the plot area and station B is adjacent to the plot area. Water samples from the Drain have been collected weekly at the two sites since December 4, 1971. The electrical conductivity of the drainage water collected at the two sites was determined for each sampling date in the laboratory. The data are shown in Figure 5. Time is shown in days on the abcissa. Day zero corresponds to September 27, 1971.

Periodically, determinations of the constituent ions and the pH of the samples are made. These determinations for the current project year are shown in Table 10 for Site A and in Table 11 for Site B.

Figure 6 shows total drain flow at the two stations in cubic feet per second. In 1971, project water was released from Elephant Butte Reservoir in early March (Day 150) and irrigation with surface water commenced, causing an increase in drain flow through mid-April (Day 180). At this time, the gates at Elephant Butte were closed, and subsequent irrigation was from groundwater which resulted in a decrease in drain flow from April through mid-June (Day 260). In mid-June, an additional surface water allocation was made to valley farmers which resulted in an increased drain flow from mid-June until the latter part of August (Day 325). Flows then declined and remained low through the winter months of 1972 and early 1973. From February 16 (Day 508) through March 9, 1973, a rise in flow was recorded. At the time of the peak of this rise, electrical conductivity was higher than the winter norm and there was a sharp increase in nitrate (NO_3) concentration. A total of eighty-four hundredths of an inch of rain was recorded for February 21 and 22.

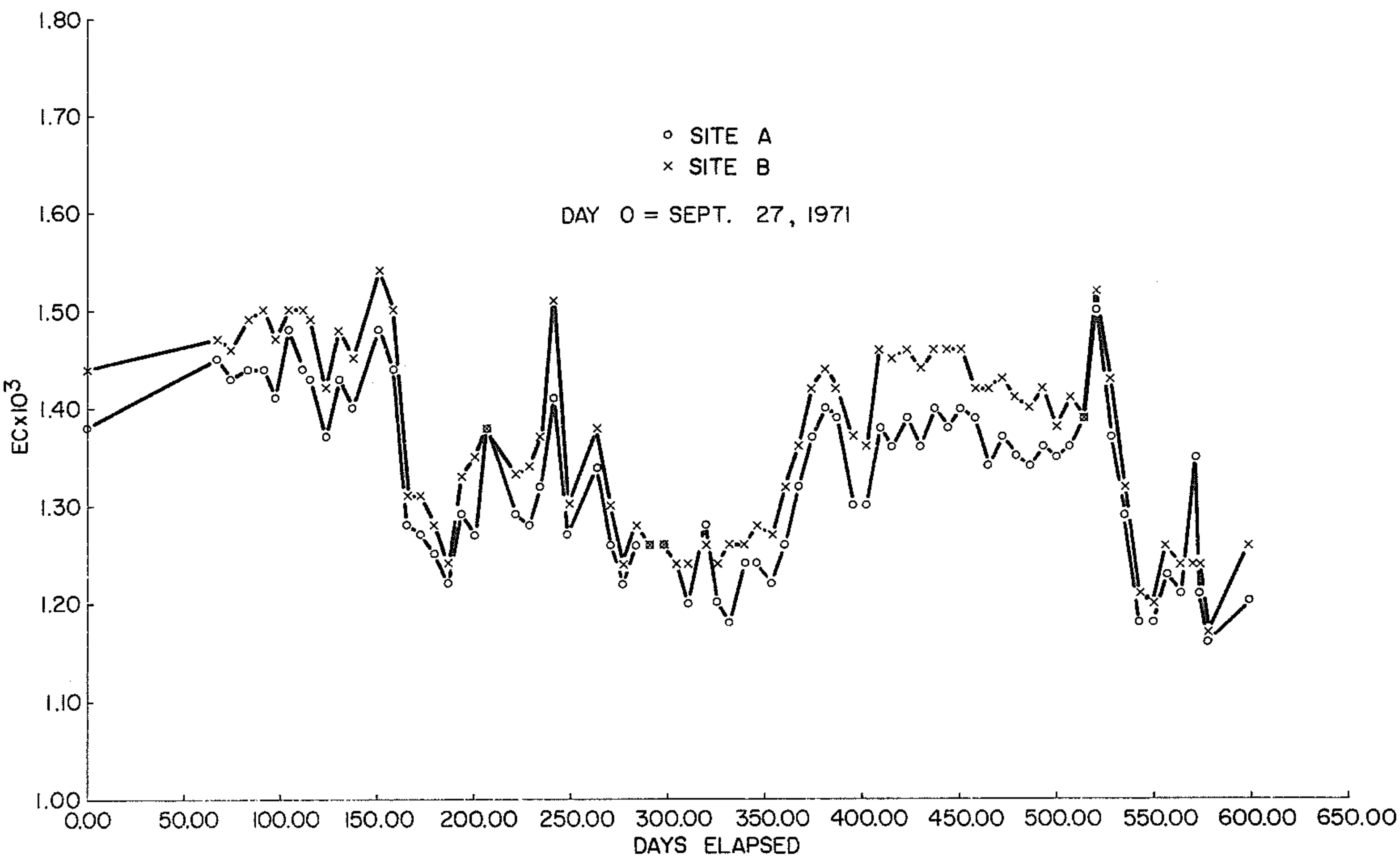

Figure 5. Del Rio Drain - EC x 10^3 vs. elapsed time.

Table 10. Chemical constituents of drain water--Site A, 1972-73 Fiscal Year

Date	EC x 10^{-3}	pH	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	Cl (meq/l)	CO_3 (meq/l)	HCO_3 (meq/l)	SO_4 (meq/l)
7/07/72	1.26	7.44	5.67	1.65	5.72	.22	3.35	--	4.35	5.77
7/21/72	1.26	7.81	3.80	1.68	6.02	.23	3.25	.60	3.42	5.22
8/03/72	1.20	7.74	4.35	1.66	5.74	.22	3.15	--	2.94	5.22
8/18/72	1.20	7.33	5.30	1.61	5.87	.22	3.26	--	3.84	5.16
9/01/72	1.24	7.90	5.50	1.70	5.99	.23	3.33	.80	3.17	5.56
9/15/72	1.22	7.92	5.50	1.67	6.12	.23	3.33	.08	3.78	5.50
9/29/72	1.32	7.68	5.57	1.70	6.16	.24	3.67	--	4.02	6.73
10/13/72	1.40	7.36	6.48	1.78	6.54	.24	3.85	.24	4.64	7.40
10/27/72	1.30	7.73	3.55	1.93	5.93	.22	3.60	.46	1.52	6.30
11/10/72	1.38	7.62	3.80	1.80	6.24	.23	3.78	.40	1.79	6.49
11/24/72	1.39	7.61	5.83	1.87	6.17	.22	3.75	.22	3.03	6.65
12/08/72	1.40	7.68	6.20	1.88	6.17	.23	3.73	.10	3.66	6.76
12/22/72	1.40	7.31	6.01	1.95	6.19	.21	3.78	.48	3.62	6.65
1/05/73	1.34	7.15	6.39	1.89	5.98	.22	3.69	.30	4.37	6.38
1/19/73	1.35	6.35	4.90	1.82	6.17	.22	3.71	.56	3.17	5.72
2/02/73	1.36	7.00	5.85	1.83	6.14	.20	3.69	--	4.15	5.99

Table 11. Chemical constituents of drain water--Site B, 1972-73 Fiscal Year

Date	EC x 10^{-3}	pH	meq/l Ca	Mg	Na	K	meq/l Cl	CO_3	HCO_3	SO_4
7/07/72	1.28	7.55	5.79	1.65	5.58	.23	3.38	.70	3.42	5.61
7/21/72	1.26	7.89	3.80	1.69	6.05	.23	3.34	1.20	2.95	5.67
8/03/72	1.24	7.71	3.55	1.68	6.05	.23	3.29	.20	1.85	5.89
8/18/72	1.24	7.65	3.90	1.65	6.09	.23	3.34	.44	2.31	5.72
9/01/72	1.26	8.06	5.10	1.68	6.05	.22	3.38	.70	2.81	5.78
9/15/72	1.27	7.75	5.85	1.71	6.15	.23	3.40	--	3.83	5.89
9/29/72	1.36	7.75	6.24	1.74	6.42	.24	3.69	.64	3.75	7.27
10/13/72	1.44	7.48	6.77	1.85	6.74	.25	3.84	.40	4.06	7.62
10/27/72	1.37	7.98	5.56	1.91	6.56	.24	3.66	.86	2.69	6.95
11/10/72	1.46	7.72	4.30	1.96	6.60	.23	3.84	.44	1.82	6.88
11/24/72	1.46	7.56	6.24	2.01	6.45	.23	3.85	.30	2.87	7.14
12/08/72	1.46	7.80	5.25	2.14	6.38	.23	3.83	.96	3.17	6.37
12/22/72	1.46	7.35	6.40	2.09	6.49	.22	3.80	.46	3.72	7.48
1/05/73	1.42	7.06	7.00	2.01	6.27	.21	3.72	.20	4.41	7.13
1/19/73	1.41	6.78	5.05	1.89	6.50	.21	3.79	.14	3.77	5.94
2/02/73	1.42	7.11	5.00	1.88	6.43	.20	3.77	.80	3.68	5.94

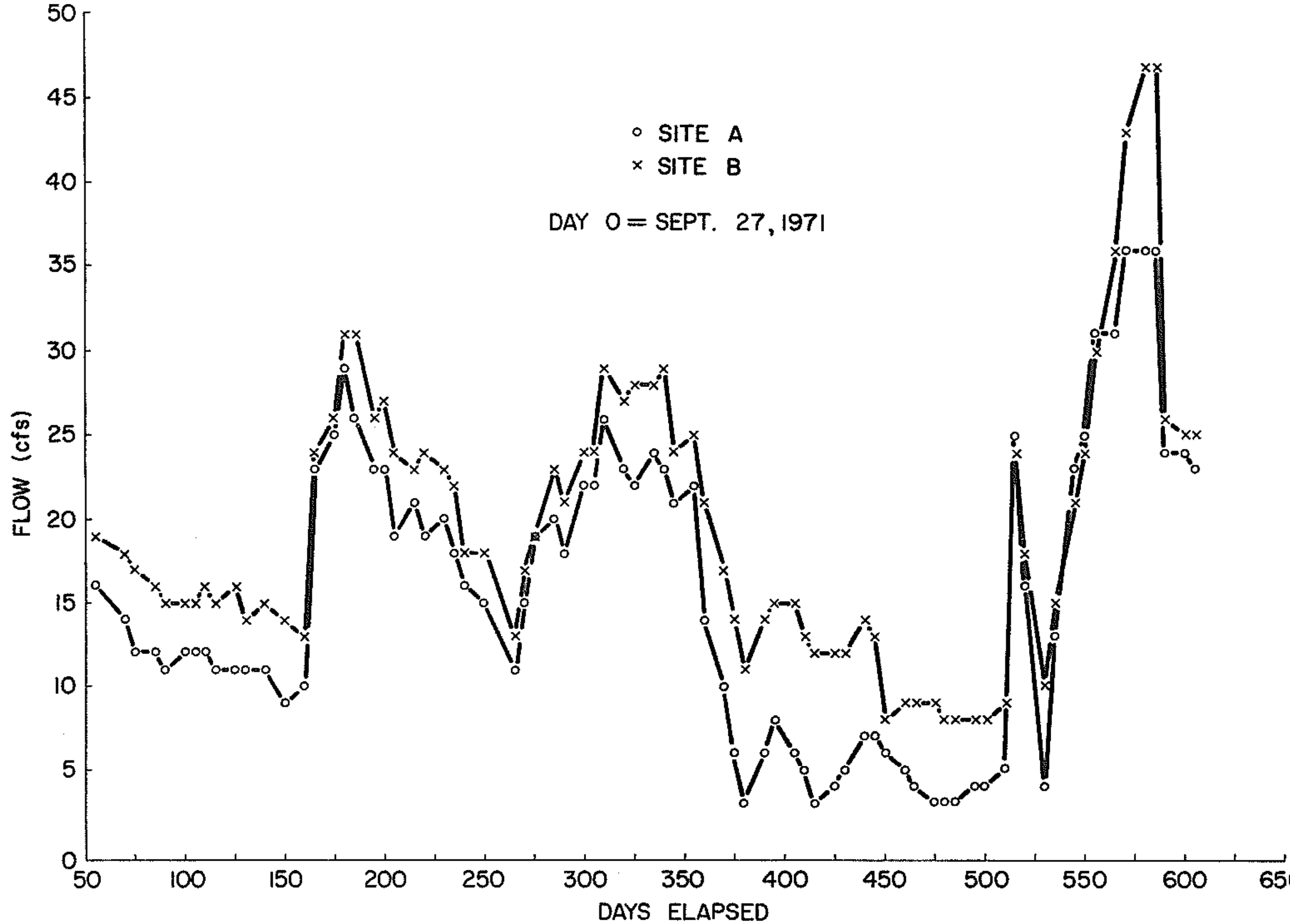

Figure 6. Del Rio Drain - Flow vs. elapsed time

This rise, prior to preplant irrigations, is probably a result of surface runoff and accidental discharge from the Las Cruces city sewer plant.

During the majority of the time analyzed, higher drain flows correlate with lower concentrations of TDS; and during periods of low drain flow, salt concentrations are relatively high.

Preplant irrigations on cotton land and the first irrigation on alfalfa commenced in the valley during the first week of March, 1973. Response of drain flow to this watering starts just after March 9 (Day 529), and peak flows were reached at both monitoring sites during April. Surface runoff from improper on-farm water management, influence on the water table of water flowing in the river channel, and deep percolation losses all contribute to this increase in flow. Surface runoff and bleeding of canals and laterals above Site A were probably responsible for the increased flows from March 9 to early April, since the quantities at Site A and Site B were nearly equal. However, subsurface inflow to the drain was probably dominant during April, as evidenced by the nearly 10 cfs increase between Site A and Site B. Inflow to the test reach averaged 3.6 cfs per mile during April. Salt concentrations during the period of preplant irrigation were relatively low (1.2 mmhos/cm).

F. Well Observations

Tables 12 through 16 show the electrical conductivities and chemical constituents of the waters from the five test wells. Average conductivity of the five test wells approximates the quality of the irrigation water applied to the plots and the conductivities of the saturation extracts from the plots. Figure 7 shows the relationship of the electrical conductivity of water from each well with time.

Table 12. Chemical constituents--Well No. 1, Depth = 75 feet

			meq/1				meq/1			
Date	EC x 10^{-3}	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
7/07/72	1.18	7.74	4.96	1.52	4.44	.19	2.79	.94	3.42	5.44
8/03/72	1.14	7.67	3.87	1.56	4.78	.18	2.74	--	3.96	4.87
9/01/72	1.14	7.64	5.65	1.66	4.78	.18	2.72	.54	4.00	5.21
10/07/72	1.13	7.48	5.62	1.50	4.66	.19	2.75	--	4.54	4.47
11/10/72	--	7.70	4.21	1.57	4.53	.18	2.75	.62	2.03	4.85
12/08/72	1.10	7.65	4.80	1.53	4.18	.17	2.73	--	3.86	3.44
1/05/73	.98	7.35	5.36	1.58	3.51	.16	2.71	--	3.66	3.74
2/02/73	1.14	7.16	5.94	1.60	4.46	.17	2.77	.88	3.72	4.23

Table 13. Chemical constituents--Well No. 2, Depth = 50 feet

			meq/1				meq/1			
Date	EC x 10^{-3}	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
7/07/72	1.80	7.55	11.09	2.67	5.98	.24	4.13	--	7.49	8.80
8/03/72	1.46	7.62	5.35	2.03	5.77	.21	3.21	--	6.10	7.06
9/01/72	1.44	7.48	8.01	2.14	5.67	.21	3.15	.74	5.17	6.63
10/07/72	1.40	7.47	7.78	2.00	5.49	.23	3.15	--	6.10	6.22
11/10/72	--	7.54	6.20	2.07	5.25	.21	3.26	--	4.70	6.49
12/08/72	1.44	7.55	6.69	2.06	5.22	.21	3.20	--	5.72	5.62
1/05/73	1.40	7.27	8.18	2.09	5.17	.21	3.22	--	5.95	5.94
2/02/73	1.44	7.16	8.04	2.05	5.45	.20	3.23	.71	5.24	5.94

Table 14. Chemical constituents--Well No. 3, Depth = 35 feet

			meq/l				meq/l			
Date	EC x 10^{-3}	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
7/07/72	1.60	7.57	7.50	2.32	5.95	.25	3.40	--	6.98	7.59
8/03/72	1.62	7.57	5.89	2.35	7.00	.26	3.49	--	6.68	7.96
9/01/72	1.56	7.44	9.18	2.39	6.45	.23	3.42	.08	6.46	7.71
10/07/72	1.56	7.26	9.21	2.30	6.29	.25	3.56	--	6.54	7.40
11/10/72	1.60	7.45	6.19	2.38	5.87	.23	3.45	--	4.45	6.83
12/08/72	1.64	7.47	6.90	2.57	5.97	.23	3.52	--	6.63	5.82
1/05/73	1.58	7.25	7.46	2.57	6.36	.24	3.50	--	7.17	6.82
2/02/73	1.58	7.16	8.09	2.39	6.08	.22	3.44	.80	5.61	5.50

Table 15. Chemical constituents--Well No. 4, Depth = 25 feet

			meq/l				meq/l			
Date	EC x 10^{-3}	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
7/07/72	1.42	7.58	7.00	2.20	5.25	.22	3.07	--	5.78	7.31
8/03/72	1.38	7.59	5.70	2.23	5.49	.23	3.01	--	5.74	6.62
9/01/72	1.38	7.40	6.24	2.17	5.58	.22	3.04	.10	4.39	6.90
10/07/72	1.41	7.30	7.78	2.23	5.52	.25	3.01	.12	6.42	6.17
11/10/72	1.44	7.42	4.58	2.27	5.42	.23	2.97	--	3.94	5.34
12/08/72	1.52	7.56	5.95	2.70	5.90	.24	2.95	--	7.57	4.03
1/05/73	1.54	7.25	9.03	2.72	5.73	.25	3.01	--	8.37	6.16
2/02/73	1.54	7.04	8.36	2.58	5.83	.23	2.95	--	7.82	4.56

Table 16. Chemical constituents--Well No. 5, Depth 19 feet

			meq/l				meq/l			
Date	EC x 10^{-3}	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
7/07/72	1.60	7.45	7.31	3.16	5.75	.31	3.49	--	7.14	7.48
8/03/72	1.52	7.60	4.80	2.81	5.93	.32	3.31	--	6.77	6.67
9/01/72	1.44	7.49	5.65	2.73	5.83	.30	3.16	.06	4.87	6.96
10/07/72	1.38	6.57	7.06	2.60	5.40	.31	3.08	--	6.28	6.11
11/10/72	1.36	7.31	2.95	2.57	5.05	.28	2.97	.84	3.02	4.11
12/08/72	1.35	6.35	6.19	2.63	5.00	.28	2.95	--	5.30	5.92
1/05/73	1.32	7.31	6.91	2.57	5.14	.28	2.94	--	6.97	4.84
2/02/73	1.32	7.05	6.83	2.44	5.05	.27	2.97	--	6.41	3.35

A new pumping system has been purchased for the test wells which will, when installed, insure that no mixing of waters can occur during test pumping and allow redevelopment of each well.

G. Irrigation Scheduling

In the original proposal for this project, determination of the time at which the various treatments received irrigation water was to result from changes in water content of the root zone as measured by the neutron meter.

Although this method is frequently used in studies such as this one, it was agreed in July of 1972 that irrigation scheduling would be based upon climatological data and on soil and crop data from the experimental plots. During the 1972 season, irrigation times were determined by pan evaporation data, corrected with a stage of growth dependent crop coefficient, and adjusted for rainfall.

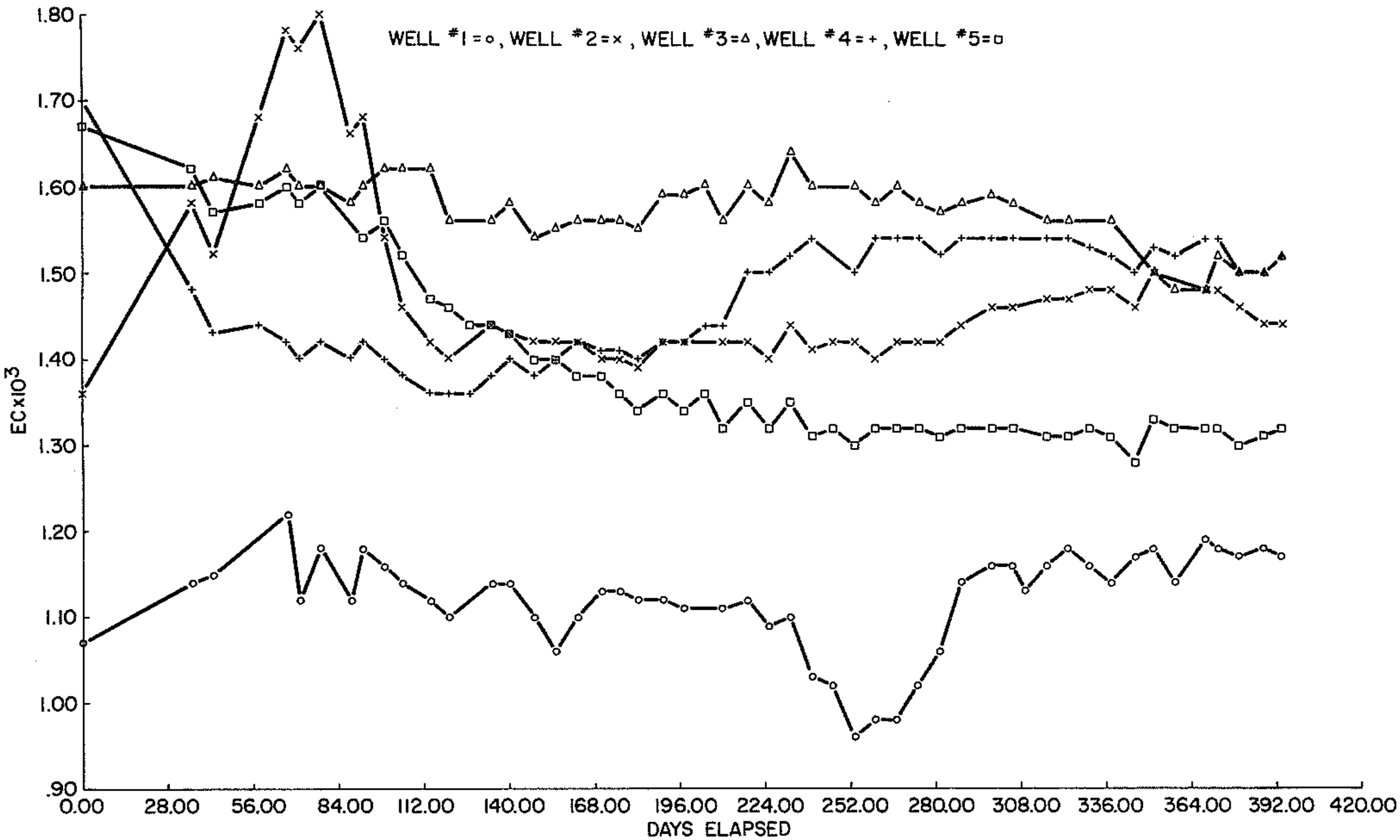

Figure 7. Variation of electrical conductivity of water samples from each well with time.

The coefficients used, based on stage of growth, were those developed for use on the Salt River Project in Arizona. These were modified slightly (correlation values reduced due to cooler nights). The shape of the modified relationship is shown in Figure 8. All treatment groups received water which was believed to be in excess of that prescribed by the treatment using this procedure, even with the modification outlined above.

During the 1973 crop year, again as agreed in July of 1972, irrigation scheduling is to be based on the methods developed by Jensen. Two-way cooperation between the project and the U. S. Bureau of Reclamation in El Paso will make this possible. Equipment for monitoring hourly temperature, relative humidity, solar radiation, and daily wind speed has been installed at the project site. This climatological input will be used in the existing Bureau scheduling programs. Depletions calculated by the Jensen method will be field checked with neutron equipment on the plot site, affording the Bureau the capability of calibrating scheduling parameters used in conjunction with the model.

Pan evaporation will continue to be monitored and adjustments made in the pan evaporation evapo-transpiration factor to refine this method for this particular locality.

H. The 1973 Growing Season

From December 1972 to February 1973, all plots were irrigated with 16-18 inches of water to determine the hydraulic properties of the subsoil. The surface irrigated plots were covered with polyethylene plastic to prevent evaporation from the plots. Two weeks before planting, the polyethylene covers were removed to allow the surface soil to dry. The trickle plots were preirrigated with 16 inches of water. No cover was applied over the trickle

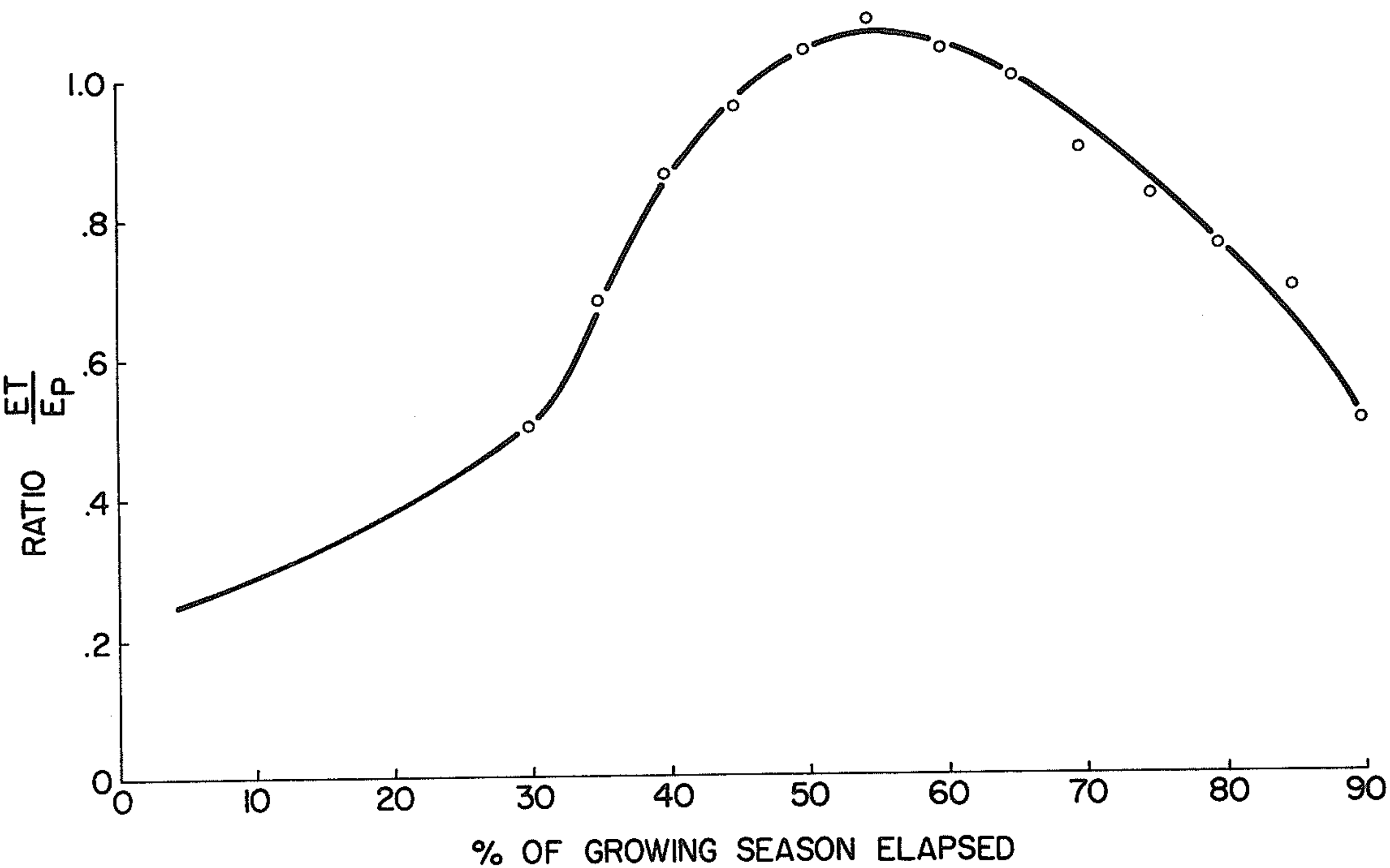

Figure 8. Evapo-transpiration - Pan evaporation ratio as a function of stage of growth.

irrigated plots. The soil in the surface irrigated plots was loosened with a tool to allow planting in the loose top soil. No cultivation was done on the trickle plots.

On April 23, all plots were planted with Acala 1517-70 cotton on 40-inch row spacing. The furrows made by a small hand planter in the surface irrigated plots were covered with sand to allow easier germination of the cotton. Sand capping was not found necessary in the trickle irrigated plots. After planting, the plots were irrigated with about 4 inches of water. Plant establishment was somewhat delayed by root rot. Thinning of the cotton was accomplished in the last week of May.