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The Influence of Trickle Irrigation on the Quality of Irrigation Return Flow

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THE INFLUENCE OF TRICKLE IRRIGATION ON THE QUALITY OF IRRIGATION RETURN FLOW

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SUMMARY

The influence of trickle irrigation on the quality of irrigation return flow was investigated in a field study and by means of computer simulation models. Six undisturbed buried monolith lysimeters were utilized to quantify the leachate from treatment including two different qualities of irrigation water applied through a trickle irrigation system. Both moisture and salt balances were followed inside and outside the lysimeters during a growing season the remainder of the calendar year. A sorghum crop was grown on the lysimeters and in the adjacent area. Irrigation was scheduled based on pan evaporation losses. The irrigation water of high salt content was obtained from a deep well while the irrigation water of low salt content was drawn from the district irrigation canal. The water balance monitored by the neutron probe showed that differences between inside and outside lysimeters were small. The soil contained significant amounts of salt at the begining of the experiment and trends in the leachate concentration resulting from irrigation treatment are difficult to see after one year of monitoring. Differences between paired lysimeters are large indicating large variability in soil characteristics across the field.

Differences in water use inside and outside the lysimeters indicated that during the 1974 growing season, which was dryer than normal, the sorghum crop may have extracted approximately 8% of the water required from the water table.

Yield and growth data indicated that the plant root environment inside and outside lysimeters were relatively comparable. Nitrogen, saline water and irrigation treatments did not significantly influence growth and yields of sorghum in 1974.

During the test period, NO_3-N loss in effluents ranged from a low of 14 kg/ha from a lysimeter treated with 112kg/ha to a high of about 75 kg/ha from a lysimeter treated with 224 kg/ha of N. Nitrate losses were negligible compared to checks when N application rates to sorghum were 112 kg/ha. Most of the NO_3-N losses occurred during non-cropped periods when lysimeter drainage volumes were at a maximum. Total salt in drainage waters ranged from about 2600 to 4200 kg/ha during the test period. Inherent soil variability was an important factor in salt and nitrate loss in drainage waters from the lysimeters.

Preface

This is the final report of an investigation conducted by members of the staff of the Soil and Crop Sciences Department at Texas A&M University, the Texas Agricultural Experiment Station at Weslaco and the Industrial Engineering Department of Texas A&M University, and supported by funding from the Texas Water Resources Institute and the Texas Agricultural Experiment Station.

In order to achieve an understanding of the influence of trickle irrigation on the quality of irrigation return flow, research was conducted in the field.

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CHAPTER I

Introduction and Objectives

To sustain or increase our food production in the future, with our limited water supply, new methods of increasing the efficiency of water use in crop production as well as methods of utilizing lower quality water for irrigation must be found. Many areas of the world which have long growing seasons and good soils have only limited supplies of fresh water for irrigation. Such areas, however, often have large reserves of water which are normally considered too salty for crop production. Since lower quantities of water may be needed to produce crops when trickle irrigation is used, less salt will be added to the soil each season. Provided the salt does not build up in the root zone during the growing season and provided that rainfall during the year is sufficient to leach the salts from the soil so that the long term balance will result in no increase in salt content, it should be possible to utilize more saline water in a trickle system than could be used by conventional irrigation methods. Trickle irrigation may also offer an advantage over sprinkle irrigation with saline water in that the water does not come in contact with the foliage when applied through a trickle system. With furrow irrigation, however, this difference does not exist.

Other advantages have been suggested for trickle irrigation over conventional methods. A review by Cole (1971) suggests that trickle irrigation may result in water savings, savings in labor, may produce beneficial crop responses, savings of fertilizer, better water control, better weed and insect control and more uniform application.

Many of the tests conducted thus far have been on sandy soils which have high percolation rates and may not suffer the consequences of soil dispersion resulting from salt accumulation. Golstein and Shumeli (1969) found that under trickle irrigation, salts accumulated near the surface and at the edges of the wetted zone. Cho and Yamamoto (1973) reported on a greenhouse study using trickle irrigation in a sand culture. They found greater yields with saline water applied through trickle systems, when compared to sprinkle irrigation for both cotton and tomatoes. They also reported accumulation of salts at the fringes of the wetted zone. Tscheschke et al. (1974) using a loamy sand also found that salts accumulated near the edge of the wetting front. They tested different irrigation levels with saline water and found that in order to avoid yield loss when trickle irrigating with saline water it was necessary to supply amounts equivalent to or greater than the evapotranspiration rates.

Seifert et al. (1975) reported on a study using a silt loam soil. They found that yields of grain sorghum were reduced at high salt concentrations even with trickle systems. The yield of the trickle irrigated plots however, were greater than those from the surface irrigated plots.

No studies have been conducted on the influence of trickle irrigation on the quantity and quality of irrigation return flow as compared to conventional irrigation methods. Surface runoff from a trickle irrigation system should not occur, thus trickle eliminates the return stream from irrigated fields. The influence of trickle on deep leaching concentrations is however, less clear. On one hand, if less water is required, certainly less salts will be applied per acre; if, however, as suggested by some researchers, sufficient water must be applied to equal or exceed evapotranspiration in order to not suffer a yield decrease then more salts will be put on per acre. Assuming all the salts must eventually be leached out, the concentrations in the leachate will depend on the amount deposited in the soil as a result of irrigation and the water balance both during and after the growing season.

Because of the complexities of the soil system and the influences of the climatic condition and those of the developing root system on the movement of water and salts in the natural system, experimental results are often difficult to interpret. Several efforts have been made to simulate flow from trickle irrigation systems with computer models in order to gain a better understanding of the problems.

A trickle system may either be considered a line source of water, or may be considered a group of point sources of water, depending on the system used or the detail with which one needs to look at it. Philip (1971) has developed specialized solutions to both the two and three dimensional cases of flow in porous medium. Their utilization for modeling irrigation with complications including surface evaporation and root water uptake distributed over depth has not been demonstrated. Another specialized solution for line sources of water has been presented by Raats (1970). Digital computer solutions for some two dimensional transient flow problems have been developed by Rubin (1968). Brandt et al. (1971) compared two numerical models for infiltration from a line source.

Van Bavel et al (1975) presented a simulation model which incorporates root with uptake, but presented solutions only for a buried line source and were not able to handle a soil profile consisting of two or more soil layers.

The task thus remains to develop a model that will allow consideration of sources at the surface, and buried at various depths, a series of soil horizons with different properties, and root water uptake variable in both time and depth. In addition, many agricultural fields are now bedded, and the consequence of this practice and the influence of relative positions of the emitters with respect to the beds also needs to be investigated.

This project was thus initiated to collect field data on the quantity and quality of irrigation return flow as well as to develop a model which would aid in the interpretation and extrapolation of such data.

CHAPTER 2

Experimental Procedures

Details of the lysimeters used in this study and their installation have been described by Brown et al. (2). The six undisturbed drainage lysimeters were obtained in close proximity of each other. Two each were taken at three locations in the field. This was done in an attempt to secure paired lysimeters representative of the variability of field soil conditions. The paired lysimeters were taken on an average of 2.5 m from each other and the maximum distance from site of sampling lysimeters 1 through 6 was about 75 meters.

Paired lysimeters, each with a surface area of 3 m^2, were installed in 135 m^2 plots in the same field where they were taken. Lysimeters 1, 2 and 3 were moved 60 meters and lysimeters 4, 5 and 6 were moved 30 meters. This was done to minimize disturbance at sites of lysimeter installation. These 120 cm deep lysimeters were taken and placed with the lip just below the plow layer (25 cm) so that normal agricultural practices including plowing, bedding and irrigation could be performed. After placement, the top soil was put in place.

Soil properties were determined on undisturbed cores taken at different depths at each location where the monoliths were taken. Bulk densities, saturated hydraulic conductivities and volumetric H_2O content of 7.5 x 7.5 cm cores at selected soil suctions were determined and are reported in Table 1.

During the course of the study, a vacuum pump and suctions cups with a bubbling pressure of 0.5 bar were used to maintain approximately the same suctions inside the bottom of all lysimeters as was measured outside and adjacent to lysimeters. Drainage from each lysimeter was collected and measured once a week.

Table 1. Selected physical properties of soil where monoliths for indicated lysimeters were taken.

Depth cm	K cm/hr	Bulk Density gm/cm^3	Volumetric Water Content			Particle Class		
			-0.1 bar	- 0.33 bar	-1 bar	sand	silt	clay
							%1/	
			NORTH (Lysimeters 3 and 6)					
0 - 30	2.00	1.35	29.5	23.0	20.0	72.6	15.2	12.2
30 - 60	0.12	1.60	32.3	29.9	27.1	68.6	17.2	14.2
60 - 90	0.16	1.50	34.2	30.8	25.6	57.6	23.6	18.8
90 - 120	0.11	1.47	35.4	33.3	29.1	58.6	18.6	22.8
120 - 150	0.06	1.50	36.1	33.2	30.2	60.6	16.6	22.8
			MIDDLE OF FIELD (Lysimeters 2 and 5)					
0 - 30	1.40	1.41	28.9	25.1	21.6	69.6	17.6	12.8
30 - 60	0.01	1.61	35.6	33.0	31.7	64.2	19.0	16.8
60 - 90	0.002	1.60	38.9	35.2	34.9	53.6	25.6	20.8
90 - 120	0.012	1.73	36.8	35.6	33.7	49.6	23.6	26.8
120 - 150	0.004	1.74	41.4	--	37.0	47.6	23.6	28.8
			SOUTH (Lysimeters 1 and 4)					
0 - 30	0.61	1.47	32.6	26.8	24.6	64.4	24.0	11.6
30 - 60	0.045	1.50	36.5	34.0	31.5	60.0	20.2	19.8
60 - 90	0.028	1.62	43.4	42.3	38.7	53.2	19.0	27.8
90 - 120	0.009	1.72	40.6	37.9	36.4	53.2	19.0	27.8
120 - 150	0.011	1.70	40.5	38.5	35.4	52.6	20.2	27.2

1/ Determined using hydrometer method

These leachates were analyzed for total salts, Ca^{++}, Mg^{++}, Cl^- and NO_3^--N. Ca, Mg and Na determination were made by atomic absorption. Chloride was measured by solid state electrode and NO_3-N by NO_3 electrode with standards containing Cl^- in similar concentrations as samples measured. During the fall and early spring of 1973-74, the plot area was kept bedded and fallow. On April 1, 1974, Oro-T sorghum (Sorghum bicolor (L.) Moench) was planted in single rows 102 cm apart at a rate of one seed every 3 cm. Sorghum emerged to a satisfactory stand on April 6, 1974. Plot areas over lysimeters 1, 2 and 3 did not receive any nitrogen fertilizers in 1974. However, nitrogen at a rate of 112 kg/ha in the form of NH_4NO_3 was applied on April 24 to lysimeters 4, 5 and 6. Salinity sensors were installed at depths of 15, 30, 60, 90 and 120 cm (except for the 60 cm depth near lysimeter 5) under drippers and halfway between drippers in the row in the area surrounding lysimeters 4, 5 and 6. Description of the plot layer is given in Table 2.

Sorghum was drip irrigated to supply 50, 100 or 150% of sunken pan evaporation. Each plot area drip irrigated was about 135 m^2. The lysimeters were about 3 m^2 and centrally located in the 135 m^2 plots. Lysimeters 1 and 4 and similarly treated plot areas received 50% pan evaporation; lysimeters 2 and 5 and similarly treated plot areas received 100% pan evaporation; and lysimeters 3 and 6 and similarly treated plot areas received 150% pan evaporation. Sunken pan evaporation was evaluated daily at an official National Weather Service Station which is located about 500 meters south of the experi-

Table 2. Layout of experiment in 1974.

N

	150%[a/] 3[b/]	150%[a/] 6[b/]	
W	100%[a/] 2[b/]	100%[a/] 5[b/]	E
	50%[a/] 1[b/]	50%[a/] 4[b/]	

S

a/ Refers to percentages of pan evaporation (sunken pan) applied to 135 M^2 plot areas. Lysimeters which are 3 m^2 were centrally located in treated area.

b/ Lysimeter numbers.

mental site. Submatic* emitters, spaced about 75 cm apart in the row, were used to deliver the required water to respective plots. Three emitters were centrally positioned with respect to sides and corners of each lysimeter. Pressure regulators were used to uniformly distribute required water on the various plots and lysimeters. Amounts of water applied to each lysimeter through the emitters are given in Table 3. The well water had an EC of 4.1 mmho/cm and an GAR of 14.4. It contained 3.2 ml/liter Mg, 5.1 ml/liter Ca, 29.4 ml/liter Na and 21.2 ml/liter Cl. Dates and amounts of irrigation water applied to each lysimeter and similarly treated plot areas are given in Table 4.

In early May, mercury tensiometers were installed inside the lysimeters at depths of 25, 35, 45, 55, 65, 85, 105, 125 cm and 25, 35, 45, 55, 65, 85, 105, 125 and 145 cm depths outside the lysimeters. These were read and serviced 3 to 5 times per week.

Soil moisture was determined at 7 to 10 day intervals at depths of 30, 45, 60, 75, 90, 105, 120 and 135 cm depths inside and outside lysimeters by neutron scattering technique. Soil moisture content of the top 30 cm of soil was determined gravimetrically and converted to volumetric water content.

Porous ceramic cups installed in the bottom of each lysimeter and connected to a vacuum pump maintained essentially the same suction inside and outside lysimeters. The cups were under suction during the entire period of study.

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* Use of trade name does not imply endorsement.

Table 3. Amount and quality of water and N applied to each lysimeter in 1974.

Lysimeter No.	Applied N	Water Applied
	kg/ha	cm
1	0	7.74
2	0	15.59
3	0	23.30
4	112	7.74
5	112	15.59
6	112	23.30

Table 4. Dates and amounts of irrigation for individual lysimeters and plot areas around each lysimeter.

Dates	Lysimeters					
	1	2	3	4	5	6
	cm					
04/30	0.40	0.82	1.22	0.40	0.82	1.22
05/13	0.51	1.05	1.57	0.51	1.05	1.57
05/16	0.63	1.29	1.92	0.63	1.29	1.92
05/20	0.98	1.97	2.91	0.98	1.97	2.91
05/22	0.53	1.09	1.62	0.53	1.09	1.62
05/24	0.41	0.81	1.22	0.41	0.81	1.22
05/27	0.80	1.60	2.40	0.80	1.60	2.40
05/29	0.48	0.97	1.45	0.48	0.97	1.45
05/31	0.60	1.19	1.79	0.60	1.19	1.79
06/03	0.58	1.17	1.75	0.58	1.17	1.75
06/05	0.36	0.71	1.07	0.36	0.71	1.07
06/07	0.60	1.19	1.79	0.60	1.19	1.79
06/10	0.86	1.73	2.59	0.86	1.73	2.59
TOTAL - cm	7.74	15.58	23.30	7.74	15.58	23.30

Root growth was evaluated on April 17 and July 17. Positions of sampling were top of bed, midway between bed and furrow and in the furrow. Root growth at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths were determined. Roots were separated from dry soil, weighed and root length determined. Top growth was also evaluated on April 17 and May 9, 1974.

Yields and growth of sorghum in each lysimeter, outside of each lysimeter and on non-irrigated adjacent grown grain sorghum were evaluated on July 2, 1974.

CHAPTER 3.

RESULTS AND DISCUSSION

Soil physical properties given in Table 1 show that soil permeability is highly variable with respect to locations and depths. These properties may have contributed to variability in the amount and quality of drainage waters which will be discussed later.

Summary of water applied, rainfall and drainage from July 17, 1973, to July 2, 1974, are reported in Tables 5 , 6 , 7 and 8. The percent of water in the form of rain which percolated through each lysimeter prior to the 1974 grain sorghum crop varied from 17 to 39% (Table 5). Drainage during the crop year varied from 1.4 to 3.3% (Table 6). The percentages of water applied plus rainfall draining from different lysimeters for the entire year were almost identical with percentages of water draining from these lysimeters in 1972-1973. The amounts of water which drained from other lysimeters and the accumulative drainage with time from each lysimeter for the period of July, 1973 to July, 1974 is shown in Figure 1 . The low permeability and drainage of soil in lysimeters 2 and 4 compared to permeability of soil in other lysimeters is depicted in Figure 1. The soil properties in lysimeters also had a marked influence on chemical properties of drainage waters to be discussed later.

Estimates of soil moisture use inside and near each lysimeter are reported in Tables 9 and 10. Drip irrigation can cause marked differences in water content of soil at different depths and locations with

Table 5. Rainfall and subsurface drainage prior to 1974 crop year.

Lysimeter No.	Rainfall 7/17/73 - 3/31/74	Drainage	Drainage
	cm	cm	%
1	47.57	17.75	37.3
2	47.57	8.02	16.9
3	47.57	14.22	29.9
4	47.57	9.05	19.0
5	47.57	17.49	36.8
6	47.57	18.55	39.0

Table 6. Amounts of water applied, rainfall and subsurface drainage during 1974 crop year.

Lysimeter No.	Rainfall 4/1 - 7/2	Water Applied	Drainage	Drainage
	cm	cm	cm	%
1	9.70	7.74	0.48	2.8
2	9.70	15.585	0.50	2.0
3	9.70	23.295	0.46	1.4
4	9.70	7.74	0.26	1.5
5	9.70	15.585	0.91	3.6
6	9.70	23.295	1.09	3.3

Table 7. Rainfall, water applied and subsurface drainage from July 17, 1973 to July 2, 1974.

Lysimeter No.	Rainfall	Water Applied	Drainage	Drainage
	cm	cm	cm	%
1	57.27	7.74	18.23	28.0
2	57.27	15.58	8.52	11.7
3	57.27	23.29	14.68	18.2
4	57.27	7.74	9.31	14.3
5	57.27	15.58	18.40	25.3
6	57.27	23.29	19.64	24.4

Table 8. Rainfall from July 17, 1973 through July 2, 1974.

Months	Rainfall 1973 cm
July	0.13*
August	13.11
September	11.63
October	7.39
November	5.03
December	0.53
	1974
January	4.62
February	0.00
March	5.13
April	3.94
May	3.58
June	2.18
Total Rainfall	57.27

* July 17 - 31, 1973.

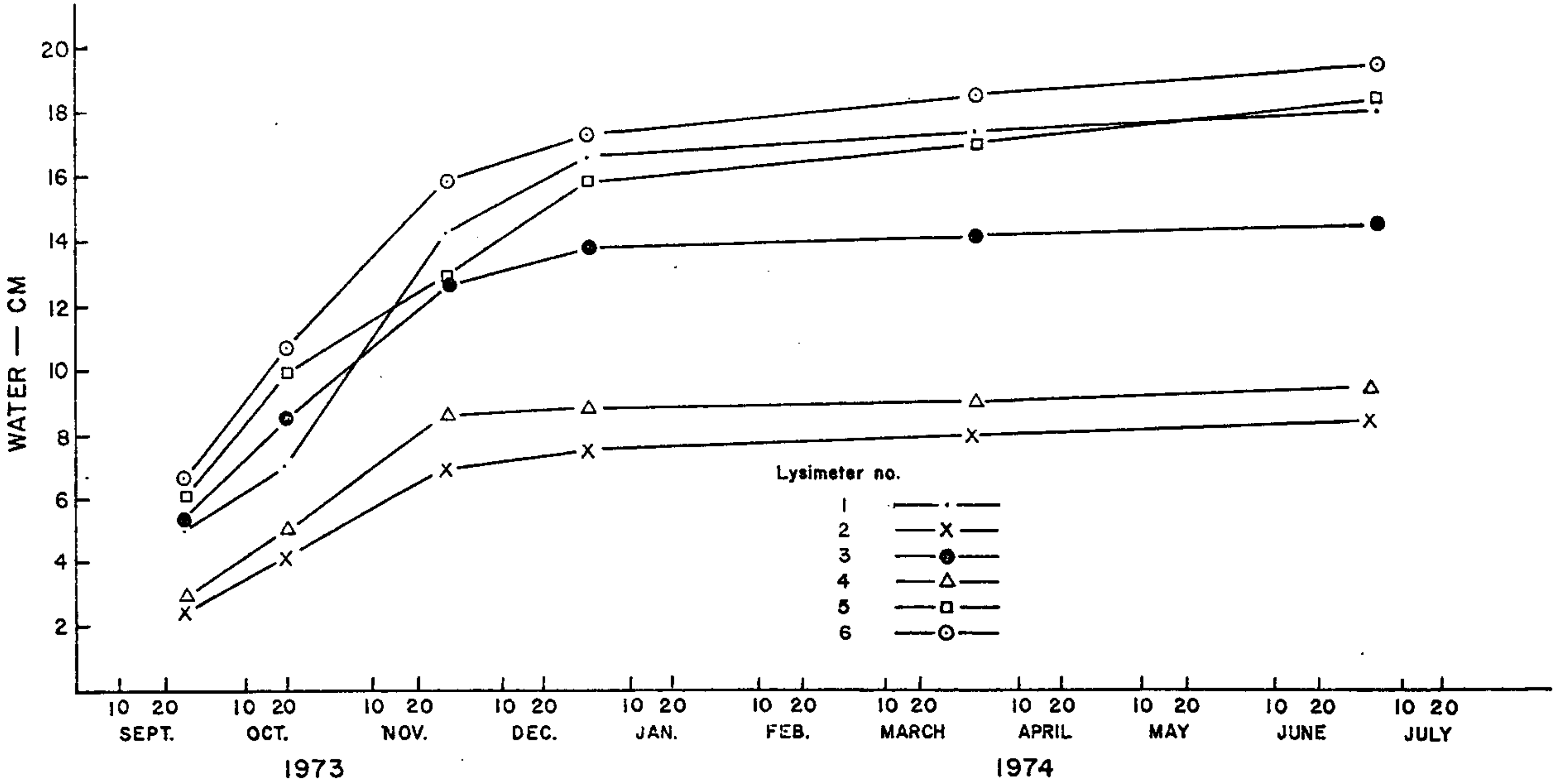

Figure 1. Depth of drainage as a function of time from lysimeters 1, 2, 3, 4, 5 and 6 in 1973 - 74.

Table 9. Moisture use by grain sorghum in and outside lysimeters in 1974.

Period of Evaluation	Lysimeters				Outside Lysimeters		
	1	2	3		1[a]	2[a]	3[a]
		cm				cm	
04/18 - 04/29/74	2.46	1.80	2.34		3.00	3.02	2.34
04/29 - 05/09/74	4.39	4.19	3.40		3.93	3.36	3.45
05/09 - 05/15/74	0.005	+ 0.88	+ 0.69		+ 0.15	1.51	1.01
05/15 - 05/23/74	5.62	6.09	9.93		4.52	3.83	6.27
05/23 - 05/31/74	6.72	3.78	3.49		5.25	4.29	4.71
05/31 - 06/06/74	0.34	4.24	4.84		+ 0.57	2.49	4.64
06/06 - 06/12/74	3.82	3.66	3.95		3.72	3.89	4.03
06/12 - 06/24/74	5.33	2.77	6.15		4.65	3.81	6.02
06/24 - 07/01/74	1.73	3.58	0.71		1.17	3.99	1.37
TOTAL	30.42	29.23	34.12		25.52	30.19	33.84
Drainage	0.48	0.50	0.46	% error	-16.1[b]	+ 3.3[b]	- 0.8[b]
GRAND TOTAL	30.90	29.73	34.58				

[a] Refers to area comparably treated to similarly numbered lysimeters.

[b] % error refers to $\frac{1^{a/}\cancel{*} - 1}{1}$ x 100; etc.

Table 10. Moisture use by grain sorghum in and outside lysimeters in 1974.

Period of Evaluation	Lysimeters				Outside Lysimeters		
	4	5	6		4[a]	5[a]	6[a]
		cm				cm	
04/18 - 04/29/74	4.70	5.38	3.15		3.05	3.94	2.95
04/29 - 05/09/74	1.70	3.20	4.52		1.11	2.67	4.24
05/09 - 05/15/74	1.10	2.86	0.78		1.55	2.12	0.42
05/15 - 05/23/74	3.69	6.22	6.04		3.53	4.49	6.35
05/23 - 05/31/74	4.10	4.70	5.60		3.72	3.23	6.24
05/31 - 06/06/74	2.71	2.49	3.85		3.06	1.63	4.92
06/06 - 06/12/74	1.39	4.27	4.87		1.59	3.99	4.31
06/12 - 06/24/74	3.91	5.54	5.46		3.89	4.85	4.14
06/24 - 07/01/74	2.26	2.46	3.25		3.12	1.73	3.23
TOTAL	25.56	37.12	37.52		24.62	28.65	36.80
Drainage	0.26	0.91	1.09	% error	- 3.7[b]	-22.8[b]	- 1.9[b]
GRAND TOTAL	25.82	38.03	38.61				

a/ Refers to area comparably treated to similarly numbered lysimeters.

b/ % error refers to $\frac{4^{a/}* - 4}{4}$ x 100; etc.

respect to emitters. For this reason, the water use data for short intervals shown in Tables 9 and 10 must be considered as estimates. However, the water use values for the season of April 18 to July 1, 1974, are considered valid. The 1974 crop year, unlike the 1973 crop year, was very dry. Moisture use estimates from depletion data by grain sorghum (outside lysimeters) on plot areas receiving 50, 100 and 150% pan evaporation was about 8% less than the moisture use estimate from plots receiving comparable levels of drip irrigation (Tables 11 and 12).

These results may suggest that in dry years such as 1974 that non-irrigated sorghum and sorghum receiving 1 to 2 irrigations may make use of water from the water table. Water use estimates from lysimeters 1 and 5 were 16 and 23% more, respectively, than water use estimates from the adjacent areas. However, the average differences shown in Table 12 are small but all negative ranging from about -1.0 to -11.0%. Deviations from the averages ranged from 2.0 to 12.0% as indicated in Tables 11 and 12. Soil property differences discussed earlier may have contributed to the magnitude of these differences. Moisture use by non-irrigated grain in 1974 is shown in Table 13. Use was approximately 70% of sorghum irrigated at 50% pan evaporation.

Soil moisture conditions inside and outside lysimeters as evaluated by neutron scattering technique are reported in Figures 2 through 8 . Soil moisture conditions under grain sorghum irrigated at 50% pan evaporation (lysimeter 1) and adjacent plot area are similar as indicated in Figures 2 and 3 . As expected under this level of irrigation in 1974, moisture extraction by grain sorghum was significant at

Table 11. Average moisture use by grain sorghum in lysimeters drip irrigated at 50%, 100% and 150% pan evaporation in 1974.

Period of Evaluation	50% P.E.[a]	100% P.E.[b]	150% P.E.[c]		50% P.E.[a]	100% P.E.[b]	150% P.E.[c]
		cm				cm/day	
04/18 - 04/29/74	3.58	3.59	2.75		0.33	0.33	0.25
04/29 - 05/09/74	3.05	3.70	3.96		0.31	0.37	0.40
05/09 - 05/15/74	0.55	0.99	0.05		0.09	0.17	0.01
05/15 - 05/23/74	4.66	6.16	7.99		0.58	0.77	1.00
05/23 - 05/31/74	5.41	4.24	4.55		0.68	0.53	0.57
05/31 - 06/06/74	1.53	3.37	4.35		0.26	0.56	0.73
06/06 - 06/12/74	2.61	3.97	4.41		0.44	0.66	0.74
06/12 - 06/24/74	4.62	4.16	5.81		0.39	0.35	0.48
06/24 - 07/01/74	2.00	3.02	1.98		0.29	0.43	0.28
TOTAL	28.01	33.20	35.85		--	--	--
Drainage	0.37	0.71	0.78		--	--	--
GRAND TOTAL	28.38	33.91	36.63	Ave cm/d	0.37	0.44	0.45
Deviation $\overline{x}$ (%)[d]	± 8.8	±12.0	± 4.8				

[a] Average of lysimeters 1 and 4.

[b] Average of lysimeters 2 and 5.

[c] Average of lysimeters 3 and 6.

[d] % deviation from average.

Table 12. Average moisture use by grain sorghum adjacent to lysimeters drip irrigated at 50%, 100% and 150% pan evaporation in 1974.

Period of Evaluation	50% P.E.[a]	100% P.E.[b]	150% P.E.[c]		50% P.E.[a]	100% P.E.[b]	150% P.E.[c]
	cm				cm/day		
04/18 - 04/29/74	3.03	3.48	2.65		0.28	0.32	0.24
04/29 - 05/09/74	2.52	3.02	3.85		0.25	0.30	0.39
05/09 - 05/15/74	0.70	1.82	0.72		0.12	0.30	0.12
05/15 - 05/23/74	4.03	4.16	6.31		0.50	0.52	0.79
05/23 - 05/31/74	4.49	3.76	5.48		0.56	0.47	0.69
05/31 - 06/06/74	1.25	2.06	4.78		0.21	0.34	0.80
06/06 - 06/12/74	2.66	3.94	4.17		0.44	0.66	0.70
06/12 - 06/24/74	4.27	4.33	5.08		0.36	0.36	0.42
06/24 - 07/01/74	2.15	2.86	2.30		0.31	0.41	0.33
TOTAL	25.10	29.43	35.34	Ave cm/d	0.34	0.40	0.48
% error[d]	-10.4	-11.4	-1.4				
Deviation $\bar{x}$ (%)[e]	± 1.9	± 2.7	± 4.2				

a/ Average of water use by grain sorghum grown and drip irrigated similarly to grain sorghum in lysimeters 1 and 4.

b/ Average of water use by grain sorghum grown and drip irrigated similarly to grain sorghum in lysimeters 2 and 5.

c/ Average of water use by grain sorghum grown and drip irrigated similarly to grain sorghum in lysimeters 3 and 6.

d/ % error refers to $\frac{25.10 - 28.01}{28.01}$ x 100 = -10.4%.

e/ % deviation from average.

Table 13. Average moisture use by non - irrigated grain sorghum in 1974.

Period of Evaluation	1[a]	2[b]	3[c]	Average	Use
		cm			cm/day
04/18 - 04/29/74	4.45	3.58	3.05	3.69	0.34
04/29 - 05/09/74	0.86	2.18	2.67	1.90	0.19
05/09 - 05/15/74	1.91	2.13	1.68	1.91	0.32
05/15 - 05/23/74	3.76	1.93	2.29	2.66	0.33
05/23 - 05/31/74	2.49	1.30	2.11	1.97	0.25
05/31 - 06/06/74	1.91	2.18	2.26	2.12	0.35
06/06 - 06/12/74	1.19	0.74	0.08	0.67	0.11
06/12 - 06/24/74	2.16	2.95	2.29	2.47	0.21
06/24 - 07/01/74	1.68	1.75	1.12	1.52	0.22
TOTAL	20.41	18.74	17.55	18.90	0.26

a/ Plot area between lysimeters 1 and 4.

b/ Plot area between lysimeters 2 and 5.

c/ Plot area between lysimeters 3 and 6.

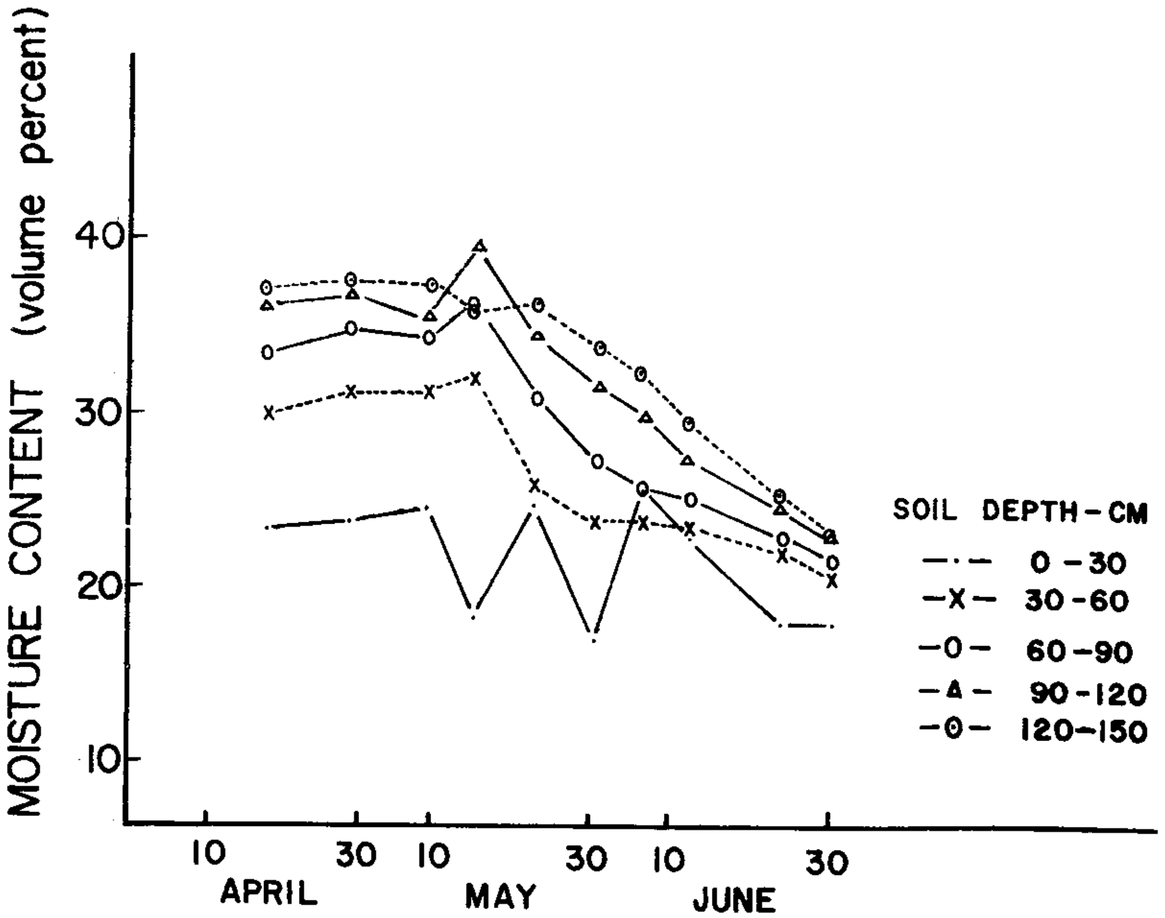

Figure 2. Influence of grain sorghum irrigated at 50% pan evaporation on soil moisture at different depths inside lysimeter No. 1.

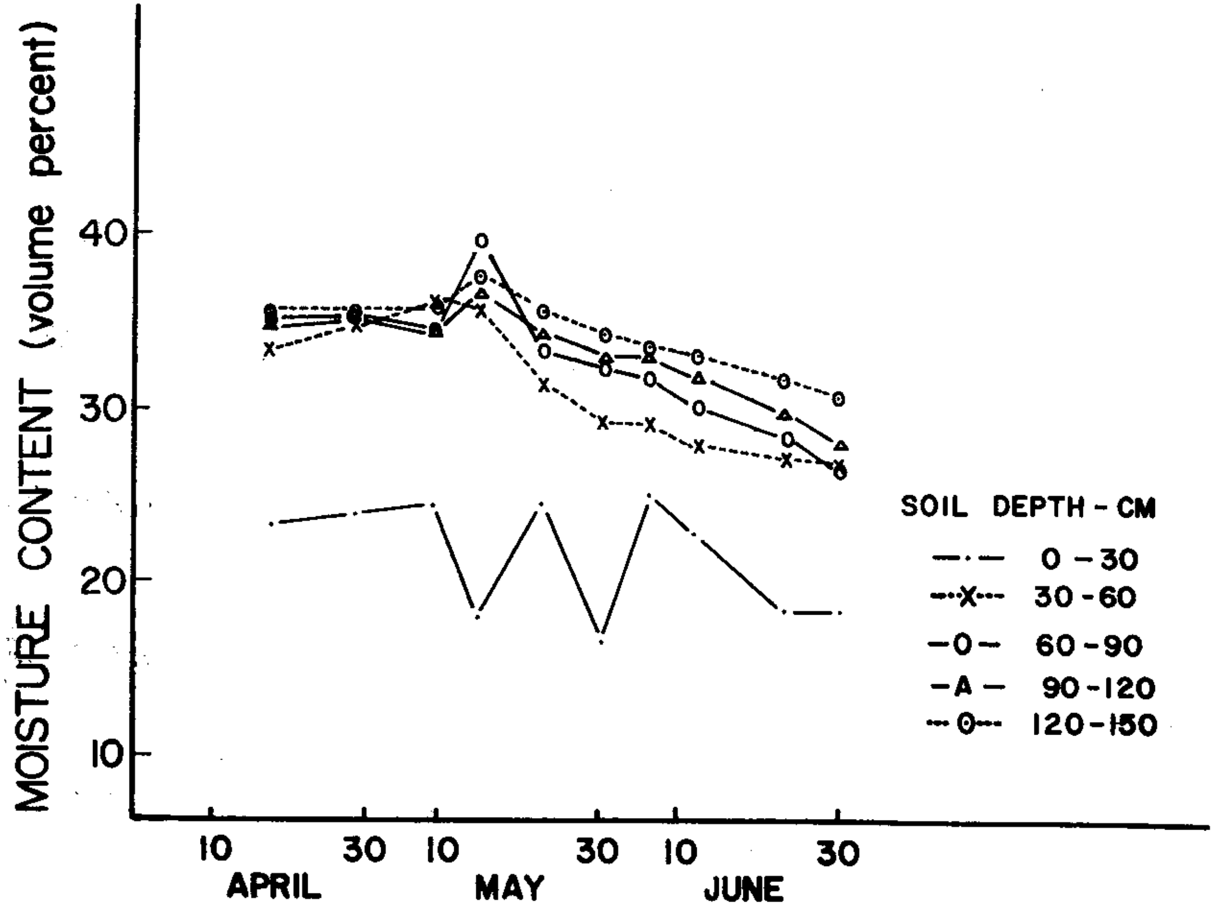

Figure 3. Influence of grain sorghum irrigated at 50% pan evaporation on soil moisture at different depths outside but near lysimeter No. 1.

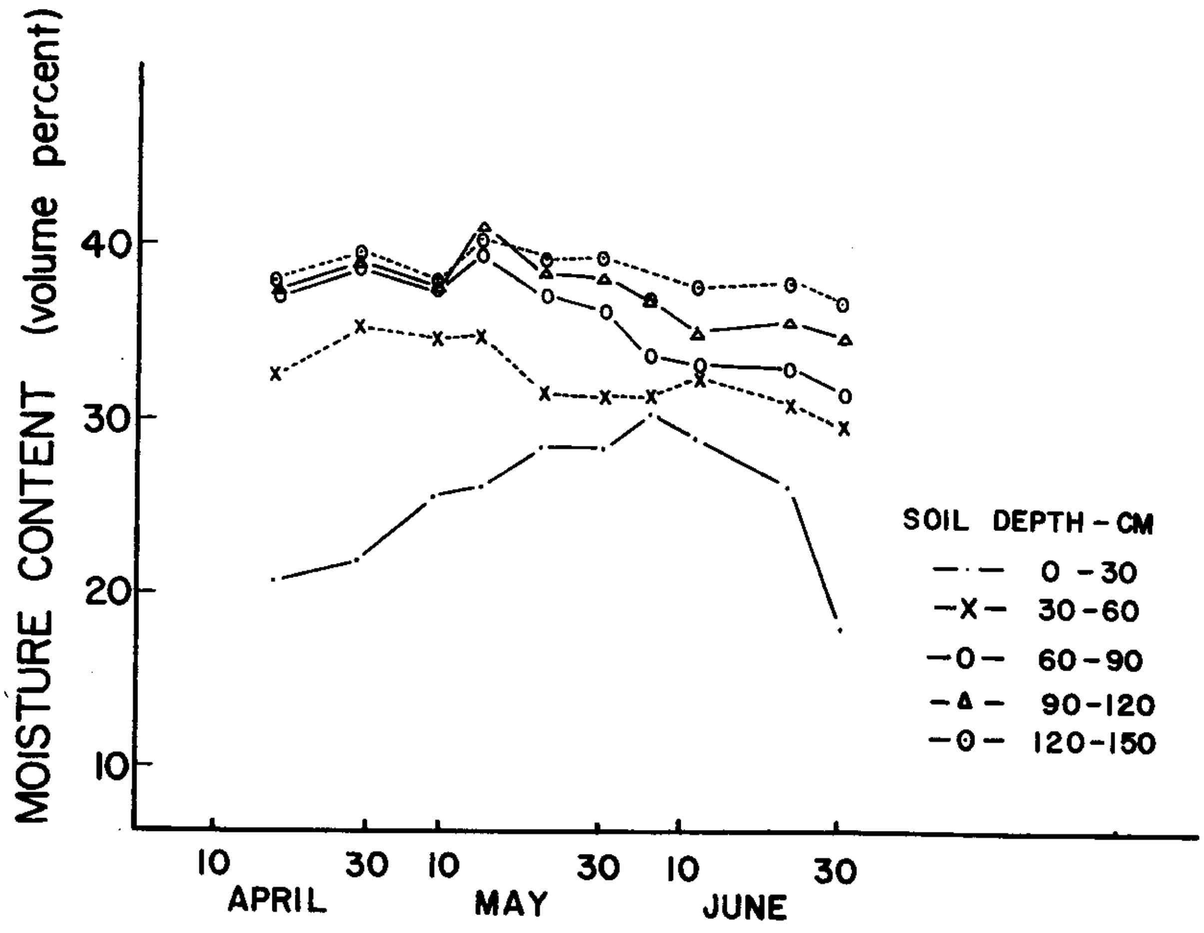

Figure 4. Influence of grain sorghum irrigated at 100% pan evaporation on soil moisture at different depths inside lysimeter No. 2.

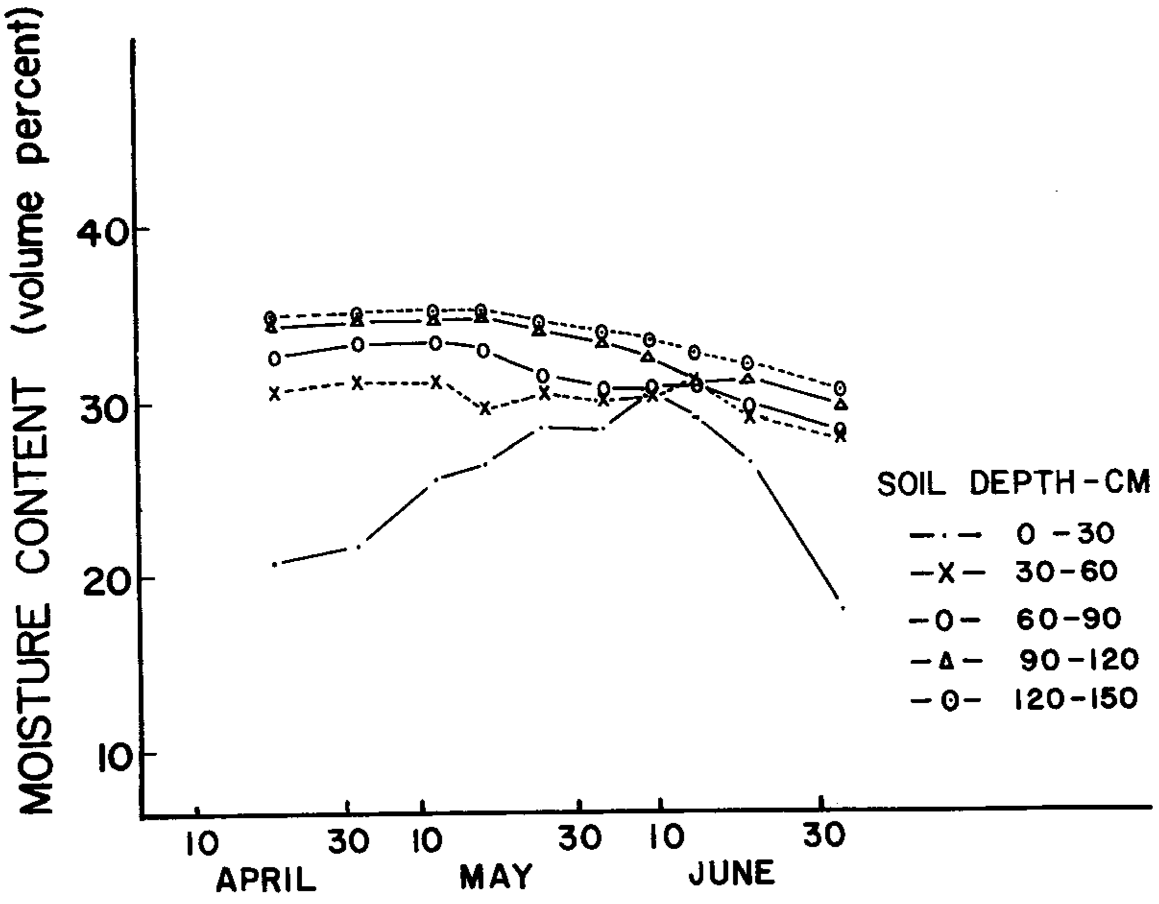

Figure 5. Influence of grain sorghum irrigated at 100% pan evaporation on soil moisture outside but near lysimeter No. 2.

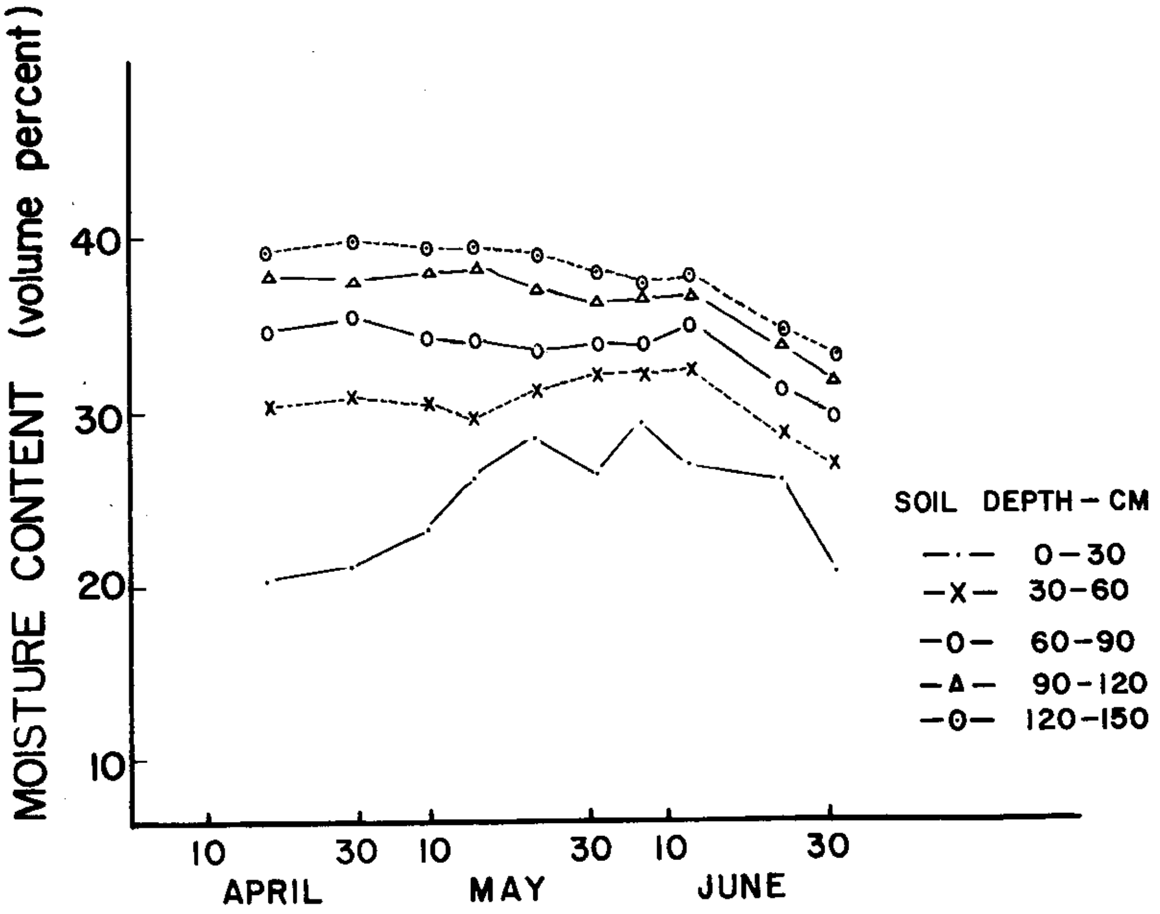

Figure 6. Influence of grain sorghum irrigated at 150% pan evaporation on soil moisture at different depths inside lysimeter No. 6.

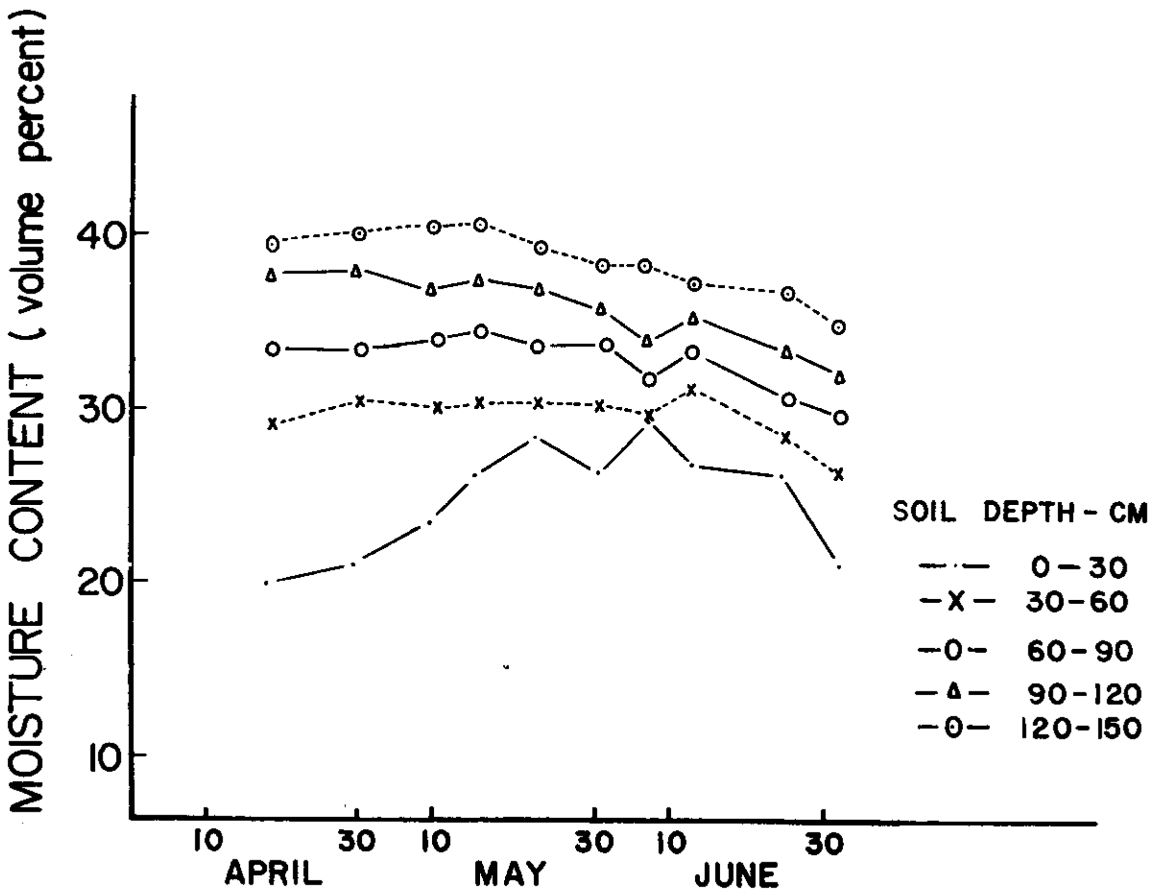

Figure 7. Influence of grain sorghum irrigated at 150% pan evaporation on soil moisture at different depths outside but near lysimeter No. 6.

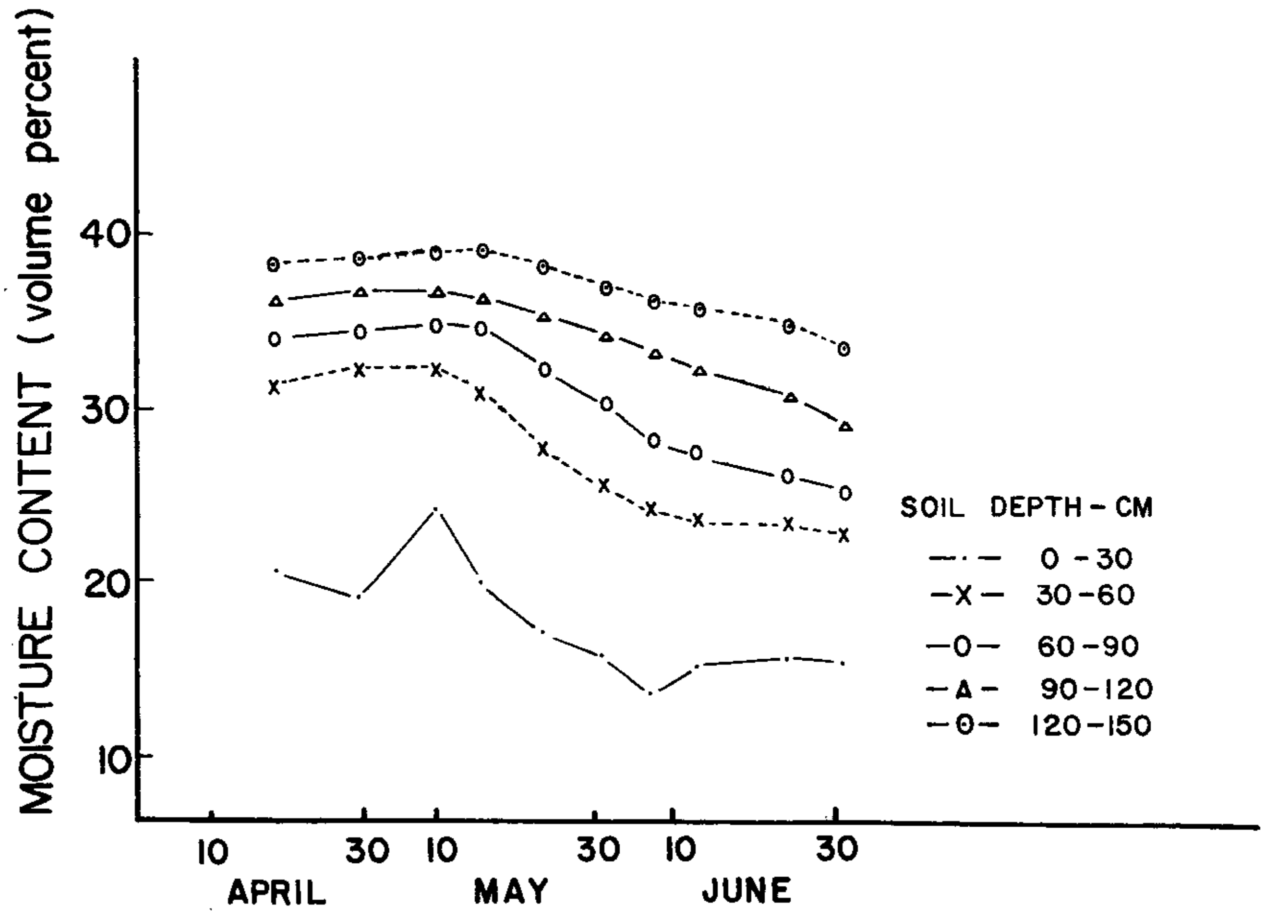

Figure 8. Influence of non - irrigated grain sorghum on soil moisture at different depths.

120 to 150 cm depth. Soil moisture conditions under grain sorghum irrigated at 100% pan evaporation (lysimeter 2) and adjacent plot area are somewhat similar as indicated in Figures 4 and 5 . Moisture extraction by grain sorghum at lower soil depths at this level of drip irrigation was considerably less in 1974. Soil moisture conditions under grain sorghum irrigated at 150% pan evaporation (lysimeter 6) and adjacent areas are shown in Figures 6 and 7 . Moisture extraction by grain sorghum at lower soil depths was considerably less and did not occur until drip irrigation was discontinued (June 10). Soil moisture conditions under non-irrigated grain sorghum at different soil depths are indicated in Figure 8. Moisture extraction by non-irrigated grain sorghum was less at lower depths than grain sorghum irrigated at 50% pan evaporation. Moisture extraction from different soil depths in 1974 may be expressions of root growth which will be discussed later.

Soil moisture suction at selected depths is shown in Figures 9 through 14. Some of the tensiometers in these studies did not function properly. However, soil suction at lower soil depths under sorghum irrigated at 50% pan evaporation as shown in Figures 9 and 10 indicated moisture extraction at lower soil depths in May and June. Soil suction conditions at lower depths under sorghum irrigated at 100% pan evaporation are intermediate as indicated in Figures 11 and 12, but soil suction at all depths under sorghum irrigated at 150% pan evaporation are relatively low as indicated in Figures 13 and 14. Soil moisture at different depths (Figures 2 through 8) and soil suction (Figures 9 through 14) show similar trends.

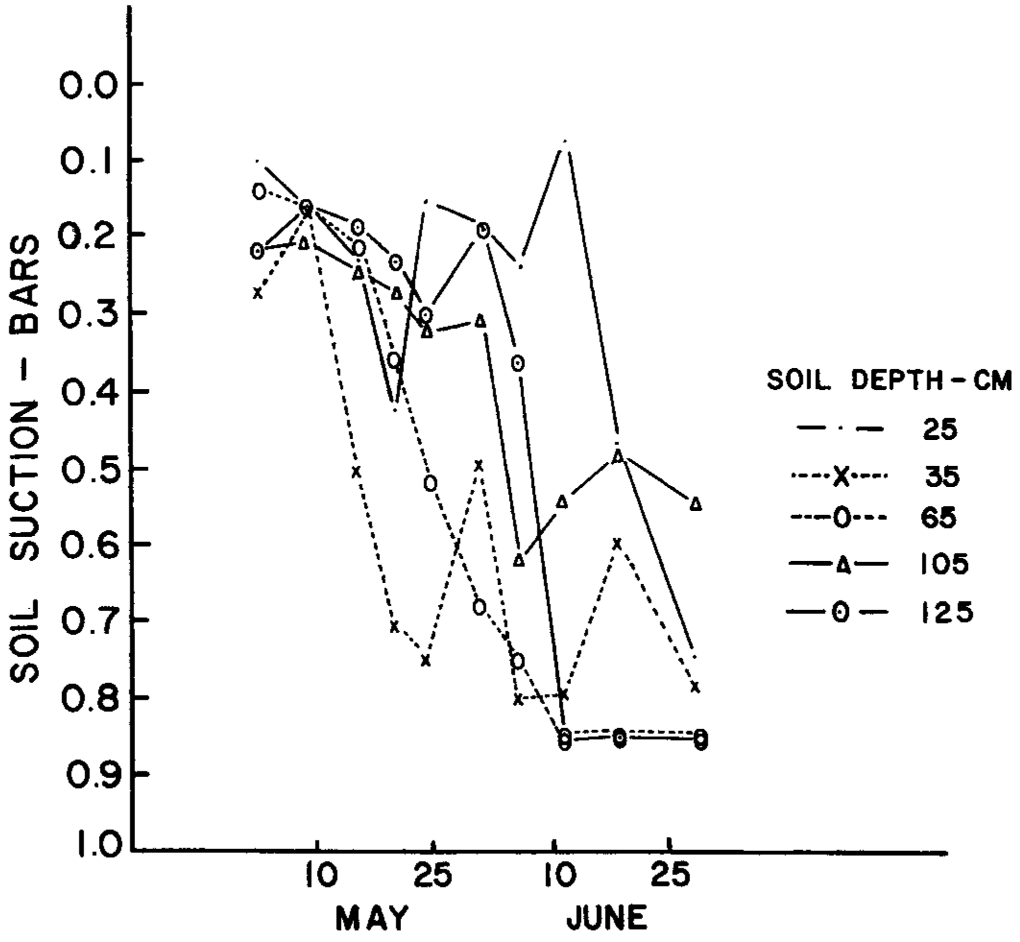

Figure 9. Influence of grain sorghum irrigated at 50% pan evaporation on soil moisture suction at different depths inside lysimeter No. 1.

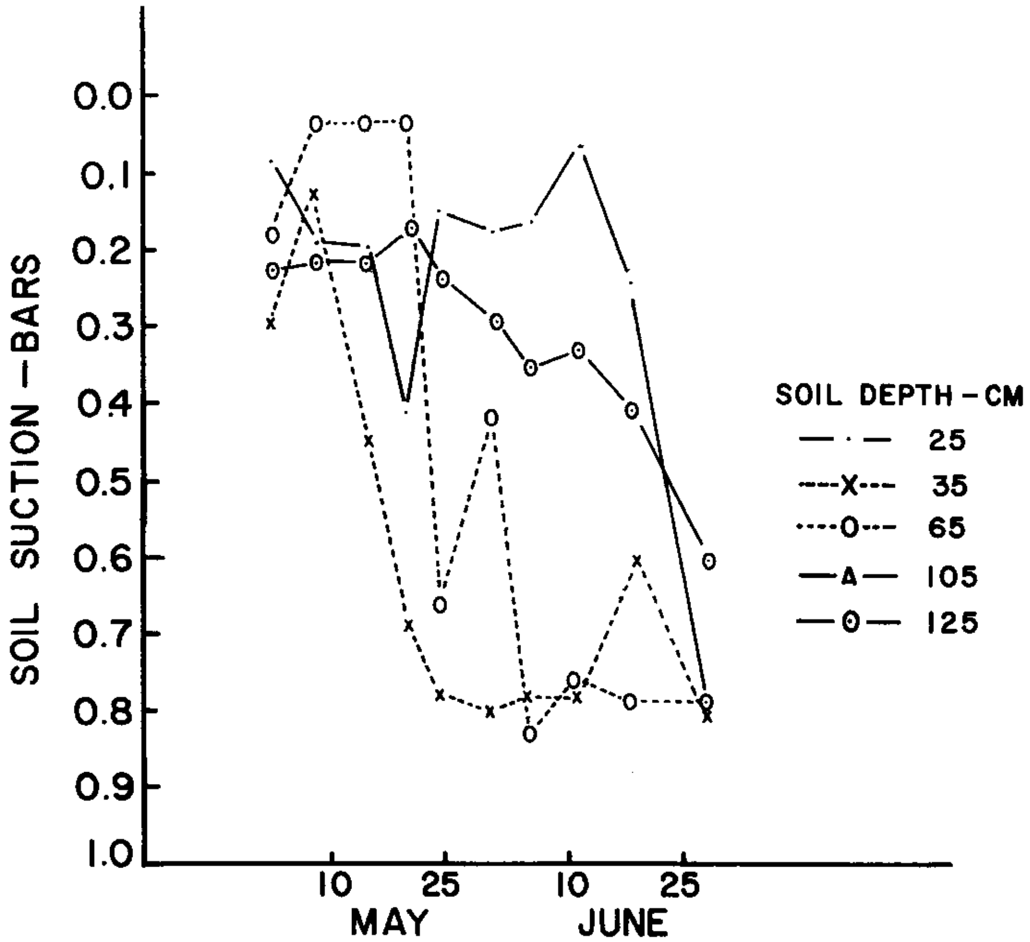

Figure 10. Influence of grain sorghum irrigated at 50% pan evaporation on soil moisture suction at different depths outside but near lysimeter No. 1.

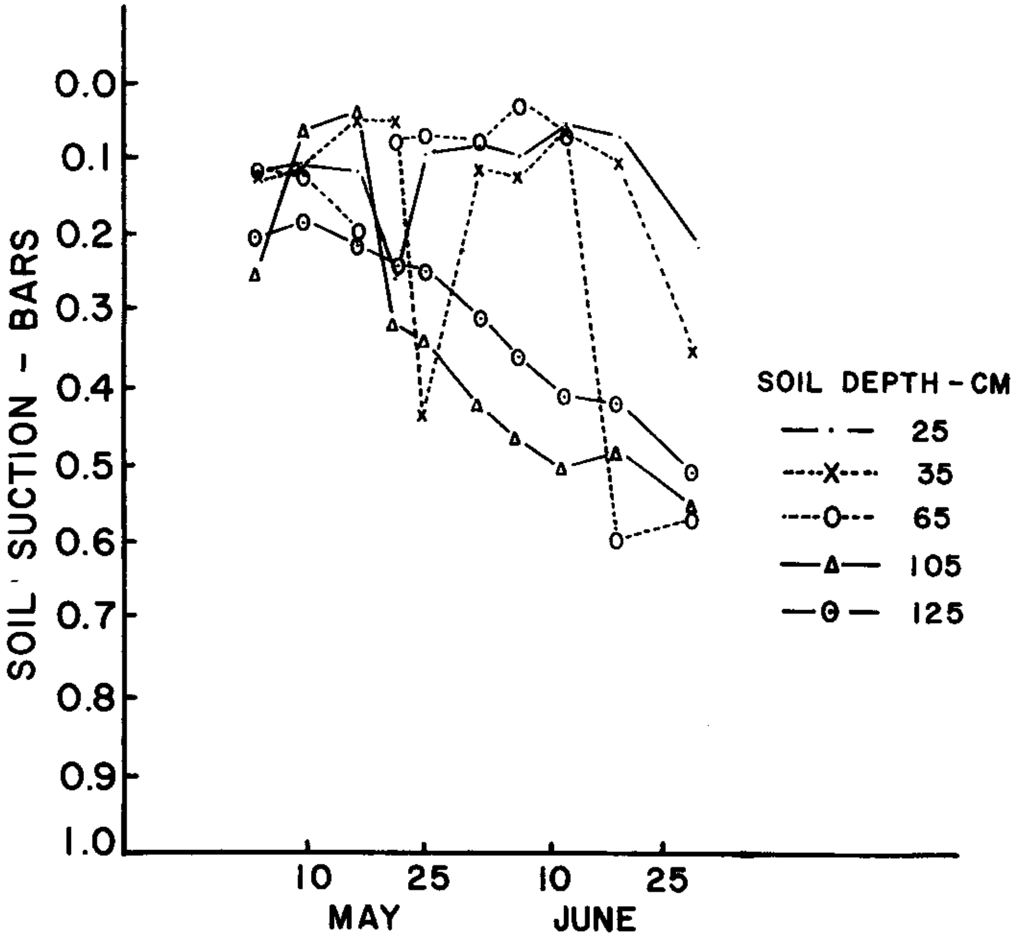

Figure 11. Influence of grain sorghum irrigated at 100% pan evaporation on soil moisture suction at different depths inside lysimeter No. 2.

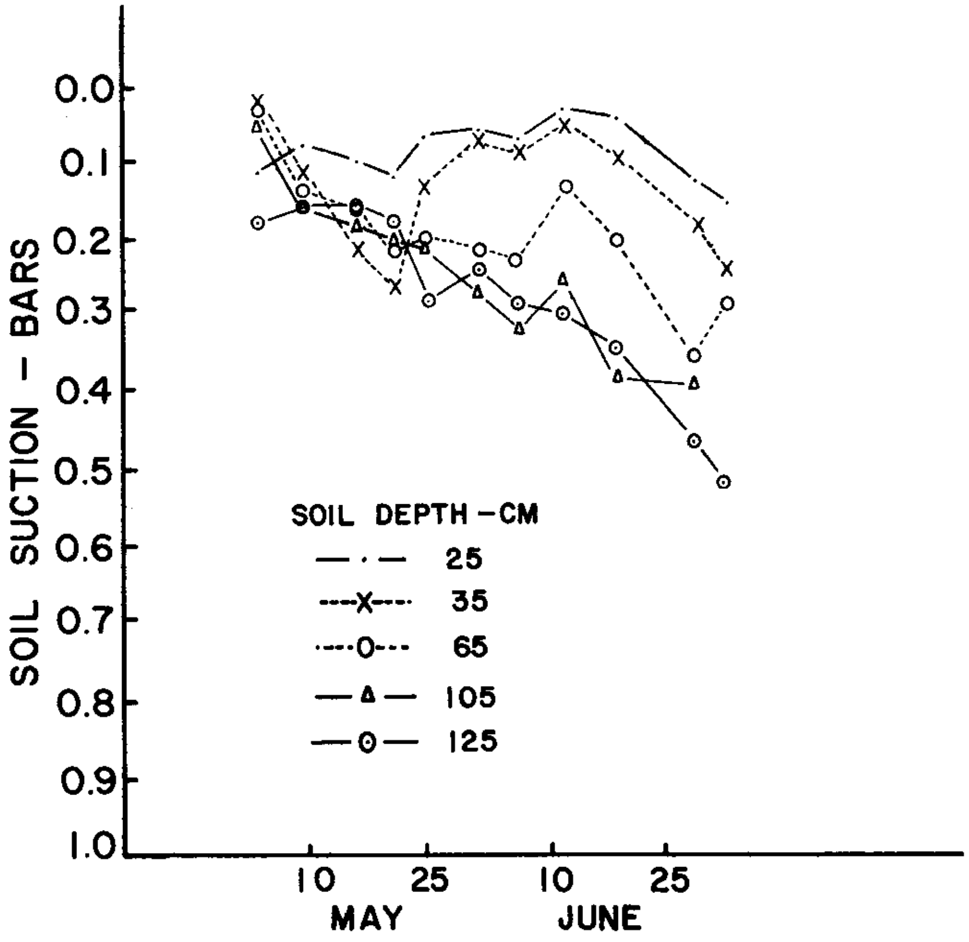

Figure 12. Influence of grain sorghum irrigated at 100% pan evaporation on soil moisture suction at different depths outside but near lysimeter No. 2.

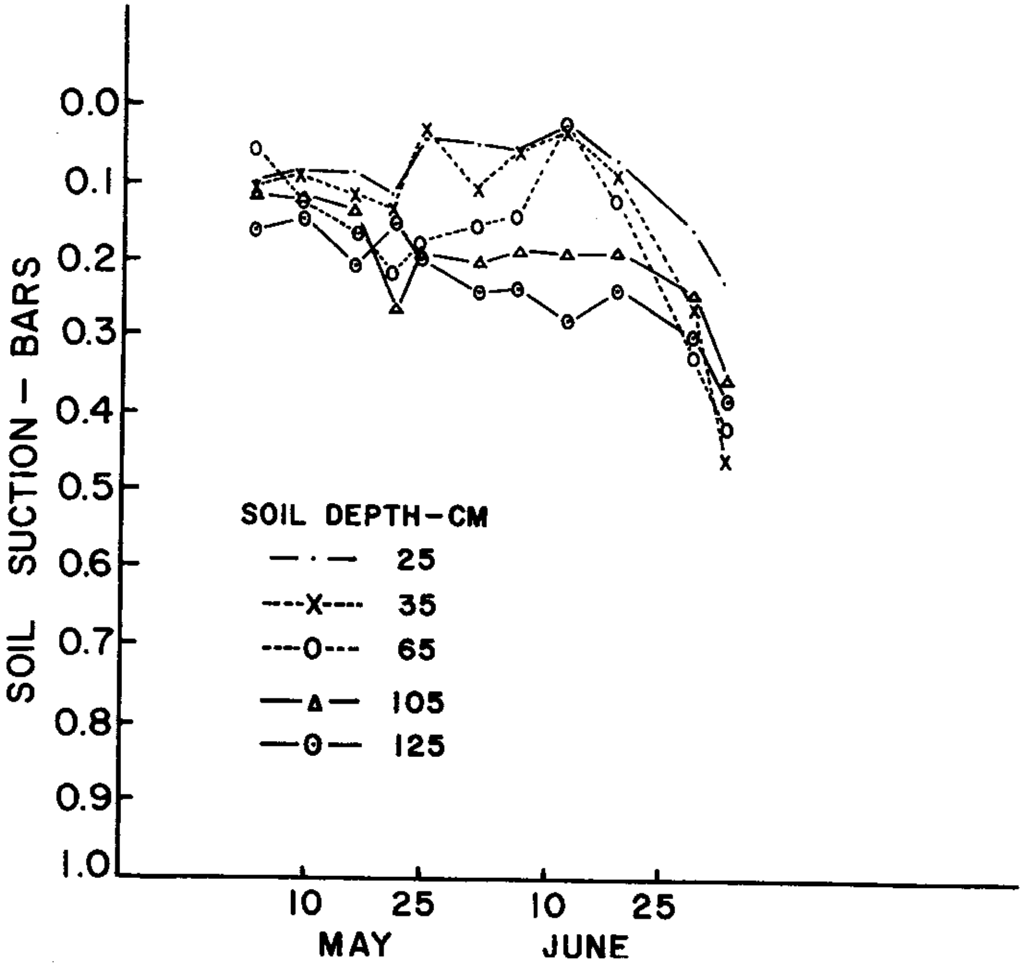

Figure 13. Influence of grain sorghum irrigated at 150% pan evaporation on soil moisture suction at different depths in lysimeter No. 3.

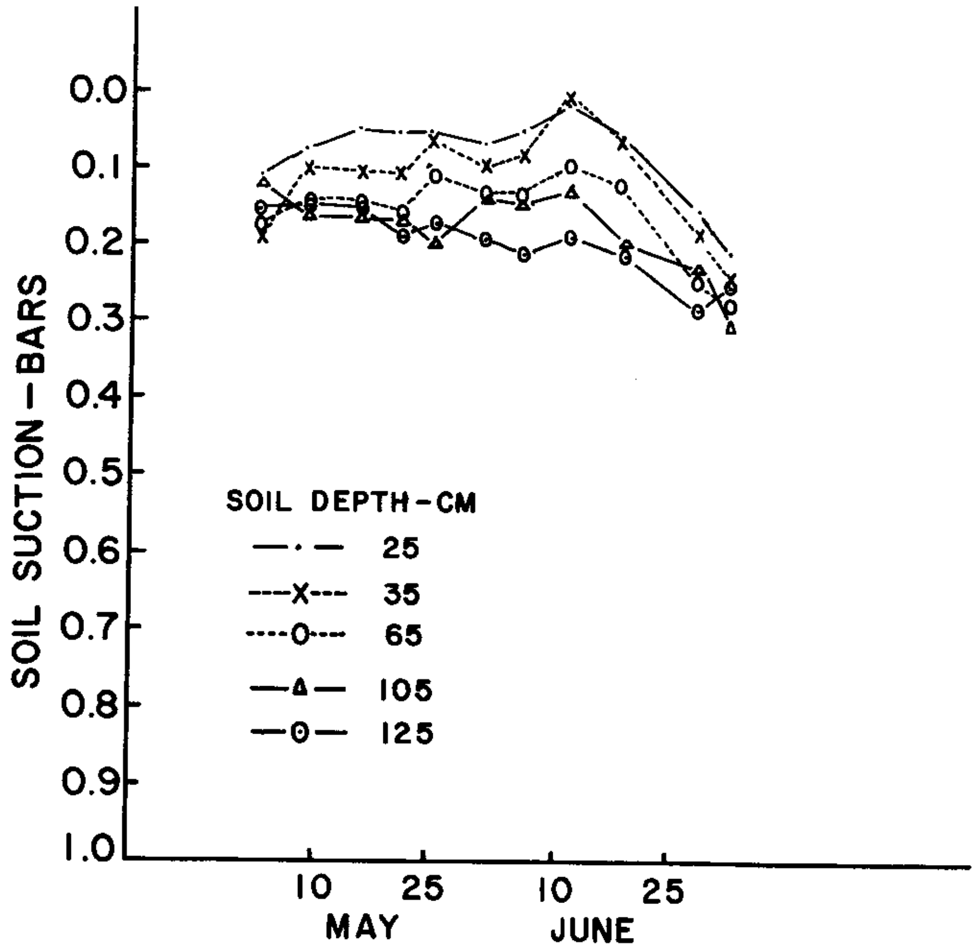

Figure 14. Influence of grain sorghum irrigated at 150% pan evaporation on soil moisture suction at different depths outside but near lysimeter No. 3.

Root growth in early April (Table 14) was restricted. In July, root growth by sorghum irrigated at 50% pan evaporation was greater than non-irrigated sorghum which was slightly greater than sorghum irrigated at 100 and 150% pan evaporation. Root growth by sorghum in the area adjacent to lysimeters 1, 2 and 3 was generally greater than root growth in the area adjacent to lysimeters 4, 5, and 6. The applied N to grain sorghum in lysimeters 4, 5 and 6 should not have caused these differences. No explanation can be given for these results. However, root growth shown in Figure 15 seems to partially explain the moisture extraction at lower soil depths under different treatments. The root growth at lower soil depth and order of moisture extraction by grain sorghum at lower soil depths in 1974 were sorghum irrigated at 50% pan evaporation was >0% pan evaporation > 100% pan evaporation > 150% pan evaporation.

Leaf area indices for April 26 and May 9 are shown in Table 15. Early growth was very uniform. The differences in leaf area due to drip irrigation treatments shown in Table 15 were not apparent. However, the grain sorghum drip irrigated at 150% pan evaporation lodged and appeared iron deficient. This was especially true of grain sorghum grown over and adjacent to lysimeter 6.

Yields of stalk and grain in and outside lysimeters are reported in Table 16. Yields of grain and stalk were highly variable and not significantly influenced by treatments. Growth and yields of grain sorghum inside and outside of lysimeters were variable but comparable. For unexplained reasons, yields outside lysimeters 2 and 6 were low in 1974. Sorghum grown in the plot area in and outside lysimeter 6 was chlorotic and produced low yields. Yields of non-irrigated grain

Table 14. Influence of location and time on root growth in 1974.

SAMPLING DATE: April 17, 1974

Lysimeter No.	Depth cm	Sampling Site			Average
		A*	B**	C***	
		microns/cm^3			
1 and 4	0 - 15	2770	75	310	1050
	15 - 30	150	0	0	50
	30 - 60	0	0	0	0
	60 - 90	0	0	0	0
	90 - 120	0	0	0	0
2 and 5	0 - 15	1615	0	790	800
	15 - 30	590	0	0	195
	30 - 60	0	0	0	0
	60 - 90	85	0	0	30
	90 - 120	0	0	0	0
3 and 6	0 - 15	260	1140	460	620
	15 - 30	0	0	0	0
	30 - 60	0	0	0	0
	60 - 90	0	0	0	0
	90 - 120	0	0	0	0

* Location A is on top of bed.

** Location B is midway between bed and furrow.

*** Location C is in the furrow.

Table 14. (Continued)

SAMPLING DATE: July 17, 1974

	Depth cm	Sampling Site			
		A	B	C	Average
		microns/cm^3			
Lysimeter 1	0 - 15	2700	1335	890	1640
	15 - 30	3640	900	1415	1985
	30 - 60	730	540	1495	920
	60 - 90	705	295	705	570
	90 - 120	995	190	1155	780
Lysimeter 2	0 - 15	1830	205	285	775
	15 - 30	280	565	680	510
	30 - 60	245	390	725	455
	60 - 90	2095	300	595	995
	90 - 120	530	115	245	295
Lysimeter 3	0 - 15	1925	1225	30	1060
	15 - 30	1785	440	750	995
	30 - 60	25	85	175	95
	60 - 90	165	320	225	235
	90 - 120	80	0	823	300
Lysimeter 4	0 - 15	210	85	1555	615
	15 - 30	1800	315	1095	1070
	30 - 60	250	115	285	215
	60 - 90	1505	410	30	650
	90 - 120	1355	180	405	645
Lysimeter 5	0 - 15	625	265	25	305
	15 - 30	510	150	1005	555
	30 - 60	1490	400	40	645
	60 - 90	455	355	7	270
	90 - 120	35	85	0	40
Lysimeter 6	0 - 15	1610	80	35	575
	15 - 30	750	535	0	430
	30 - 60	15	85	75	60
	60 - 90	75	980	100	385
	90 - 120	705	100	60	285

Table 14. (Continued)

SAMPLING DATE: July 17, 1974

	Depth cm	Sampling Site A	Sampling Site B	Sampling Site C	Average
		microns/cm^3			
Dry plot between Lysimeters 1 and 4	0 - 15	1245	1895	1125	1420
	15 - 30	190	210	695	365
	30 - 60	250	235	60	180
	60 - 90	165	275	1260	565
	90 - 120	725	135	290	385
Dry plot between Lysimeters 2 and 5	0 - 15	1795	670	675	1045
	15 - 30	150	525	615	430
	30 - 60	315	290	615	410
	60 - 90	140	75	915	375
	90 - 120	365	170	425	320
Dry plot between Lysimeters 3 and 6	0 - 15	3990	130	380	1500
	15 - 30	1640	0	435	695
	30 - 60	330	450	255	345
	60 - 90	60	175	850	360
	90 - 120	250	115	180	185

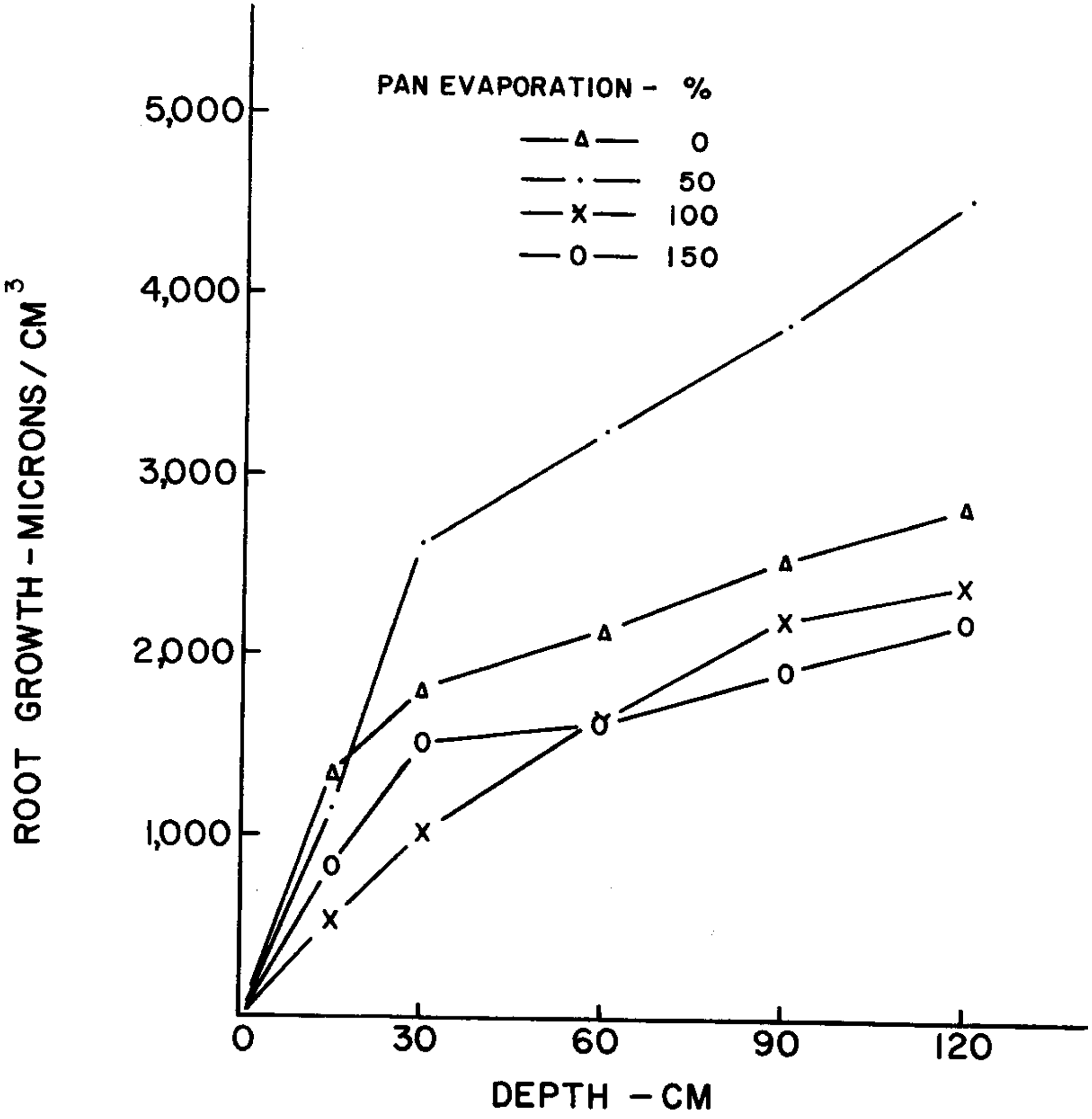

Figure 15. Average accumulative root growth for different drip-irrigated grain sorghum at different soil depths in July, 1974.

Table 15. Leaf area indices of grain sorghum as influenced by location, time and treatment in 1974.

Level of Irrigation % P.E.	Date	LAI[a]
50	04/17/74	0.07
100	04/17/74	0.07
150	04/17/74	0.07
50	05/09/74	1.67
100	05/09/74	1.87
150	05/09/74	2.10

[a] Estimates were made of sorghum irrigated at indicated levels of pan evaporation.

Table 16. Grain and stalk yields of drip irrigated grain sorghum in 1974.

Lysimeter No.	Drip Irrigation Treatment	N	Yield Grain	Stalk
	Pan Evaporation %	kg/ha	kg/ha	kg/ha
1	50	0	3703	5109
2	100	0	4713	5943
3	150	0	5022	6030
4	50	112	4051	4479
5	100	112	4684	4566
6	150	112	4250	5284
Average			4404	5235
Outside Lysimeter				
1*	50	0	3367	4186
2*	100	0	2676	4186
3*	150	0	5550	4391
4*	50	112	4918	4566
5*	100	112	4566	4566
6*	150	112	1435	7494
Average			3752	4898

* Refers to area receiving same treatment as sorghum in designated numbered lysimeters.

sorghum were as high as the irrigated grain sorghum (Table 17). Grain sorghum yields from irrigated and non-irrigated grain sorghum were comparable to grain yields reported by local growers in 1974. Nitrogen had little or no effect on yields in 1974 (Table 16).

Estimates of consumptive use by grain sorghum in 1974 inside and outside lysimeters are also reported in Table 18. The differential amounts of water applied to lysimeters in 1974 may have caused the greater standard deviation than was found in the previous year. Estimates of consumptive use by grain sorghum outside lysimeters were less than consumptive use by grain sorghum inside lysimeters. The 1974 crop year was dry and the upward movement of water from wet soil was probably significant. Average estimates of consumptive use inside and adjacent to lysimeters in 1974 are shown in Table 19. It must be emphasized that monitoring water conditions in areas wetted with drip irrigation may give misleading short time estimates of evapotranspiration. However, average estimates of evapotranspiration adjacent to lysimeters were only 2 to 13% less than average estimates of evapotranspiration inside lysimeters.

Electrical conductivity of drainage water from lysimeter 1 was relatively constant at about 3.5 mmhos/cm throughout the 1974 test period (Figure 16). Nitrate nitrogen concentration in the effluent from lysimeter 1 ranged from 40 to about 52 ppm with maximum concentrations during February and April. Electrical conductivity of effluent from lysimeter 2 ranged from 5.0 to 5.9 mmhos/cm while NO_3-N concentration was relatively constant at 12 to 22 ppm (Figure 17). Salinity of drainage water from lysimeter 3 was constant at about 3.5 mmhos/cm until June then increased sharply to 4.8 mmhos/cm (Figure 18). Ni-

Table 17. Grain and stalk yields of non-irrigated grain sorghum in 1974.

Location	Grain Yield	Stalk
	kg/ha	kg/ha
1	4040	4222
2	4595	4037
3	4356	4807
Average	4330	4355

Table 18. Estimates of consumptive use by grain sorghum in and outside lysimeters during 1974.

	Consumptive Use		
Lysimeter No.	Inside Lysimeter	Adjacent to Lysimeter	Error
	cm		%
1	30.4	25.5	
2	29.2	30.2	
3	34.1	33.8	
4	25.6	24.6	
5	37.1	28.7	
6	37.5	36.8	
Average	32.3	29.6	- 7
Standard Deviation	4.7	4.7	

Table 19. Average comparisons between soil water depletion and evapotranspiration from lysimeters during 1974.

Time of Evaluation				
Days[a]	Number of Days	Evapotranspiration	Depletion	Error
		cm	cm	%
1974 (Drip Irrigation)				
Before Irrigation				
18 - 29	11	3.31	3.05	- 8
After initiation of irrigation				
29 - 39	10	3.57	3.13	-12
39 - 54	15	6.80	5.91	-13
54 - 62	8	4.73	4.58	- 3
62 - 68	6	3.08	2.70	-12
68 - 74	6	3.66	3.59	- 2
74 - 86	12	4.86	4.56	- 6
86 - 93	7	2.33	2.44	- 5

[a] Refers to days after planting.

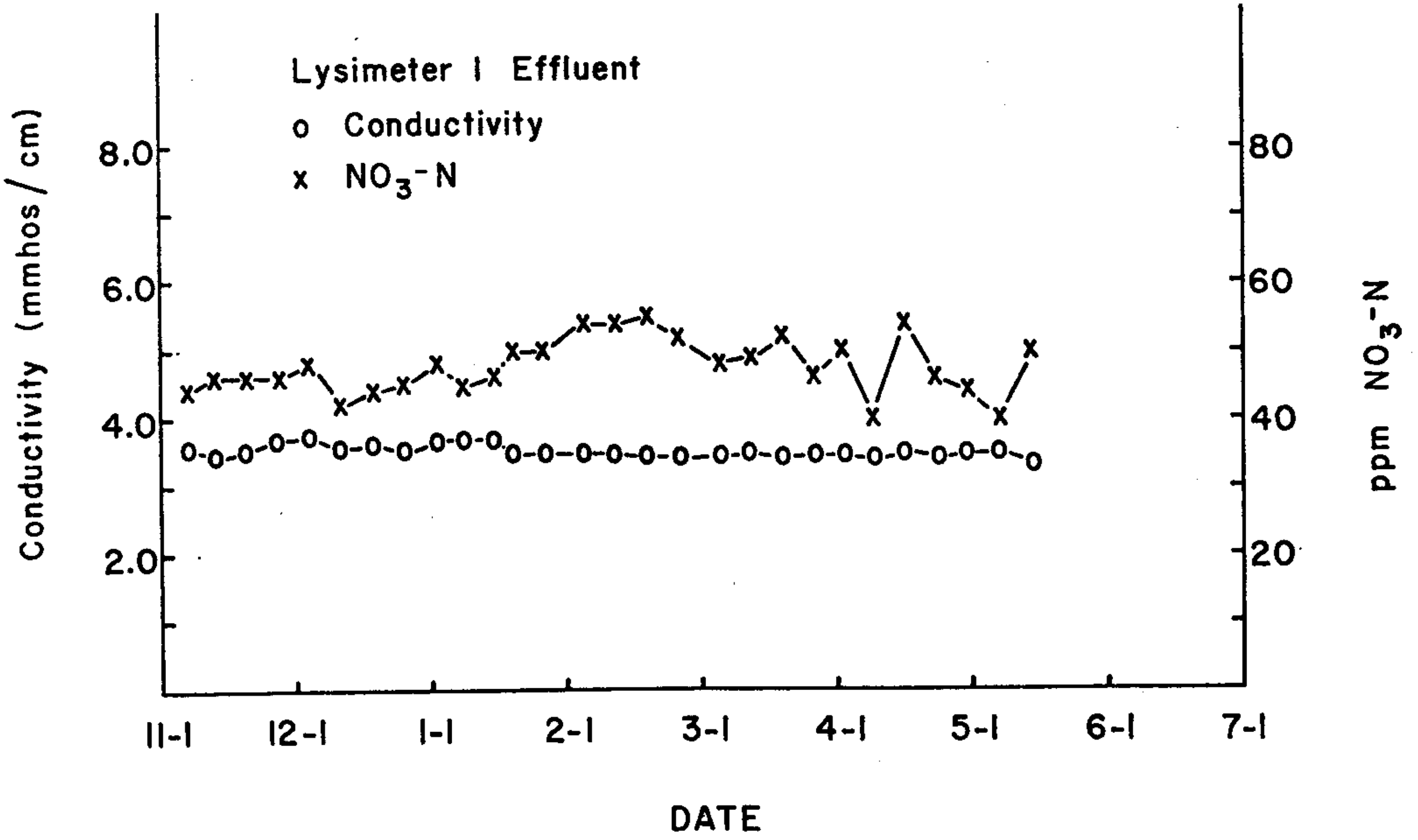

Figure 16. Electrical conductivity and NO_3-N concentration of drainage water from lysimeter 1.

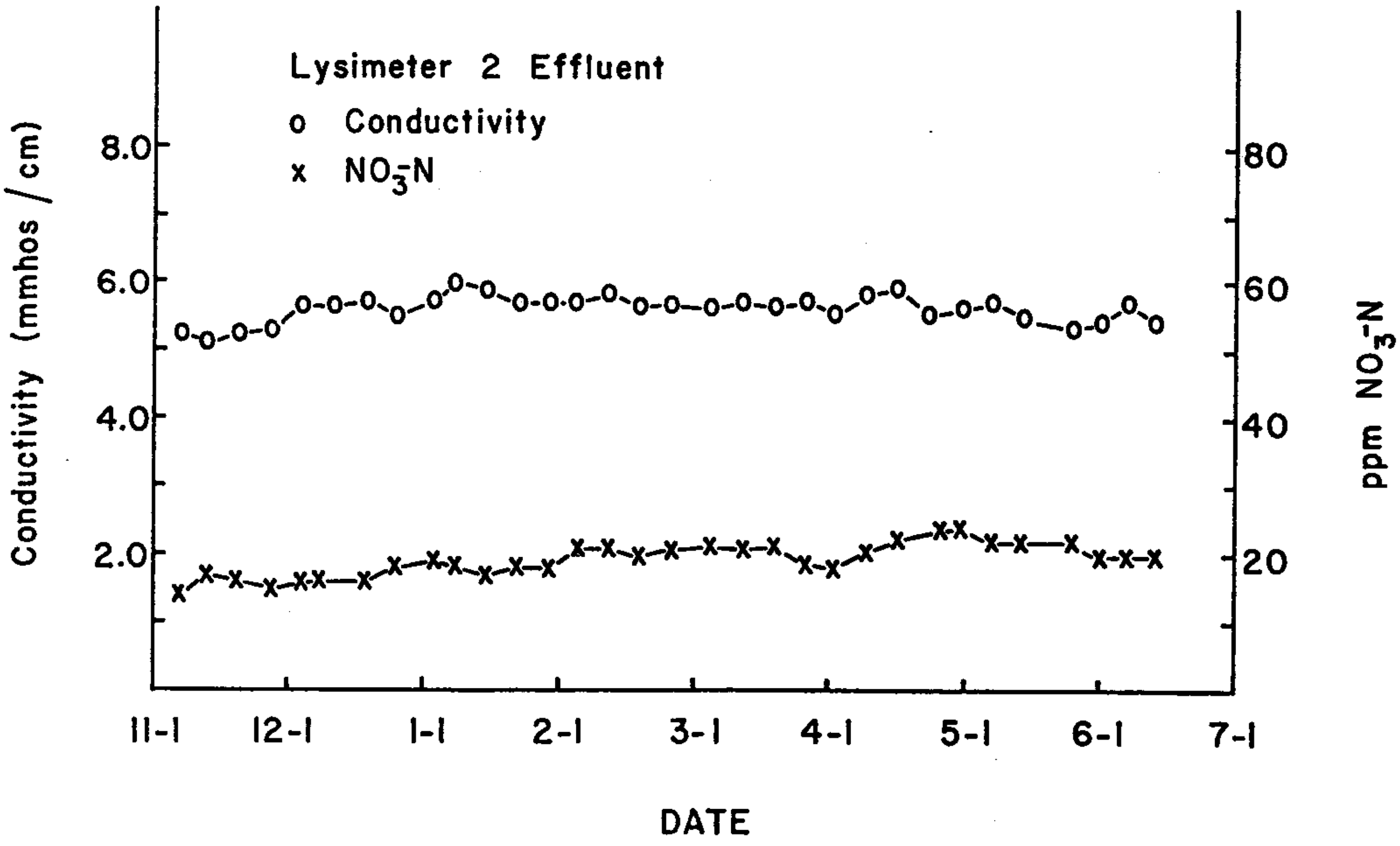

Figure 17. Electrical conductivity and NO_3-N concentration of drainage water from lysimeter 2.

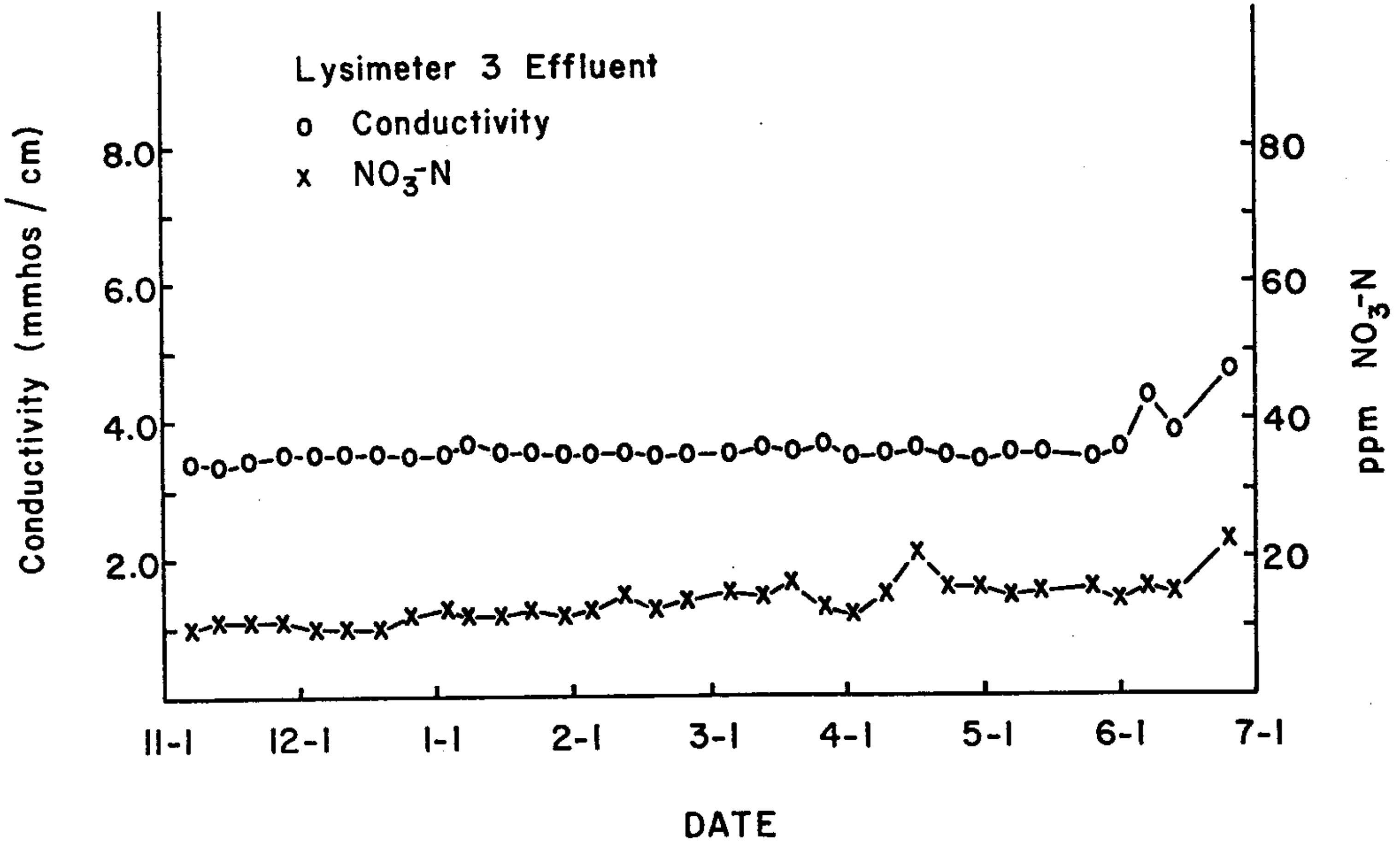

Figure 18. Electrical conductivity and NO_3-N concentration of drainage water from lysimeter 3.

trate nitrogen concentration in the effluent from lysimeter 3 was about 10 ppm in November, 1973, and gradually increased to 18 ppm in March, 1974. Maximum NO_3-N concentrations in April and June were probably not related to N application because N had not been applied to lysimeter 3 during the past 3 years. Effluent from lysimeter 4 (Figure 19) contained a wide variation in salt and NO_3-N concentration depending upon time of sampling. Electrical conductivity was generally about 6 to 7 mmhos/cm but reached values of 10.0, 11.2 and 8.3 in January, April and May, respectively. Nitrate nitrogen concentrations varied throughout the year with peak concentrations of 65 ppm appearing at the same time as peak salt concentrations. Concentrations of salt and NO_3-N were related to flow rate from the lysimeters in that low flow periods resulted in high concentrations and high flow resulted in low concentrations.

Salt and NO_3-N concentrations in effluents remained rather low throughout the test period in lysimeter 5 (Figure 20) and effluents from lysimeters 6 remained at low and constant concentrations except in March and June (Figure 21). Salt and NO_3-N concentrations in effluents were similar to that of the 1973 test period in that lysimeters with high concentrations in effluents remained high all year and those with low concentrations remained relatively low all year.

Total NO_3-N in drainage from lysimeters receiving 224 kg of N/ha in April, 1973 (1 and 4) was higher than those receiving 112 kg (2 and 5) and those receiving no N (3 and 6) as indicated in Figures 22 and 23. Maximum NO_3-N losses were about 75 kg/ha from lysimeter 1 and about 30 kg/ha from lysimeter 4. The remainder of the lysimeters lost from 14 to 20 kg/ha of NO_3-N in drainage water from August, 1973, until mid-June of 1974. In every case, the major accumulation of NO_3-N in drainage water

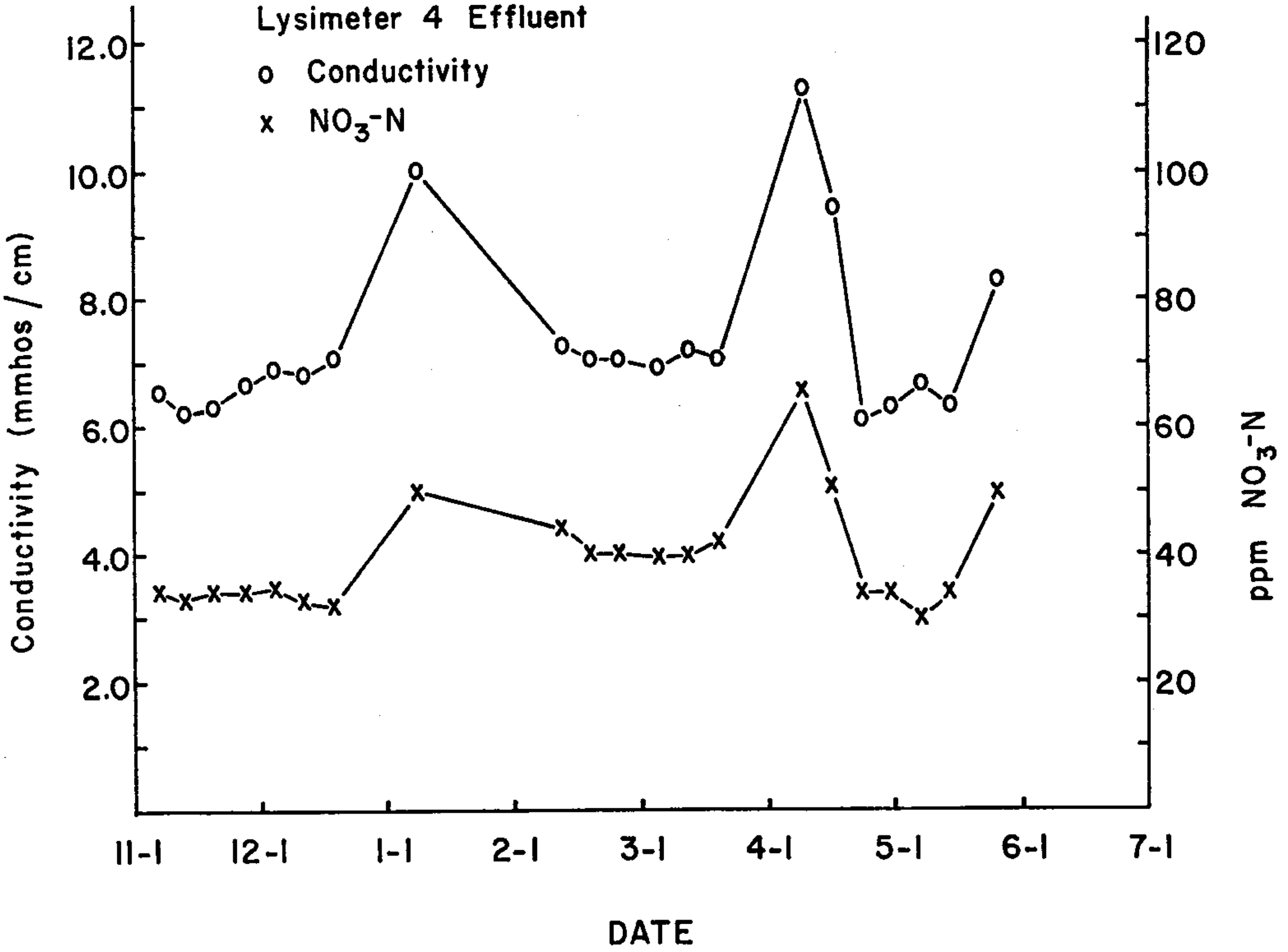

Figure 19. Electrical conductivity and NO3-N concentration of drainage water from lysimeter 4.

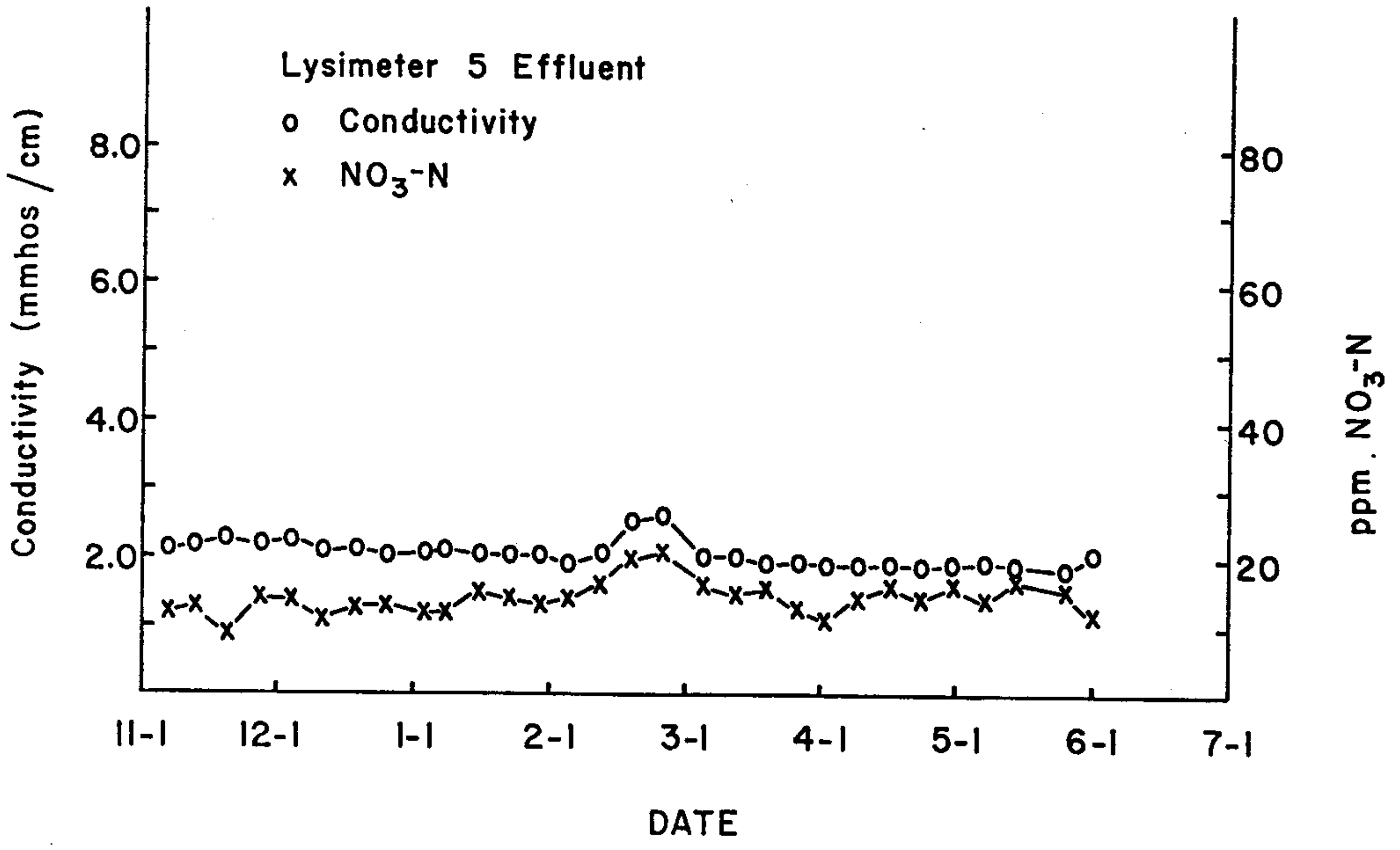

Figure 20. Electrical conductivity and NO_3-N concentration of drainage water from lysimeter 5.

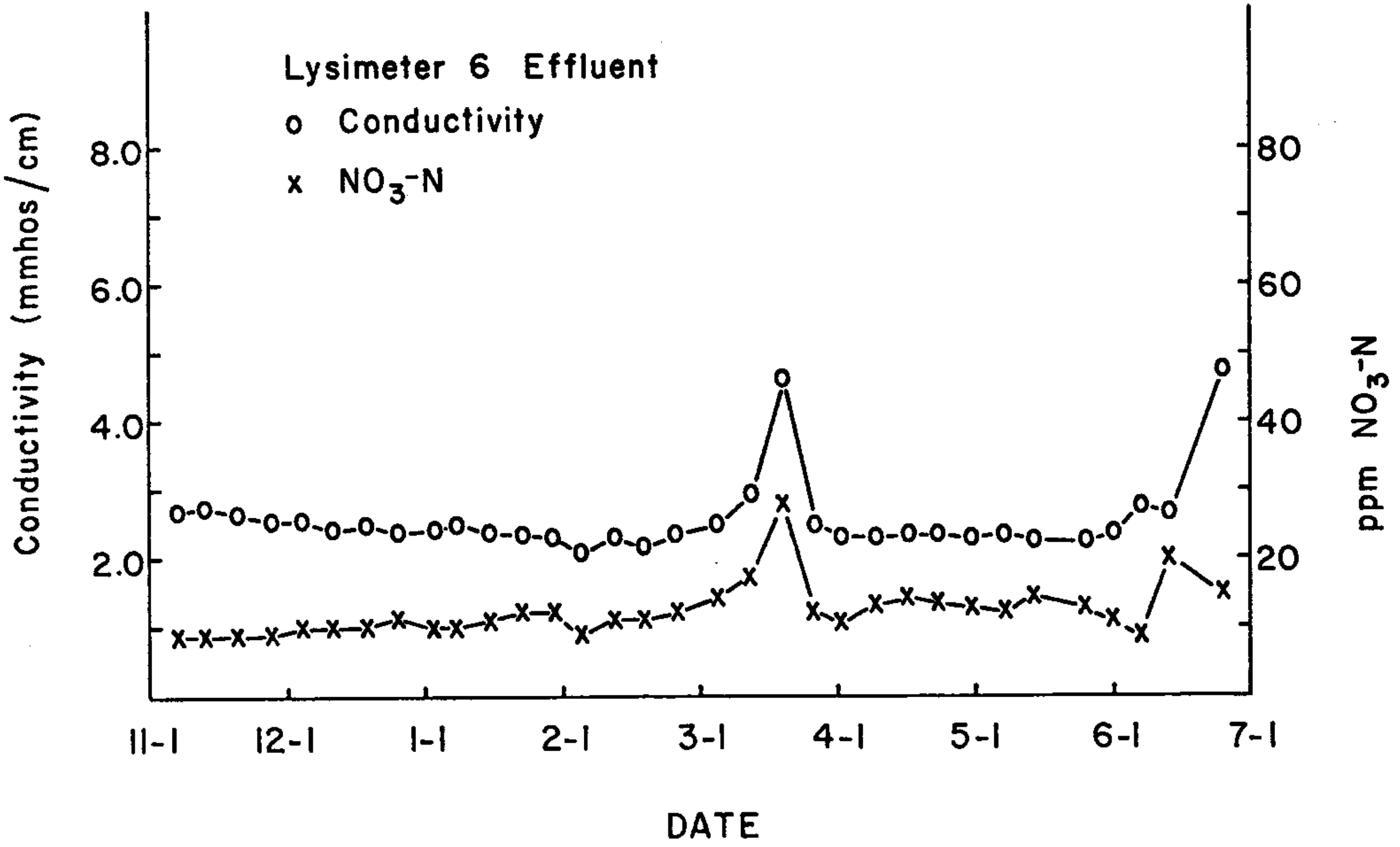

Figure 21. Electrical conductivity and NO_3-N concentration of drainage water from lysimeter 6.

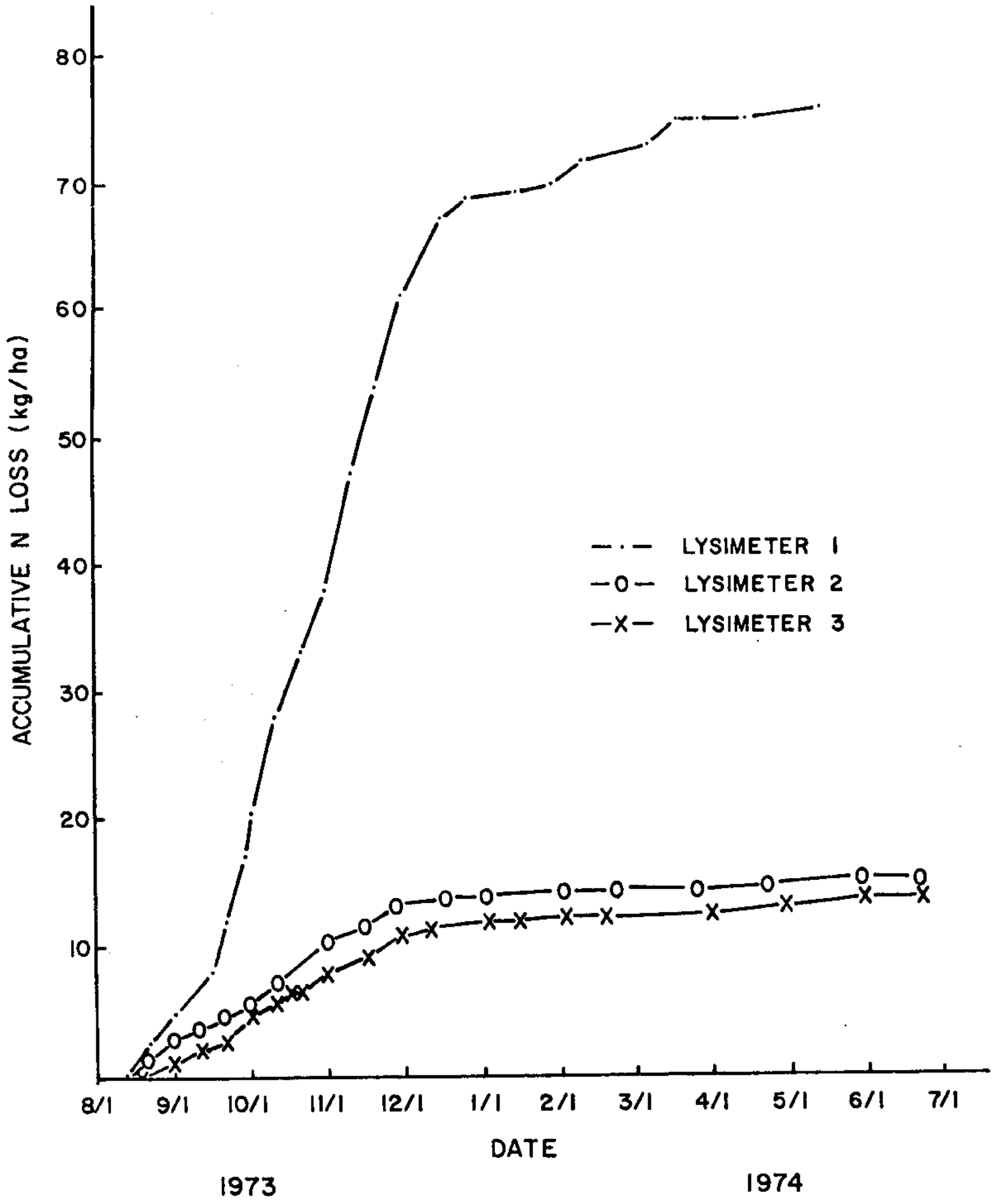

Figure 22. Accumulative NO_3-N loss in drainage waters from lysimeters 1, 2 and3.

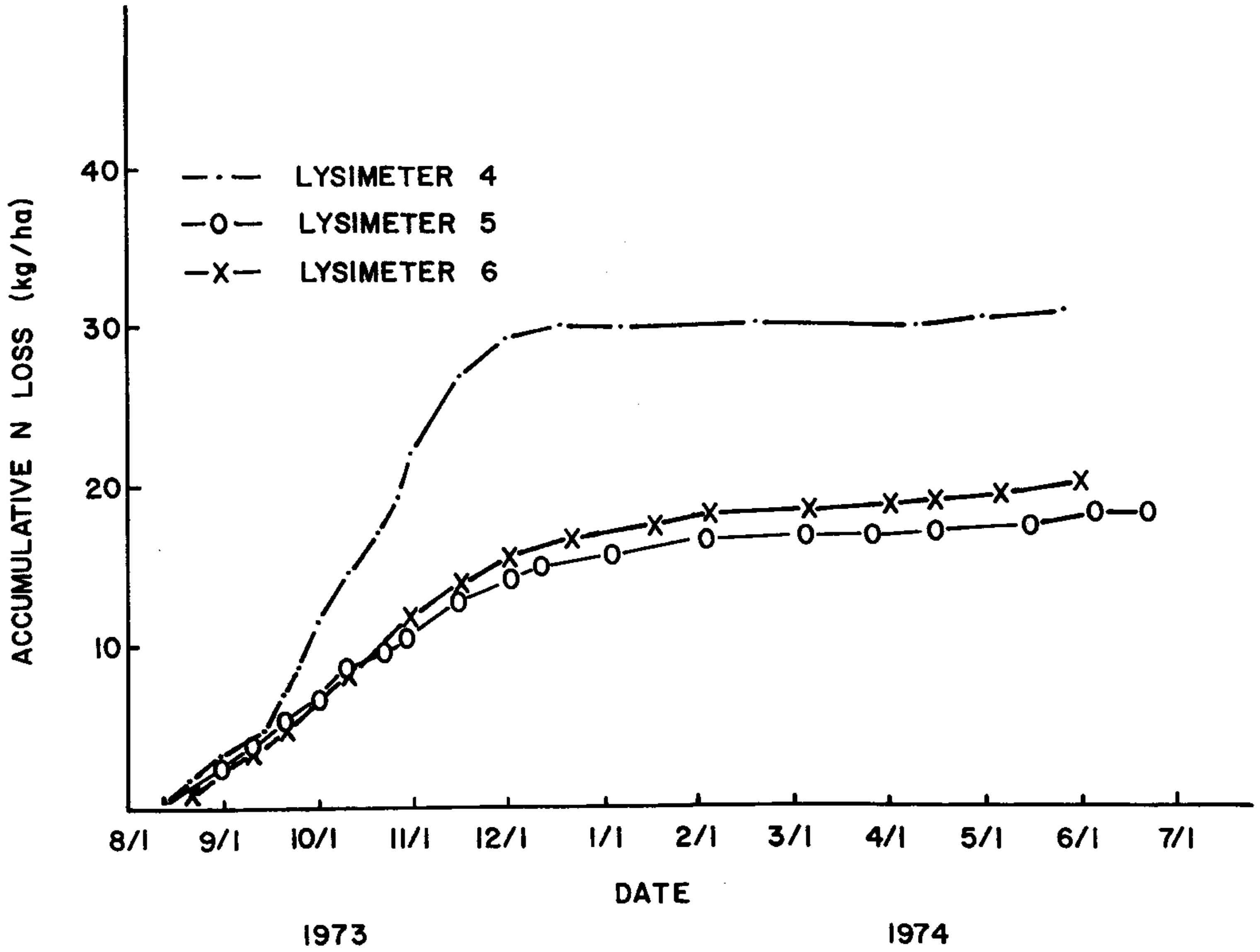

Figure 23. Accumulative NO_3-N loss in drainage waters from lysimeters 4, 5 and 6.

was during the non-cropped period from August until December. This was the period of high drainage because of fall rains which are typical of Rio Grande Valley conditions. There was almost no NO_3-N loss during the cropping period of March, April, May and June because very little drainage occurred during that period. The 112 kg/ha of N applied to lysimeters 4, 5 and 6 on April 24, 1974, did not increase NO_3-N in drainage water during the period of study.

The major salt loss in drainage from lysimeters was similar to NO_3-N loss in that most of the salt was lost during the high drainage period from August until December (Figures 24 and 25). Salt loss ranged from about 2600 kg/ha to 4200 kg/ha but was influenced more by variability between lysimeters than water quality or application rate. Irrigation regime did not influence salt or NO_3-N loss because of the low drainage volume during the cropping period.

Salinity evaluated with salinity sensors placed under the drippers at 15 and 30 cm depths (Figures 26 and 27) increased to 4 to 6 mmhos/cm when irrigated at 50% PE (pan evaporation) but decreased to 2 to 3 mmhos/cm at the 90 and 120 cm depth (Figures 28 and 29) as the season progressed. Soil salinity was similar between drippers except for low salinity readings at 15 cm after mid-June. However, this was probably due to improper function of sensors because of dry soil around the sensors. Soil salinity at 15 and 30 cm soil depth was initially low under the 100% PE treatment (Figures 30 and 31) but increased at mid-season, then decreased after irrigation was discontinued during July. Maximum salinity at 100% PE was about 5.8 mmhos/cm between drippers on about June 1. Salinity at 90 cm depth increased with time under drippers when

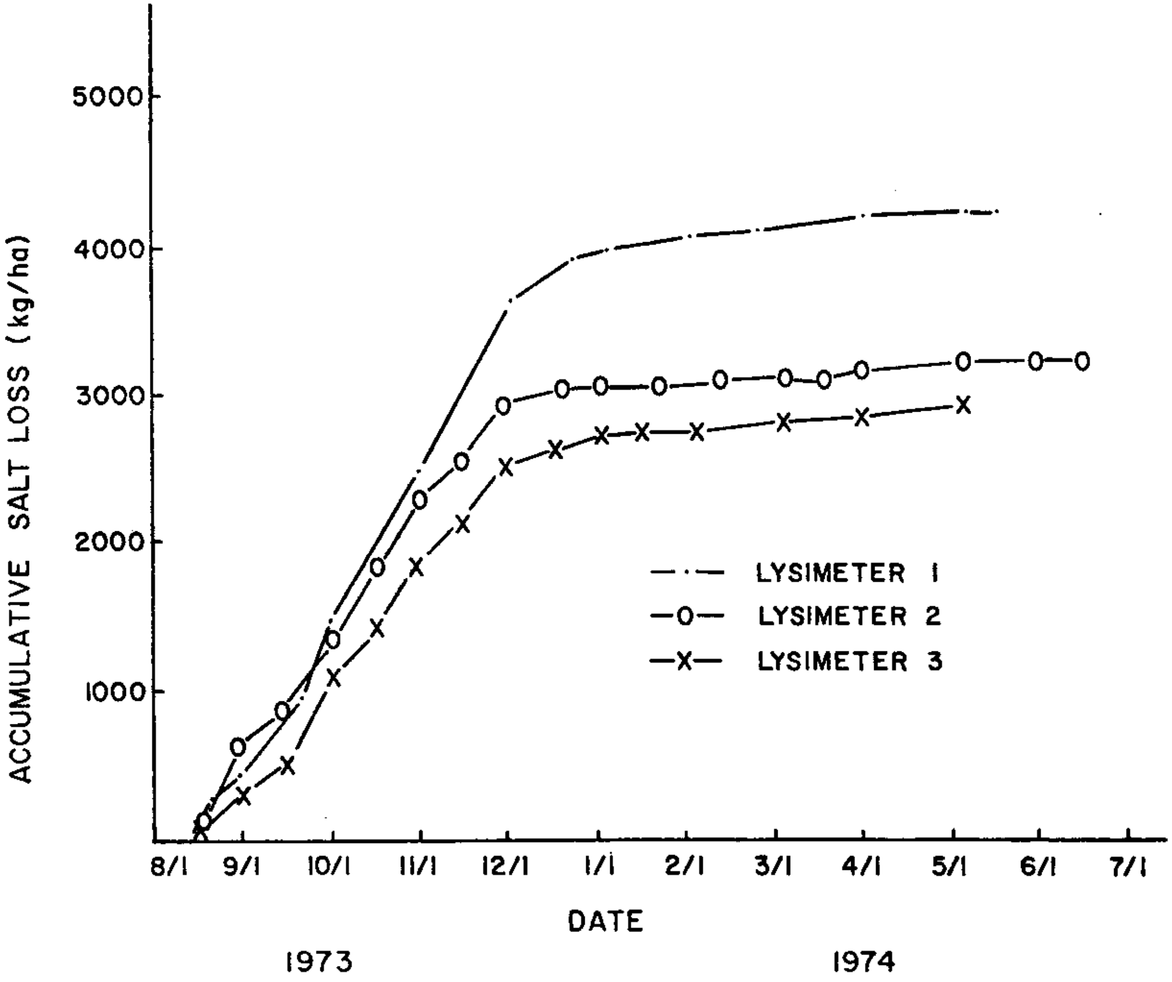

Figure 24. Accumulative salt loss in drainage waters from lysimeters 1, 2 and 3.

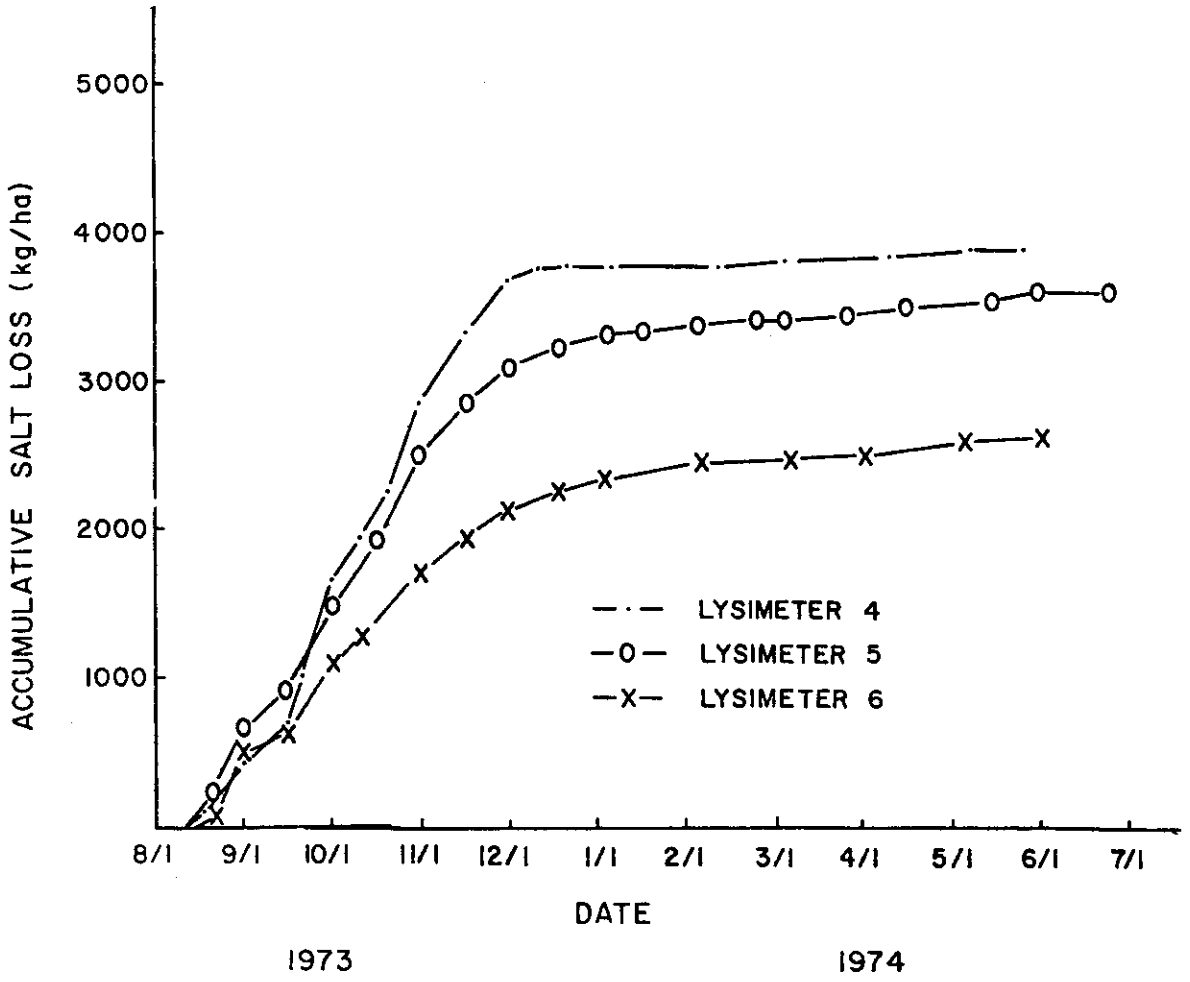

Figure 25. Accumulative salt loss in drainage waters from lysimeters 4, 5 and 6.

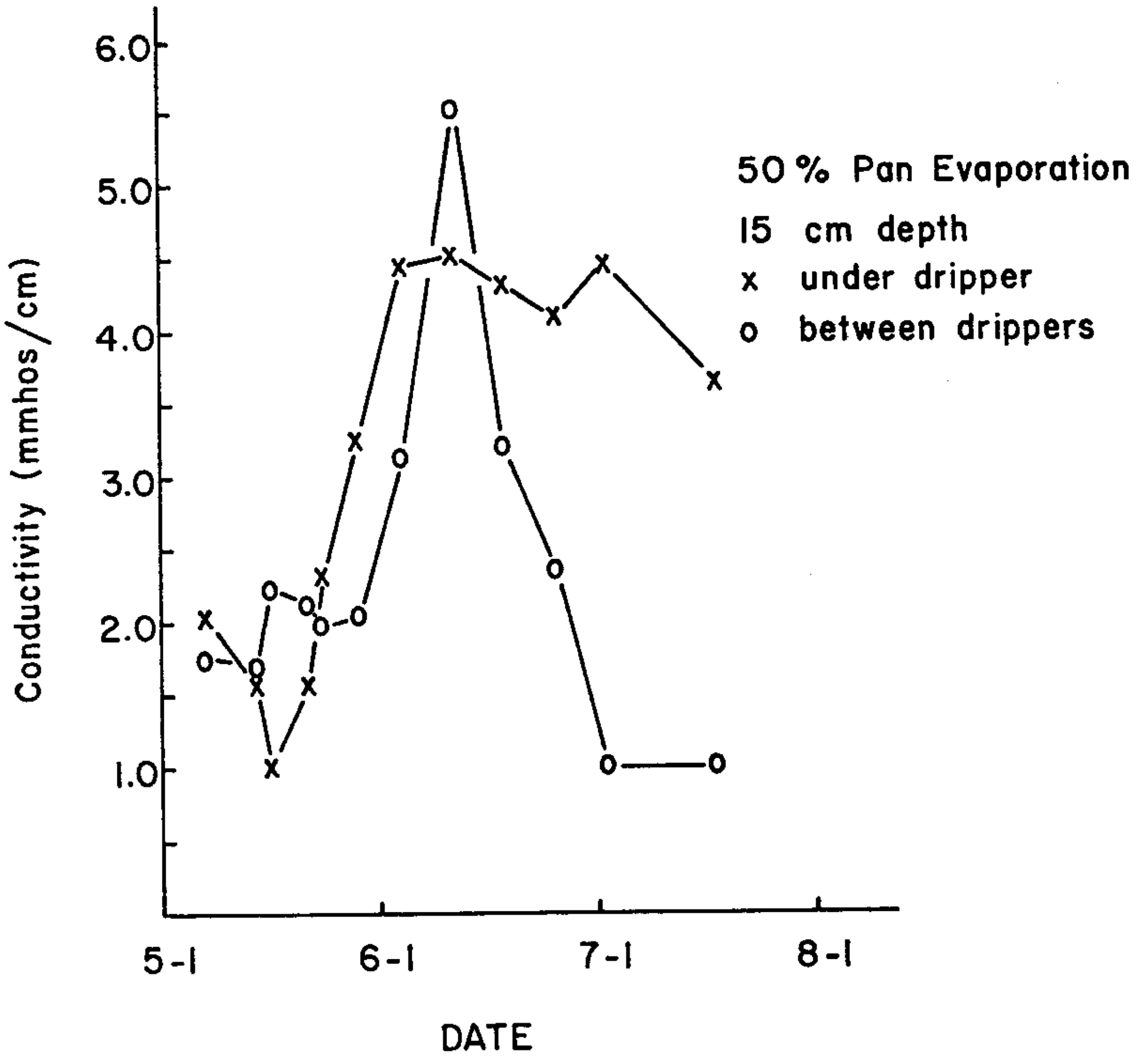

Figure 26. Soil salinity as measured by salinity sensors at 15 cm depth under 50% PE treatment.

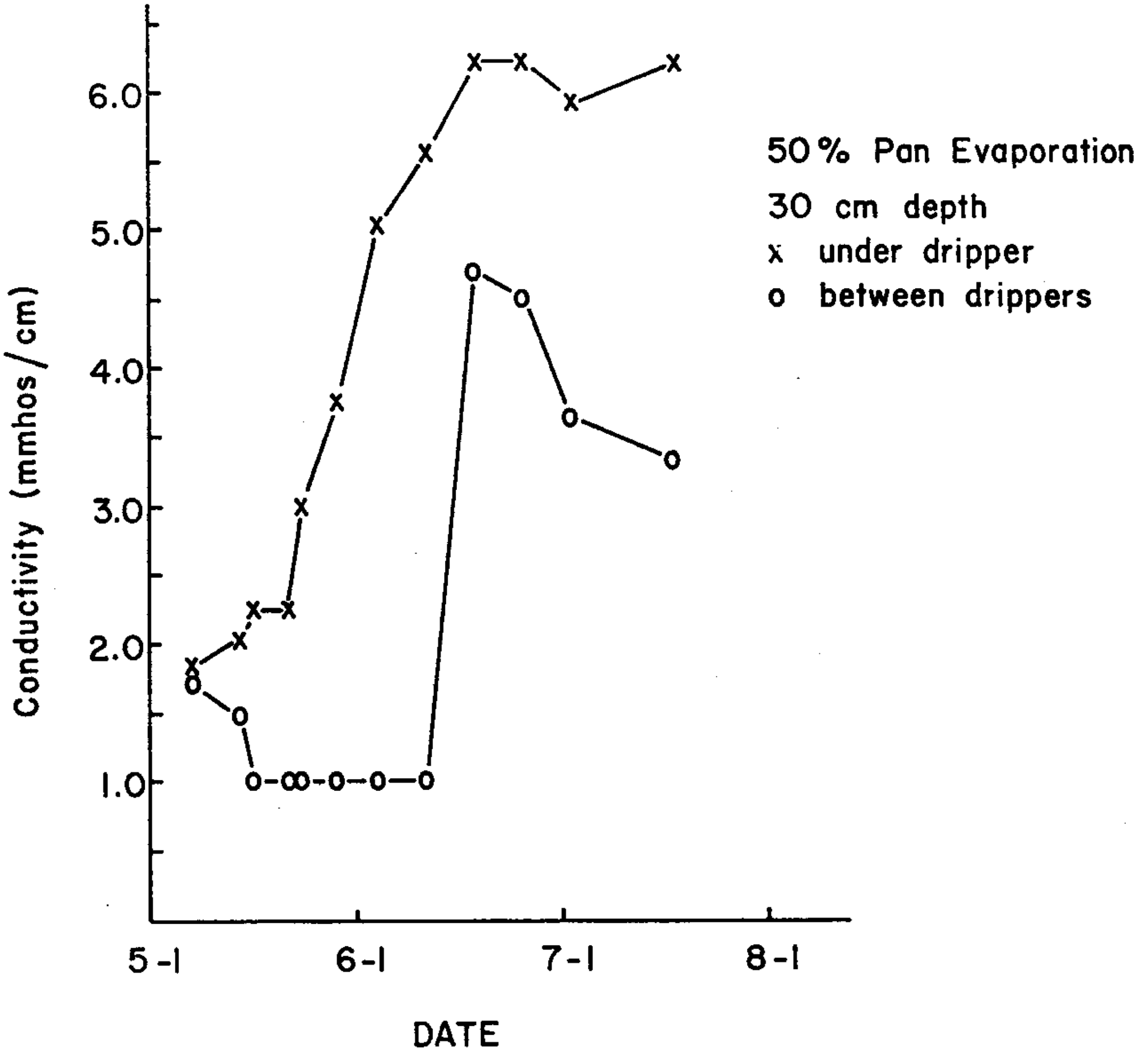

Figure 27. Soil salinity as measured by salinity sensors at 30 cm depth under 50% PE treatment.

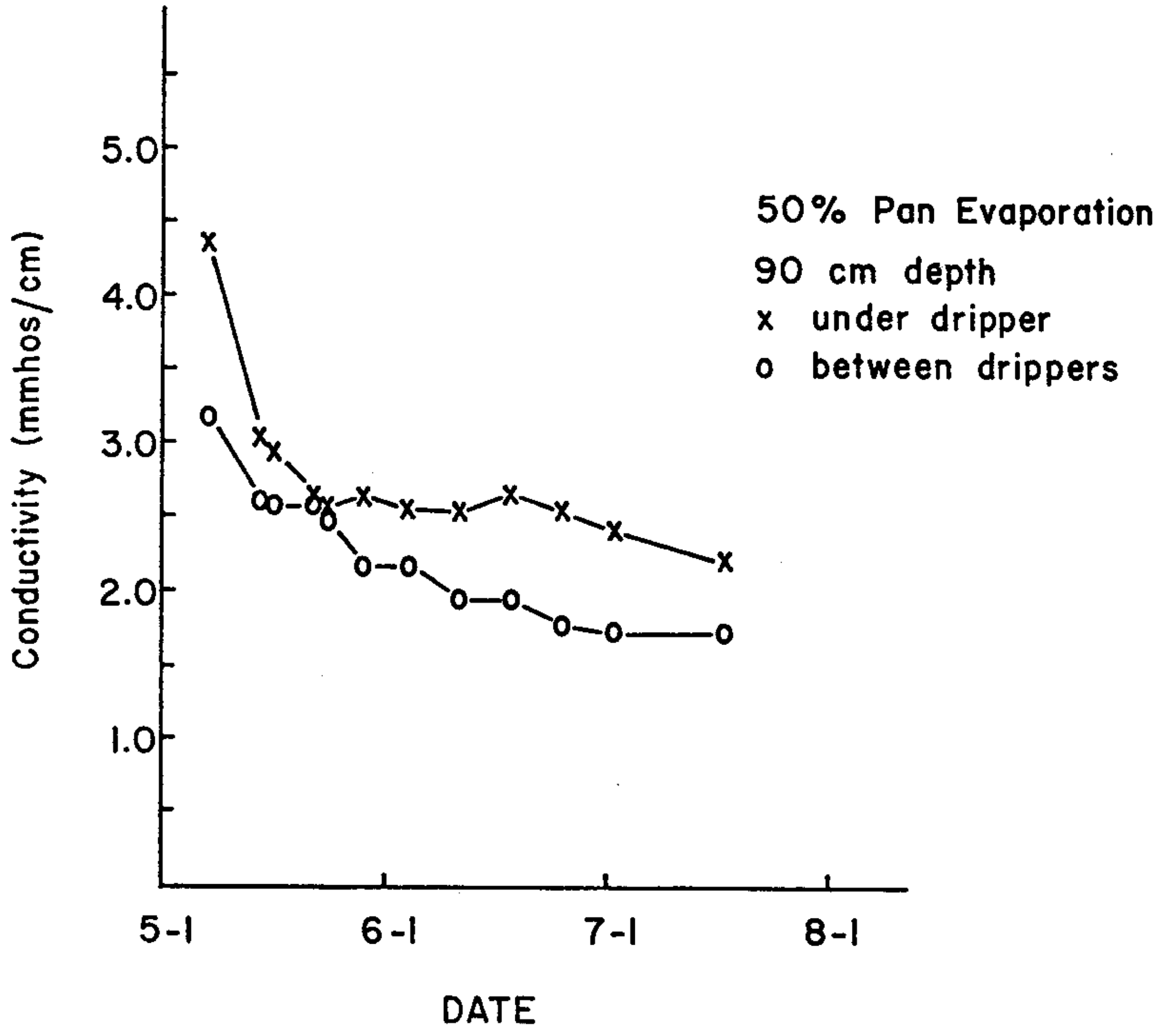

Figure 28. Soil salinity as measured by salinity sensors at 90 cm depth under 50% PE treatment.

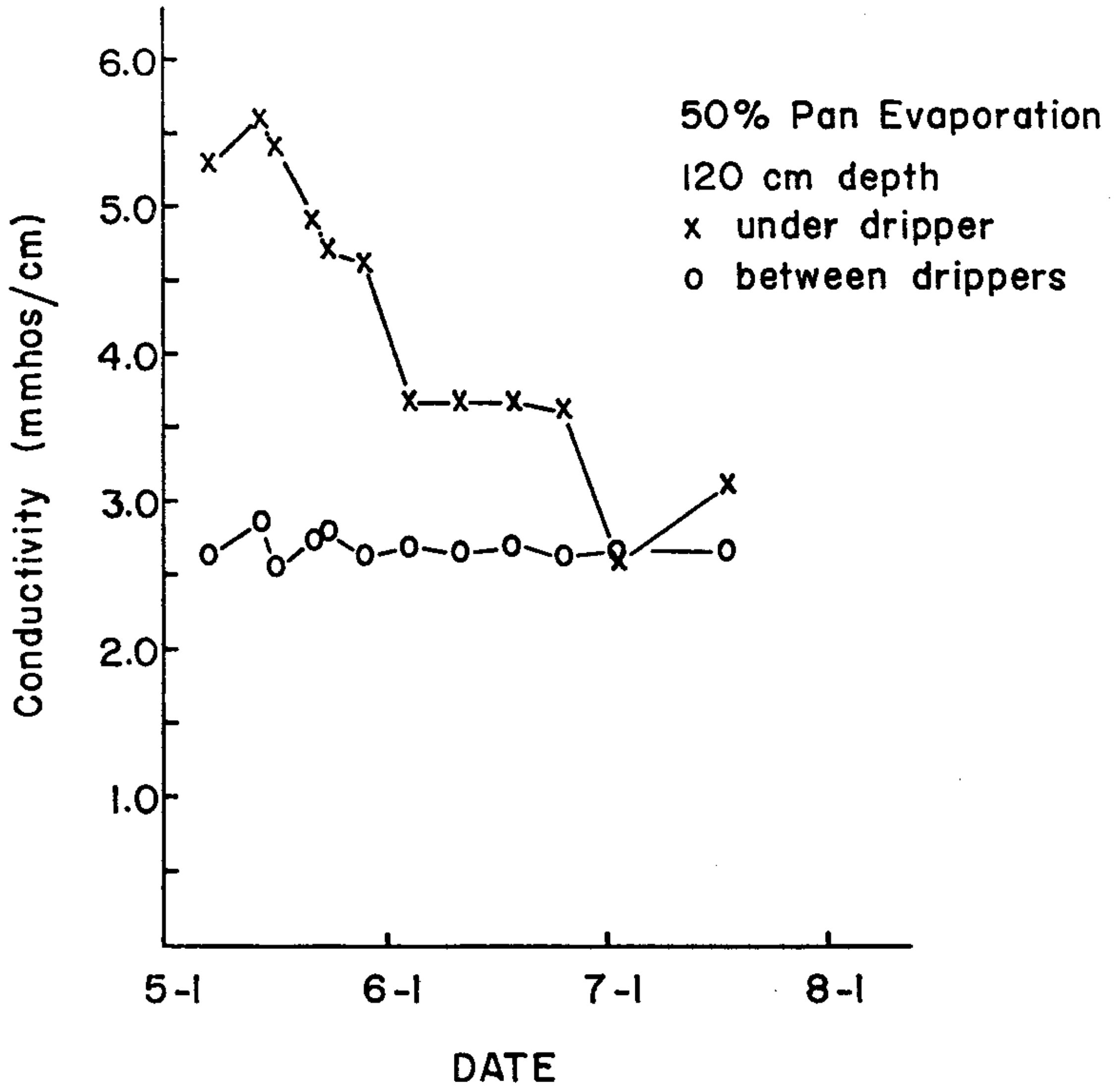

Figure 29. Soil salinity as measured by salinity sensors at 120 cm depth under 50% PE treatment.

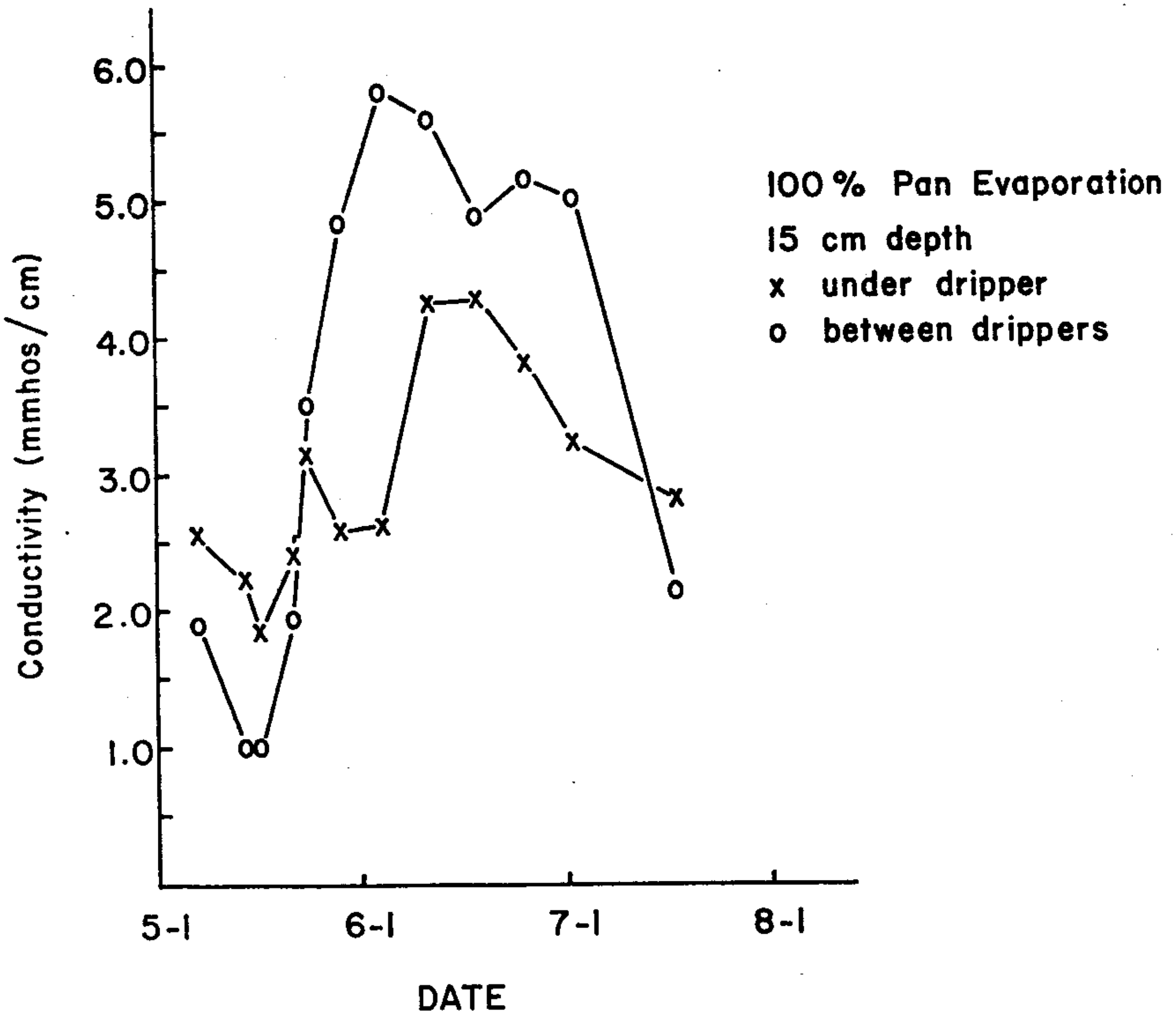

Figure 30. Soil salinity as measured by salinity sensors at 15 cm depth under 100% PE treatment.

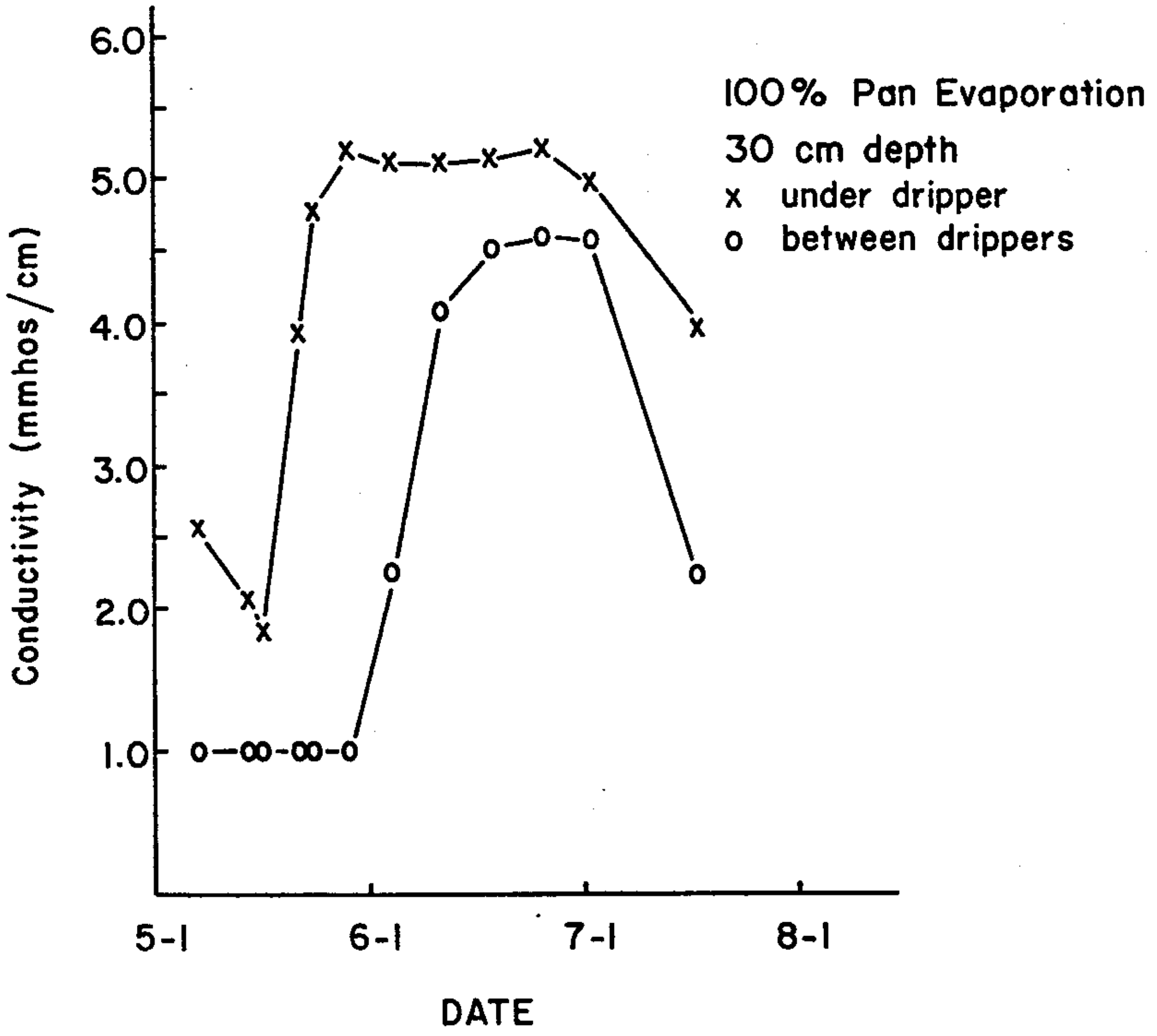

Figure 31. Soil salinity as measured by salinity sensors at 30 cm depth under 100% PE treatment.

irrigated at 100% PE but decreased at 90 cm depth between drippers (Figure 32). Salinity sharply increased throughout the season at 120 cm depth under the drippers when irrigated at 100% PE (Figure 33). Salinity increased during period of irrigation to 4 to 5 mmhos/cm at 15 and 30 cm depth under 150% PE irrigation but decreased after irrigation was discontinued in July (Figures 34 and 35). At the 60, 90 and 120 cm depth, there was an initial decrease in salinity but salinity increased at these depths for the remainder of the test period (Figures 36-38). Erratic salinity patterns in the soil profile are probably a result of non-steady state conditions during the short period of time that treatments were imposed.

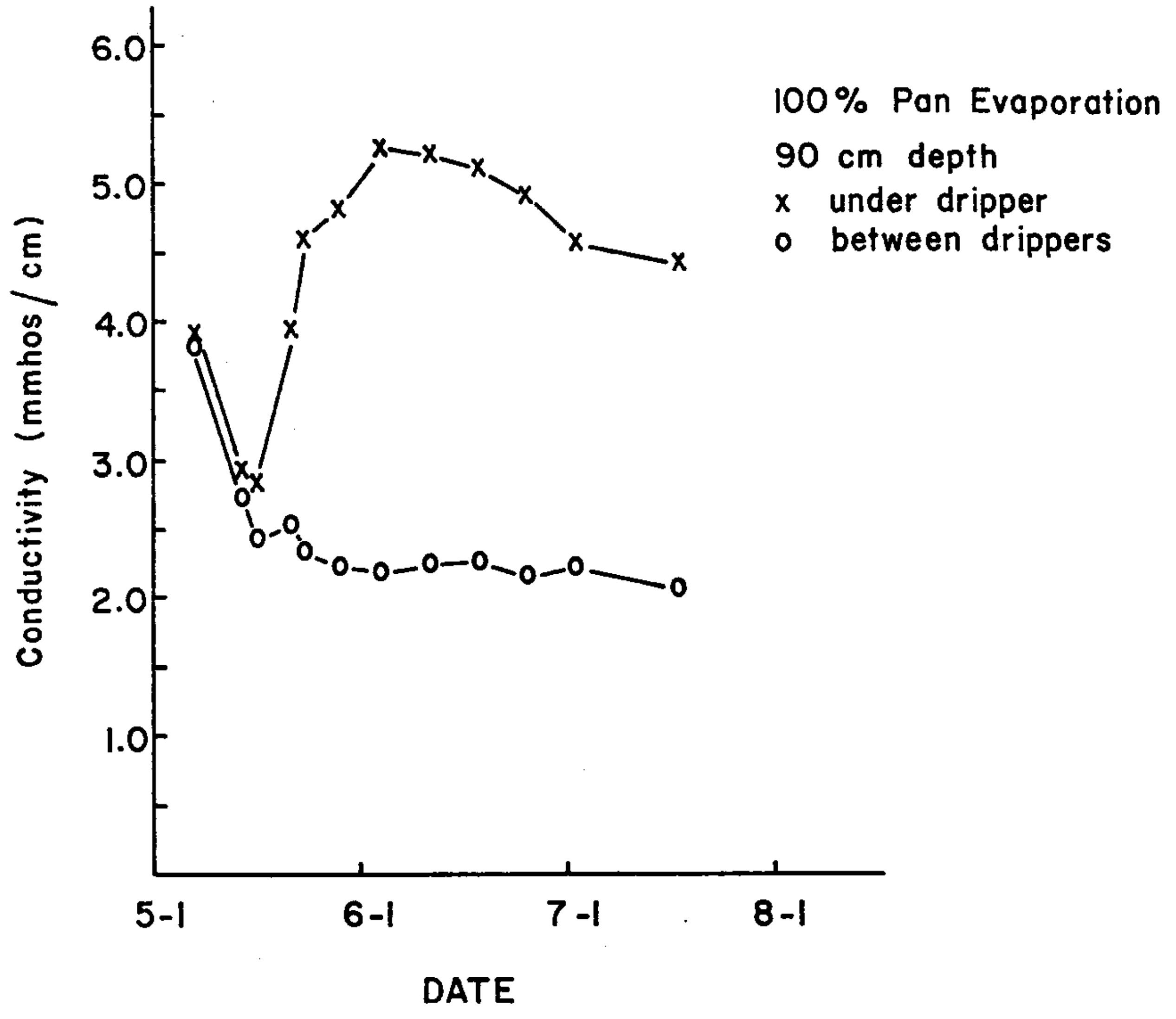

Figure 32. Soil salinity as measured by salinity sensors at 90 cm depth under 100% PE treatment.

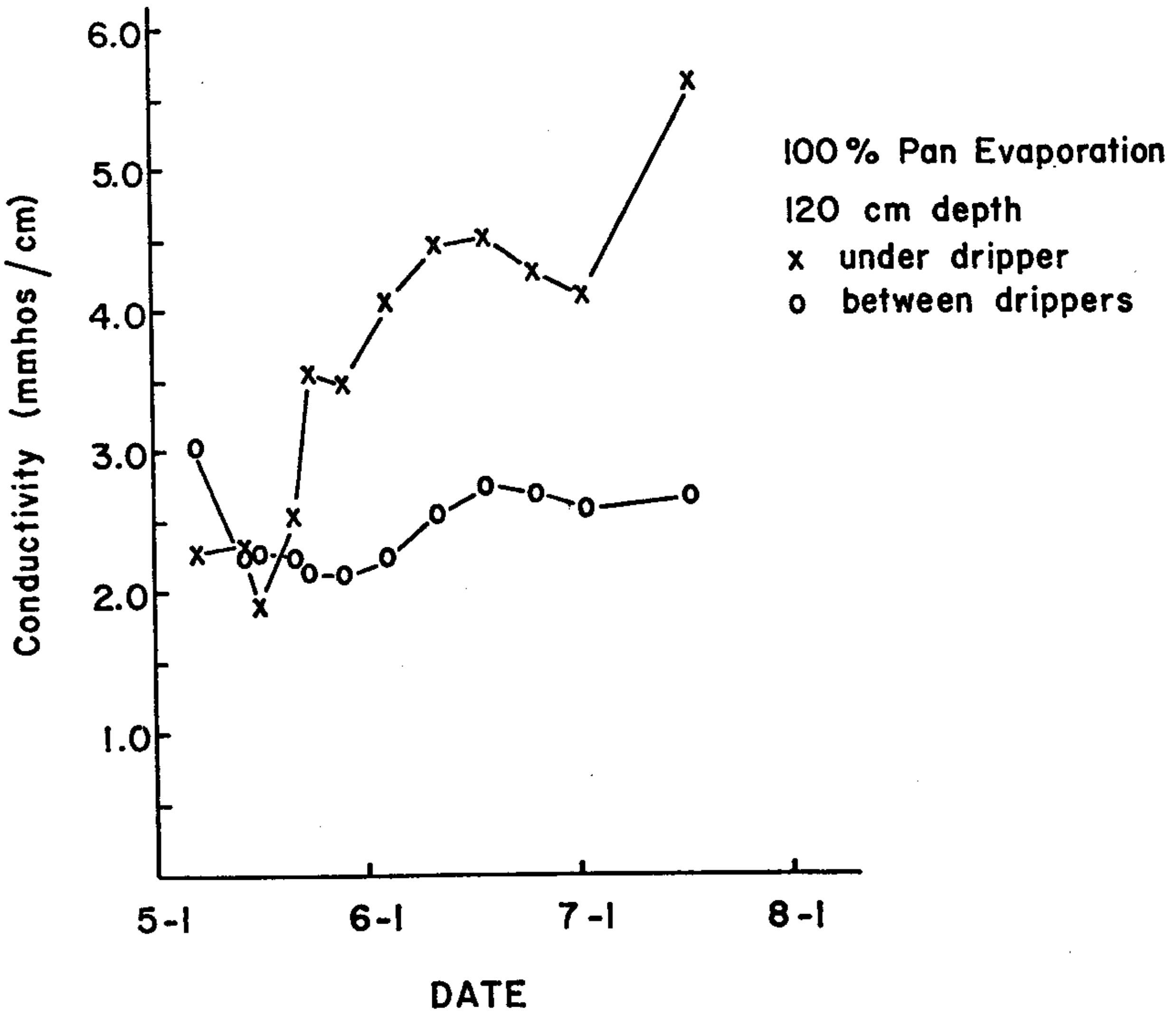

Figure 33. Soil salinity as measured by salinity sensors at 120 cm depth under 100% PE treatment.

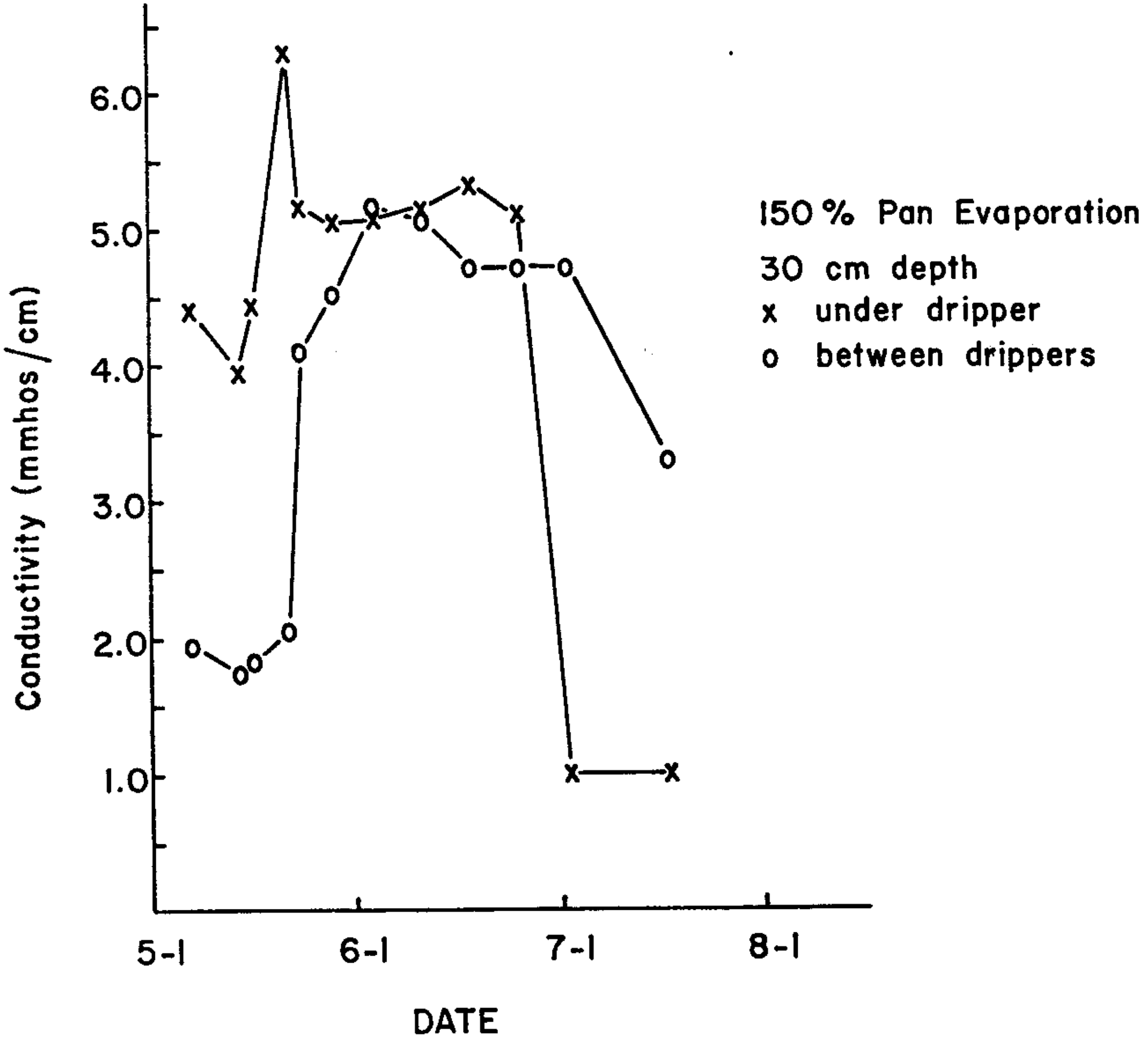

Figure 34. Soil salinity as measured by salinity sensors at 15 cm depth under 150% PE treatment.

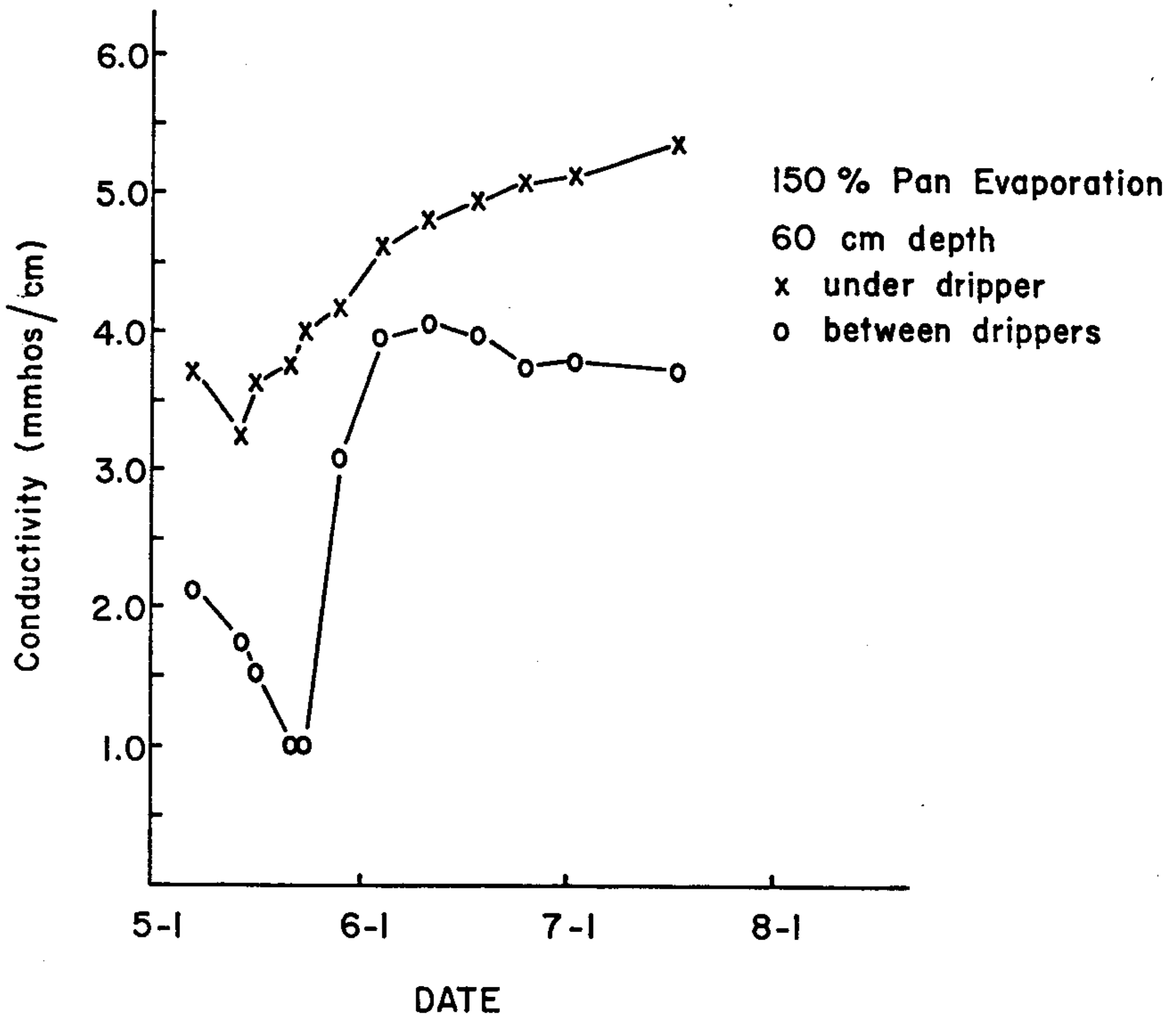

Figure 35. Soil salinity as measured by salinity sensors at 30 cm depth under 150% PE treatment.

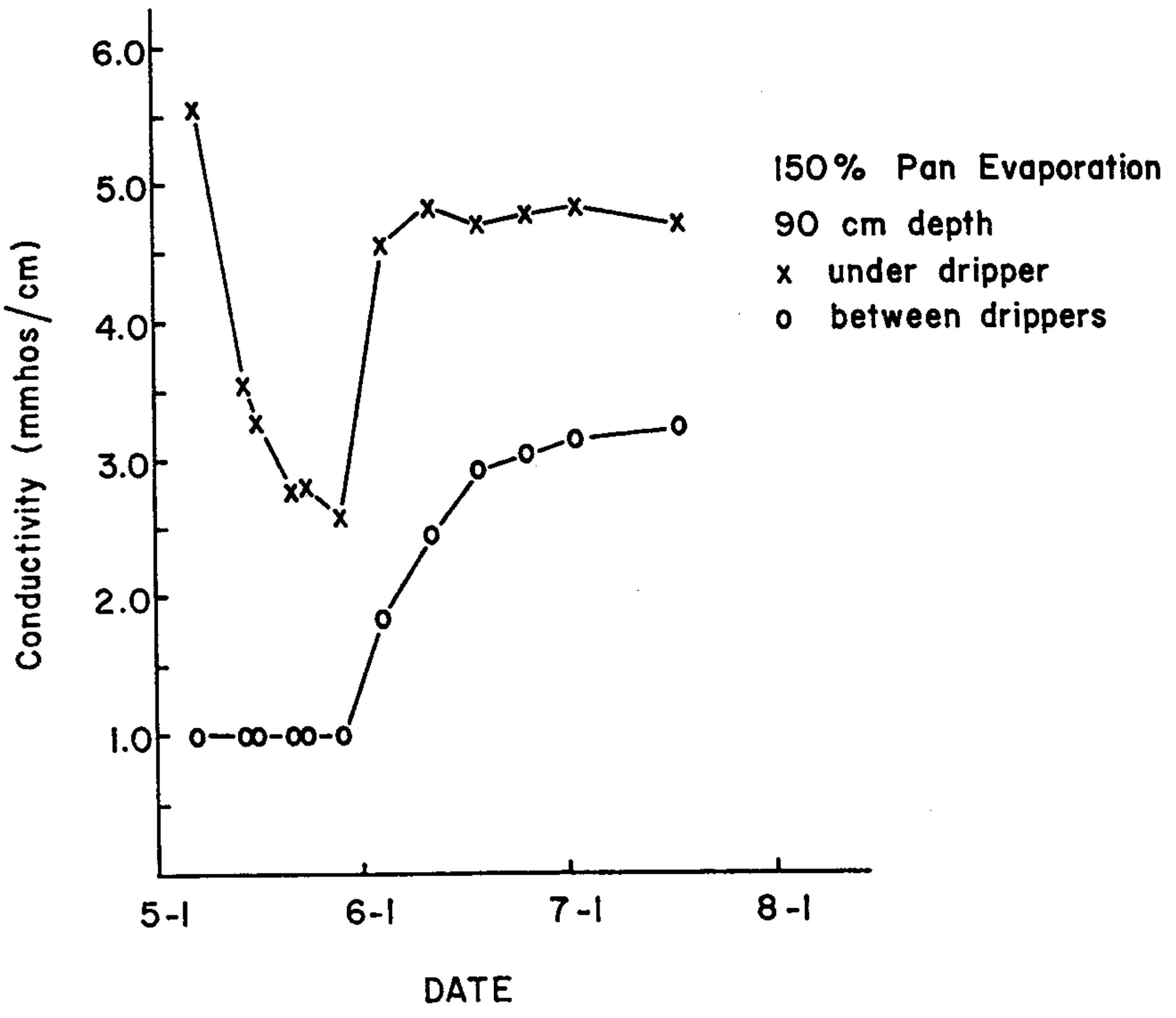

Figure 36. Soil salinity as measured by salinity sensors at 60 cm depth under 150% PE treatment.

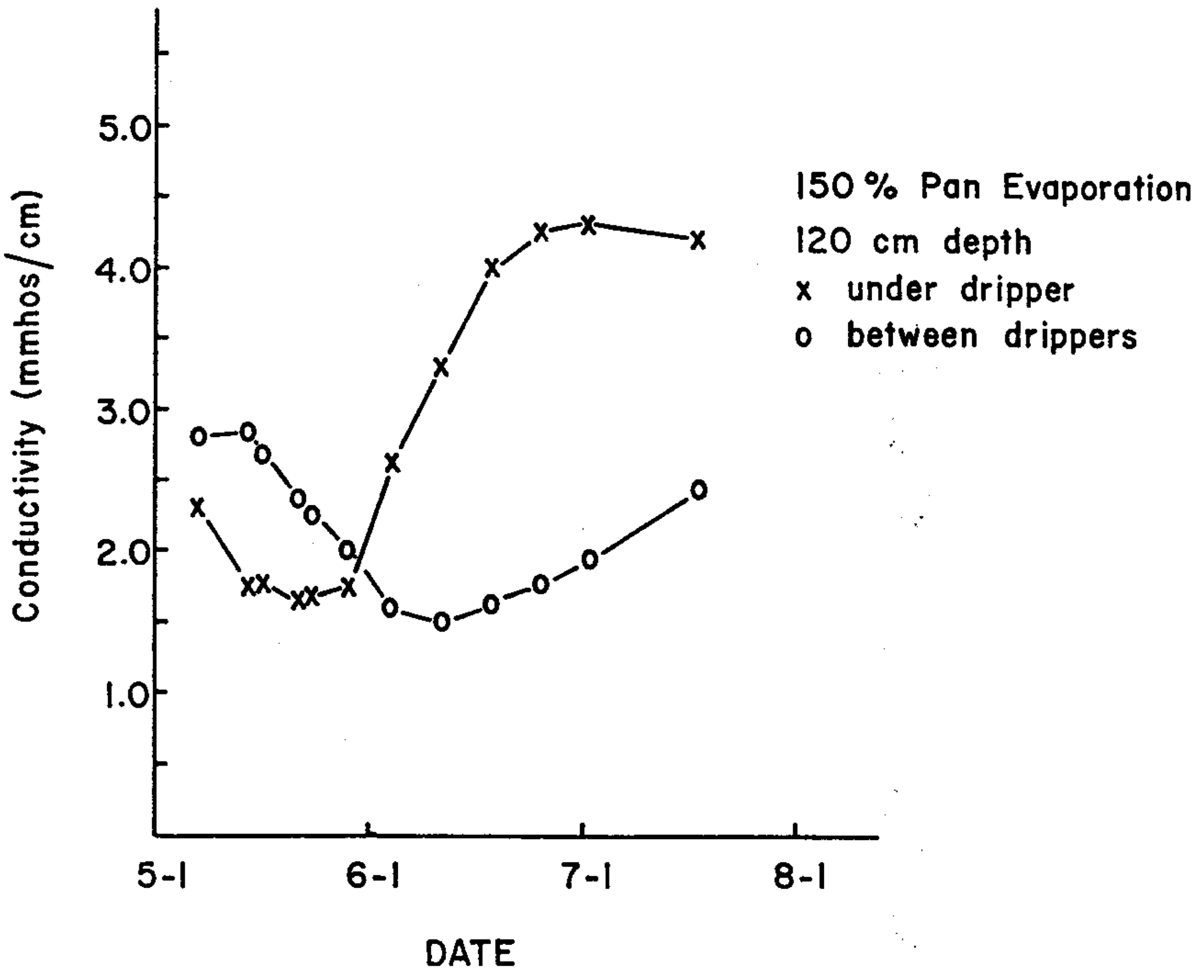

Figure 37. Soil salinity as measured by salinity sensors at 90 cm depth under 150% PE treatment.

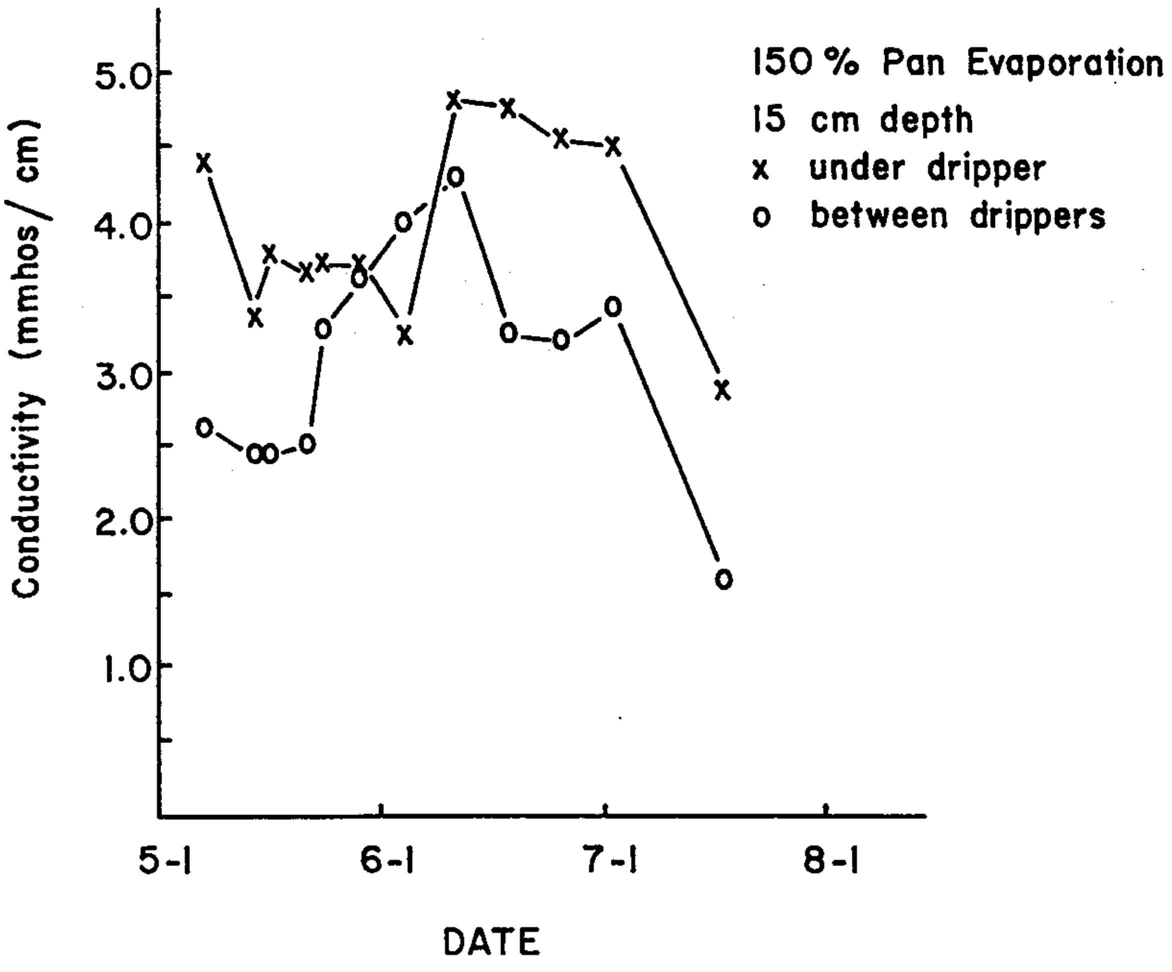

Figure 38. Soil salinity as measured by salinity sensors at 120 cm depth under 150% PE treatment.

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