Degradation of Water Quality in Irrigation Return Flows

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Introduction

Irrigation water for agriculture is used in many parts of the western United States where rainfall during the growing season is insufficient for dependable crop production. If a rank of beneficial uses of water were established according to priority, agriculture would probably be second only to municipal and domestic requirements. In magnitude, withdrawals for irrigation far exceed those for municipal and other rural uses and are second only to industrial uses.

In 1955, MacKichan (15) estimated that withdrawal rates for irrigation and industrial uses in the United States were about equal at 110,000 million gallons per day (mgd). In 1960, MacKichan (16) reported that irrigation usage had not increased significantly while industrial use had increased to about 140,000 mgd. By contrast, the water use pattern presents a different picture owing to the influence of climate and seasonal rainfall on water consumption. Of the 48 contiguous states, the 17 western states comprise 60.6 percent of the total area. Over 90 percent of the irrigation water withdrawal for agricultural purposes occurs in these 17 western states; and, of this amount, approximately 60 to 66 percent of the water is actually consumed or transpired by the growing crops. About 85 percent of industry's withdrawal occurs in the 31 eastern states. Owing to the fact that over 90 percent of industry's water is used for cooling, only about two percent of their withdrawal is consumed or evaporated.

Because of the high consumptive use of irrigation water by plants, 80 percent of the total water consumption occurs in the 17 western states. Since the West has an estimated 25 percent of the United States water supply, it is readily apparent that the greatest depletion occurs where water is least abundant. Therein lies the basis for the great concern for the potential pollution effects of irrigation return flows in the semiarid and subhumid regions of the West.

Irrigation waters contain variable quantities of dissolved salts. These salts undergo changes in concentration and composition once applied to the soil. Because the quality of irrigation water is judged by the concentration and composition of the dissolved constituents (22, 25), its quality may be greatly altered or degraded by irrigation usage (26). The processes by which this degradation of water quality occurs are natural consequences of the high consumptive use by growing crops. Furthermore, it has been shown that salt removal by surface and subsurface waters is a necessary and essential requirement if irrigation agriculture is to continue successfully in any given area (27).

Scofield (18) was one of the first to recognize that plants remove water from the soil while leaving most of the salts behind in the soil profile. In irrigated areas where inadequate leaching and drainage occur, the soil may soon become salt laden and unproductive. Therefore, the leaching and removal of excess salts from the soil in irrigated areas by drainage and surface water frequently cause an undesirable increase in the salt burden of the receiving stream.

Several authors (4, 8, 10, 12, 19, 20, 24) have discussed the pollutional effects of irrigation return flows on surface and groundwater resources. These discussions were based primarily on the overall effects in river drainage basins receiving predominantly irrigation return flows from large areas. Eldridge (9) reviewed the data from a variety of sources in his report on the characteristics and effects of irrigation return flows. His report covered such widespread areas as the Rio Grande and Pecos Rivers in New Mexico and Texas; Yakima River and Sunnyside Irrigation District in Washington; the upper Colorado, Arkansas, and Columbia River Basins; the Boise River in Idaho; and the San Joaquin and Sacramento Rivers and delta area in California. In each of these areas, it was found that water quality was degraded progressively downstream. Extreme cases of pollution had occurred in the Rio Grande below El Paso. At that point in the river, high sulfate and chloride contents rendered the water unfit for municipal and many industrial uses. It was only due to dilution from tributaries below this point that the water could later be used beneficially.

Apparently, little research has been conducted to evaluate the quality of irrigation return flows from individual field plots as opposed to drainage from entire irrigation districts. Therefore, a preliminary study on a field plot basis was initiated. In so doing, it was believed that a better basic understanding of the fate and movement of the increased mineralization could be obtained.

Study Objectives

A cooperative agreement was drawn up between the Agronomy Department of Oklahoma State University and the Robert S. Kerr Water

Research Center, Ada, Oklahoma, to conduct this study during the 1966 calendar year. The objectives of the study as set forth in the agreement were as follows:

1. To determine the degradation of water quality in irrigation return flows as compared with that of the water applied.
2. To determine the salinity status of a clay loam soil after prolonged irrigation with high salt water.
3. To relate the results of this study to the effect of irrigation return waters on the quality of surface and groundwaters in the area.

Experimental Procedure

Plot Description

The field selected for this study was located on the Oklahoma State University Irrigation Research Station, Altus, Oklahoma. The agricultural area surrounding the station has been under irrigation for about 15 years, with cotton being the principal crop. The plot area studied had been used as a cotton variety and breeding nursery. Uniform treatments of irrigation water, fertilizer, and pesticides had been used during the past 15 years. No experimental treatment variations within the plot had been practiced.

Cotton rows were spaced on 40-inch centers and ran east and west. Irrigation water was applied from the supply canal on the east end by means of siphon tubes to each furrow. The water proceeded downslope in a westerly direction to the collection ditch at the west end of the field. The collection ditch sloped to the north with all surface drainage water from the plot directed through a 6-inch Parshall flume equipped with a Stevens water level recorder. The quanity of irrigation water applied to the field at each irrigation was determined by measuring the water level and flow rate in the feeder canal at a point between the main irrigation canal and the supply canal.

Soil Description

The soils on the Irrigation Research Station, including the area studied, are described as nearly level upland soils with clayey subsoils. They are mapped as Tillman and Hollister clay loams, 0 to 1 percent slope (21). These soils occur in a complex pattern on the station and are not mapped separately. Hollister is the dominant soil and occurs at slightly lower elevations than does Tillman. The main difference in the two soils appears in the lower horizons where the Tillman has a redder color than the Hollister. Both soils and their variations are slowly to very slowly permeable to water. Furrow and border irrigation methods have proven satisfactory for these soils.

The Hollister series is comprised of deep, clayey soils that have a grayish-brown, granular, clay loam surface soil. The subsoil contains a very dark gray to gray clay that has a blocky structure below about 16 inches. The thickness of the surface soil is about 9 inches, and that of the subsoil, about 27 inches. Below a depth of 36 inches, the underlying material is a gray, calcareous clay that grades at about 60 inches to a reddish-brown clay.

Soils of the Tillman series have a reddish-brown, granular, clay loam surface layer. The subsoil, of about the same color as the surface, is more clayey and has a blocky structure in the lower part. The surface layer is about 10 inches thick and the subsoil about 18 inches. Below 28 inches is a material similar to that from which the soil is formed, a stiff, calcareous clay that contains many soft carbonate concretions. In general, the Hollister and Tillman soils are so intermingled they cannot be mapped separately.

The Tillman and Hollister clay loams have a low water intake rate and are very sticky when wet. Their permeability to water ranges from 0.30 to 0.05 inch per hour, and their moderate to high shrink-swell potential indicates the presence of montmorillonite type clays in the clay fraction.

Sampling Procedure

Sampling included the collection of cores from the soil profile prior to the 1966 irrigations; incoming irrigation water and surface return flows at each irrigation; and soil water samples at various depths following each irrigation.

Soil Samples. Prior to the beginning of irrigation in June, 1966, soil cores were collected from the field for soil salinity analyses. Three rows 60 feet apart and 900 feet long were located in the field running east to west, and four sampling positions 180 feet apart, were selected in each row. Samples were collected in 6-inch increments to a depth of 96 inches where possible. Owing to the difficulty of obtaining samples in the saturated zone, no definite depth increment was maintained. After a three-day period, the depth to the water table from the soil surface was measured in each of the cored holes and these measurements are presented in Table 1. Water samples were collected from each hole, where free water occurred, in order to characterize the water quality of this shallow water table.

At the end of the season, following harvest, four additional soil cores were collected in order to compare the soil salinity status before and after an irrigation season.

Table 1. Depth to the water table in the soil core holes after 3 days.

Core No.[1]	Table, inches Depth to Water
10	75
11	77
12	72
13	72
20	72
21	78
22	No Water
23	78
30	82
31	79
32	78
33	No Water

[1] The first number designates the row with 1 being the south and 3 the north row and the second number represents the sampling position moving east to west within each row.

Surface Water Samples. Surface water samples were collected at different sampling locations during each irrigation period. The sampling locations are described in Table 2 as sites numbered 1 through 4. One water sample was collected at Site No. 1 and two at Site No. 2 during each irrigation period. Samples were collected at Site No. 3 every 3 to 4 hours throughout each irrigation, and Site No. 4 was sampled hourly after water started through the flume and continuing throughout the irrigation period.

Soil Water Samples. Following each irrigation, soil water samples were collected from various depths at three locations in the field. These are described in Table 2 as sites number 5, 6, and 7. At each site, soil water sampling tubes were installed at depths of 6, 12, 18, 24, and 30

Table 2. Water Sampling Locations

Sampling Site No.	Description
1	Irrigation water from the main canal, 1 mile below the dam at Altus Reservoir.
2	Irrigation water from the main canal at the Irrigation Research Station approximately 21 canal miles from Altus Reservoir.
3	Irrigation water from the supply canal at the field.
4	Surface return flow (runoff) sampled at the Parshall flume on the drainage end of the field.
5	Soil water sampling tubes located near the east end of field at depths of 6, 12, 18, 24, and 30 inches.
6	Same as No. 5, except located midway in the field.
7	Same as No. 5, except located near west end of field.

inches. The soil water sampling tubes consisted of a porous ceramic cup attached to a 2-inch diameter plastic pipe. The tubes were inserted in the soil to the desired depth and remained in place throughout the irrigation season. Water samples were collected by applying a vacuum with a small hand pump. The procedure was continued for 24 to 48 hours after the application of each irrigation. The volume of sample obtained was generally small but sufficient for the selected number of analyses. One composite sample from each depth was obtained following the second and third irrigations and after the rainfall on August 7. The tubes were not installed prior to the first irrigation.

Schedule of Operations

The operations performed on the field in 1966 are described in Table 3. At least five and frequently six irrigations are necessary during

Table 3. Schedule of Operations

Date	Operation	Application Rate per acre	Percent Surface Runoff
May 18	Cotton Planted with Super-phosphate	9 lbs. P_2O_5	
June 16-17	Rainfall	0.42 inch	None
June 24	Cultivation with Ammonium Nitrate	45 lbs. Nitrogen	
June 28	First Irrigation	4.14 inches	7.2
July 4	Fertilizer Applied (Ammo-Phos)	19 lbs. Nitrogen 9 lbs. P_2O_5	
July 11	Rainfall	0.42 inch	None
July 16	Methyl Parathion	0.2 lb.	
July 18	Second Irrigation	3.41 inches	5.6
July 28	Final Cultivation		
August 7	Rainfall	1.63 inches	Not Measured
August 18	Third Irrigation	2.02 inches	10.6
August 19 August 25 September 1 September 7 September 12	Insecticide Applied	2 lbs. DDT 1 lb. Toxaphene 0.5 lb. Methyl Parathion	
August 22-31	Rainfall	3.83 inches	
September	Rainfall	3.47 inches	

the cotton growing season in this area; however, owing to unusual amounts of rainfall, this was not true during the 1966 growing season. The third irrigation scheduled on August 7 began at midnight on August 6. Rain started to fall just as the irrigation was initiated, and the third irrigation was postponed until August 18. Additional rainfall during the latter part of August resulted in cancellation of further irrigations. A total of three irrigations were made during the season.

Analytical Procedures

Water Analyses

Field Tests. Immediately after sampling, the following analyses were performed on each water sample: temperature, pH, alkalinity, and specific conductance. Procedures given in Standard Methods (1) were followed in determining alkalinity and specific conductance (EC).

Laboratory Tests. Two one-liter samples of surface water were collected for analysis. These samples were returned to the laboratory for analyses. One liter of each sample sent to the laboratory for phosphorus and nitrogen analyses was "fixed" in the field with 1 ml of concentrated sulfuric acid.

Laboratory analyses, conducted by Standard Methods' (1) procedures, included total dissolved solids (TDS) at 105°C, ammonium nitrogen, chloride, total and calcium hardness, orthophosphate, boron, and sodium.

Total Kjeldahl nitrogen was determined by macro-Kjeldahl digestion. Nitrate nitrogen was determined by the modified brucine method described by the Robert A. Taft Water Research Center (11). Sulfate was determined by a turbidimetric method. Potassium was determined using an atomic absorption spectrophotometer. Total phosphorus was determined with the aid of an auto-analyzer (13) following a 30-minute digestion of the sample in the presence of sulfuric acid and potassium persulfate.

Soil Analyses

Each soil sample was placed in a plastic bag in the field and transferred to the laboratory where they were air-dried. The air-dry samples were ground to pass a 2-mm sieve. The determination of soluble salts in a soil sample consists of two steps: (a) the preparation of a soil-water extract and (b) the measurement of the concentration of the salt constituents of interest in that extract. The soil-water extracts were prepared on a one to one (1:1) weight basis using 100 gm of dry soil and 100 ml of distilled water. After 24 hours of shaking, separation of soil and water was achieved by filtering under vacuum. A determination of pH was made on the soil paste prior to filtration and again on the water extract after filtration.

Laboratory analyses of the 1:1 soil-water extracts, conducted by procedures described in the USDA Handbook 60 (22), included total dissolved solids (TDS), electrical conductivity (EC), calcium, magnesium, and sodium. Other analytical methods employed are described in the ASA Monograph No. 9 (2) and included determinations for chloride, sulfate, and nitrate nitrogen.

Results and Discussion

Surface Water Quality

The irrigation water supply and surface return flow (runoff) from the irrigated field were sampled and analyzed during each of the three irrigations in 1966. Water quality results are summarized in Figure 1, and the data are presented in the Appendix (Tables I and II). The

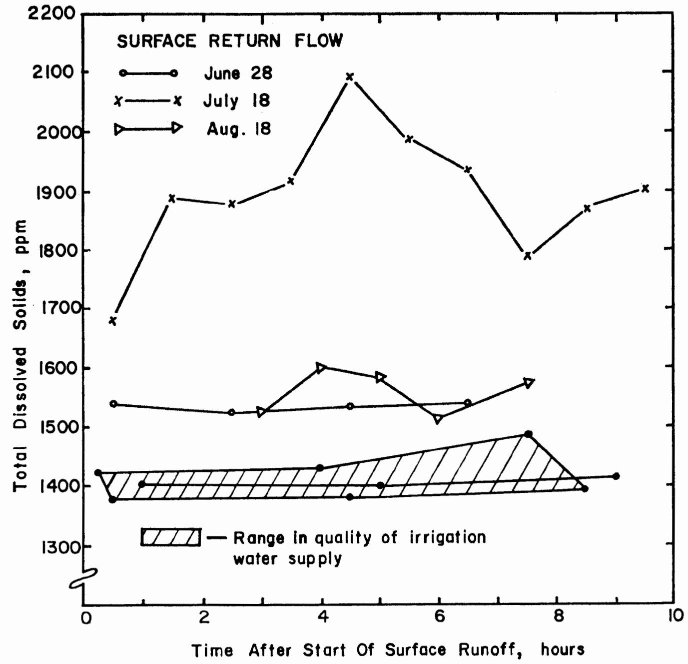


Figure 1. Salt content of the irrigation water and surface return flow at three sampling periods during the 1966 irrigation season.

shaded area (Figure 1) represents the range in total dissolved solids (TDS) in the irrigation supply during the season, and the other three curves represent the TDS of the surface return flow for the three sampling periods. Comparison of the mean TDS in the supply (1412 ppm) with those of surface runoff shows an increased salt concentration of 8.5 percent for the first irrigation (June 28), 34.2 percent for the second (July 18), and 10.5 percent for the third (August 18). Surface conditions and previous irrigations significantly influence the amount of salt in the surface water. No rain was received between the first and second irrigations to leach the accumulated salt from the soil surface, and a large increase in salinity of the surface return flow was noted. A rainfall of 1.6 inches occurred between the second and third irrigations which reduced the salinity in the surface runoff at the third irrigation.

Using the classification scheme of the U. S. Salinity Laboratory (22), the irrigation supply was rated as a high salinity (bordering on very high) low sodium (SAR of 3.3) water. The bicarbonate concentration was low compared to the calcium and magnesium content; therefore, significant amounts of residual sodium carbonate were not present (7). The continued use of this water for irrigation purposes requires that leaching of soluble salts below the root zone must be achieved in order to control total salinity within the soil profile. Rainfall and irrigation practices play significant roles in meeting this requirement. The mean annual rainfall for the region is 25 inches with the greater amount generally being received in the spring and fall.

Salinity Status of Soil Profiles

The increased soluble salt content of an irrigated soil profile as compared to a similar nonirrigated profile is shown in Figure 2. An increase of fourfold in the plow layer to a maximum of twentyfold at the 18 to 24 inch depth is noted, decreasing below that depth to a sevenfold increase at the 48 to 60 inch depth. The results from the irrigated area were collected prior to the first irrigation of the 1966 season. Under these conditions, the soluble salt content represents as nearly as possible the lowest salt condition resulting from prolonged high salt water usage, since it followed the fall and spring rains and was not influenced by recent irrigations.

Because the irrigation water is the primary source of salts applied to an irrigated soil, it is appropriate to examine the chemical composition of the irrigation water supply. The data of Table 4 show the mean chemical composition of the irrigation water for three sampling periods during 1966. Records from previous years show that there have been no significant changes in the quality of water from the Altus Reservoir; therefore, these data are taken to be representative.

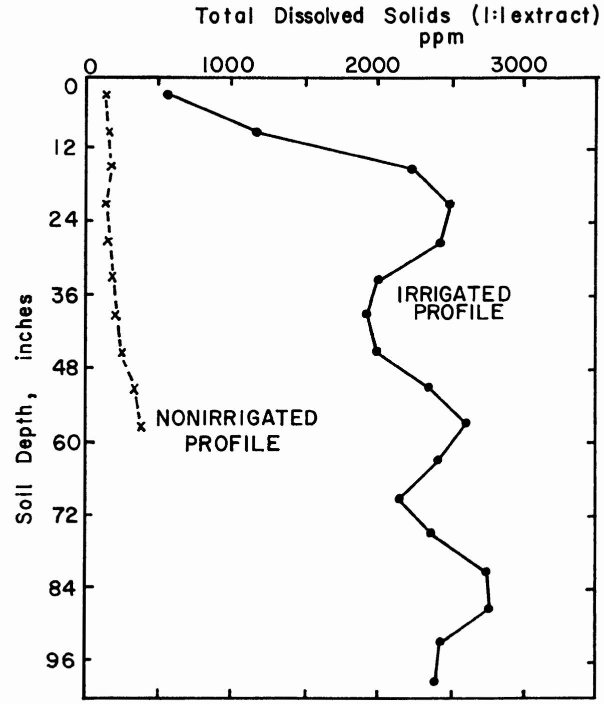


Figure 2. **Soluble salt content of 1:1 extracts of soil samples from irrigated and nonirrigated profiles.**

The salts from the irrigation water accumulate in the soil owing to plant extraction and evaporation; and, as the soil solution becomes more concentrated, certain salts precipitate from solution. Because of low solubility, the first to precipitate is calcium carbonate. If an excess of bicarbonate remains, magnesium carbonate will also be precipitated. Finally, if excess calcium remains, it will be precipitated as calcium sulfate. The data of Table 4 show that the water has a high sulfate content and a mean total cation content of 21 milliequivalents per liter. According to Doneen's (6) concept of "effective salinity," the salinity of the water will be reduced by the precipitation of calcium as carbonate and sulfate to an effective salinity level of 12.7 me/l. This effective salinity level is still high and considered critical under restricted leaching and slow drainage conditions. Other salts occurring in the irrigation water are soluble and may or may not accumulate in the soil profile.

When the soluble salts from the 1:1 soil water extracts were analysed, zones of high sulfate point out the depths of gypsum accumulation (Fig-

Table 4. Mean Chemical Composition of the Irrigation Water Supply During 1966 Season

Date	Total Dissolved Solids	Cations, me/1					Anions, me/1			Effective Salinity[1]
1966	ppm	Ca	Mg	Na	K	Total	HCO_3	SO_4	Cl	me/1
June 28	1405	8.4	4.5	7.6	0.2	20.7	2.6	11.3	6.5	12.3
July 18	1384	8.3	4.4	7.6	0.2	20.5	2.2	12.5	6.7	12.2
Aug. 18	1448	8.2	4.8	8.5	0.2	21.7	2.0	12.3	7.5	13.5
Average	1412	8.3	4.6	7.9	0.2	21.0	2.3	12.0	6.9	12.7

[1]As proposed by Doneen (6).

ure 3). A high sulfate content at the 18 to 30 inch depth is shown in Figure 3. The total salt content shown in Figure 2 follows a similar pattern to that of the sulfate and calcium plus magnesium curves of Figure 3 for the irrigated soil. The only measurable amount of sulfate found in the nonirrigated soil occurred below 32 inches (C horizon) where cal-

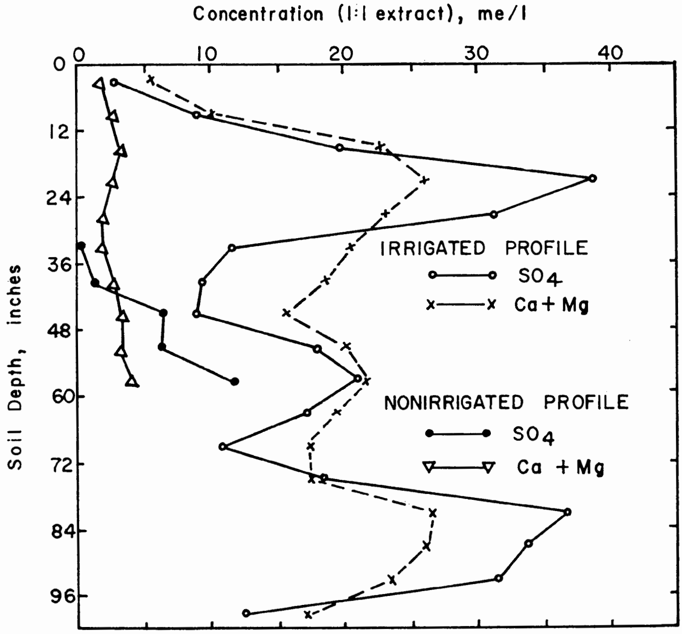


Figure 3. **Sulfate and calcium plus magnesium content of the 1:1 extract from soil samples of irrigated and nonirrigated profiles.**

cium carbonate and gypsum occur naturally in this soil. The high sulfate concentrations in the lower part of the irrigated profile may result from fluctuations of the groundwater and naturally occurring gypsum.

The highly soluble salts found in the soil profiles are represented by the sodium and chloride curves in Figure 4. Accumulations similar to that of sulfate were not found in the upper part of the profile. Instead, a gradual increase was noted to the 42 inch depth. This was true of both the irrigated and nonirrigated profiles, the only difference being one of magnitude. The higher salt content in the irrigated profile resulted from salts brought in by the irrigation water. These results show that during unsaturated flow or water redistribution following an irrigation or rainfall, there is a downward displacement of salts into the lower depths. Again, the role of leaching by irrigation and rainfall is stressed as an important factor in this salt movement and present salt status.

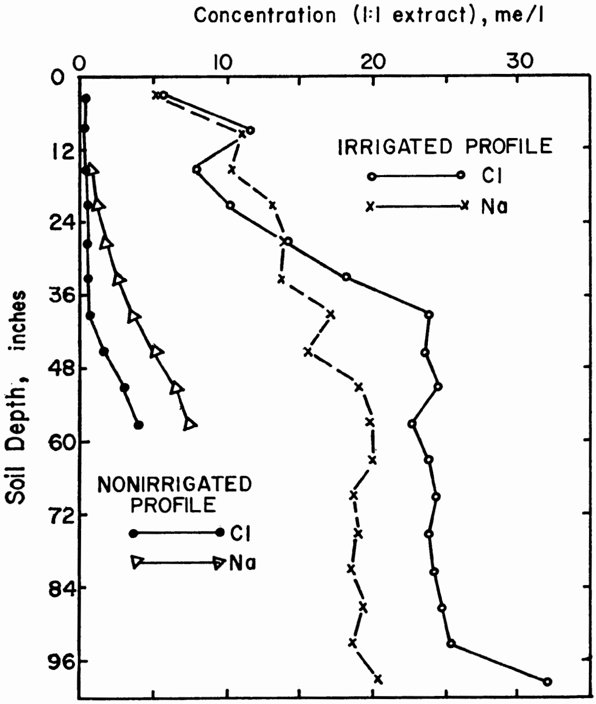


Figure 4. Sodium and chloride content of the 1:1 extract from soil samples of irrigated and nonirrigated profiles.

Nitrate concentrations in the 1:1 extracts of the irrigated soil profile samples were also determined. Concentrations found below the plow layer were less than 0.2 me/l, and the mean value for the entire profile was 0.16 me/l. In addition, several groundwater samples were collected from the irrigated area and analyzed for nitrate content. Wide variations in the nitrate content were observed among the samples with a low of 0.5 and a high of 15 me/l being measured. Due to the high solubility of nitrate salts, they would be expected to move with the soil solution and be displaced along with other soluble salts. Once below the plant root zone, unsaturated downward movement of the soil solution would carry them to the saturated groundwater zone.

Percolating Soil Water

The total dissolved solids (TDS) content of the percolating soil water is shown in Figure 5 for the three sampling periods (see Appendix,

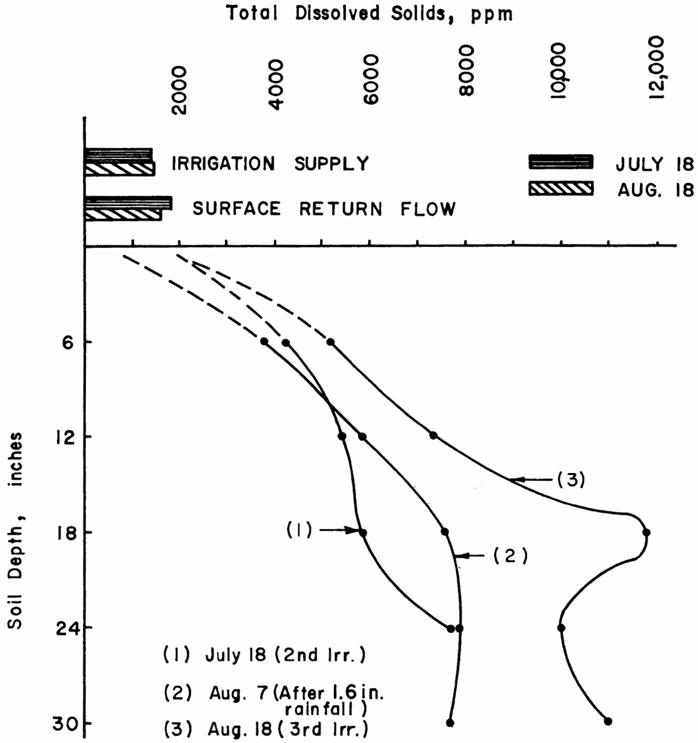


Figure 5. **Salt content of the percolating soil water at three sampling periods during 1966. Mean values for irrigation water and surface return flow are shown for comparison.**

Table III). The data clearly show the greater TDS content in the soil profile as the season progresses, reaching its highest value at the 18 inch depth after the third irrigation. By way of comparison, the mean TDS values for the irrigation supply and surface return flow are shown at the top of Figure 5. The rainfall of August 7 succeeded in diluting the soil solution in the plow layer and moving the dissolved salts to a lower depth. The change in sodium adsorption ratio (SAR) with soil depth is shown in Figure 6. These data were almost identical for each sampling period; thus, only one curve is shown.

A cotton crop never utilizes all of the applied nitrogen fertilizer during the growing season. If the residual nitrogen occurs as nitrate, it is susceptible to denitrification and/or leaching below the root zone. Because nitrate ions are negatively charged, they move more freely in

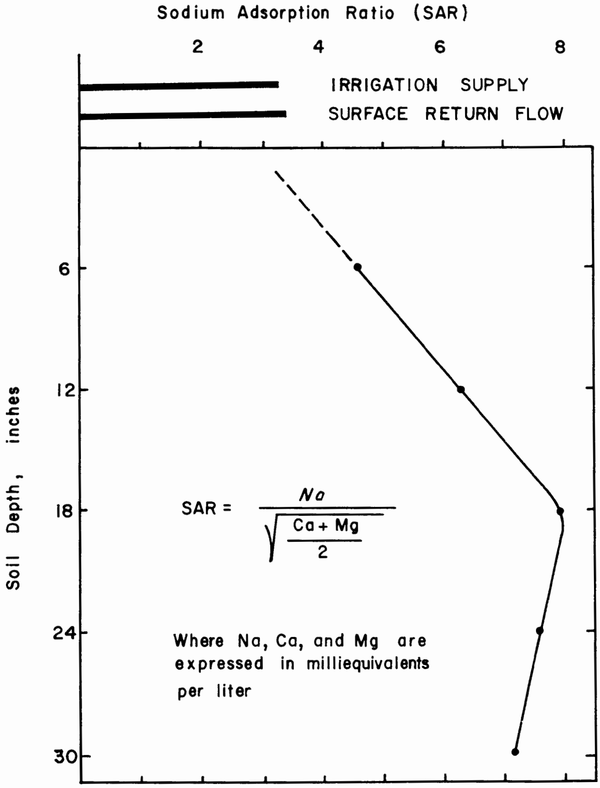
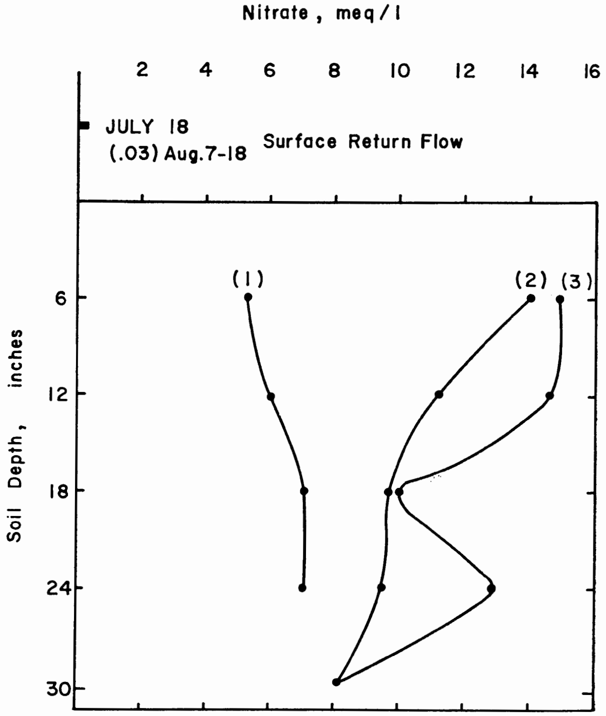


Figure 6. **Change in SAR value of percolating soil water with depth as compared with the irrigation water and surface return flow.**

the soil (23). Ammonium, the cationic form of nitrogen, may be absorbed by the soil and is much less susceptible to movement. Under aerobic conditions, the ammonia-N is subject to the nitrifying action by soil microorganisms.

A conflict of interests arises in irrigation agriculture when excess water is necessary to satisfy the leaching requirement for salinity control. This practice results in nitrate movement downward with the leachate and their subsequent loss from the root zone. Soil water samples were analyzed for nitrate content, and the data for the three sampling periods are summarized in Figure 7. Note that the nitrate concentration in the soil solution continued to increase in the top 12 inch as the season progressed. Similar increases were also noted at the 24 inch depth. Nitrate



(1) July 18 (2nd Irr.)

(2) Aug. 7 (After 1.6 in. rainfall)

(3) Aug. 18 (3rd Irr.)

Figure 7. **Nitrate content of the percolating soil water at three sampling periods, 1966.**

that moved beyond the 24 inch depth was probably lost from the root zone.

Boswell and Anderson (3) found that mineral nitrogen compounds in fallowed soil profiles move with the soil solution. Upward movement during dry periods of moisture stress, and downward movement following various rainfalls were observed. Wagner (23) found high concentrations of nitrate at the 36 and 48 inch depths in fields of sudan grass during a two-year period, but it decreased rapidly with time. Also, he noted that high (200-400 lb of N/Acre) nitrogen fertilization leads to significant loss by leaching.

Nutrients in Irrigation Return Flow

The water samples (surface and subsurface) collected in this study were analyzed for nitrogen and phosphorus compounds. The surface water samples, where sample volume was sufficient, were analyzed for nitrogen in the form of nitrate, ammonia, and organic nitrogen. Total phosphate and orthophosphate were determined on these samples, also. The soil water samples were limited in quantity, and only nitrate nitrogen and total phosphate were determined. The results of those analyses are shown in Table 5 as mean values for each sampling period. The data show that large amounts of nitrate are present in the soil and capable of moving downward with the percolating soil water while the surface return flows carried smaller amounts. By contrast, the data indicate relatively little movement of phosphates with the soil water and surface return flows.

The data from this study permit the calculation of quantitative losses of nitrogen and phosphorus in the surface return flows as a result of both concentration and quantity (except for the rainfall of August 7) of water being measured at each irrigation. The losses to deep percolation can only be estimated, however. In order to make such an estimate, a few general assumptions are necessary. The fate of the applied irrigation water may be threefold: evaporation, surface runoff, and infiltration. Water which infiltrates the soil surface may be further subdivided into that which is transpired by the plant or evaporated from the soil surface, that which drains below the plant root zone, and that which is retained in "storage" in the soil profile. The latter quantity is dynamic, fluctuating greatly between irrigations, but is never completely depleted before another application is made.

Eldridge (9, 10) considered the quantity of deep drainage and found that actual values varied from 20 to 60 percent of the applied irrigation water, depending on such local conditions as soil profile characteristics, crops grown, climatic variables, and management practices. His studies revealed that an acceptable average value for the western

Table 5. Mean nitrogen and phosphorus content of the soil water according to sampling depth as compared to mean values for irrigation water supply and surface return flow.

Sampling Period	Sampling Site	NO_3	NH_3	Organic N	Total Phosphate	Ortho-Phosphate
		mg/l N			mg/l PO_4	
First Irrigation	Supply	0.1	0.1	1.2	0.1	0.1
	Surface	0.4	1.3	3.4	0.34	0.24
Second Irrigation	Supply	0	0.1	1.1	0.1	0.1
	Surface runoff	5.1	0.9	2.6	1.2	1.2
	Soil water					
	6″	74.0			0.6	
	12″	85.0			0.1	
	18″	100.0			0.1	
	24″	100.0			0.1	
Following 1.63-inch rainfall on Aug. 7	Surface runoff	0.45	0.8	3.2	0.6	
	Soil water					
	6″	198.0			0.4	
	12″	158.0			0.1	
	18″	137.0			0.4	
	24″	133.0			0.2	
	30″	112.0			0.1	
Third Irrigation	Supply	0.3	0.2	1.0	0.2	0.1
	Surface runoff	0.4	0.1	2.6	1.1	0.4
	Soil water					
	6″	208.0			[1]	
	12″	205.0			[1]	
	18″	140.0			[1]	
	24″	180.0			[1]	
	30″	113.0			0.7	

[1]/Reliable analyses were not possible due to insufficient sample size.

states was approximately one-third of the quantity applied. Owing to the difference in soil water flow characteristics between several Western and Oklahoma soils (5, 17) we will consider that one-fifth of the infiltrating water was lost to deep percolation below the 30-inch soil depth.

Further assumptions are necessary in order to account for the fate of the 1.60-inch rainfall in a two-hour period on August 7. The drainage ditches overflowed, and no measure of runoff was possible. Based strictly upon visual observation of the large runoff from this rainfall, it was estimated that at least half of the total was lost, and approximately half entered and was retained by the recently cultivated surface.

Based on these assumptions and the measured concentrations of nitrogen and phosphorus compounds at the 30-inch soil depth, and surface water, the total losses of these nutrients from the 7.08-acre field were estimated as shown in Table 6. The total fertilizer applications to the 7.08-acre area are shown at the bottom of Table 6. If the assumptions

Table 6. Estimated Nutrient Losses for Each Sampling Period on the 7.08-Acre Field

	1st	2nd	Rainfall (Aug. 7)	3rd	Totals
Surface Runoff (acre-inches)	2.1	1.3	5.6	1.5	10.5
Infiltration (acre-inches)	26	21.7	5.6	12	66.3
Percolation Below Root Zone (acre-inches)	8.7	7.2	1.7	4	22.0
Total Nitrogen Lost in Surface Runoff, (lbs. N)	1.8	2.2	5.6	0.5	10.1
Total Nitrogen Leached Below Root Zone, (lbs. N)		98	28	61	187 (Incomplete)
Total Phosphorus Lost in Surface Runoff, (lbs. PO_4)	0.23	0.7	0.8	0.4	2.1
Total Phosphorus Leached Below Root Zone, (lbs. PO_4)		0.1	0.03	0.4	0.53 (Incomplete)

Total Nitrogen added to field = 453 lbs. N
Total phosphorus added to field = 127 lbs. P_2O_5 or 85 lbs. PO_4

and estimates can be considered valid, then approximately 43.5 percent of the applied nitrogen was lost to surface runoff and percolating soil water between July 18 and August 18, while only about 3.1 percent of the applied phosphorus was lost during the same period. By comparison, Johnston *et al.* (14) found losses of 70 percent of applied nitrogen and 3 percent of applied phosphorus from a tile-drained cotton field with other fields showing lesser losses. This loss will decline sharply without additional fertilizer applications.

Data such as these permit the general conclusion that large percentages of applied nitrogen fertilizers may be lost to surface and percolating return flows while insignificant losses of applied phosphorus occur. In irrigated areas where heavy applications of commercial fertilizers are common, it is apparent that nutrients added to surface and groundwaters can be detrimental to water quality requirements for other beneficial uses.

Summary and Conclusions

Although this study was preliminary in nature and incomplete in many details, the data do permit several general conclusions. With respect to the objectives set forth for the study, the data clearly show the degradation of water quality in irrigation return flows as compared with that of the irrigation water applied. For example, the data indicate that the overall mean total dissolved solids content increased about 20 percent in the surface return flow, while the percolating soil water showed a five- to eightfold increase over the salinity of the applied water.

After 15 years of irrigation with a high-salt water, the clay loam soil showed an increase in soluble salt content throughout the profile. This, no doubt, represents an approximate equilibrium condition which may fluctuate during the irrigation season. Leaching by rain during the off-season contributes to the maintenance of a favorable salt balance from year to year. This becomes significant when the total quantity of salt brought in by the irrigation water is considered. At an average total dissolved solids content of 1,428 ppm, the irrigation water carries about two tons of salt per acre-foot. For an equilibrium salt condition to exist in the soil, this quantity of salt must also be carried away in the drainage water. Percolating water at five times this concentration, therefore, transports about 10 tons of salt per acre-foot. From the above considerations, it is apparent that the drainage waters from the irrigated area suffer a degradation of quality that would adversely affect both surface and groundwater resources in the area.

It is recognized that this study has not begun to answer the questions that arise concerning the dynamics of salt movement in a soil profile; however, it illustrates that with prolonged high salt water usage under varying conditions of rainfall, evaporation, irrigation management, and quality of irrigation water, a satisfactory balance can be reached. More detailed field studies of this type are needed with consideration given to composition and movement of the soil water solutes as they pass through the unsaturated soil. Future studies should consider seasonal fluctuations and the direction and movement of soil water and solutes as well as the quality and quantity of drainage water leaving the area.

Additional questions arise concerning the movement, degradation, and fate of the many agricultural biocides employed in modern day practices. Studies are urgently needed under field conditions in order to assess the potential problems associated with surafce and groundwater pollutions. No attempt was made in this study to detect the occurrence of the various insecticides in the water or soil samples.

References Cited

1. APHA, AWWA, and WPCF. Standard Methods for the Examination of Water and Wastewaters, (12th Edition). American Public Health Association, Inc., 1790 Broadway, New York, New York 10019. 1965.
2. Black, C. A. *et al* (ed.) Methods of Soil Analysis. American Society of Agronomy, Monograph No. 9, Madison, Wisconsin. 1965.

3. Boswell, F. C. and O. E. Anderson. Nitrogen Movement in Undisturbed Profiles of Fallowed Soils. Agron. Jour. 56:278-281. 1964.

4. Cunningham, Morris B., Paul D. Haney, Thomas W. Bendixen, and C. S. Howard. Effect of Irrigation Runoff on Surface Water Supplies. (Panel Discussion). Jour. AWWA, Vol. 45, No. 11, p. 1159-1178 (November 1953).

5. Davidson, J. M., L. R. Stone, D. R. Nielsen, and M. E. LaRue. Field Measurement and Use of Soil-Water Properties. Water Resc. Res. 5:1312-1321. 1969.

6. Doneen, L. D. Salination of Soils by Salts in the Irrigation Water. Trans. Amer. Geophysical Union 35:943-950. 1954.

7. Eaton, F. M. Significance of Carbonates in Irrigation Waters. Soil Sci. 69:123-133. 1950.

8. Eldridge, Edward F. The Effect of Irrigation on the Quality of Water for Industrial Use. Proc. 14th Ind. Waste Conf., Purdue Univ., 104:52-67. 1959.

9. Eldridge, Edward F. Return Irrigation Water — Characteristics and Effects. U.S. Public Health Service, Region IX, Portland, Oregon. (May 1960).

10. Eldridge, Edward F. Irrigation as a source of Water Pollution. Jour. WPCF, Vol. 35, No. 5, p. 614-625 (May 1963).

11. Finger, James H. Nitrate Determination in Saline and Estuarine Waters: Comparison of Hydrazine Reduction and Brucine Modification Methods. Laboratory Investigations No. 3, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, October 1964.

12. Flaigg, Norman G. The Effect of Irrigation Return Flow on Water Supplies. Southwest Water Works Jour., Vol. 34, No. 12, p. 9-16 (March 1953).

13. Gales, Morris E., Jr. Procedure for the Determination of Total Phosphate in Water (Organic and Inorganic). Memorandum to Project Director, Raritan Bay Project, Metuchen, New Jersey, from Morris E. Gales, Jr., Robert A. Taft Sanitary Engineering Center, Cincinnati, dated May 14, 1965.

14. Johnston, W. R., F. Ittihadieh, R. M. Daum, and A. F. Pillsbury. Nitrogen and Phosphorus in Tile Drainage Effluent. Soil Sci. Soc. Amer. Proc. 29:287-289. 1965.

15. MacKichan, Kenneth A. Estimated Use of Water in the United States, 1955. Jour. AWWA, Vol. 49, No. 4, p. 369-391 (April 1957).

16. MacKichan, Kenneth A. Water Use in the United States, 1960. Jour. AWWA, Vol. 53, No. 10, p. 1211-1216 (October 1961).

17. Nielsen, D. R., J. M. Davidson, J. W. Biggar, and R. J. Miller. Water Movement through Panoche Clay Loam Soil. Hilgardia 35: 491-505. 1964.

18. Scofield, C. S. The Effect of Absorption by Plants on the Concentration of the Soil Solution. Jour. Agr. Res. 35:745-756. 1927.

19. Scofield, C. S. Stream Pollution by Irrigation Residues. Jour. Ind. Engr. Chemistry. 24:1223 (November 1932).

20. Sylvester, R. O. and R. W. Seabloom. Quality and Significance of Irrigation Return Flow. Jour. Irr. and Drain. Div., Proc. ASCE. 89:IR3:1-27. 1963.

21. U. S. Department of Agriculture. Soil Survey of Jackson County, Oklahoma. Series 1958, No. 4. (June 1961).

22. U. S. Salinity Laboratory Staff. Diagnosis and Improvement of Saline and Alkali Soils. U. S. Department of Agriculture Handbook 60. 1954.

23. Wagner, George H. Changes in Nitrate-N in Field Plot Profiles as Measured by the Porous Cup Technique. Soil Sci. 100:397-402. 1965.

24. Webb, Hubert J. Water Pollution Resulting from Agricultural Activities. Jour. AWWA, Vol. 54, No. 1, p. 83-87 (January 1962).

25. Wilcox, L. V. Water Quality from the Standpoint of Irrigation. Jour. AWWA 54:217-222. 1958.

26. Wilcox, L. V. Salinity Caused by Irrigation. Jour. AWWA 54:217-222. 1962.

27. Wilcox, L. V. and W. F. Resch. Salt Balance and Leaching Requirement in Irrigated Lands. U. S. Department of Agriculture Tech. Bull. No. 1290. 23 pages. 1963.

Appendix Table I — Chemical Composition of the Irrigation Water Supply

Sampling Site[1]	Date Sampled	Time of day	ECx10^6 at 25°C μmhos/cm	TDS ppm	Milliequivalents per liter										Boron ppm	SSP %	SAR
					Ca	Mg	Na	K	Sum of cations	CO_3	HCO_3	SO_4	Cl	Sum of anions			
1	6/28/66	9:45 am	1790	1408	8.60	4.42	7.48	0.15	20.65	0	2.72	10.93	6.43	20.08	0.33	36.2	2.9
2		7:30 am	1820	1395	8.60	4.40	7.70	0.23	20.93	0	2.64	11.97	6.57	21.18	0.41	36.8	3.0
2		7:00 pm	1855	1429	8.50	4.60	7.83	0.15	21.08	0	2.56	11.41	6.54	20.51	0.42	37.1	3.0
3		7:30 am	1940	1388	8.40	4.46	7.48	0.15	20.49	0	2.56	11.18	6.51	20.25	0.35	36.5	2.9
3		11:00 am	1935	1454	8.30	4.60	7.83	0.13	20.86	0	2.56	10.93	6.49	19.98	0.38	37.5	3.1
3		3:00 pm	1850	1399	8.30	4.64	7.61	0.15	20.70	0	2.48	10.93	6.46	19.87	0.41	36.8	3.0
3		7:00 pm	1870	1400	8.30	4.60	7.83	0.15	20.88	0	2.64	10.93	6.54	20.11	0.43	37.5	3.1
3		11:00 pm	1970	1417	8.40	4.54	7.17	0.15	20.26	0	2.72	12.22	6.57	21.51	0.42	35.4	2.8
		Means	1879	1411	8.43	4.53	7.62	0.16	20.74	0	2.61	11.31	6.51	20.43	0.39	36.7	3.0
1	7/18/66	8:45 am	1850	1406	8.62	4.32	7.39	0.20	20.53	0.12	2.44	12.67	6.54	21.77	0.50	36.0	2.9
2		6:30 am	1805	1406	8.14	4.62	7.61	0.15	20.52	0.12	2.20	12.67	6.94	21.93	0.38	37.1	3.0
2		2:30 pm	1960	1388	8.34	4.38	7.70	0.15	20.57	0.16	2.16	12.67	6.63	21.62	0.44	37.4	3.0
3		6:30 am	1880	1377	8.28	4.36	7.48	0.15	20.27	0.12	2.20	12.23	6.63	21.18	0.36	36.9	3.0
3		10:30 am	1910	1379	8.56	4.32	7.48	0.15	20.51	0.16	2.20	12.67	6.71	21.74	0.35	36.5	2.9
3		2:30 pm	1910	1395	8.18	4.62	7.70	0.15	20.65	0.16	2.16	12.23	6.77	21.32	0.35	37.3	3.0
		Means	1886	1392	8.35	4.44	7.56	0.16	20.51	0.14	2.23	12.52	6.70	21.59	0.40	36.9	3.0
1	8/17/66	5:45 pm	2120	1520	8.10	5.00	8.26	0.15	21.51	0	2.08	12.22	7.56	21.88	0.41	38.4	3.2
2	8/18/66	12:45 am	2170	1520	8.20	4.80	8.48	0.15	21.63	0.08	2.04	13.26	7.50	22.91	0.45	39.2	3.3
2		7:30 am	2120	1416	8.20	4.80	8.48	0.15	21.63	0	2.00	12.74	7.42	22.19	0.30	39.2	3.3
3		12:45 am	2150	1538	8.20	4.80	8.48	0.15	21.63	0.08	2.00	11.70	7.50	21.30	0.39	39.2	3.3
3		4:00 am	2120	1430	8.30	4.90	8.48	0.15	21.83	0.08	1.84	12.49	7.44	21.87	0.38	38.9	3.3
3		7:30 am	2120	1498	8.20	4.80	8.70	0.15	21.85	0	1.92	11.70	7.44	21.08	0.38	39.8	3.4
		Means	2133	1487	8.20	4.85	8.48	0.15	21.68	0.04	2.00	12.35	7.48	21.87	0.39	39.1	3.3
		Overall Mean		1428													

[1] See Table 2 for description of sampling sites.

Appendix Table II — Chemical Composition of the Surface Return Flow (Runoff) Water[1]

Sampling Period	Date Sampled	Time of day	ECx10^6 at 25°C μmhos/cm	TDS ppm	Milliequivalents per liter										Boron ppm	SSP %	SAR
					Ca	Mg	Na	K	Sum of cations	CO_3	HCO_3	SO_4	Cl	Sum of anions			
First Irrigation	6/28/66	5:15 pm	2025	1540	9.20	4.42	8.13	0.28	22.03	0	2.64	11.97	7.08	21.69	0.43	36.9	3.1
		6:15 pm	2100	1516	9.10	4.44	8.35	0.26	22.15	0	2.48	10.93	6.82	20.23	0.42	37.7	3.2
		7:15 pm	2140	1524	9.30	4.30	8.04	0.23	21.92	0	2.32	11.97	6.99	21.28	0.43	36.7	3.1
		8:15 pm	2140	1535	9.50	4.30	8.13	0.28	22.21	0	2.32	12.74	7.08	22.14	0.42	36.6	3.1
		9:15 pm	2150	1540	9.50	4.26	8.13	0.26	22.15	0	2.40	13.01	6.91	22.32	0.38	36.7	3.1
		10:15 pm	2260	1544	9.40	4.60	7.83	0.33	22.16	0	2.40	13.26	6.97	22.63	0.43	35.3	3.0
		11:15 pm	2260	1534	9.50	4.24	8.04	0.26	22.04	0	2.40	14.05	6.99	23.44	0.39	36.5	3.1
		Means	2154	1533	9.36	4.37	8.09	0.23	22.10	0	2.42	12.56	6.98	21.96	0.41	36.6	3.1
Second Irrigation	7/18/66	6:30 am	2245	1683	10.06	6.04	9.13	0.33	25.56	0	2.00	15.35	7.98	25.67	0.40	35.7	3.2
		7:30 am	2350	1892	11.80	5.30	10.09	0.31	27.50	0	2.12	17.18	8.54	28.22	0.34	36.7	3.5
		8:30 am	2260	1878	11.70	5.30	9.78	0.33	27.11	0	2.40	16.91	8.54	28.22	0.34	36.1	3.4
		9:30 am	2320	1917	12.34	5.30	10.30	0.38	28.32	0	2.12	16.39	8.80	27.65	0.39	36.4	3.5
		10:30 am	2460	2097	12.94	5.14	10.22	0.41	28.71	0	2.04	17.18	8.97	28.51	0.38	35.6	3.4
		11:30 am	2560	1986	13.12	4.92	10.43	0.41	28.88	0	2.04	17.18	8.83	28.37	0.39	36.1	3.5
		12:30 pm	2420	1935	12.28	5.08	10.09	0.38	27.83	0	2.04	17.18	8.52	28.10	0.43	36.3	3.4
		1:30 pm	2390	1789	13.72	3.50	10.09	0.38	27.69	0	2.08	16.91	8.57	27.94	0.36	36.4	3.4
		2:30 pm	2435	1868	13.04	3.60	9.87	0.36	26.87	0	2.04	17.18	8.46	28.11	0.43	36.7	3.4
		3:30 pm	2380	1902	12.92	3.08	9.57	0.33	25.90	0	2.12	15.98	8.09	26.62	0.49	36.9	3.4
		Means	2382	1895	12.39	4.73	9.96	0.36	27.44	0	2.10	16.74	8.53	27.37	0.40	36.3	3.4
Surface runoff from 1.63-inch Rainfall	8/7/66	1.30 am	1520	1141	7.00	3.90	6.52	0.20	17.62	0	1.60	8.33	5.81	15.74	0	37.0	2.8
Third Irrigation	8/18/66	3:00 am	2260	1526	9.80	3.80	8.91	0.26	22.77	0	1.92	12.74	7.84	22.52	0.36	39.1	3.4
		4:00 am	2210	1600	8.60	4.60	8.48	0.26	21.94	0	1.92	12.22	7.47	1.64	0.40	38.7	3.3
		5:00 am	2190	1587	9.00	4.20	8.48	0.23	21.91	0	2.08	11.97	7.64	21.72	0.37	38.7	3.3
		6:00 am	2210	1515	8.50	5.10	8.70	0.23	21.53	0	2.08	11.70	7.61	21.41	0.37	40.4	3.5
		7:30 am	2190	1575	8.40	4.60	8.70	0.23	21.93	0	1.92	11.45	7.53	20.92	0.32	39.7	3.4
		Means	2212	1560	8.86	4.46	8.65	0.24	22.21	0	1.98	12.02	7.62	21.62	0.36	39.3	3.4
Overall Mean (8/7 not included)				1704													

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[1] Samples were collected at the flume on the drainage end of the field.

Appendix Table III — Mean chemical composition of the soil water according to sampling depth as compared to mean values for irrigation water supply and surface return flow

Sampling Period	Sampling Site	pH	ECx10^6 at 25°C mhos/cm	Ca	Mg	Na	K	me/1 Sum of cations	SO_4	Cl	NO_3	Sum of anions	Boron ppm	SAR
Second Irrigation	Supply	8.1	1,886	8.35	4.44	7.56	0.16	20.51	12.52	6.70	0	21.59	0.40	3.0
	Surface Ret. flow	7.8	2,382	12.39	4.73	9.96	0.36	27.44	16.74	8.53	0.37	27.37	0.40	3.4
	6"	8.0	5,833	30.50	16.90	24.34	0.92	72.67	87.55	23.11	5.29	115.95	0.80	4.9
	12"	8.4	7,733	31.00	27.20	33.91	0.92	93.03	106.71	41.78	6.05	154.54	0.76	6.5
	18"	8.4	8,225	34.50	21.70	41.74	0.91	98.85	98.84	53.80	7.14	159.78	0.90	7.7
	24"	8.2	10,850	41.50	39.90	46.52	0.83	128.75	101.51	84.69	7.14	193.34	0.73	7.3
Following 1.63-inch rainfall on Aug. 7	Surface Runoff	7.8	1,520	7.00	3.90	6.52	0.20	17.62	8.33	5.81	0.03	14.17	0	2.8
	6"	8.1	5,290	31.30	29.00	20.14	0.62	81.06	36.16	24.48	14.17	74.81	0.84	3.7
	12"	8.2	8,390	41.50	30.00	38.47	0.41	110.38	44.87	52.34	11.25	108.46	0.71	6.4
	18"	8.1	10,867	49.70	46.00	48.26	0.60	144.56	52.05	84.41	9.76	146.22	0.74	7.0
	24"	8.1	11,377	50.30	49.40	50.15	0.67	150.52	49.00	93.06	9.52	151.58	0.75	7.1
	30"	8.1	11,057	46.70	50.00	47.10	1.19	144.99	46.43	95.22	7.97	149.62	0.87	6.8
Third Irrigation	Supply	8.3	2,133	8.20	4.85	8.48	0.15	21.68	12.35	7.48	0.02	19.85	0.39	3.3
	Surface Ret. flow	8.6	2,212	8.86	4.46	8.65	0.24	22.21	12.02	7.62	0.03	19.67	0.36	3.4
	6"	8.0	7,323	31.67	43.66	27.25	0.95	103.52	38.59	34.83	14.88	88.30	0.72	4.6
	12"	7.8	10,650	52.67	31.83	40.87	1.03	126.40	54.66	64.06	14.64	133.36	0.58	6.3
	18"	7.8	17,200	73.00	61.00	65.22	0.79	200.01	46.85	151.58	10.00	208.43	0.85	7.9
	24"	7.6	14,750	58.00	52.00	56.52	1.01	167.53	52.68	114.92	12.85	180.45	0.52	7.6
	30"	7.5	16,033	55.00	66.00	55.36	1.12	177.48	52.05	126.80	8.09	186.94	0.73	7.2